INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING,
MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XII, December 2024

Assess the Dilemma between the Use of Conventional and Unconventional Energy in Nigerian Shallow Water Oil Fields

Victor Ozuruaka Chuku

Emerald Energy Institute, University of Port Harcourt

DOI : https://doi.org/10.51583/IJLTEMAS.2024.131201

Received: 05 December 2024; Accepted: 20 December 2024; Published: 30 December 2024

Abstract: This study focused on a techno-economic modelling, simulation, and analysis approach, which was used to determine the techno-economic and environmental sustainability feasibility of Solar PV-BESS as the proposed case and an outright replacement of the existing fossil fuel power generation technology based on the load profile of the given location of study. The result from the technical analysis presented shows that the study area was able to utilize an annual solar radiation at 4.14 kWh/m^2/d via horizontal positioning at 15^o inclination, which was optimal enough to meet the electrical power demand at 17,520,000kWh annually of the facility when the number of solar panels was increased to deliver 100% fraction of load, most especially in the low sunny days from May to October. Also, the economic analysis presented showed positive NPV and IRR on the proposed case. Although the initial cost of the proposed is quite high as already associated with renewable energy solutions but showed substantial payback results andoverall cost-benefit ratio at 1. The results showed that the proposed case eliminated 100% of the GHG emissions from the base case, with tremendous benefits for revenue generation from emission trading schemes. The study recommends that NUPRC and its stakeholders should form strategic partnerships with existing local solar panel manufacturing collaborators and manufacturers, in other to promote in-country production of solar PVs to reduce the initial cost of the solar projects.

Keywords: Conventional, Unconventional, Oilfields

I. Introduction

Unconventional energy sources like solar and wind energy are emerging as promising alternatives for oil and gas production facilities. These renewable energy sources, particularly solar photovoltaic systems, offer abundant and clean resources, reducing both the carbon footprint and operational costs of oil and gas-powered facilities. This shift is driven by the evolving energy landscape and environmental concerns (Sarvi et al., 2020). The petroleum industry is exploring unconventional energy sources for cost savings and environmental responsibility, as they reduce dependence on conventional power grids and volatile fuel prices, while also addressing environmental concerns like carbon emissions.

Moreover, renewable energy integration in oil and gas facilities extends beyond electricity generation. Combined heat and power (CHP) systems, which generate electricity and heat simultaneously, utilize unconventional energy sources like waste biogas for sustainable, diversified power generation (Adaramola et al., 2019).

On the other hand, Unconventional energy sources in oil and gas facilities face operational uncertainties due to their periodic nature. To address this, energy storage solutions like batteries are being integrated to store surplus energy during high generation and release it during low-generation periods, ensuring uninterrupted power supply throughout operations (Abu-Bakar et al., 2021).

The adoption of renewable energy systems in oil and gas facilities is becoming increasingly attractive due to declining costs, financial incentives, and government initiatives. Advancements in financing models, such as power purchase agreements and leasing arrangements, offer alternative pathways for companies to access renewable energy technologies without substantial upfront investments (Sarvi et al., 2020). Other unconventional energy sources, such as waste heat recovery and geothermal energy, are also being explored. As the world shifts towards low-carbon energy sources, the oil and gas industry is expected to re-align their portfolios and operations accordingly (Eghbal et al., 2019).

By this, the renewable energy sector is reducing costs and demonstrating dedication to reducing carbon emissions. Despite challenges like infrequency of supply and upfront costs, technological advancements and supportive policy frameworks are facilitating the integration of unconventional energy sources into the mainstream energy mix. This integration holds the promise of a more environmentally responsible and economically viable future for oil and gas production facilities.

In contrast, the IEA predicts global oil consumption will rise to 104.1 mb/d by 2026 without changes in fossil fuel exploitation. Oil and gas operations contribute to 15% of overall GHG emissions (IEA, 2011). Meanwhile, Upstream operators face pressure to reduce their carbon footprints, which contribute to environmental and climate change externalities. However, strategies for the energy transition are needed for these companies (Shojaeddini et al, 2019; Zhong et al, 2018; George et al, 2016; as seen in McKenna et al, 2021).

Nigeria's Shallow water oil fields traditionally use conventional fuels like natural gas for electricity generation, leading to reliable and cheap power generation. The Federal Government's "Decade of Gas" Policy has strategically adopted natural gas for energy transition, despite accounting for 27% in-scope emissions (Dioha, 2022). Nigeria aims to achieve carbo neutrality by 2060 through its Energy Transition Plan.

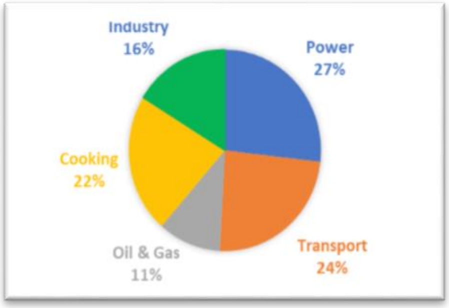


Figure 1.0: Nigeria’s energy sector emission profile in 2020 *(*Dioha, 2022*)*

Unconventional energy like Solar PV offers green power generation in oil fields, but faces intermittency and high capital costs. Upstream Operators must make pragmatic decisions between conventional fuels and solar PV for environmental and economic benefits.

The petroleum industry, known for its energy-intensive operations, has been reevaluating alternative energy sources like solar PV due to environmental and operational challenges. However, there is limited literature on Nigeria's petroleum industry, despite extensive research on power generation technological choices in oil fields (Edalat, Salehib, and Shahriaric, 2019).

This study focuses on the integration of unconventional energy sources like Solar PV-BESS in oil and gas production facilities, aiming to address the global energy transition towards sustainability and a reduced environmental footprint. The research shifts from HOMER Pro software to RETScreen Expert software, providing a new perspective on power generation technology and method of analysis. This research aligns with the global agenda of mitigating climate change and transitioning towards a low-carbon future. Also, the study explores the economic feasibility, cost-effectiveness, and potential long-term savings of incorporating unconventional energy sources in oil and gas facilities, highlighting the industry's need for strategic decision-making in the face of fluctuating fuel prices and the traditional reliance on diesel generators and grid electricity. The research further evaluates unconventional energy solutions for petroleum production facilities in remote environments, focusing on renewable energy and energy storage systems.

The study seeks to explore the alignment between unconventional energy integration and regulatory requirements, providing a roadmap for oil and gas companies to navigate evolving compliance standards. In summary, the justification for conducting this study lies in its potential to address critical challenges faced by the oil and gas industry, including environmental impact, economic efficiency and regulatory compliance. By systematically investigating the integration of unconventional energy sources for electricity generation, the study aims to contribute valuable insights that can inform strategic decision-making within the industry, foster sustainable practices, and propel the oil and gas sector towards a more resilient, efficient, and environmentally responsible future.

In this vain, the aim of the study is to assess the dilemma between the use of conventional and unconventional energy in Nigerian shallow water oil fields, through techno-economic/environmental sustainability analysis.

II. Materials and Methods

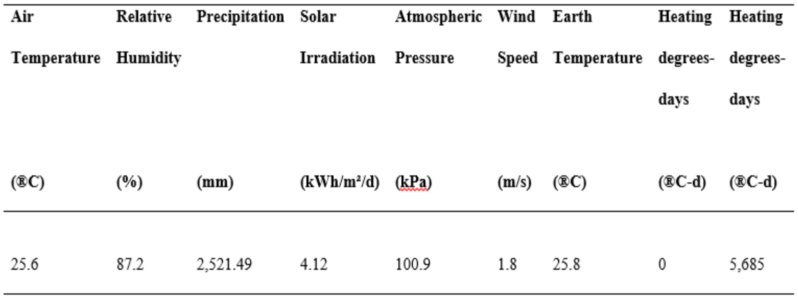
This study uses experimental-based research to investigate the feasibility of switching from Natural Gas engine-driven generators to Solar PV with battery storage technologies in Shallow water oil fields in Nigeria. The study uses RETScreen Expert software for techno-economic and environmental sustainability analysis, with quantitative measurements used to represent variables. The study is divided into two parts: determining the LCOE of Natural Gas engine-driven generators as the base case and evaluating the techno-economic and environmental sustainability feasibility of Solar PV-BESS as the proposed case. The main part evaluates the outcomes of switching from Gas Generators to Solar PV-BESS in Shallow water oil fields.

Nature and Sources of Data

Solar Resource availability

This study examines solar energy potential in swamp-locked terrain, focusing on the base climate and geographical state of the area. RETScreen Expert software was used to obtain annual solar irradiance and meteorological data from the Awoba Oil field, assessing its techno-economic viability. The study provides a summary of renewable resources available in the chosen location as given in table 2.1 below;

Table 2.1: Annual Average Climate data for the study location of this study.



Air Temperature (®C)	Relative Humidity (%)	Precipitation (mm)	Solar Irradiation (kWh/m²/d)	Atmospheric Pressure (kPa)	Wind Speed (m/s)	Earth Temperature (®C)	Heating degrees-days (®C-d)	Heating degrees-days (®C-d)
25.6	87.2	2,521.49	4.12	100.9	1.8	25.8	0	5,685

Source: Author's extract from study location, 2022.

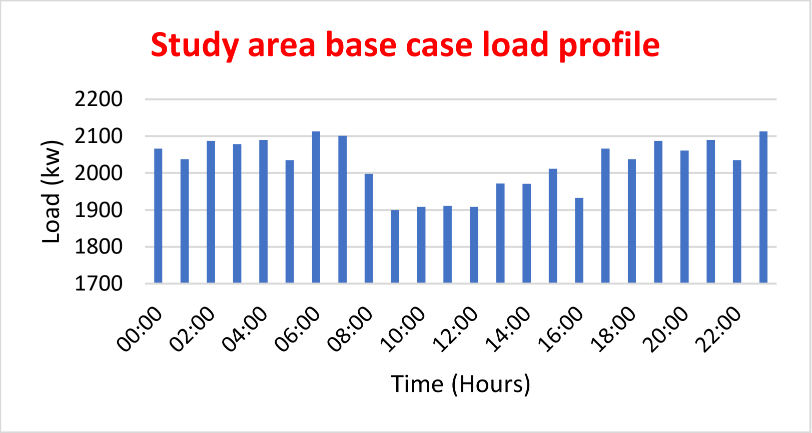
Load Profile of the study area

Table 2.2: Load data for the location of study

Load Design Capacity (MW)	Base Load (MW)	Peak Load (MW)
2.5	2.0	2.12

Source: Author's extract from study location, 2022.

Figure 2.1: Load profile of the proposed case



Source: Author's extract from study location, 2022.

Table 2.3 Techno-economic input data for the base case of this study

Input Variables (in '000s)	Values
Initial Investment Cost ($)	2
O & M Cost ($)	2,815
O & M Growth Rate (%)	2
Annual Fuel Gas Cost ($)	96
Annual Electricity Produced (kWh)	17,520
Project Life (Years)	15
Discount Rate (%)	16.50
FX Rate ($:NGN)	1:430

Source: Author's extract from web data, 2022

Power Generating Factor

The panel generation factor (PGF) is a crucial factor in determining the size of solar photovoltaic technology, with the PGF for Awoba Oil field calculated at 2.55 with the equation (Leonics, 2009) below;

Panel Generation Factor = S. I x TCF = 0.62 x 4.12 = 2.55 ………. (1)

Where;

S. I = Solar Irradiance

TCF = Total Correction factor

Energy Demand

The energy demand of a solar PV loop is determined through an energy survey, which examines energy flows in a building or system to reduce input without impairing outputs (Allouhi et al, 2011). This study uses the base power consumption loads in steady state production per day of the Awoba oil field.

Energy demand = sum of base power consumption x 24 = 2,000 x 24 = 48,000kWh/day = 48MWh/day.

Solar PV Energy Required

The solar PV energy demand is described as the energy that needs to be produced by the photovoltaic module. It represents the total watt-hour per day needed from the photovoltaic modules and is computed by multiplying the peak energy requirement of the system (which is the total watt-hour per day for the facilities) by the energy lost in the system.

Peak load requirement = 17,520,000

Energy lost in the system = 1.3 (Chandel et al, 2013; Leonics, 2009)

Energy required from photovoltaic modules = 17,520,000 x 1.3 = 22,776,000 Wh/day. ……………..(2)

Photovoltaic Module sizing

To calculate the size of the PV modules that is needed, the total watt-peak rating for the Photovoltaic must be estimated. The watt-peaking rating is the design rating of each PV panel that has the ability for power supply and withstand for a brief period of time.

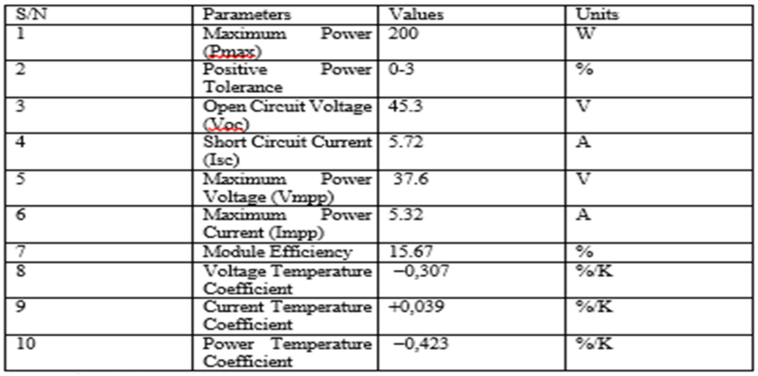
Total Watt-peak rating = $\frac{\text{Solar PV energy Required}}{\mathit{Panel\ Genetation\ Factor}} = \frac{48{,}000}{2.55}$ = 18,824kWh/d …………(3)

Hence, by determining the PV module dimensions, which is the result of dividing the total watt peak rating, as computed in the equation mentioned earlier, by the PV output power rating, as indicated in the equation below. Consequently, this yields a solar module with a capacity of 30,000 at an output power rating of 200 W.

PV module size = $\frac{\mathit{Total\ Watt\ peak\ rating}}{\mathit{PV\ output\ power\ rating}}$

The China Sunergy mono-si-CSUN200-72M solar PV module was chosen due to its market penetration, accessibility, and affordability. It can withstand wind forces and snow pressures, and has been tested for salt mist, ammonia, blowing sand, and hail. The panel has a high conversion efficiency and performs well in low-light situations like Nigeria (Owolabi et al, 2019). However, using more modules may improve system performance and battery life, as factors like size, position, wattage, and site environment affect panel output (Rehman et al, 2017).

Table: 2.4: The technical details of china sunergy mono-siCSUN200-72M



S/N	Parameters	Values	Units
1	Maximum Power (Pmax)	200	W
2	Positive Power Tolerance	0-3	%
3	Open Circuit Voltage (Voc)	45.3	V
4	Short Circuit Current (Isc)	5.72	A
5	Maximum Power Voltage (Vmpp)	37.6	V
6	Maximum Power Current (Impp)	5.32	A
7	Module Efficiency	15.67	%
8	Voltage Temperature Coefficient	−0,307	%/K
9	Current Temperature Coefficient	+0,039	%/K
10	Power Temperature Coefficient	−0,423	%/K

Source: (Owolabi et al, 2019).

Inverter Sizing

The dimension of the inverter employed for the envisioned scenario relies on both the overall power consumption and the safety margin, as delineated by Hussein (2013). The calculation for this is presented in the equation below.

Peak energy requirement = 17,520 KW

Factor of safety = 1.3 (Hussein, 2013)

Size of inverter = Peak energy requirement X Factor of safety …………….. (4)

This dissertation uses a Digital Luminous Inverter with a capacity rating of 10 Kva/180V, available in Nigeria, for its high output capacity and backup performance. The inverter's input rating should exceed the total watt of all appliances (leonics, 2019; Chandel et al, 2013).

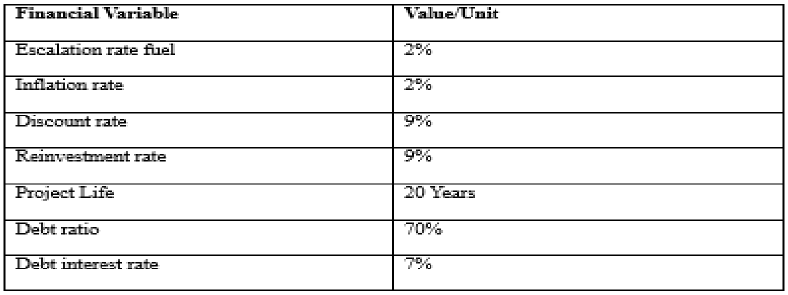
Battery Sizing

The recommended battery variety for the suggested scenario is the deep cycle battery. A deep-cycle battery is designed to withstand repeated, profound discharges that utilize a significant portion of its capacity. The conventional interpretation of this term typically pertains to lead-acid batteries sharing the same structure as car batteries, unlike starter or "cranking" automotive batteries, which are designed to provide only a fraction of their capacity in a short, high-current burst for initiating an engine (Wikipedia, 2022). The battery at project modelling, should be big enough to store and supply sufficient energy on demand as it relates to this project. The capacity of the battery required for the proposed case can be calculated using the equation below.

$$\mathrm{BC} = \frac{\mathrm{DPC\ X\ DoA}}{Battery\ Efficiency\ X\ DoD\ X\ Battery\ nV} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

Where the BC = Battery Capacity, DPC is the daily power consumption at 48,000kW, DoA is the Days of autonomy which is given as 3 days, Battery efficiency is given 0.9, DoD is depth of discharge and given as 0.5 because of the nature of the proposed case for industrial purposes to keep the battery in the best state of health. Lastly, the Battery nV is the nominal voltage of the battery given as 12V.

Table 2.5: Economic input data for the base case of this study



Financial Variable	Value/Unit
Escalation rate fuel	2%
Inflation rate	2%
Discount rate	9%
Reinvestment rate	9%
Project Life	20 Years
Debt ratio	70%
Debt interest rate	7%

Methods of Data Analysis

This project uses descriptive data analysis for both base and proposed cases, utilizing discounted method and Excel modelling for base case analysis. LCOE is used for base case analysis, while RETScreen software answers research questions.

Overview of RETScreen

RETScreen International is a unique tool that aids in decision-making processes for renewable energy sources. It is developed and managed by the Canadian government through the CANMET Energy Diversification Research Laboratory (CEDRL) (Thevenard et al, 2000; Mehmood et al, 2014; RETScreen, 2019).. The software, which is user-friendly and available in 37 languages, is used for feasibility analysis of clean energy projects, including solar photovoltaic, wind energy, and hydro projects (Lee et al, 2012). It follows a five-step assessment process, including cost evaluation, greenhouse gas assessment, financial overview, and sensitivity and risk analyses. The software serves decision-makers by facilitating the evaluation of a project's potential for swift and cost-effective implementation within the energy sector. The RETScreen International PV project model accurately gauges energy production, life-cycle costs, and greenhouse gas emissions for three primary PV applications: on-grid, off-grid, and water pumping (Mirzahosseini et al, 2012) (Mehmood et al, 2014; RETScreen, 2019; as indicated in Owolabi et al, 2019).

RETScreen Expert Worksheet

RETScreen Expert is a software that models various sustainable and unconventional energy sources, including energy efficiency, heating and cooling, and power generation. It includes three main analytical tools: Benchmark analysis, Feasibility analysis, and

Performance analysis. Benchmark analysis compares energy efficiency of standard facilities with actual energy usage, allowing designers, operators, and decision-makers to evaluate facilities and identify areas for improvement. The feasibility analysis strategy involves a five-step study, including energy, costs, emissions, finances, and sensitivity and risk, using benchmark, product, project, hydrology, and climate databases. Generally, the feasibility analysis strategy is adopted to answer and address the research question as follows.

a) Is switching to solar PV-BESS from Gas Generators in Nigerian shallow water oil fields technically viable?

b) Is switching to solar PV-BESS from Gas Generators in Nigerian shallow water oil fields economically viable?

c) What is the Emission reduction potential and benefits of switching to solar PV-BESS from Gas Generators in Nigerian shallow water oil fields?

Figure 3.4: RETScreen Expert project life workflow.

Source: RETScreen Expert Software, 2022.

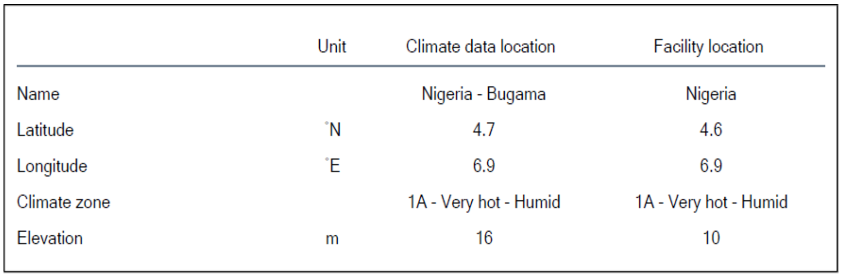
III. Result and Discussion

The dissertation uses RETScreen Expert to evaluate the feasibility of switching to Solar PV-BESS from Gas Generators in Nigerian shallow water oil fields. The study uses NASA database data and climatic data to estimate annual solar irradiation and monthly variation. Results presentation and feasibility analysis are discussed.

Technical Feasibility of the Proposed Case

The study area's location was obtained from RETScreen Expert, which helps retrieve climate data from a proxy location if the system cannot retrieve it, as shown in FIG 3.1.

Figure 3.1: Relative coordinates of the climate data and Facility location.

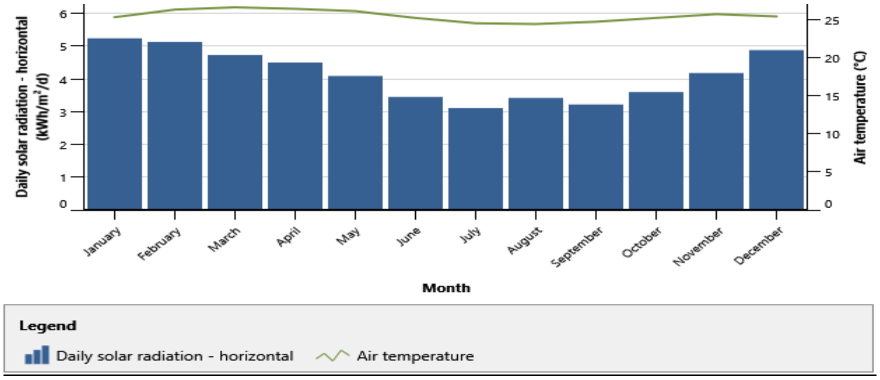


	Unit	Climate data location	Facility location
Name		Nigeria - Bugama	Nigeria
Latitude	˚N	4.7	4.6
Longitude	˚E	6.9	6.9
Climate zone		1A - Very hot - Humid	1A - Very hot - Humid
Elevation	m	16	10

Source: Author’s extract from RETScreen Expert, 2022.

Solar PV modules utilize potential energy primarily through solar irradiation and air temperature. A correlation matrix table reveals a significant relationship between air temperature and solar radiation, with a global scale direct relationship. An increase in solar radiation raises air temperature.

Figure 3.2: Climate Data of the study location for the proposed case



Source: Author's extract from RETScreen Expert, 2022.

In relation to the energy required for the study area base power supply, the cumulative solar irradiation annually, must be able to deliver electricity to the load with maximum level of degree of

confidence to ensure uninterrupted and reliable power supply in low sunny days are shown in Table 4.2.

Table 3.1: Solar PV module energy summary for the proposed case

Month	Daily Solar radiation - Horizontal kWh/m^2/d	Daily Solar radiation - tilted kWh/m^2/d	Electricity delivered to load kWh	Fraction of load delivered %
January	5.24	5.65	1,488,000.000	100
February	5.13	5.33	1,344,000.000	100
March	4.73	4.71	1,488,000.000	100
April	4.50	4.31	1,440,000.000	100
May	4.09	3.81	1,488,000.000	100
June	3.45	3.21	1,440,000.000	100
July	3.11	2.93	1,488,000.000	100
August	3.42	3.27	1,488,000.000	100
September	3.22	3.17	1,440,000.000	100
October	3.60	3.64	1,488,000.000	100
November	4.18	4.40	1,440,000.000	100
December	4.88	5.29	1,488,000.000	100
Annual	**4.12**	**4.14**	**17,520,000.000**	**100**

Source: Author's extract from RETScreen Expert, 2022.

Furthermore, the parametric characteristics of the solar PV modules was estimated by REScreen, providing the estimated results for the critical capital equipment for the proposed case targeted at delivering base and peak load for the study area as shown in Table 3.3.

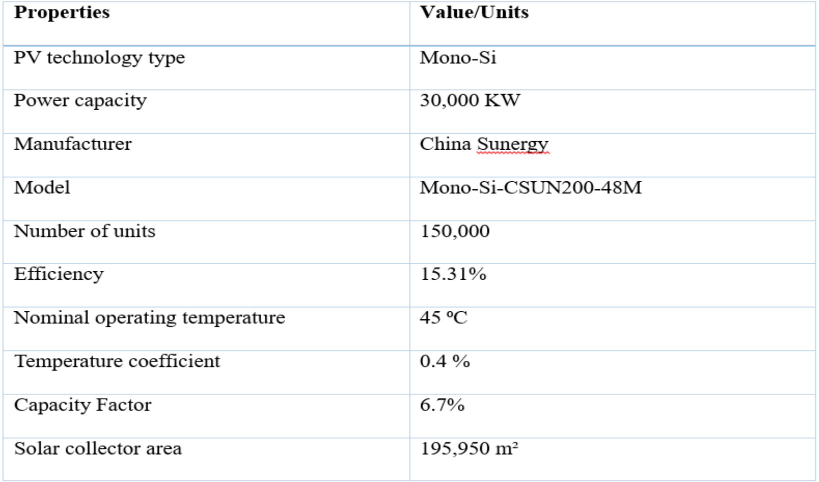
Table 3.2: BESS for the proposed case

Equipment	Capacity	Unit
Inverter	2120	kW
Battery	294466	kWh

Source: Author's extract from RETScreen Expert, 2022

Technical sustainability is crucial in engineering design, focusing on product specifications for efficiency and effective use. The study area in Nigeria's coastal region has greater potential for solar energy output than southern areas. RETScreen climatic data analysis showed uneven solar irradiation and air temperature, with low days and months affecting output. To maximize solar energy output, tilted daily solar irradiation is considered. The southern region of Nigeria has a solar radiation potential between 3.54 and 5.43 kWhm-2, with high annual output at 4.14 kWh/m2/d. The study considers a fixed solar tracking mode with a 15^{0} inclination solar PV module for optimal solar irradiance utilization, especially on low sunny days. The proposed case delivers 100% load supply to the facility, even on low sunny days, as per model simulation by RETScreen Expert software, as shown in the Parametric Characteristics of the China Sunergy mono-si-CSUN200-72MSolar PV Modules.

Table 3.3: Parametric Characteristics of the Solar PV Modules for the proposed case.



Properties	**Value/Units**
PV technology type	Mono-Si
Power capacity	30,000 KW
Manufacturer	China Sunergy
Model	Mono-Si-CSUN200-48M
Number of units	150,000
Efficiency	15.31%
Nominal operating temperature	45 ºC
Temperature coefficient	0.4 %
Capacity Factor	6.7%
Solar collector area	195,950 m²

Source: Author’s extract from RETScreen Expert, 2022

The solar irradiation and sunlit days significantly impact the electricity generation of a solar PV module, affecting the yearly cumulative energy delivered to the facility. The capacity utilization factor (CUF) determines the proportion of solar photovoltaic plants' annual electrical energy production (Khandelwal and Shrivastava, 2018).. The proposed case model simulated 150,000 solar PV panels and capacity to deliver a 100% load fraction on peak demand at 17,520,000 kWh annually. Libya has significant solar energy potential, with Al Jabal al Akhdar having the lowest power generation and Al Kufrah having the most. The project considers an inverter and battery backup type of inverter, which exports surplus energy and draws electricity from a battery (Kaseem et al, 2020). The battery's capacity is estimated at 294,466Ah with 98% efficiency and 3 days of autonomy.

Table 3.4: BESS for the proposed case

Equipment	Capacity	Unit
Inverter	2120	kW
Battery	294466	kWh

Source: Author’s extract from RETScreen Expert, 2022.

Economic Feasibility of the Proposed Case.

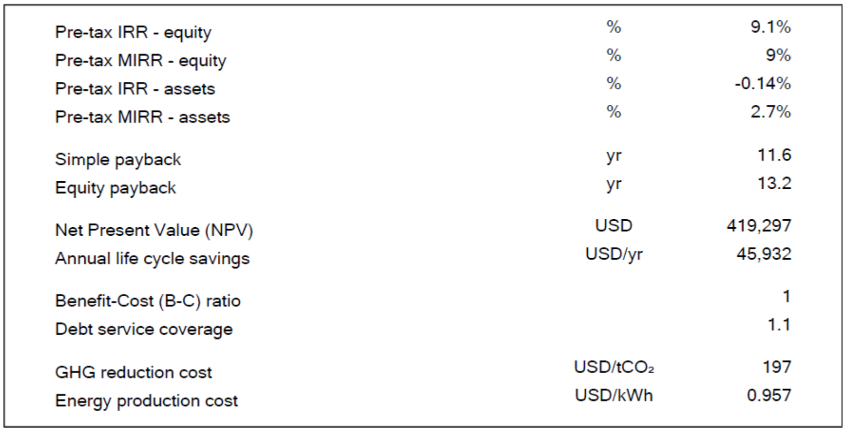
In modelling a techno-economic feasibility to switch from fossil fuels power generation technology to renewable energy technology, the economic and financial incentives is considered. The results are 3.4. presents an estimated economic outlook of the proposed case with key variables like the total initial cost of the project and its breakdown that requires further analysis in this work.

Figure 3.3: Cost, savings, and revenue estimations for the proposed case

Initial costs			
Power system	100%	USD	162,998,400
Total initial costs	100%	USD	162,998,400
Incentives and grants		USD	0
Yearly cash flows - Year 1			
Annual costs and debt payments			
O&M		USD	300,000
Debt payments - 15 yrs		USD	12,527,444
Total annual costs		USD	12,827,444
Annual savings and revenue			
Fuel cost - base case		USD	14,273,105
GHG reduction revenue - 15 yrs		USD	73,467
Other revenue (cost)		USD	0
Total annual savings and revenue		USD	14,346,572
Net yearly cash flow - Year 1		USD	1,519,128

Source: Author’s extract from RETScreen Expert, 2022

Figure 3.4: Financial outlook for the proposed case

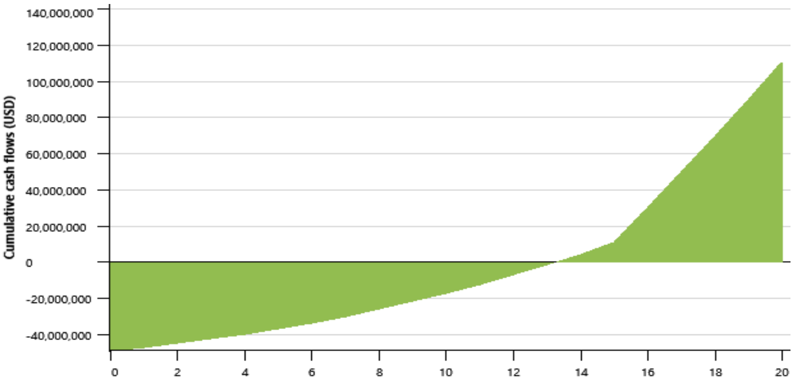


Pre-tax IRR - equity	%	9.1%
Pre-tax MIRR - equity	%	9%
Pre-tax IRR - assets	%	-0.14%
Pre-tax MIRR - assets	%	2.7%
Simple payback	yr	11.6
Equity payback	yr	13.2
Net Present Value (NPV)	USD	419,297
Annual life cycle savings	USD/yr	45,932
Benefit-Cost (B-C) ratio		1
Debt service coverage		1.1
GHG reduction cost	USD/tCO₂	197
Energy production cost	USD/kWh	0.957

Source: Author’s extract from RETScreen Expert, 2022

Furthermore, the financial outlook that basically informs money managers and key stakeholders is also presented in Figure 4.5. with key parameters like Internal Rate of Returns and Equity, payback, NPV, measurable benefits and LCOE of the proposed case that will be further analyzed in this session.

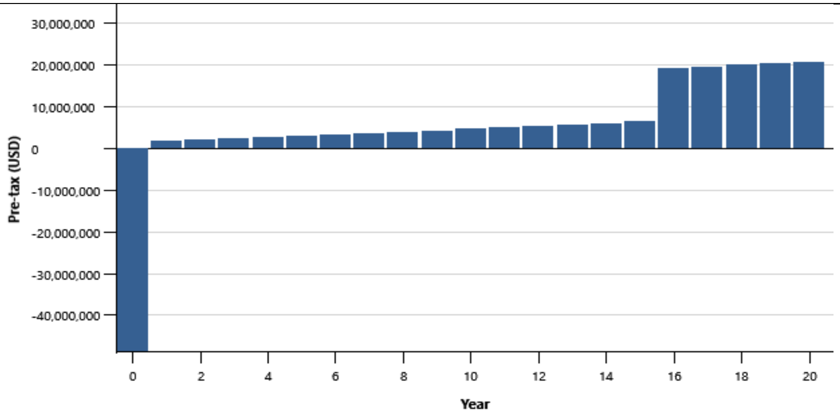
Figure 3.5: Cumulative Cashflow for the proposed case



Source: Author’s extract from RETScreen Expert, 2022

Other important results that are presented in graphs include the Annual and Cumulative cash flow of the proposed case with payback indicators as shown if Figure 3.5 and 3.6 to be analyzed.

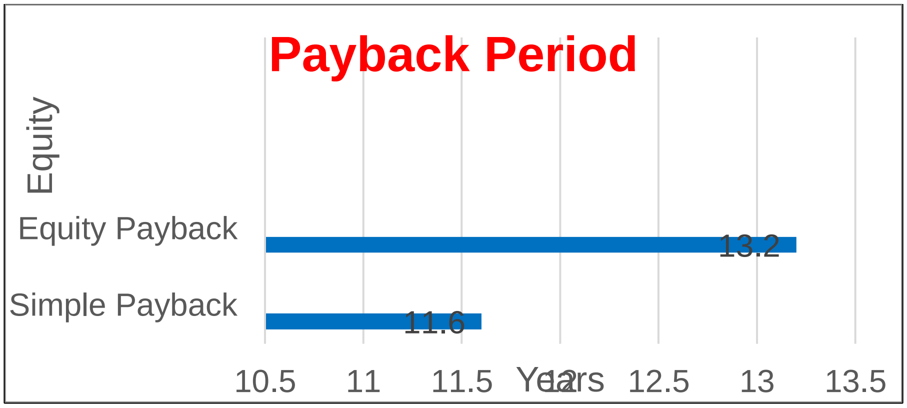
Figure 3.6: Annual Cashflow for the proposed case



Source: Author’s extract from RETScreen Expert, 2022

Economic viability is the potential economic potential of a solar photovoltaic project to address research questions. The RETScreen Expert software calculates critical financial parameters such as inflation rate, discount rate, reinvestment rate, project life, debt ratio, and debt interest. The project has an exorbitant initial cost of 162,786,500 USD due to high manufacturing costs and the need for more solar panels. The total land space required for the project is 195,950 m², equivalent to 48 acres or 218 plots of land in Nigeria. The Net Present Value (NPV) and Internal Rate of Return (IRR) are calculated at 419,217 USD and 9.1%, respectively. The NPV method surpasses the IRR method when evaluating projects that are mutually incompatible, as it relies on more realistic reinvestment rate assumptions, providing a more precise assessment of profitability and shareholder wealth (Rashwan et al, 2017; Rehman et al, 2017; Mehmood et al, 2014; Mirzahosseini and Taheri, 2012; Khandelwal and Shrivastava, 2017; Bosri, 2019. This makes the proposed case economically viable when considering the NPV and IRR.

Figure3.7 : Payback analysis of the proposed case



Source: Author’s extract from RETScreen Expert, 2022.

Financial managers consider the payback period when assessing investment feasibility, but it often overlooks the time value of money (Kagan et al, 2022). The proposed case requires 13.2 years equity payback and 11.6 years simple payback to regain its initial cost. This is a strong investment metric compared to a solar PV project in Nigeria with a 14.6-year payback period (Owolabi et al, 2019), making the proposed case more economically viable.

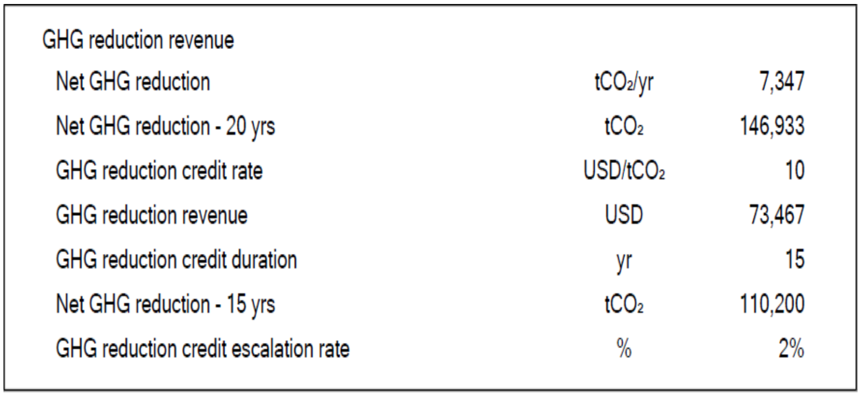
The proposed case's economic feasibility is assessed through annual life cycle savings estimated by RETScreen Expert software. Life cycle cost analysis (LCCA) provides a foundation for assessing supplementary costs and enhancing cash outflow management by foreseeing project requirements (Corporate Finance Institute, 2022).

The proposed case's benefit-cost ratio (BCR) was estimated using RETScreen Expert software, indicating that the project's cost is equal to its benefit. The BCR result is 1, indicating the project is economically viable. The energy production cost was estimated using discounted energy delivered and cashflow analysis, with the LCOE of the proposed case being 0.956 USD/kWh, indicating it is expensive for the study area. The proposed case is not a hybrid solution, as alternative energy sources may not significantly reduce energy production costs. The operating and maintenance cost is relatively low at 300,000 USD, covering the project's life span. Overall, the economic and financial outputs from RETScreen Expert software suggest the project is profitable and economically viable.

Emission Reduction Feasibility of the Proposed Case.

The proposed case's greenhouse gas emission reduction is calculated using RETScreen Expert software, which also estimates potential sales revenue from these reductions.

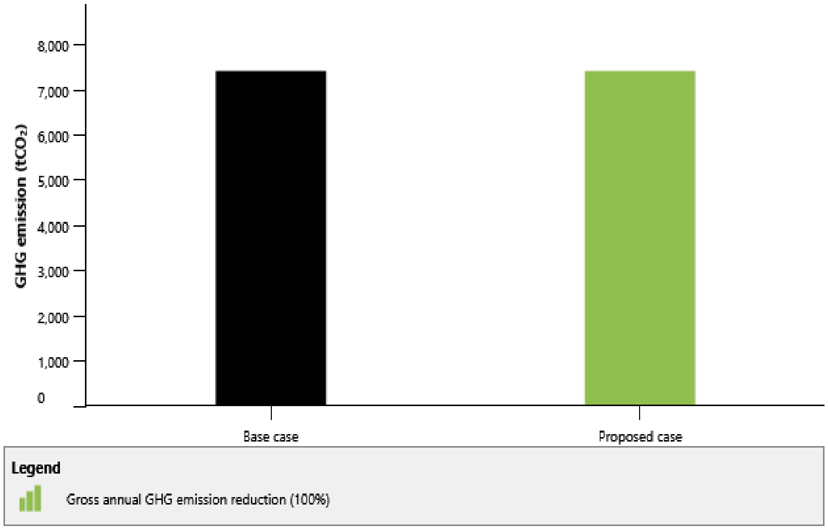
Figure 3.8: Annual GHG Emission revenue of the proposed case



GHG reduction revenue		
Net GHG reduction	tCO_2/yr	7,347
Net GHG reduction - 20 yrs	tCO_2	146,933
GHG reduction credit rate	USD/tCO_2	10
GHG reduction revenue	USD	73,467
GHG reduction credit duration	yr	15
Net GHG reduction - 15 yrs	tCO_2	110,200
GHG reduction credit escalation rate	%	2%

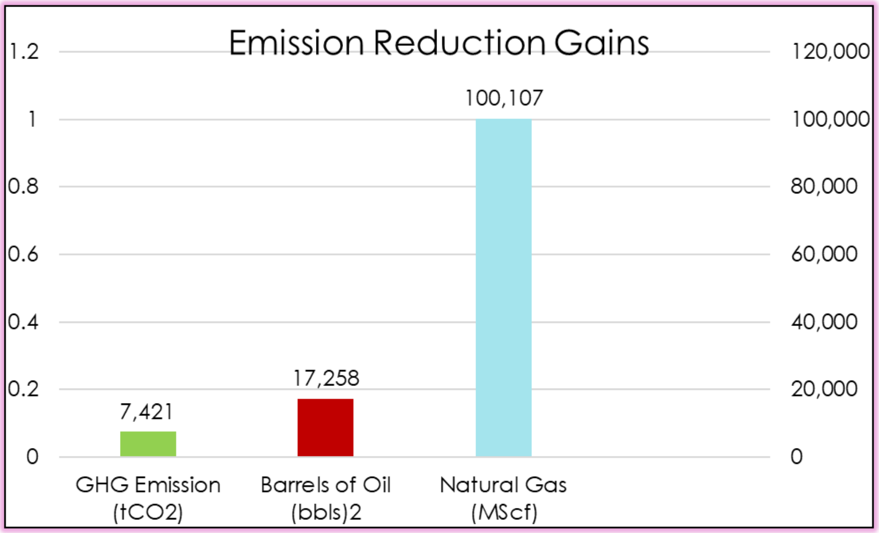
Source: Author’s extract from RETScreen Expert, 2022

Figure 3.9: Gross GHG Emission Comparative report for both the base and proposed case



Source: Author’s extract from RETScreen Expert, 2022

Figure 3.10: Gross GHG Emission benefits of the proposed case



Source: Author’s extract from RETScreen Expert, 2022

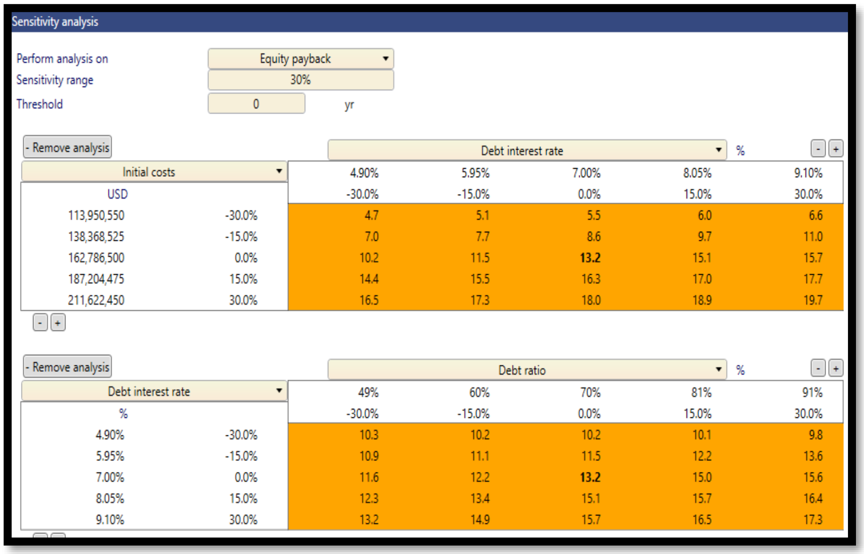
This study assesses the emission reduction feasibility of a proposed renewable energy solution in a study area. The proposed case reduces greenhouse gas emissions by 100%, equivalent to a reduction of 7,420.9 tCO2 of emissions. This reduction is equivalent to 100,107 Mscf of natural gas and 17,258 barrels of oil in the oil and gas industry. The project also saves over 600 hectares of forest, serving as a carbon sink. The study aligns with the United Nations' Sustainable Development Goals (SDGs), which aim to address challenges like poverty eradication, hunger mitigation, climate change adaptation, inclusive growth promotion, and sustainable management of natural resources by 2030.

The proposed carbon trading scheme in Africa aims to increase revenue through carbon tax and trading, with a credit rate of 10 USD/tCO2 for GHG reduction. The scheme is still in its early stages, and governments are urged to expand coverage to mitigate global warming. The GHG emission reduction credit duration is 15 years, with escalation and transaction rates of 2% and 1% respectively. Transaction costs in forest carbon initiatives vary, with insurance accounting for 41-89% of total expenditures, monitoring accounting for 3-42%, and regulatory approval accounting for 8-50%. The study suggests that more revenue can be generated throughout the project's life, making it more economically and environmentally sustainable.

Sensitivity Analysis

The project's uncertainty is influenced by input variables' variability, affecting calculated financial parameters. The RETScreen Expert software's sensitivity analysis worksheet helps adjust this uncertainty. The analysis manipulated equity payback and debt interest rate against initial project cost, with variations of ±30%. The chosen financial parameters were based on existential funding bottlenecks in the Nigerian upstream sector.

Figure 3.11: Sensitivity assessment result for the proposed case



Perform analysis on: Equity payback
Sensitivity range: 30%
Threshold: 0 yr

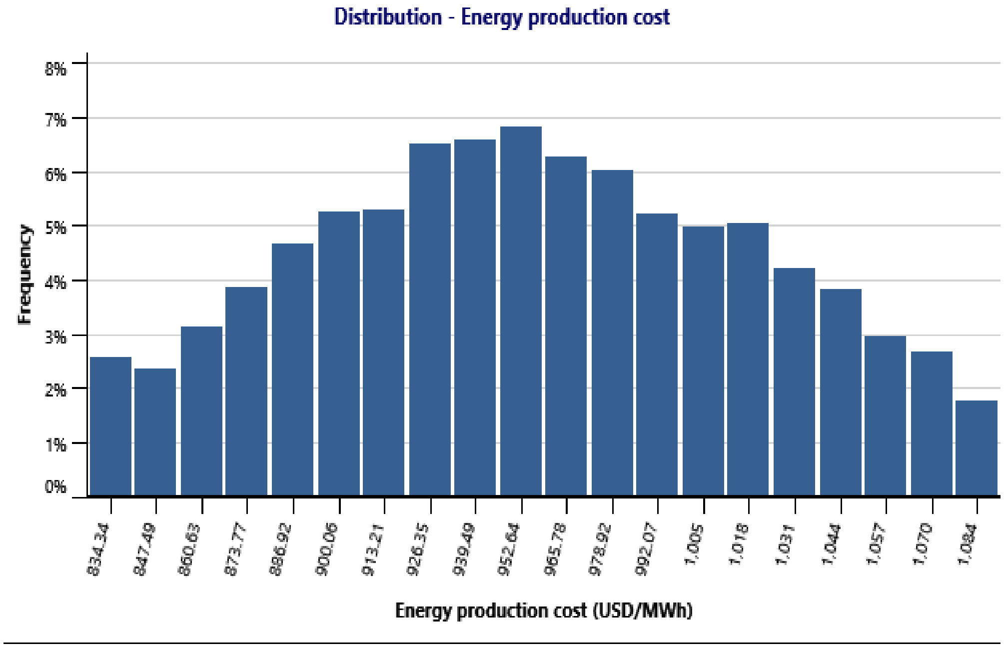
Initial costs		Debt interest rate %				
		4.90%	5.95%	7.00%	8.05%	9.10%
USD		-30.0%	-15.0%	0.0%	15.0%	30.0%
113,950,550	-30.0%	4.7	5.1	5.5	6.0	6.6
138,368,525	-15.0%	7.0	7.7	8.6	9.7	11.0
162,786,500	0.0%	10.2	11.5	**13.2**	15.1	15.7
187,204,475	15.0%	14.4	15.5	16.3	17.0	17.7
211,622,450	30.0%	16.5	17.3	18.0	18.9	19.7

Debt interest rate		Debt ratio %				
		49%	60%	70%	81%	91%
%		-30.0%	-15.0%	0.0%	15.0%	30.0%
4.90%	-30.0%	10.3	10.2	10.2	10.1	9.8
5.95%	-15.0%	10.9	11.1	11.5	12.2	13.6
7.00%	0.0%	11.6	12.2	**13.2**	15.0	15.6
8.05%	15.0%	12.3	13.4	15.1	15.7	16.4
9.10%	30.0%	13.2	14.9	15.7	16.5	17.3

Source: Author’s extract from RETScreen Expert, 2022

The project's initial cost is estimated to be 162,786,500 USD with a 30% sensitivity without a tenure threshold. The sensitivity values are 113,950,550 USD and 211,622,450 USD, respectively. The actual debt interest rate is 7%, but with a 30% sensitivity, it would be 9.10% and 4.90%. The sensitivity simulation shows that an increase in initial cost and a decrease in debt interest rate will increase the equity payback period to 16.5 years, 6.6 years, 14.4 years, and 9.7 years.

Figure 3.12: Risk assessment result for Distribution analysis for the proposed case



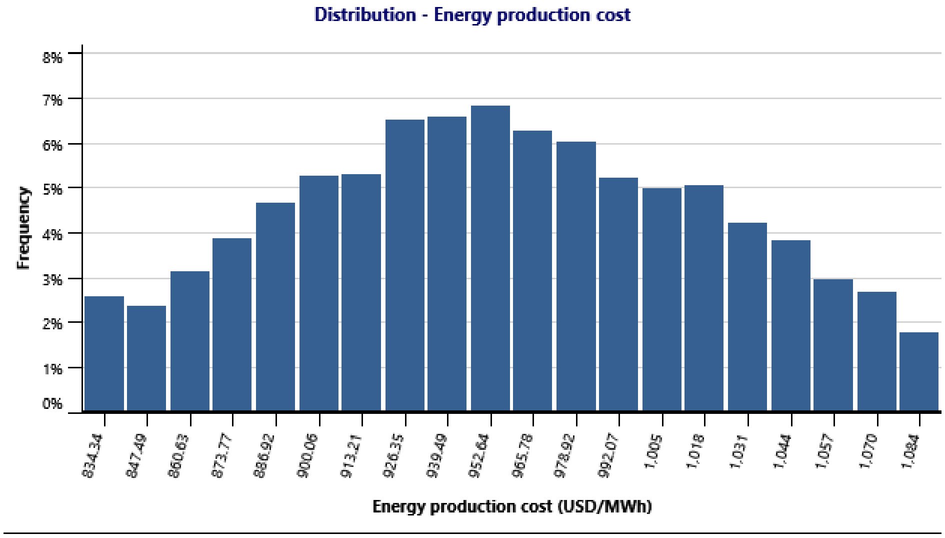
Source: Author's extract from RETScreen Expert, 2022

In Plot 2, the debt interest rate and debt ratio are compared, revealing that an increase in debt interest rate and a decrease in ratio will increase the equity payback period to 13.2 years, while a decrease in interest rate and ratio will reduce it to 9.8 years, making the proposed case economically viable.

Risk Analysis

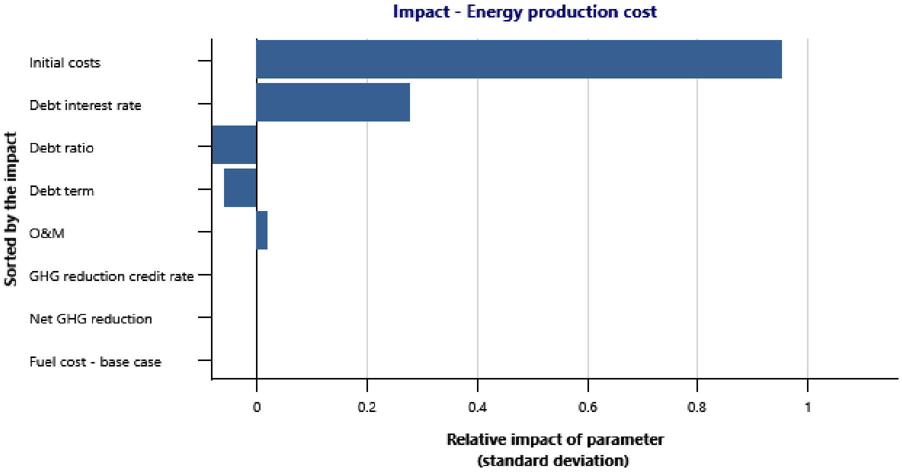
Risk analysis is a crucial decision-making process in renewable energy projects, allowing for parameter variation within a defined range. It differs from sensitivity analysis, which relies on two parameters. The energy production cost is considered, with a 25% range. Monte Carlo simulation techniques are used to calculate energy production costs.

Figure 3.12: Risk assessment result for Distribution analysis for the proposed case



Source: Author's extract from RETScreen Expert, 2022

Figure 3.13: Risk assessment result for Impact analysis for the proposed case



Source: Author’s extract from RETScreen Expert, 2022

The impact graph shows that changes in parameters cause fluctuations in energy production costs. An increase in initial costs leads to an increase, while an increase in GHG reduction credit rate mitigates this. The distribution graph shows a 10% risk level, indicating the proposed case is economically viable.

IV. Conclusions

The IPCC report of 2022 warns of a global warming of 1.5°C within two decades, urging companies to reduce carbon emissions, particularly in power generation. This study aims to provide an uninterrupted power solution in Nigerian shallow water oil fields by assessing the techno-economic and environmental sustainability of switching to solar PV-BESS from gas generators. The study suggests that upstream operators and financial managers should invest in renewable energy to reduce carbon emissions in power generation.

Recommendations

Power Generation technologies is critical to sustain and improve the supply of crude oil and natural gas that propels the global economy. On the other hand, the choice of fuel and technology is vital in recent discourse to provide clean energy and reduce carbon emissions that has adversely impacted planet earth over the years. However, the dilemma between cost of renewable power generation and reduction of carbon emission remains a puzzle for specific discussions. This dissertation proposed enabling polices and strategies of switching to solar PV-BESS from Gas Generators in Nigerian shallow water oil fields. A technical, Economic/Financial, and Emission reduction strategies will be discussed and proposed in the section, that may be most effective in Nigeria.

Strategic Collaboration with Relevant Industry stakeholders

The study focuses on the exorbitant initial cost of solar panel installation in the Nigerian Oil and Gas industry. To reduce the project's initial cost, the Nigerian Upstream Petroleum Regulatory Commission (NUPRC) should form strategic partnerships with university subject experts to conduct research on solar panel development. These research programs can be co-funded by NUPRC and E&P companies, as scientific research produced by universities is crucial for scientific advancements (Fleming et al., 2019; Poege et al., 2019). Nigeria's abundant silicon resources can also be utilized to promote local solar panel manufacturing. For example, NASENI Solar Energy Limited (NSEL), a company under the National Agency for Science and Engineering Infrastructure (NASENI), has a solar PV module manufacturing facility with an annual capacity of 7.5 MW. The facility aims to create new businesses, generate income, develop capacity, and transfer technology.

Central Bank of Nigeria and International Lenders Initiatives

Solar Energy Projects have experienced significant growth in capacity additions, with a record 150 GW installed in 2021 (EIA, 2022). This rapid global solar energy penetration is attributed to robust financing schemes from international money lenders. The Central Bank of Nigeria (CBN) has sponsored the Solar Connection Facility Scheme, aiming to enhance energy accessibility for 25 million individuals by establishing 5 million fresh connections. The scheme focuses on solar home systems and mini grid integration, fostering local involvement in the off-grid solar value chain and expanding the domestic manufacturing sector. It also aims to create 250,000 new jobs within the energy sector. The Oil and Gas sector can benefit from the scheme, which supports the production of solar components, assembly, repair, maintenance, and research and development. The CBN can designate activities within the off-grid solar value chain, providing flexibility for the industry's evolving needs. The Multilateral Investment Guarantee Agency (MIGA) can also be leveraged for solar PV funding, with a portfolio of $6.6 billion as of FY21. MIGA projects have successfully reduced 10.8 million tons in annual greenhouse gas emissions between 2015 and 2021.

Carbon Market Schemes in the Petroleum Industry

Emission reduction from power generation technologies is crucial for combating climate change. Countries like the European Union and Asian countries like China and South Korea have adopted carbon trading as an incentive for emission reduction programs. Carbon markets are trading systems were buying and selling carbon credits occur. Compliance markets are set by national, regional, or global policies, while voluntary markets involve the voluntary issuance, acquisition, and exchange of carbon credits. This study presents voluntary carbon markets as a policy to maximize the economic potential of carbon trading schemes in Nigeria's oil and gas power generation sector. The Nigerian voluntary carbon market could generate 30 million carbon credits annually by 2030, amounting to $500 million annually.

Contribution to the body of Knowledge

So far, much work have been done for several power generation technological choices in Oil fields across the world, most especially (Edalata, Salehib, and Shahriaric, 2019) research on the Techno-Economic Assessment of Power Supply in Offshore Platforms by Renewable and Conventional Sources using Wind Energy Technology.

However, in this study, I tried to shift focus to an alternative renewable energy source like Solar PV-BESS, due to the peculiarity of the study area.

Also, this study proffered a shift in focus on the method of analysis, from HOMER Pro software that was previously used by some researchers to RETScreen Expert software.

In all, this study created new perspective for the study area, power generation technology, and method of analysis which serves as a vast contribution to the body of knowledge.

References

1. Akintoye, O., (2022). Oil exports account for 80% total national revenue. Retrieved from: https://punchng.com/oil-exports-account-for-80-total-national-revenue/
2. Black, S., Parry, I., Zhunussova, ., (2022). More Countries Are Pricing Carbon, but Emissions Are Still Too Cheap. Retrieved from; More Countries Are Pricing Carbon, but Emissions Are Still Too Cheap. Retrieved from: https://www.imf.org/en/Blogs/Articles/2022/07/21/blog-more-countries-are-pricing-carbon-but-emissions-are-still-too-cheap
3. Blaufelder, C., Levy, C., Mannion, P., and Pinner, D. (2021). A blueprint for scaling voluntary carbon markets to meet the climate challenge. Retrieved from: https://www.mckinsey.com/capabilities/sustainability/our-insights/a-blueprint-for-scaling-voluntary-carbon-markets-to-meet-the-climate-challenge
4. Bosri, R., (2019). Evaluation of Managerial Techniques: NPV and IRR. *UITS Journal* Volume:5 Issue: 1. Retrieved from: https://uits.edu.bd/wp-content/uploads/2019/06/04-Evaluation-of-Managerial-48-57.pdf
5. Bosri, R., (2019). Evaluation of Managerial Techniques: NPV and IRR. *UITS Journal* Volume: 5 Issue: 1. Retrieved from: https://uits.edu.bd/wp-content/uploads/2019/06/04-Evaluation-of-Managerial-48-57.pdf
6. Central Bank of Nigeria, (2020). Framework for Implementation of the Solar Connection Facility. Retrievedfrom:https://www.cbn.gov.ng/out/2020/dfd/solar%20connections%20facility%20guidelines%201.0.pdf
7. Chandel, M., Agrawal, G.D., Mathur, S., and Mathur, A., (2014). Techno-economic analysis of solar photovoltaic power plant for garment zone of Jaipur city. Case Stud Therm Eng 2014;2:1–7. https://doi.org/10.1016/j.csite.2013.10.002.
8. Corporate Finance Institute, (2022). Life Cycle Cost Analysis. Retrieved from: https://corporatefinanceinstitute.com/resources/accounting/life-cycle-cost-analysis/ http://www.leonics.com/ support/article2 12j/articles2 12j en.php (accessed
9. Dioha, M., (2022). Making Nigeria's Energy Transition Plan A Reality. Retrieved from: https://www.energyforgrowth.org/memo/making-nigerias-energy-transition-plan-a-reality/
10. Dioha, M.O, (2022). Nigeria's energy sector emission profile in 2020. *Carnegie Institution for Science, Stanford*. Retrieved from*:* Making Nigeria's energy transition plan a reality (energyforgrowth.org)
11. E.A.Abdelaziz[a] R.Saidur S.Mekhilef[b] (2011). A review on energy saving strategies in industrial sector. *Renewable and Sustainable Energy Reviews*. Vol. 15. Issue. 1. Page150 165 Retrieved from: https://doi.org/10.1016/j.rser.2010.09.003
12. Edalati, S., Ameri, M., Iranmanesh, M., & Tarmahi, H. (2016) "Technical and economic assessments of grid-connected photovoltaic power plants : Iran case study. Energy 2016;114:923e34. https://doi.org/10.1016/j.energy.2016.08.041.
13. Eghbal, M., Hejazi, H., Maréchal, F., & Royapoor, M. (2019). A review on waste heat recovery from exhaust in the oil and gas sector. Journal of Cleaner Production, 237, 117734.
14. Elsayed, A. T., and Mohammed, O. A., (2013). Design control and management of PV system forEnergies, 15 (2022), p. 828
15. Energy Agency, Technical; 2017. 1016/j.rser.2012.01.0661109/PVSC.2000.916211.2017) 2018. p. 1–6. https://doi.org/10.1109/ICOMICON.2017.8279175.218.

16. Ganoe, R. E., Stackhouse Jr, P. W., and DeJong, R. J., 2014. RETScreen Plus Software Tutorial. *Langley Research Center, Hampton, Virginia.* 23681-2199. Retrieved from: https://ntrs.nasa.gov/api/citations/20150000447/downloads/20150000447.pdf
17. Hayes, A., (2022). Benefit-Cost Ratio (BCR): Definition, Formula, and Example. Retrieved from: https://www.investopedia.com/terms/b/bcr.asp#:~:text=If%20the%20BCR%20is%20equal,it%20should%20not%20be%20considered.
18. Hayward, R., (2022). The Dark Side of Renewable Energy. Hayward Environmental Consulting.Retrievedfrom:https://www.hechayward.com/the-dark-side-of renewableenergy/#:~:text=The%20biggest%20dark%20side%20of,our%20electricity%20from%20solar%20panels.
19. Heyard, R. and Hottenrott, H., (2021). The value of research funding for knowledge creation and dissemination: A study of SNSF Research Grants. *Humanities and Social Sciences Communications*. volume 8, Article number: 217. Retrieved from; https://www.nature.com/articles/s41599-021-00891-x How to Design Solar PV System - Guide for sizing your solar photovoltaic system n.https://doi.org/10.1016/j.rser.2017.05.233.
20. Hussein BN. Introducing a PV design program compatible with Iraq conditions. Energy Procedia 2013;36:852–61. https://doi.org/10.1016/j.egypro.2013.07.098.
21. Hussein, B. N., (2013). Introducing a PV design program compatible with Iraq conditions. Energy Procedia 2013;36:852–61. https://doi.org/10.1016/j.egypro.2013.07.098.
22. Ibrahim, K.A., Gyuk, P. M., and Aliyu, S., (2019). The Effect of Solar Irradiation on Solar Cells. *Science World Journal* Vol 14(No 1) 2019. Retrieved from: https://www.ajol.info/index.php/swj/article/view/208351/196389 International Energy Agency (IEA). Independent Statistics & Analysis. International
23. Jennifer, L., (2022). Nigeria Pioneers a Billion-Dollar Voluntary Carbon Market. Retrieved from: https://carboncredits.com/nigeria-billion-dollar-voluntary-carbon-market/
24. Kagan, J., Drury, A., and Clarine, S., (2022). Payback Period Explained, With the Formula and How to Calculate It. Retrieved from: https://www.investopedia.com/terms/p/paybackperiod.asp#:~: text=The%20payback%20period%20is%20calculated,the%20time%20value%20of%20money.
25. Kassem, Y., Camur, H., and Abughinda, O. A. M., (2020). Solar Energy Potential and Feasibility Study of a 10MW Grid-connected Solar Plant in Libya. *Engineering, Technology & Applied Science Research* Vol. 10, No. 4, 2020, 5358-5366. Retrieved from: https://etasr.com/index.php/ETASR/article/download/3607/2295
26. Khandelwal, A., and Shrivastava, V., (2-17). Viability of grid-connected solar PV system for a village of Rajasthan. IEEE Int Conf Information, Commun Instrum Control (ICICIC
27. Khandelwal, A., and Shrivastava, V., (2-17). Viability of grid-connected solar PV system for a village of Rajasthan. IEEE Int Conf Information, Commun Instrum Control (ICICIC2017) 2018. p. 1–6. https://doi.org/10.1109/ICOMICON.2017.8279175.
28. Kong, L., Zhang, Y., Lin, Z., Qiu, Z., Li, C., and Le, P., (2020). Optimal design of the solar tracking system of parabolic trough concentrating collectors. *International Journal of Low-Carbon Technologies*, Volume 15, Issue 4, November 2020, Pages 613–619, https://doi.org/10.1093/ijlct/ctaa065
29. Lee, K. H., Lee, D. W., Baek, N. C., Kwon, H. M., and Lee, C. J., (2012). Preliminary determination of optimal size for renewable energy resources in buildings using RETScreen. Energy 2012;47:83–96. https://doi.org/10.1016/j.energy.2012.08.040.
30. Lucheroni, C., and Mari, C., (2016). Stochastic systemic LCOE: integration of not-dispatchable renewable power sources in the LCOE theory. *Research Gate*. (DOI: 10.13140/RG.2.1.3404.8729) https://www.researchgate.net/publication/305996463 (February 8, 2018)
31. Maribus, G., (2014). The World Ocean Review-Marine Resources Opportunities and Risks. Maribus Ggmbh, Hamburg, Germany, 978–3–86648–221–0; 2014. May 3, 2019).
32. McKenna, R., D'Andrea, M., Gonzalez, M. G., (2021). Analysing long-term opportunities for offshore energy system integration in the Danish North Sea. *Advances in Applied Energy 4 (2021) 100067.* DOI: https://doi.org/10.1016/j.adapen.2021.100067
33. Mehmood, A., Shaikh, F. A., and Waqas, A., (2014). Modelling of the solar photovoltaic systems to fulfill the energy demand of the domestic sector of Pakistan using RETScreen software. Int Conf Util Exhib Green Energy Sustainable Dev 2014;2014:1–7.
34. Mirzahosseini, A. H., and Taheri, M., (2012). Environmental, technical and financial feasibility study of solar power plants by RETScreen, according to the targeting of energy subsidies in Iran. Renewable Sustainable Energy Rev 2012;16:2806–11. https://doi.org/10.
35. Ogunjo, S. T., Adediji, A. T., Dada, J.B., (2017). Investigating chaotic features in solar radiation over a tropical station using recurrence quantification analysis. *Theoretical and Applied Climatology*. 2017;127(1-2):421-7.
36. Ogunjo, S. T., Obafaye, A. A., and Rabiu, A. B., (2021). Solar energy potentials in different climatic zones of Nigeria. *IOP Conf. Series: Materials Science and Engineering* 1032 (2020) Publishing doi:10.1088/1757-899X/1032/1/012040
37. OpenAI, 2017. Green Button. Retrieved from: Green Button | Open Energy Information (openei.org)

38. Owolabi, A. B., Emmanuel, B., Nsafon, K., & Roh, J. W. (2019), Validating the techno-economic and environmental sustainability of solar PV technology in Nigeria using RETScreen Experts to assess its viability. Sustain. Energy Technol. Assessments 2019;36:100542. https://doi.org/10.1016/j.seta.2019.100542.
39. Rashwan, S. S., Shaaban, A. M., and Al-Suliman, F., (2017). A comparative study of a small-scale solar PV power plant in Saudi Arabia. Renewable Sustainable Energy Rev 2017;80:313–8.
40. Rehman S, Ahmed MA, Mohamed MH, Al-Sulaiman FA. Feasibility study of the grid connected 10 MW installed capacity PV power plants in Saudi Arabia. Renewable Sustainable Energy Rev 2017;80:319–29. https://doi.org/10.1016/j.rser.2017.05.218.
41. Rehman, S., Ahmed, M, A., Mohamed, M. H., and Al-Sulaiman, F. A., (2017). Feasibility study of the grid connected 10 MW installed capacity PV power plants in Saudi Arabia. Renewable Sustainable Energy Rev 2017;80:319–29. https://doi.org/10.1016/j.rser.2017.05. residential applications with weak grid connection. 2013. p. 1–10. RETScreen | Natural Resources Canada n.d. https://www.nrcan.gc.ca/energy/
42. Sarvi, M., Shafiee, M., Rosen, M. A., & Dincer, I. (2020). A review of renewable energy utilization in the oil and gas industry. Renewable and Sustainable Energy Reviews, 119, 109604.
43. **Shrestha**, A. K., Thapa, A., and Gautam, H., (2019). Solar Radiation, Air Temperature, Relative Humidity, and Dew Point Study: Damak, Jhapa, Nepa. International Journal of Photoenergy. 2019. Retrieved from: https://doi.org/10.1155/2019/8369231
44. SOFO 2018 - The State of the World's Forests, (n.d.). http://www.fao.org/state-offorests/en/ (accessed July 2, 2019). software-tools/7465 (accessed May 3, 2019).
45. Solargis, 2020. Direct Normal Iraddiation (Nigeria). Retrieved from: Solar resource maps and GIS data for 200+ countries | Solargis
46. Stackhouse Jr, P. W., (2020). POWER. Retrieved from: https://power.larc.nasa.gov/docs/methodology/
47. Thevenard, D., Leng, G., and Martel, S., (2000). The retscreen model for assessing potential PV projects. Conf Rec IEEE Photovolt Spec Conf 2000. p. 1626–9. https://doi.org/10.
48. U.S. Environmental Protection Agency (n.d.). GHGRP Petroleum and Natural Gas Systems Sector Industrial Profile [PDF file]. Retrieved from https://www.epa.gov/ Wikipedia, 2022. Deep cycle battery. Retrieved from: https://en.wikipedia.org/wiki/Deep-cycle_battery