Impact of Photovoltaic (PV) Solar Power for Reducing Carbon Dioxide (Co_2) Emission in Kakuri Industrial Area, Kaduna

Suraj Aliyu*, Abubakar Kabir Tudun wada, Gambomi Abdulkadir and Abubakar Yusha'u

Department of Applied Physics, Kaduna Polytechnic Kaduna

***Corresponding Authors**

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ABSTRACT

This study offers a solar energy road map to entice investors to fund clean energy technology in Kaduna, Nigeria, which has abundant and underutilized solar energy. The goal is to both improve the region's sustainable technological development and lessen the impact of global warming caused by the burning of wood. Up order to do this, the techno-economic and environmental sustainability of putting up a grid-connected solar PV system in the area is verified using RETScreen Expert software. RETScreen Expert software aids in evaluating the financial viability of renewable energy projects through benchmark, feasibility, and performance analyses. It utilizes climate data, energy performance comparisons, and detailed financial assessments to provide a comprehensive evaluation. In designing a photovoltaic system for Kakuri Industrial Area in Kaduna, Nigeria, key considerations include PV module size, inverter and battery sizing, and energy demand calculations. A proposed 3MW system would cater to the energy needs of five industries, ensuring reliability even during cloudy days. The study also highlights the economic and environmental benefits, demonstrating significant potential for greenhouse gas emission reductions and financial returns. The project underscores the importance of thorough feasibility studies and sustainable design in implementing solar PV systems, showcasing their role in reducing reliance on fossil fuels and promoting renewable energy adoption.

Keywords: RETScreen, Photovoltaic cell, Solar energy, Carbon dioxide (Co_2).

INTRODUCTION

Sunlight is the most abundant energy source on Earth, and photovoltaic systems (PV) turn it directly into electricity. Their silent operation, flexibility in different weather conditions and installation settings, and lack of moving components are only a few of their many benefits. They also have a long lifespan and need little upkeep. Their ability to produce power without emitting greenhouse gasses or any other kind of gas emissions is perhaps their greatest asset. A photovoltaic cell is made up of two or more thin layers of primary silicon, a semiconducting semiconductor. Electrical charges are produced when they are exposed to light, and these charges are carried away as DC current by metal contacts. Since a single cell often produces very little electricity, several cells are connected in series and parallel to generate the necessary current and voltage. These cells are then typically enclosed in a glass cover and plastic sheet to form a module that is commonly referred to as a panel [4].

The process of converting light into electricity using semiconducting materials that display the photovoltaic effect is known as a photovoltaic (PV) cell. The photovoltaic effect is a phenomena that is economically used for the production of electricity and photosensors in the fields of physics, photochemistry, and electrochemistry. PV cells are put together into flat plate systems that are installed in various locations or other sunny areas. They produce power without the need for moving components, run silently and emit no emissions, and require no upkeep. Usually, a single solar cell can provide one to two watts. A module is created by connecting multiple cells together to improve the power output. Small rooftop residential systems

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(less than 10 kWe), medium-sized systems (10 to 100 kWe), and larger systems (more than 100 kWe) connected to utility distribution feeders are the three types of photovoltaic systems that are available.

MATERIALS AND METHODS

RETScreen Expert Worksheet

With a study that spans the project life cycle, RETScreen software is used to assess if a renewable energy project makes financial sense. Benchmark analysis, feasibility analysis, and performance analysis are its three main analytic techniques.

Benchmark analysis workflow

By creating reference climate conditions at a facility site for any location on Earth, the benchmark worksheet enables the user to quickly assess a facility's energy performance. It does this by comparing the energy performance of different types of reference facilities with the estimated or measured annual energy consumption of the same facility. The two worksheets under the benchmark are the location worksheet and the facilities worksheet.

Feasibility analysis workflow

A thorough and in-depth examination is completed in the feasibility analysis worksheet. Through the use of a five-step standard study that includes energy, cost, emission, financial, and sensitivity/risk analysis, users are able to simulate any clean energy project. The worksheet includes links to global energy resource maps, a comprehensive database of clean energy project templates that is completely integrated with individual case studies, and databases for benchmarks, products, projects, hydrology, and climate.

Performance analysis workflow

With the use of the performance analysis worksheet, facility operators, managers, and senior decision-makers may keep an eye on, evaluate, and report on important energy performance data, such as the difference between the facilities actual and expected energy performance. The spreadsheet tracks a facility's actual energy performance against its expected performance using advanced regression and predictive models that account for normalized energy performance based on varying characteristics, such as weather data obtained from NASA.

Design Parameters for a Photovoltaic Solar System

This chapter discusses the design process, constraints, and technical details of the photovoltaic system under consideration for the solar PV project at Kakuri Industrial Area, Kaduna. This includes the size of the PV modules, the inverter, the batteries, the power generation factor, the energy demand, and the amount of energy from solar PV. For the project, a 3MW photovoltaic solar system is suggested to power five (5) industries.

Power generating factor

Panel generation factor (PGF) is a significant component taken into account when sizing solar photovoltaic technology based on the system's total peak wattage. The formula below is used to determine Nigeria's PGF, which comes out at 3.41.

$$Panel\ Generation\ Factor = \frac{Solar\ irradiance \times Sunshine\ hours}{Standard\ test\ conditions\ irradiance}$$

Energy demand

Calculating the total power and energy consumption of all loads that the system would supply for each enterprise or home is the first stage in developing a solar PV system. This number is then added together to

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determine the project's overall energy demand (Elsayed and Mohammed 2013). The power estimate for an average 5 industries in Kakuri area Kaduna, Nigeria are 68493 Wh/day, 41095 Wh/day, 178082 Wh/day, 123287.67 Wh/day and 136986 Wh/day respectively. This gives a total watt-hour per day of 547944 which is the energy that is needed by the 5 industries.

Solar PV energy required

The total Watt-hour required from the PV modules each day, or the peak energy requirement, is determined by multiplying the energy lost in the system by the total Watt-hour required for each of the five (5) industries. This is the amount of energy that the PV module must create.

- Peak energy requirement = 547944
- Energy lost in the system = 1.3
- Energy required from PV modules=547944× 1.3 = 712,327.2 Wh/day

PV module sizing

The first step in determining the necessary size of the photovoltaic modules is to estimate the overall Watt-peak rating for the PV modules, using the formula below.

$$Total\ Watt\ peak\ rating = \frac{Solar\ PV\ energy\ required}{Panel\ generation\ factor}$$

Subsequently, the size of the PV module is determined by dividing the total watt peak rating by the PV output power rating, as indicated by the formula below. Taking into account the China Sunergy mono-si-CSUN200-72M, which has an output power rating of 200 W, this results in a solar module of 30,000.

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

Inverter sizing

Any solar PV project's inverter size is determined by multiplying the total wattage of energy utilized by the safety factor [2], and the result is displayed below.

Peak energy requirement = 547.944 kW

Factor of safety = 1.3 [2]

Inverter size=547.944×1.3 = 712.3272 kW

For this project, a 2,564-digit Digital Luminous Inverter rated at 10 kVA/180 V is taken into consideration, with a power factor of 0.8 used when converting kVA to kW.

Battery sizing

Using the formula below, the deep-cycle battery's Ampere-hour capacity for each of the industries is rated at 24 V 1230 Ah.

$$CB = \frac{Daily\ power\ consumption\ \times Days\ of\ autonomy}{Battery\ efficiency\ Depth\ of\ discharge\ \times Battery\ nominal\ voltage}$$

Where the battery efficiency is 0.85, the battery nominal voltage is 24 V, the battery depth of discharge is 0.6, and the daily power consumption is 547.944 kW. There are also three days of autonomy. Deep cycle batteries with low energy level discharge specifications are advised for solar energy projects. The energy storage system's main component, the lead acid battery, needs to be big enough to hold enough energy to run the entire

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building or all of the appliances at night and on cloudy days in order to prevent power outages from the solar photovoltaic system [1, 2].

RESULTS AND DISCUSSION

The feasibility of setting up a 3MW grid-connected solar photovoltaic system at Kakuri Industrial Area, Kaduna, Nigeria, was evaluated using RETScreen Expert software. Using information from the National Aeronautics and Space Administration (NASA) as mentioned in Table 2. An extensive feasibility study reveals the outcome of the risk/sensitivity, technical, economic, and environmental analyses.

Table 1: Average Daily Power Consumption of the industries (Wh/day)

S/N	Industries	Daily Power Consumption (Wh/day)
1	Nigerian-German Chemicals PLC	68493
2	Green Camel Energy	41095
3	Peugeot Automobile Nigeria and Chanchangi Motors Ltd	178082
4	Seven Up Bottling Company	123287.67
5	Nigeria Breweries	136986

Table 2: Climatic data of the location

Latitude	10.5
Longitude	7.4
Elevation (m)	615
Heating design Temperature (℃)	17.5
Cooling design Temperature (℃)	32.8
Earth Temperature amplitude (℃)	14.1
Average monthly radiation ($KWh/m^2/d$)	5.64

Economic sustainability

An essential step in determining if a solar PV project will be financially feasible and sustainable is the economic analysis. As demonstrated in Table 4, the software's financial analysis worksheet includes the following financial characteristics as input variables: inflation rate, discount rate, reinvestment rate, debt ratio, and debt interest rate. The starting cost and the manually entered operation and maintenance costs are not included in the standards that are used as input variables; instead, they are obtained directly from the program. The RETScreen software determined the Internal Rate of Return (IRR), Net Present Value (NPV), annual life savings, and other financial characteristics based on the supplied inputs, as indicated in Table 5.

As per reference [5], the NPV, IRR, and payback period of a project are indicators of its economic viability. The project is financially and economically feasible since the net present value (NPV) for the industrial region

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over a given period of time is positive and represents the difference between the present value of cash inflows and outflows [5, 6, 7, 8, 9]. Furthermore, the industrial area's project's necessary rate of return is less than the project's internal rate of return (IRR), which is a measure of a project's profitability [5, 7]. When the required rate of return for the project is taken into account along with the discount rate, this renders the projects in the area economically reasonable.

As shown in Fig. 1, the simple payback period represents the amount of time needed to recover the project's original investment in the Kakuri industrial area of Kaduna. The planned photovoltaic project in Kakuri Industrial area, Kaduna State, has an equity payback duration of 1.2 years and a payback period of 3 years. It is financially sensible to install solar PV systems throughout the industrial area.

This essentially indicates that for 18.8 years, the project will generate interest in the Kakuri industrial area of Kaduna. Table 6 and Fig. 2 illustrate the profit that the industrial location will accrue following the project's complete cost recovery.

Table 3: Cost/Savings/Revenue

Initial cost	
Incremental initial costs 100%	$174,929
Total costs	**$174,929**
Annual costs and debt payments	
O&M costs (savings)	$3,477
Fuel cost-proposed case	$248,400
Debt payments - 15 years	$13,444
Total annual costs	**$265,322**
Annual savings and revenue	
Fuel cost - base case	$309,548
Total annual savings and revenue	**$309,548**

Table 4: Financial input variables from RETScreen Expert

Fuel cost escalation rate	2%
Inflation rate	2%
Discount rate	9%
Project life	20 yrs.
Debt ratio	70%
Debt	$122,450
Equity	$52,479

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Debt interest rate	7%
Debt term	15 yrs.
Debt repayment	$13,444/yrs

Table 5: Financial output variables from the RETScreen Expert

Pre-tax IRR - Equity	89.1%
Pre-tax IRR - Assets	28.3%
Simple payback	3 years
Equity payback	1.2 year
Net Present Value (NPV)	$456,681
Annual life cycle savings	$50,028/yr
Benefit-Cost (B-C) ratio	9.7
Debt service Coverage	4.4

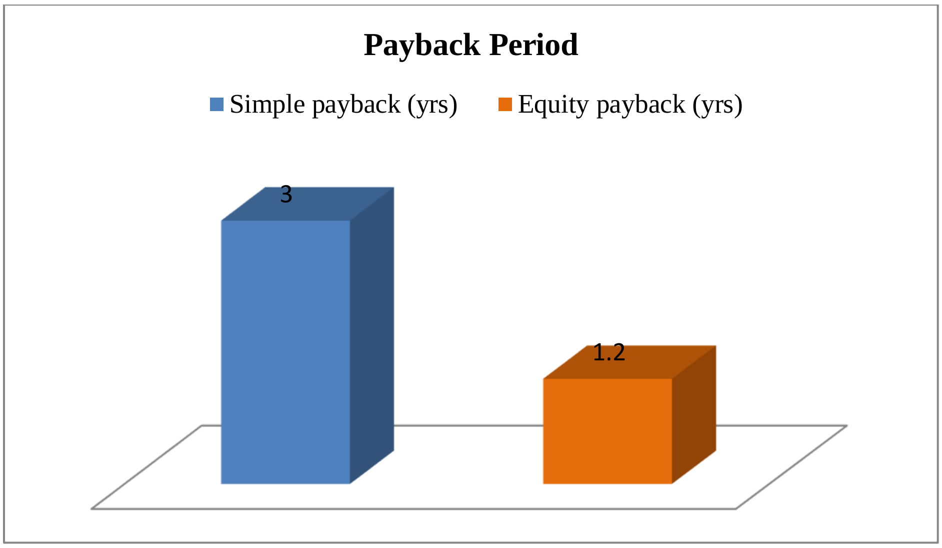

Fig. 1: The project payback period for the Kakuri industrial area Kaduna

Table 6: Yearly cash flow

Year	Pre-tax ($)	Cumulative ($)
0	-52478.7	-52478.7
1	45379.23	-7099.47
2	46555.7	39456.22

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3	47755.7	87211.92
4	48979.7	136191.6
5	50228.18	186419.8
6	51501.63	237921.4
7	52800.56	290722
8	54125.45	344847.5
9	55476.85	400324.3
10	56855.28	457179.6
11	58261.27	515440.9
12	59695.38	575136.2
13	61158.18	636294.4
14	62650.23	698944.6
15	64172.12	763116.8
16	79168.84	842285.6
17	80752.21	923037.8
18	82367.26	1005405
19	84014.6	1089420
20	85694.89	1175115

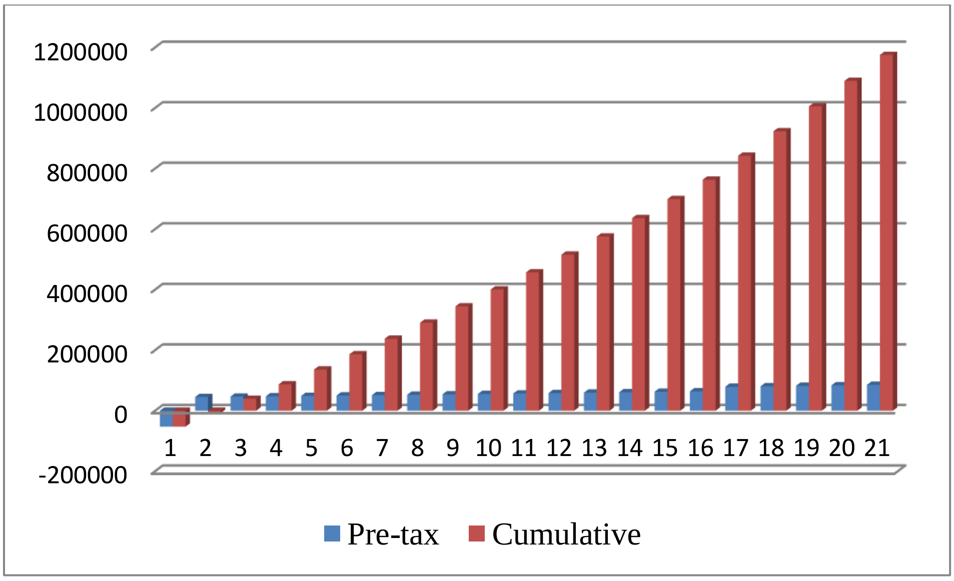

Fig. 2: The pre-tax and cumulative cash flow of the project after 20 years for the Kakuri industrial area Kaduna.

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Emission reduction assessment

The greenhouse gas (GHG) emission decrease resulting from installing solar PV is computed using the emission analysis worksheet. It is also employed in the computation of potential revenue from the sales of greenhouse gas reduction emissions. The base case Nigerian electrical system was based on transmission and distribution losses of 16% and a GHG emission factor of 0.433tCO_2/MWh. As indicated in Table 7, the program deducts the calculated emission in the basis scenario from the calculated emission in the proposed case to get the gross yearly GHG emission reduction for Kaduna locations.

Sensitivity analysis

The degree of uncertainty around the project during analysis is a gauge of the degree of uncertainty surrounding the inputting data, which influences the degree of uncertainty surrounding the financial variables that are computed.

Table 7: Annual GHG emission for Kaduna

Location	Based case (tCO_2)	Proposed case (tCO_2)	Gross annual GHG emission reduction (tCO_2)
Kaduna	1,499.2	1,209.9	289.3

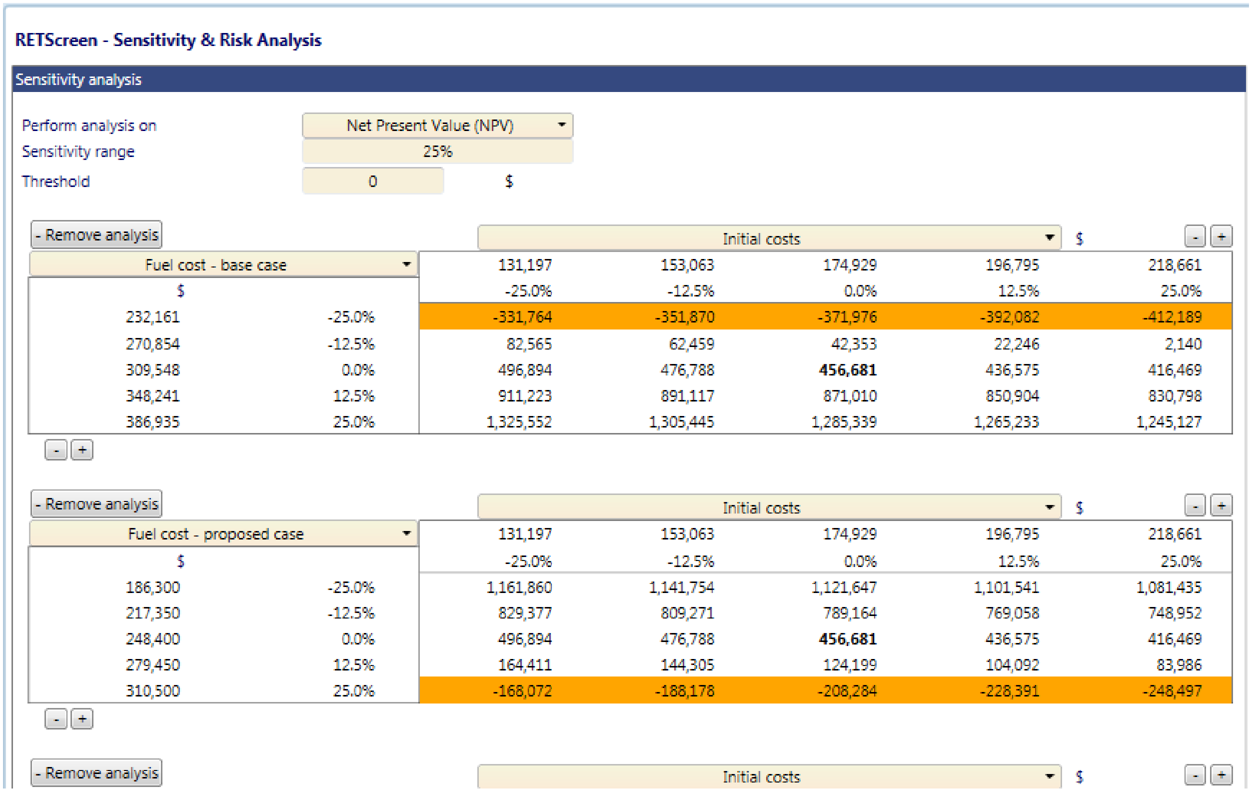

Fig. 3: Sensitivity analysis result for the solar photovoltaic project in Kakuri industrial area Kaduna State.

Risk analysis

Before starting any solar energy project, risk analysis and sensitivity analysis should be conducted to determine the project's level of uncertainty. The sole distinction between the two analyses is that, in the case of a risk analysis, all the parameters are permitted to change with each other within a predetermined range, as opposed to utilizing two parameters to reach a conclusion, as in the case of a sensitivity study. The financial indicator chosen is the cost of producing energy, with a range of ±25% taken into account for all factors.

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Similar to the sensitivity analysis, the solar photovoltaic in the industrial region undergoes a risk analysis. As seen in Figs. 4 and 5, the impact graph and distribution graph produced by the RETScreen software's repeated use of the Monte Carlo simulation technique are displayed.

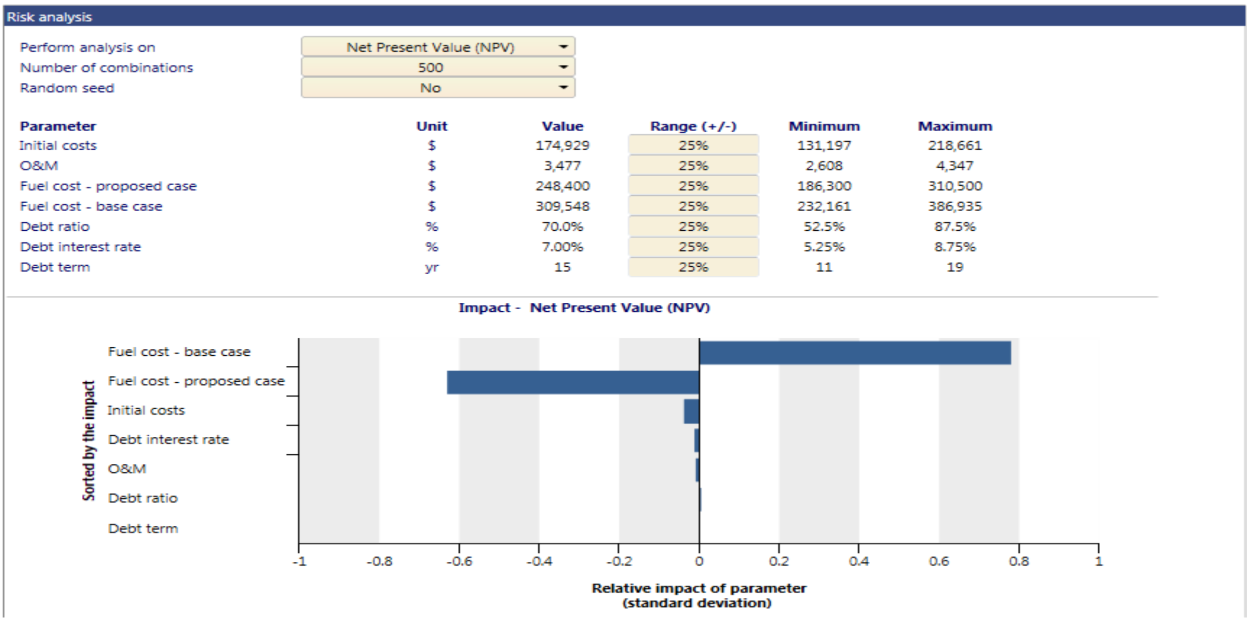

Fig. 4: Impact graph of the risk analysis result for the solar photovoltaic project in Kakuri industrial area Kaduna State.

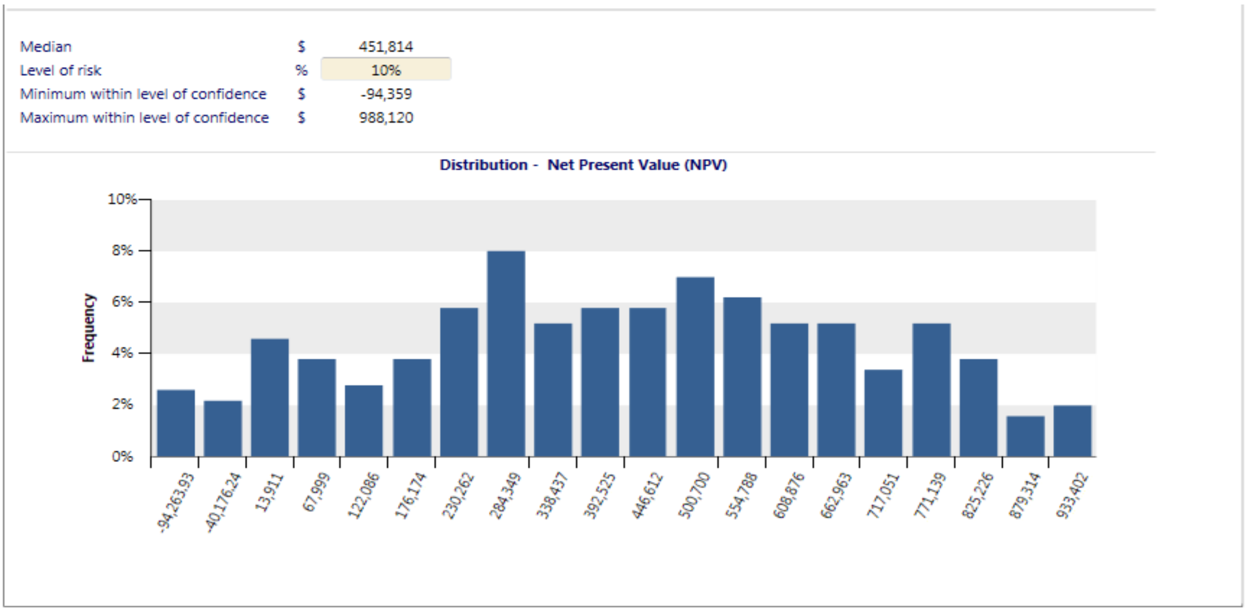

Fig. 5: Distribution graph of the risk analysis result for the solar photovoltaic project in Kakuri industrial area Kaduna State.

CONCLUSION

The present study involved a comprehensive feasibility analysis aimed at evaluating the feasibility of implementing an average 3MW grid-connected solar photovoltaic project in Kakuri industrial area, Kaduna, Nigeria. The analysis covered the project's technical, financial, risk, sensitivity, and environmental impact on society. This was done in order to create a solar energy road map that will draw solar energy investors from donor nations and international organizations to invest in Kaduna, Nigeria's plentiful and underutilized clean energy. This would improve the region's sustainable technological development while also lessening the impact of global warming brought on by local fossil fuel use. The input data for the RETScreen Expert software study included the locations' climate data from NASA as well as a few financial characteristics as the debt interest rate, inflation rate, discount rate, and reinvestment rate. The software accurately calculates the total energy generated by the solar panel and exported to the grid, the amount of greenhouse gas (GHG) emissions that will be reduced annually, the number of hectares of forest absorbing carbon, the revenue generated from greenhouse gas emissions during the project's life cycle, the financial implications of the project, including the revenue generated from the sales of the energy exported to the grid and the risk involved in carrying out the project, depending on the location and wattage of the solar panels. Based on all available indices, the location is highly suggested for the installation of the solar photovoltaic project.

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