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# Design and Assessment of a Grid-Connected Photovoltaic System for Dr. Hilla Limann Technical University: Economic and Environmental Analysis

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***ABSTRACT***
*Dr. Hilla Limann Technical University is the youngest Technical University in Ghana, located in the Upper West Region. However, the supply of reliable energy has been a major concern for the University. The University experiences the regular phenomenon of a power blackout, which affects the activities on the campus. This research questions the kind of alternative energy source that is available for the University in other to mitigate the above challenges. It further looks at the technical, economic, and environmental suitability of that option. This study aimed at designing and assessing a solar PV system for Dr. Hilla Liman Technical University to be connected to the grid. RETScreen Software was employed for the simulation over the guaranteed life of the system. Technical, Economic, and Environmental analyses were conducted on the Grid-connected solar PV system. The results of the study indicate that the designed system generated a yearly energy yield of approximately 162054.53 MWh of which 162026 MWh was delivered to the load and the remaining 28.53 MWh was exported to the grid. Also, the equity payback period of the designed Grid-connected PV system was 2.8 years, with a project duration of 25 years and a simple payback of 3.2 years. The net present value of life cycle costing (LCC) is estimated to be about Gh¢ 4097142. The designed PV system is also capable of saving up to 60059 tonnes of CO2, equivalent to 139672 barrels of crude oil given out by a thermal power station generating an equal amount of electricity. The great potential of employing solar energy in the University is confirmed by the anticipated high energy yield. It was also economically viable to implement the Grid-connected solar PV systems since their NPV is positive and also BCR is greater than 1. This project will meet 100% of Dr. Hilla Limann Technical University's energy requirements and the surplus exported to Grid. The project can save tonnes of CO2 which would have been given out by non-renewable power stations generating an equal amount of electric power, which indicates a great environmental impact for a better world.*

***KEYWORDS -*** *Grid-connected, Payback, Photovoltaic, RETScreen, Simulation.*

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## I. Introduction

The sustenance of all economies is dependent on energy, hence it enables better welfare. In a country where energy supply is lacking, the growth of its economy is brought to a standstill as well as the livelihoods of the people[1]. Electricity contributes to about 69% of modern energy used in all sectors of the economy of Ghana[2]. It happens to be the commonest modern type of energy used in the industrial and service sectors of the economy. Electricity production and supply, serves as a source of employment for a large number of professionals in Ghana. It also helps in providing foreign exchange for the country [2].

Due to the rapid rate of population growth, technological advancement, and globalization, the rate at which energy is consumed in developing countries of which Ghana is part, is rising at an astronomical rate of 5% per year[3]. For any country to experience rapid economic growth, it needs a large quantity of energy input. It is therefore imperative for every country to invest in alternative energy sources since energy cannot be created[4].

Ghana is one of the developing countries, which is dependent on the imported oil in order to meet it needs from the energy required for all sectors. The electricity supply system in Ghana is sometimes characterised by power interruptions, which seriously affect the livelihood of the people and industrial development. In the technological development of any country, dependable and economic power generation is a very critical commodity. Even though Ghana has a challenge in meeting the present energy demand, it is projected that the demand will increase by 10% per annum[5]. Therefore, the country can only achieve its developmental goals with a realistic plan to expand its generation of power.

Ghana has a very high potential for developing solar energy because of its abundant solar resources, which is approximately 35 EJ (exajoules), with mean yearly working hours of 2670 which amounts to about 53,000 MWh a year[6].

The sun's energy upon touching a solar panel transforms into electricity. Primarily, the choice of location of a PV installation is influenced by the strength of the solar radiation. This stems from the fact that the power output of a PV array is directly proportional to the solar insolation of the input of the system. The output of a PV array is limited by some climatic and environmental factors including temperature, humidity, and precipitation[7]. Amongst the energy sources, solar PV electricity is unique, for many benefits including energy and non-energy, arise from its usage.

The Government of Ghana has a target in the electricity sector, which is to ensure and provide sufficient, affordable, reliable, and maintainable power. However, Ghana is faced with several challenges[8].

Dr. Hilla Limann Technical University is the youngest Technical University in Ghana, located in the Upper West Region. It was established in September 1999 as a Polytechnic and converted into a Technical University in 2020. The Konta feeder supplies power to the University's electrical energy distribution network[9].

The overall quantity of electricity sold by the Northern Electricity Distribution Company (NEDCo) in the Upper West Region (Where Dr. Hilla Limann Technical University is located) was 348.2 GWh in 2018. The University's total electricity consumption in 2018 was 459741kWh which is 0.13% of the total energy supplied. The total amount of electricity consumed the same year nationwide was 4978.4 GWh and compared to Dr. Hilla Liman Technical University's electricity consumption, means that Dr. Hilla Limann Technical University accounts for 0.058% of the national total electrical energy consumption[10].

However, the supply of reliable and cost effective energy has been a major concern for Dr. Hilla Limann Technical University. The University sometimes experiences regular phenomenon of a power blackout, which affects the activities on the campus. Also the University accumulates a huge electricity bill at the end of each month, which when there is a default in payment, the University is disconnected from the national Grid. This research questions the kind of alternative energy source that is available for the University in other to mitigate the above challenges. It further looks at the technical, economic, and environmental suitability of that option.

The present study aims at designing a PV (photovoltaics) to provide alternative energy generation for Dr. Hilla Limann Technical University (DHLTU), Wa, Ghana. The technical analysis, economic feasibility, and $CO_2$ emission savings by implementing the proposed solar PV system have been conducted using a clean energy management software namely, RETScreen 4.0

## II. Material and Methods

2.1 Location of the Study

Dr. Hilla Liman Technical University was selected as the location for the present study. The Technical University is situated along the road leading to a village called Kpongu in the Wa Municipality of the Upper West Region. Fig. 1 shows a map of Wa municipality indicating the location of Dr. Hilla Limann Technical University (DHLTU).

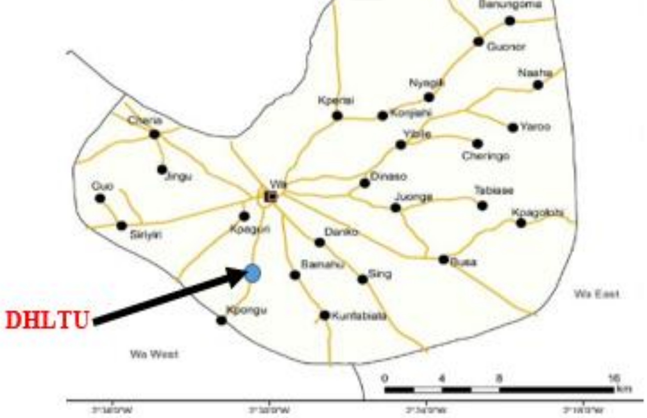



**Figure 1. Map of Wa Municipality**[11]

The geographical location of Dr. Hilla Limann Technical University (DHLTU) is latitude 10.01°N, with an altitude of 322m above sea level,[12]. The University has vast land which is able and capable of embracing renewable energy initiatives for electricity generation.

2.2 Load profile of Dr. Hilla Liman Technical University

The mean yearly electrical power usage can be assessed in two different ways, which are; using the current electrical power records in the form of electricity bills and using a load assessment sheet to conduct a load assessment analysis. In this design, however, the first option was used because it is more accurate and cheap. Table 1 shows Dr. Hilla Limann Technical University's energy consumption per day.

**Table 1: Energy (kWh) consumed by Dr. Hilla Limann Technical University, 2019**

| Date of Meter reading | Energy consumed (kWh) | Number of billing days | Average energy use per day (kWh) |
|---|---|---|---|
| **31st January** | 60530 | 30 | 2017.67 |
| **28th February** | 62223 | 28 | 2222.25 |
| **31st March** | 64422 | 31 | 2078.13 |
| **30th April** | 61303 | 30 | 2043.43 |
| **31st May** | 61274 | 31 | 1976.58 |
| **30th June** | 61312 | 30 | 2043.73 |
| **31st July** | 60226 | 31 | 1942.77 |
| **31st August** | 60370 | 31 | 1947.42 |
| **30th September** | 61240 | 30 | 2041.33 |
| **31st October** | 60988 | 31 | 1967.35 |
| **30th November** | 61852 | 30 | 2061.73 |
| **31st December** | 62532 | 31 | 2017.16 |
| **TOTAL** | 738272 | 365 | |

***Source: NEDCo (2019)***

2.3 PV System Design

A Grid-connected PV system consists of PV arrays, junction boxes, collecting boxes, inverters, transformers, and a commercial grid. PV modules generate DC power. The function of the power conditioner is to change DC voltage to AC voltage. The output from the power conditioner which is AC is then sent to the building and main grids. The PV plant's design requires a decent knowledge of the system and components The system design process is shown in Fig. 2.

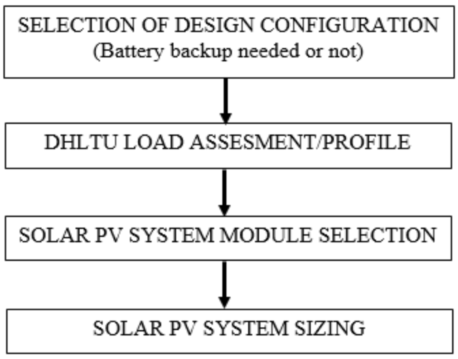



**Figure 2. System design process**

2.4 Selection of design configuration

This study presents a Grid-connected photovoltaic system with a battery backup. Because a system is required to primarily overcome the problem of power unreliability (regular power outage) at the Dr. Hilla Liman Technical University, this option was chosen because it is the most suitable.

Grid-connected PV systems with battery backup have two configurations. In one configuration, the inverter and charge controller form a single unit whiles in the second configuration, the inverter and charge controller are separate units. Fig. 3 and Fig. 4 show the two configurations[13].

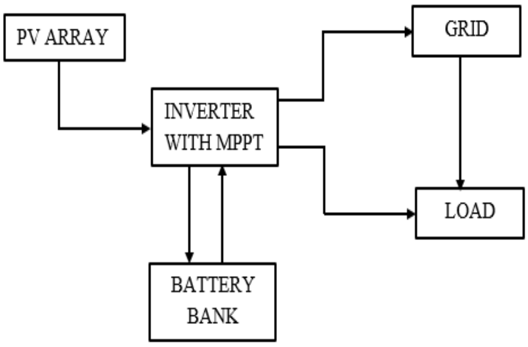



**Figure 3. System configuration with charge controller and the inverter as one unit**

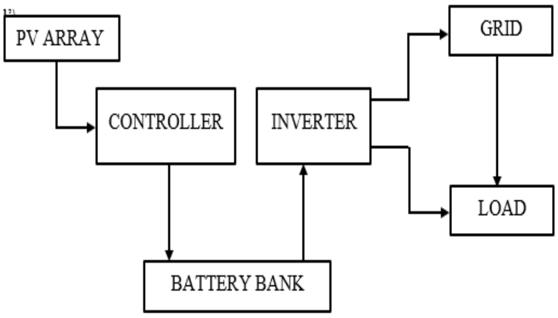



**Fig .4. System configuration with charge controller and the inverter as separate units**

The second option, where the inverter and charge controller are separate units was proposed for this thesis because it is simple and cost-effective.

2.5 PV-module selection

A PV module consists of several photovoltaic cells in series and parallel. A PV cell transforms directly the solar insolation into power in the form of dc when there is an interaction between sunlight and the semiconductor materials in the PV cells[14]. The equivalent circuit of a PV cell is shown in Fig. 5 where the non-linear I-V characteristic can be derived [14].

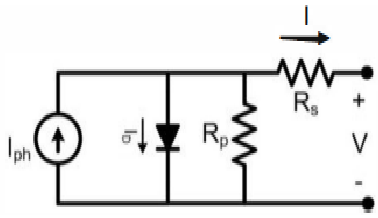



**Figure 5. Equivalent circuit of photovoltaic cell**

There are different types of Photovoltaic modules in the market with various specifications. The two common forms of PV modules are polycrystalline and monocrystalline types[15]. In this study monocrystalline silicon, NT-185U1 PV Module which is produced by Sharp Company was selected. This model was selected due to the following reasons: it is widely available in the market, it withstands rigorous operating conditions and it has relatively good efficiency compared to other mono-silicon solar panels. The proposed PV panel has a peak power output of 185Wp, 17.5% encapsulated cell efficiency, and an efficiency of 14.5% respectively[14]. The technical specifications of the selected PV module are presented in Table 2.

**Table 2. specifications of monocrystalline silicon NT-185U1 PV panel**

| Item description | Item specification |
|---|---|
| Maximum power (Wp) | 185 W |
| Open–circuit voltage (Voc) | 44.9V |
| Maximum power voltage (Vmp) | 36.2V |
| Short–circuit current (Isc) | 5.75A |
| Maximum power current(Ipm) | 5.11A |
| Module efficiency (ηc) | 14.23% |
| Length (L) | 1575mm |
| Width (W) | 826mm |

| | |
|---|---|
| Depth (D) | 46mm |
| Weight (W kg) | 17.0kg |
| Operating temperature (θ°) | - 40 °C to + 90 °C |

***Source: www.abcsolar.com/pdf/sharp185.pdf***

2.6 Power inverter specification

An inverter in a PV system transforms the DC voltage generated by solar panels into AC voltage of grid frequency[16]. The most significant characteristic of an inverter is the conversion frequency. According to[14], the inverter is responsible for converting the DC electricity in the form of energy stored in the battery to usable AC power required by the load. Factors that were considered in selecting the power inverter for the solar installation network included: efficiency, capital cost, and life service of the inverter gadget. I-P HPC-2000W model from the I-panda brand was selected for the study due to its high efficiency ranging between 95% - 99%. The technical specification of the power inverter is shown in Table 3.

**Table 3: specification of power inverter I-P HPC-2000W**

| Inverter Model (HPC-2000W) | Specification |
|---|---|
| Output power | 2000W |
| D.C. input voltage | 24V / 48V |
| A.C. output voltage | 100V/ 110V / 220V/ 230V / 240V |
| Efficiency | 95% |

***Source: www.solarcontroller-inverter.com/products/I-Panda***

**2.7** PV system input parameters

RETScreen energy software was employed to estimate the annual energy output, financial viability, and carbon dioxide reduction of the proposed PV system. The input parameters required to simulate the proposed model were identified in this study as follows. Solar tracking mode was considered to be fixed. The PV panel was assumed to be tilted at the optimal angle of $15.1^{o}$ facing south (Azimuth angle = $0^{o}$). This assumption was based on previous studies by[16, 17]. A simulation was run on the 458kW PV system capacity. The efficiency of the PV system is mostly affected by low temperatures and occasional dust storm incidents in Ghana. Miscellaneous losses of the PV model and inverter were assumed to be 10% and 5% respectively.

2.8 Determination of power demand

The first step in designing solar power plants is the determination of the daily load demand which is given below:

The load consumption was deduced from the monthly electricity bills. The energy consumed (kWh) in each month was added for one year. This gave the total energy consumption in a year.

$\text{Total power consumption in a year} = 738272.36\text{kWh}$

The total energy consumed in a year was divided by 365 (number of days in a year) to get the total average energy required in kW/day. Total PV panel energy demand per day $= 2022.664\text{kWh/day}$. The total average energy demand per day is usually multiplied by a factor that expresses the losses of the system components as shown in (1)[14].

$$\text{PV panel demand per day} = \text{daily average energy consumption} \times 1.3 \qquad (1)$$

This is done to avoid the risk of under-sizing the PV system[14].

2.9 Sizing of PV module system

The size of the PV module system is determined by its load requirements, solar insolation, and geographical location. In this study, the proposed system is designed for Dr. Hilla Liman Technical University where the least size of the solar array was calculated to be $427.555\text{kW}$ using (2)[14]:

$$\text{Power of solar array} = \frac{\text{daily energy requirement}}{\text{solar insolation}} \qquad (2)$$

2.10 Sizing of Inverter

AC power was supplied to the AC loads with the help of an inverter. The input rating of the inverter should be greater than the load whiles the inverter battery must have the same voltage[18]. The inverter size for stand-alone systems should be 25-30% bigger than the total Watts of load. However, if the load a is motor then the inverter size must be at least 3 times the capacity of the load. In the case of Grid-connected systems, the input rating of the inverter must be equal to the rating of the PV system in other to give allowance for safe and efficient operation[18]. Therefore the size of the inverter is $2000\text{kW}$.

2.11 Sizing of Battery

A deep cycle battery type was recommended. According to[15], deep-cycle batteries used in solar PV installation provide temporary storage for excess electricity produced by the solar PV array. The battery should be sizeable enough to be to accumulate adequate power, needed for the day as well as for the night. In this study the size of the battery was calculated as follows:

Total Watt-hours/day utilized by loads was calculated. To cater for battery losses, the total Watt-hours/day was divided by 0.95. The results obtained were divided by the depth of discharge (0.6). The resultant was subsequently divided by the nominal battery voltage. The subsequent answer was multiplied by days of autonomy (the number of days that you need the system to operate when there is no power produced by PV panels).

The required Ampere-hour capacity of the deep-cycle battery was calculated using (3)[14].

$$\text{Battery capacity} = \frac{\text{total watt} - \text{hrs/day} \ \times \text{DoA}}{0.95 \times 0.6 \times \text{nominal voltage}} \quad (3)$$

Total energy consumed per day = 2022.664kWh
Nominal voltage = 12V
Days of autonomy = 3 days = 72 hours
Depth of discharge DoD = 0.6

$$\text{Battery size} = \frac{2022.664 \times 3}{0.95 \times 0.6 \times 12} = 887.13$$

Total Ampere-hours needed is 302.05 Ah so the rating of the battery is 12 V 890Ah for 3-day autonomy[19].

2.12 Sizing of Solar charge controller

The rating of the solar charge controller is usually Ampere and Voltage capacities. Solar charge controller must tie with the voltage of PV array and batteries. In standard practice, to size, a solar charge controller, the short circuit current (Isc) of the PV array is multiplied by 1.3 times[18].

$$\text{Solar charge controller rating} = \text{Total short circuit current of PV array} \times 1.3 \quad (4)$$

PV module specification
$P_m$ = 255 $W_p$
$V_m$ = 24 Vdc
$I_m$ = 8.28A
$I_{sc}$ = 8.76 A
Solar charge controller rating = (3 strings x 8.76A) x 1.3 = 34.164 A.

2.13 Description of simulation procedures

In this section the procedure used in RETScreen 4.0 software in simulating the proposed Grid-connected PV system in Dr. Hilla Liman Technical University, Ghana is described.

Step 1: Start stage: In this section, project type, facility type, and analysis type were specified. In addition, language type, currency, units, and analysis types were also specified.

Step 2: Load identification: The monthly load for the Dr. Hilla Limann Technical University was specified and the base electricity rate in Ghana was also specified. Furthermore, the parameters specified in this section included system maximum electricity load over maximum monthly mean, electricity rate–base case, and end-use energy efficiency measures.

Step 3: Energy analysis model: In this model, the parameters described are the analysis type of the energy project, the type of PV, manufacturer, PV model, and power capacity. In turn, the annual energy generated was calculated by the RETScreen Software.

Step 4: cost analysis model: In the cost analysis stage, the parameters that were entered included the initial, annual, and periodic costs for the proposed case system as well as credits for any base case costs that are avoided in the proposed case.

Step 5: Emission analysis model: In this worksheet, the annual greenhouse gas (GHG) emission reduction as a result of implementing the proposed technology in place of the base case technology was determined. The following were considered in the study; method 1 emission analysis was used, the baseline region/country, baseline changes during project life, and GHG credits transaction fee rates were also considered.

Step 6: Financial analysis model: In this model, financial parameters, like discount rates, inflation rate, project life, and fuel escalation rate were inputted. The main financial indicators (e.g. net present value and simple payback) which are used to evaluate the viability of the project were calculated automatically by the RETScreen software. Some assumptions made were that, the initial investment year was taken to be year 0; the costs and credits were given in year 0 terms, thus the inflation rate (or the escalation rate) was applied from year one onwards and the timing of cash flows occurred at the end of the year.

## III. RESULTS AND DISCUSSION

The simulation results of the proposed photovoltaic system are presented and analysed in this section.

### 3.1 Load Network Analysis

From the electricity bills, the daily power consumption for the University was estimated to be used in the design and sizing process of the PV system and are presented in Table 3.4. The daily average energy consumption for Dr. Hilla Liman Technical University is 2022.664 kWh and the total energy consumed for the year 2019 was 738272 kWh. From Fig. 6, in the proposed case, Dr. Hilla Liman Technical University will have an annual peak load of 67643 kWh and the base case had an annual peak load of 90191 kWh.

**Base case load characteristics**

| Month | | Power gross average load kV |
|---|---|---|
| January | | 60,530 |
| February | | 62,223 |
| March | | 64,422 |
| April | | 61,303 |
| May | | 61,274 |
| June | | 61,312 |
| July | | 60,226 |
| August | | 60,370 |
| September | | 61,240 |
| October | | 60,988 |
| November | | 61,852 |
| December | | 62,532 |
| System peak electricity load over max monthly average | | 40.0% |
| Peak load - annual | | 90,191 |
| Electricity | MWh | 542,998 |
| Electricity rate - base case | GHC/kWh | 0.989 |
| Total electricity cost | GHC | 537,024,614 |

**Proposed case load characteristics**

| Month | Power net average load kV |
|---|---|
| January | 45,398 |
| February | 46,667 |
| March | 48,317 |
| April | 45,977 |
| May | 45,956 |
| June | 45,984 |
| July | 45,170 |
| August | 45,278 |
| September | 45,930 |
| October | 45,741 |
| November | 46,389 |
| December | 46,899 |
| Peak load - annual | 67,643 |

**Figure 6. Load Network analysis of Dr. Hilla Limann Technical University**

### 3.2 Technical Analysis

The PV technology selected depended on the data collected about the solar irradiance of the selected site and the daily power consumption (kWh) or types of electric loads. Fig. 7 shows the number and the specification of selected PV panels.

**RETScreen Energy Model - Power project**

**Proposed case power system**

Analysis type: ○ Method 1 ⊙ Method 2

**Resource assessment**

| | | |
|---|---|---|
| Solar tracking mode | | Fixed |
| Slope | ° | 15.1 |
| Azimuth | ° | 0.0 |

☑ Show data

| Month | Daily solar radiation - horizontal kWh/m²/d | Daily solar radiation - tilted kWh/m²/d | Electricity export rate GHC/MWh | Electricity exported to grid MWh |
|---|---|---|---|---|
| January | 5.73 | 6.41 | 0.4 | 2.732 |
| February | 6.02 | 6.44 | 0.4 | 2.460 |
| March | 6.15 | 6.25 | 0.4 | 2.635 |
| April | 6.10 | 5.89 | 0.4 | 2.428 |
| May | 5.96 | 5.53 | 0.4 | 2.367 |
| June | 5.46 | 5.00 | 0.4 | 2.092 |
| July | 4.92 | 4.57 | 0.4 | 1.998 |
| August | 4.67 | 4.47 | 0.4 | 1.965 |
| September | 5.01 | 4.98 | 0.4 | 2.100 |
| October | 5.60 | 5.87 | 0.4 | 2.511 |
| November | 5.59 | 6.16 | 0.4 | 2.531 |
| December | 5.63 | 6.39 | 0.4 | 2.718 |
| **Annual** | **5.57** | **5.66** | **0.40** | **28.537** |

| | | |
|---|---|---|
| Annual solar radiation - horizontal | MWh/m² | 2.03 |
| Annual solar radiation - tilted | MWh/m² | 2.07 |

| | | | | | |
|---|---|---|---|---|---|
| Annual solar radiation - horizontal | MWh/m² | 2.03 | | | |
| Annual solar radiation - tilted | MWh/m² | 2.07 | | | |
| **Photovoltaic** | | | | | |
| Type | | mono-Si | | | |
| Power capacity | kW | 427,555.54 | | | See product database |
| Manufacturer | | Sharp | | | |
| Model | | mono-Si - NT-185U1 | 2311111 unit(s) | | |
| Efficiency | % | 14.2% | | | |
| Nominal operating cell temperature | °C | 45 | °F | 113.0 | |
| Temperature coefficient | % / °C | 0.40% | | | |
| Solar collector area | m² | 3,006,720 | ft² | 32,364,061 | |
| Miscellaneous losses | % | 10.0% | | | |
| **Inverter** | | | | | |
| Efficiency | % | 25.0% | | | |
| Capacity | kW | 2.0 | | | |
| Miscellaneous losses | % | 10.0% | | | |
| **Summary** | | | | | |
| Capacity factor | % | 4.3% | | | |
| Electricity delivered to load | MWh | 162,026.954 | | | |
| Electricity exported to grid | MWh | 28.537 | | | |

| **Operating strategy - base load power system** | | | | |
|---|---|---|---|---|
| Electricity rate - base case | GHC/MWh | 989.00 | GHC/kWh | 0.989 |
| Fuel rate - proposed case power system | GHC/MWh | 0.00 | | |
| Electricity rate - proposed case | GHC/MWh | 0.40 | GHC/kWh | 0.000 |

| Operating strategy | Electricity delivered to load MWh | Electricity exported to grid MWh | Remaining electricity required MWh | Power system fuel MWh | Operating profit (loss) GHC | Efficiency % |
|---|---|---|---|---|---|---|
| **Full power capacity output** | **162,027** | **29** | **10,072** | **0** | **170,201,400** | - |
| Power load following | 162,027 | 0 | 10,072 | 0 | 170,201,389 | - |
| Select operating strategy | Full power capacity output | | | | | |

**Figure 7. Energy Analysis in RETScreen**

The energy yield of this PV system depended basically on the solar irradiance of the selected Municipality and the efficiency of the selected PV panel. The number of panels depended on the power required to cover the daily energy consumption.

Studies on the soiling effect on PV cells indicate energy yield of a Solar PV System can reduce drastically when dust and sand are collected on the surface of the PV cell. In a study conducted by[20], it was found that the dirt collected on solar panels ("soiling") can have a drastic impact on the performance of PV systems in regions where rainfall is limited for a dry season of several months.

The soiling effect is important in conditions that need consideration in PV system design, especially where sand storms can deposit large amounts of dust and sand on the PV cell. Regarding the previous studies, only dust was considered in this research which is expected to decrease annual energy yield by 10%. This loss of energy production on photovoltaics cells was catered to as "miscellaneous losses," in the model, which represents the percentage decrease in annual production. Furthermore, any other miscellaneous losses from the inverter or other power conditioning were taken as 5%. The selected inverter is reported to operate at 2000 kW, and the percentage of electricity the inverter successfully converts from DC to AC was 95% (Inverter Efficiency).

In this study, a total of 162055.491 MWh of electricity was produced annually of which 162026 MWh was delivered to the load and the remaining 28.53 MWh was exported to the grid.

## 3.3 Economic Analysis

After choosing those parameters from the previous and related research and performing the analysis, the details of the cost analysis are presented in Fig. 8.

RETScreen Cost Analysis - Power project

| Settings | | | |
|---|---|---|---|
| ⊙ Method 1 | ⊙ Notes/Range | Notes/Range | |
| ○ Method 2 | ○ Second currency | None | |
| | ○ Cost allocation | | |

| Initial costs (credits) | Unit | Quantity | Unit cost | Amount | Relative costs |
|---|---|---|---|---|---|
| **Feasibility study** | | | | | |
| Feasibility study | cost | 1 | GHC 691,545 | GHC 691,545 | |
| Subtotal: | | | | **GHC 691,545** | 0.1% |
| **Development** | | | | | |
| Development | cost | 1 | GHC 1,861,020 | GHC 1,861,020 | |
| Subtotal: | | | | **GHC 1,861,020** | 0.3% |
| **Engineering** | | | | | |
| Engineering | cost | 1 | GHC 844,070 | GHC 844,070 | |
| Subtotal: | | | | **GHC 844,070** | 0.1% |
| **Power system** | | | | | |
| Base load - Photovoltaic | kW | 427,555.54 | GHC 550 | GHC 235,155,548 | |
| Peak load - Grid electricity | kW | 30,251.55 | GHC 320 | GHC 9,680,496 | |
| Road construction | km | 1 | GHC 610,000 | GHC 610,000 | |
| Transmission line | km | 5 | GHC 710,750 | GHC 3,553,750 | |
| Substation | project | 5 | GHC 882,000 | GHC 4,410,000 | |
| Energy efficiency measures | project | 15 | GHC 3,000 | GHC 45,000 | |
| Inverter | cost | 2 | GHC 20,000 | GHC 40,000 | |
| | | | | GHC - | |
| Subtotal: | | | | **GHC 253,494,794** | 35.1% |
| **Balance of system & miscellaneous** | | | | | |
| Spare parts | % | 30.0% | GHC 2,236,003 | GHC 670,801 | |
| Transportation | project | 2 | GHC 532,000 | GHC 1,064,000 | |
| Training & commissioning | p-d | 15 | GHC 582,000 | GHC 8,730,000 | |
| Inverter | cost | 2 | GHC 20,000 | GHC 40,000 | |
| Contingencies | % | 20.0% | GHC 267,396,229 | GHC 53,479,246 | |
| Interest during construction | 15.00% | 200 month(s) | GHC 320,875,475 | GHC 401,094,344 | |
| Subtotal: | | | | **GHC 465,078,391** | 64.4% |
| **Total initial costs** | | | | **GHC 721,969,820** | 100.0% |

| Annual costs (credits) | Unit | Quantity | Unit cost | Amount |
|---|---|---|---|---|
| **O&M** | | | | |
| Parts & labour | project | 5 | GHC 42,825 | GHC 214,125 |
| Fuel | cost | 5 | GHC 12,500 | GHC 62,500 |
| Contingencies | % | 20.0% | GHC 276,625 | GHC 55,325 |
| Subtotal: | | | | **GHC 331,950** |
| **Fuel cost - proposed case** | | | | |
| Electricity | MWh | 10,072 | GHC 0.400 | GHC 4,029 |
| Subtotal: | | | | **GHC 4,029** |

| Annual savings | Unit | Quantity | Unit cost | Amount |
|---|---|---|---|---|
| **Fuel cost - base case** | | | | |
| Electricity | MWh | 229,465 | GHC 989.000 | GHC 226,940,557 |
| Subtotal: | | | | **GHC 226,940,557** |

| Periodic costs (credits) | Unit | Year | Unit cost | Amount |
|---|---|---|---|---|
| Over draft | cost | 25 | GHC 720,000 | GHC 720,000 |
| | | | | GHC - |
| End of project life | cost | | GHC 1,172,348 | GHC 1,172,348 |

**Figure 8. Cost analysis**

From Fig. 8, the total initial cost of the proposed project is Gh¢721,969,820 for a 25year period which included the balance of the system and Miscellaneous, power system, engineering development, and feasibility study. The initial cost depends largely on the balance of the system and miscellaneous cost which is 64.4% of the total initial cost. The annual cost is Gh¢4029.

The financial viability report and the cumulative cash flow indicated an equity payback of 2.8 years and a simple payback period of 3.2 years as shown in Table 4 and Fig. 9 respectively.

**Table 4: Financial analysis results**

| | | |
|---|---|---|
| **NPV** | **(GH₵)** | **4097142** |
| **SPB** | **(yrs)** | **3.2** |
| **EPB** | **(yrs)** | **2.8** |
| **BCR** | | **1.01** |

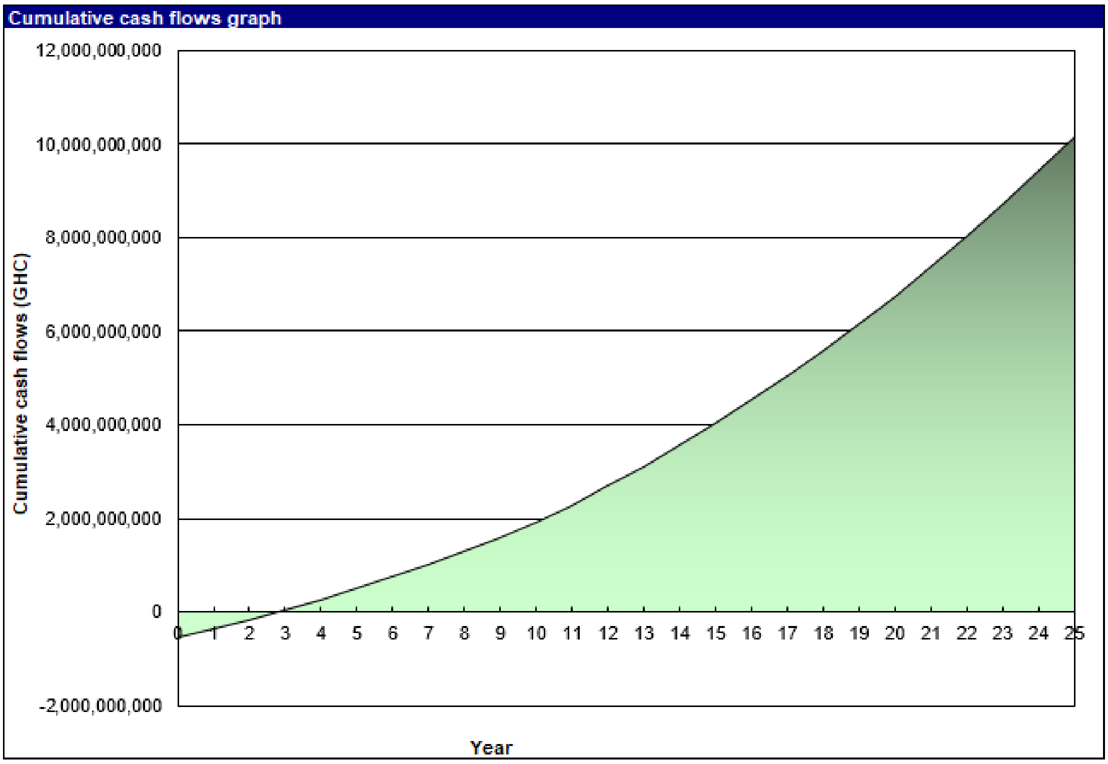


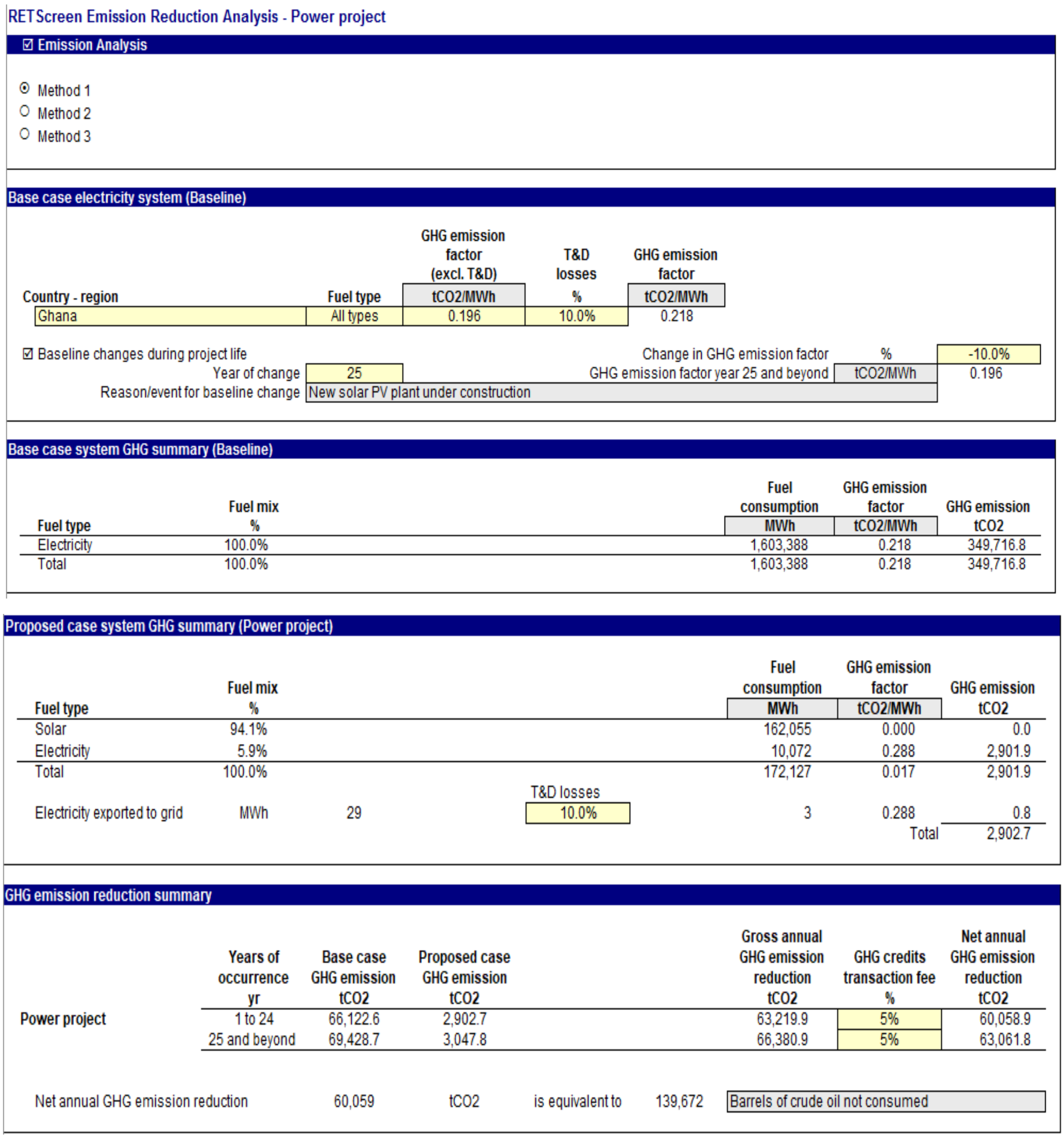

**Figure 9. Cumulative cash flow**

Considering the simulated results, the project is economically viable because it has a positive net present value (NPV) of GhȻ 4097142. The benefit-cost ratio (BCR) value also indicated a profitable project since the ratio is 1.01 which is greater than 1.

In a similar study conducted by[21], the NPV value was $6.911M (GHȻ3,939,270) and the BCR value was 1.25. These values match the present study.

3.4 GHG Emission Analysis

The reduction of GHG emissions is considered a major factor whiles comparing two energy systems. The utilization of renewable energy as a replacement for traditional power production units reduces the emission of GHG significantly[22]. This part is helpful in the prediction of the future benefits of air pollution reduction from using the proposed system in place of the base case technology. The result is given in form of the amount of carbon dioxide emissions reduced which is shown in the form of tonnes of GHG emission not emitted or other conservation equivalents as shown in Fig. 10.



RETScreen Emission Reduction Analysis - Power project

☑ Emission Analysis

- ◉ Method 1
- ○ Method 2
- ○ Method 3

**Base case electricity system (Baseline)**

| Country - region | Fuel type | GHG emission factor (excl. T&D) tCO2/MWh | T&D losses % | GHG emission factor tCO2/MWh |
|---|---|---|---|---|
| Ghana | All types | 0.196 | 10.0% | 0.218 |

☑ Baseline changes during project life

| | | | | |
|---|---|---|---|---|
| Year of change | 25 | Change in GHG emission factor | % | -10.0% |
| Reason/event for baseline change | New solar PV plant under construction | GHG emission factor year 25 and beyond | tCO2/MWh | 0.196 |

**Base case system GHG summary (Baseline)**

| Fuel type | Fuel mix % | Fuel consumption MWh | GHG emission factor tCO2/MWh | GHG emission tCO2 |
|---|---|---|---|---|
| Electricity | 100.0% | 1,603,388 | 0.218 | 349,716.8 |
| Total | 100.0% | 1,603,388 | 0.218 | 349,716.8 |

**Proposed case system GHG summary (Power project)**

| Fuel type | Fuel mix % | | T&D losses | Fuel consumption MWh | GHG emission factor tCO2/MWh | GHG emission tCO2 |
|---|---|---|---|---|---|---|
| Solar | 94.1% | | | 162,055 | 0.000 | 0.0 |
| Electricity | 5.9% | | | 10,072 | 0.288 | 2,901.9 |
| Total | 100.0% | | | 172,127 | 0.017 | 2,901.9 |
| Electricity exported to grid | MWh | 29 | 10.0% | 3 | 0.288 | 0.8 |
| | | | | | Total | 2,902.7 |

**GHG emission reduction summary**

| | Years of occurrence yr | Base case GHG emission tCO2 | Proposed case GHG emission tCO2 | Gross annual GHG emission reduction tCO2 | GHG credits transaction fee % | Net annual GHG emission reduction tCO2 |
|---|---|---|---|---|---|---|
| Power project | 1 to 24 | 66,122.6 | 2,902.7 | 63,219.9 | 5% | 60,058.9 |
| | 25 and beyond | 69,428.7 | 3,047.8 | 66,380.9 | 5% | 63,061.8 |

Net annual GHG emission reduction 60,059 tCO2 is equivalent to 139,672 Barrels of crude oil not consumed

**Fig. 10. GHG Emission analysis worksheet from RETScreen 4.0**

The data can vary as per the need. Therefore, this study was able to show that the input data for a 25-year lifetime for the system reduced the amount of GHG emission from 66122.6 tonnes to 2902.7 tonnes representing 4.39% of the base case. From Fig. 10 the net annual GHG emission reduction of the proposed case was 60049 $tCO_2$ which is equivalent to 139,672 barrels of crude oil not consumed by a power plant generating equivalent electricity to the one from the proposed case.

The results of the current study are supported by findings of previous studies in the area of carbon dioxide reduction by the installation of renewable energy, though there are differences in the mitigation volumes. Research conducted by[5], found that 90 $MMtCO_2$ will be avoided if renewable energy technology is integrated into Ghana's energy generation system and this is equivalent to a 40% reduction of current fuels used in energy generation. Also,[17], found that 1313 metric tonnes of carbon dioxide which is equivalent to a car having a $CO_2$ emission of 150g/km and covering 10000 km/year, can be avoided if a 2.5MW PV system is installed.

## IV. CONCLUSION

There is sufficient solar radiation at the selected site (Dr. Hilla Limann Technical University) for generating electricity to serve the institution and the surplus electricity can be sold to the Utility company. Considering the outcome of the simulation, it is obvious that the proposed Solar PV-based power plant can be suitably commissioned at Dr. Hilla Limann Technical University. The great potential of employing solar energy in the University is confirmed by the anticipated high energy yield. It was also economically viable to implement the Grid-connected solar PV systems since their NPV is positive and also BCR is greater than 1. This project will meet 100% of Dr. Hilla Limann Technical University's energy requirements and the surplus exported to Grid.

The project can save tonnes of $CO_2$ which would have been given out by non-renewable power stations generating an equal amount of electric power, which indicates a great environmental impact for a better world.

## REFERENCES


[1]. UNDP Regional Bureau for Africa (RBA). (2018). Transforming lives through renewable energy access in Africa UNDP's Contributions.

[2]. Ministry of Energy - Ghana. (2010). National Energy policy. Accra.

[3]. E.H. Borgstein, R. Lamberts, J.L.M. Hensen, Energy Build. 128 (2016) 734–755.

[4]. Kuamoah, C. (2020). Renewable Energy Deployment in Ghana: The Hype, Hope and Reality. Insight on Africa, 12(1), 45-64. doi:10.1177/0975087819898581

[5]. Awopoane, A. K., Zobaa, A. F., & Banuenumah, W. (2017). Techno-economic and environmental analysis of power generation expansion plan of Ghana. Energy Policy. doi:10.1016/j.enpol.2017.01.034

[6]. Eshun, M. E., & Amoako-Tuffour, J. (2016). A review of the trends in Ghana. Energy, Sustainability and Society, 5(1)

[7]. Gong, X., & Kulkarni, M. (2005). Design optimization of a large scale rooftop Photovoltaic system. Solar Energy, 78, 362–374. doi:10.1016/j.energy.2020117771

[8]. Kumi, E. N. (2017). The Electricity Situation in Ghana: Challenges and Opportunities. Washington DC: Center for Global Development.

[9]. Northen Electricity Distribution Company (2018).

[10]. Energy Commission of Ghana. (2019). National Energy Energy Statistics Review. Accra.

[11]. Ghana Statistical Service. (2013). 2010 Population and Housing Census: National Analytical Report. Accra.

[12]. Sarsah, E. A., & Uba, F. A. (2013). Monthly-Specific Daily Global Solar Radiation Estimates Based on Sunshine Hours In Wa, Ghana. International Journal of Scientific & Technology Research, 2(8), 246-254

[13]. Rehman, S., Ahmed, M. A., Mohamed, M. H., & Al-Sulaiman, F. A. (2017). Feasibility study of the grid-connected 10 MW installed capacity PV power plants in Saudi Arabia. Renewable and Sustainable Energy Reviews, 80, 319–329. doi:10.1016/j.rser.2017.05.218

[14]. Mohammed, A. Y., Mohammed, F. I., & Ibrahim, M. Y. (2017). Grid-Connected Photovoltaic System. 2017 International Conference on Communication, Control, Computing and Electronics Engineering (ICCCCEE). Khartoum.

[15]. Saani, S. H., & Mohammed, K. (2018, August). Residential solar Photovoltaic system vs grid supply: An economic analysis using RETScreen. Journal of Solar Energy Research (JSER), 3(2), 107-114.

[16]. Saleh, S. S. (2017). Feasibility Analysis of 5, 8, and 10 kW Grid-Connected Photovoltaic Systems in Saudi Arabia. Eastern Mediterranean University, Mechanical Engineering, Famagusta, North Cyprus.

[17]. Mensah, L. D., Yamoah, J. O., & Adaramola, M. S. (2019). Performance evaluation of a utility-scale grid-tied solar photovoltaic (PV) installation in Ghana. Energy for Sustainable Development, 48, 82–87. doi:10.1016/j.esd.2018.11.003

[18]. Ballaji, A., Ananda , H. M., Swamy, K. N., & Venkatesh, B. M. (2018). Design, Analysis, and Economic Investigation of Standalone Roof Top Solar PV System for Rural India. International Journal of Applied Engineering Research.

[19]. Omar, M. A., & Mahmoud, M. M. (2019). Design and Simulation of a PV System Operating in Grid-Connected and Stand-Alone Modes for Areas of Daily Grid Blackouts. International Journal of Photoenergy, 1-9. doi:10.1155/2019/5216583

[20]. Kimber, A., Mitchell, L., Nogradi, S. and Wenger, H. (2006) The Effect of Soiling on Large Grid-Connected Photovoltaic Systems in California and the Southwest Region of the United States. 4th IEEE World Conference on Photovoltaic Energy Conversion, Waikoloa, HI, 7-12 May 2006, 2391-2395. https://doi.org/10.1109/WCPEC.2006.279690

[21]. Michael Obeng , Samuel Gyamfi , Nana Sarfo Derkyi , Amos T. Kabo-bah and Forson Peprah (2019). Technical and economic feasibility of a 50 MW Grid-connected solar PV at UENR Nsoatre Campus

[22]. Rafique, M. M., & Bahaidarah, H. M. (2019). Thermo-economic and environmental feasibility of a solar power plant as a renewable and green source of electrification. International Journal of Green Energy. doi:10.1080/15435075.20191677237