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Technical Performance of Grid-Connected Rooftop Solar PVs

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Abstract – *This paper presents a comprehensive analysis of the technical performance of grid-connected rooftop solar photovoltaic (PV) systems deployed in five locations along the solar belt of Ghana, namely Sakumono, Wa, Bolgatanga, Kumasi, and Kintampo. These locations were selected based on their diverse environmental conditions, offering a representative sample for the study. The study utilized PVSyst software version 7.3 to simulate the performance of the PV systems for each location, using south orientation, which gives the best results in the tilted global irradiation across all locations. According to the simulation results, the average performance ratio for the five locations was 79.7%, indicating the PV systems' highly efficient utilization of the available solar energy. The average final yield, representing the actual energy output, was also measured to be 4.38 kWh/kWp/day for the studied locations. This study demonstrates the technical feasibility of Ghana's grid-connected rooftop solar PV installations. The results underscore the significance of optimal system design and orientation, emphasizing the potential for substantial renewable energy generation. The insights obtained from this study can aid policymakers, investors, and solar energy stakeholders in making informed decisions to promote the widespread adoption of rooftop solar PV systems in the region.*

Keywords: *Technical performance, Grid-connected rooftop PVs, Performance ratio, reference yield.*

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I. Introduction

In 2022, the International Energy Agency (IEA) conducted an evaluation and found a remarkable surge in global renewable electricity generation, surpassing 700 terawatt-hours (TWh). This increase is the most substantial annual growth ever recorded. Moreover, the trend of escalating energy production from renewable sources is anticipated to persist, driven by ongoing technological advancements in this field [1].

The significant increase in global adoption of renewable energy, mainly in developed countries, highlights the unexplored opportunities for emerging countries. Taking Ghana, for example, traditional power generation methods, such as the application of fossil fuels such as natural gas, play a central role. To a certain extent, this heavy reliance has hindered the progress of unconventional energy sources. Given the rapid growth in the number of people using electricity, providing access to alternative energy sources is imperative. According to Ghana's Renewable Energy Master Plan (REMP) for 2030, the envisioned total solar power generation capacity is 741.3 MWp, representing 53.3% of the country's renewable energy sources [2]. This implies that electricity from grid-tied solar PVs will ultimately play an immense role in the country's total energy production. The primary advantages of a grid-connected PV system include its straightforward setup and comparatively affordable operational and maintenance expenses, resulting in decreased electricity bills [3]. These solar PV systems, linked to the grid, can be installed on rooftops or on the ground. Rooftop installations are a cost-effective choice as they utilize existing space, unlike ground-mounted systems requiring a sizable land area for solar panel installation [4].

Recently, rooftop solar PV systems connected to the grid have gained significant popularity. This is due to their ability to harness solar power, thereby decreasing dependence on fossil fuels and minimizing the carbon footprint. These systems are commonly set up on the rooftops of residential and commercial buildings, where they are integrated into the electrical grid.

Technical performance assesses how effectively a solar PV system transforms solar energy into usable electricity that can be fed into the grid. The efficiency of grid-connected rooftop solar PV systems is influenced by various factors, such as solar irradiance, tilt angle, orientation, system design and setup, panel efficiency, inverter efficiency, environmental conditions, and potential shading [5]. The technical performance of grid-connected rooftop solar PV systems can exhibit significant variability based on these influencing factors. Various technical performance metrics include Energy Yield, Performance Ratio (PR), System Yield, Losses, Capacity Factor, Reference Yield, and more [6]. Given that solar energy production is influenced by various location-specific factors, assessing the technical performance of grid-connected rooftop solar PV systems is of utmost importance. This evaluation benefits countries' current and future energy markets by ensuring efficient energy generation and utilization.

The study of the technical performance of grid-connected rooftop solar PVs has been limited, especially in Sub-Saharan Africa. Quansah et al. [7] conducted a performance analysis study of PV systems with a combined capacity of 20 kW over one year. These systems were installed on the rooftops of various buildings at the College of Engineering, Kwame Nkrumah University of Science and Technology in Kumasi, Ghana. Real-time data for the performance indices were obtained by an integrated web server in the SMA Sunny Boy DC-AC inverters employed in the study. The study revealed that the total annual energy supplied to the grid ranged from 3133.2 kWh to 4572.1 kWh, and a maximum performance ratio of 71.26%. These systems delivered 20.62 MWh of actual energy to the grid. It is worth noting that this study was limited to a single location and did not encompass results for other performance metrics, including reference and losses. Again, Saxena *et al.* [8] investigated the power generation potential of solar PV systems in seven Indian cities, focusing on analysing the performance of seven 100-kWp capacity systems on the rooftops of government buildings. PVSyst version 6 was used for the study. The performance ratio obtained was between 70 and 80%. From the study, the capacity factor was found to be between 19 and 21%. However, the study did not highlight the system losses accompanying PV systems. Gautam and Darlami [9] have done a comprehensive technical performance analysis of a 1-kWp grid-tied rooftop solar PV system for residential consumers in Urban Areas at Lalitpur, Nepal. PVSyst was employed as the simulation tool for this study. Some results from the study include an average yield of 4.59 kWh/kWp/day, a system yield factor of 4.24 kWh/kWp/day, a performance ratio of 74% and a capacity factor of 17.7%. Using the PVSyst software tool, the performance parameters of a 100-kWp grid-connected rooftop PV system on the roof of Bansal Institute of Engineering and Technology in Lucknow, India, were simulated and determined by Srivastava *et al.* [10]. The study used environmental parameters that were specific to the study area. The average performance ratio recorded was 79.5%. Another study made by Ali and Abdullah [11] assessed the feasibility of installing a grid-connected PV system on selected rooftops at Universiti Tun Hussein Onn Malaysia (UTHM) to reduce annual electricity consumption and bills using the Net Energy Metering (NEM) scheme. The key results were a specific yield of 4550-kWh/kWp, a performance ratio of 74.03%, and a capacity factor of 12.79%. The demerit of the above studies is that geographical and meteorological factors significantly influence Solar PV system performance; hence, basing a study on just one location does not accurately represent the potential of solar energy for the entire country due to varying factors like solar irradiance and temperature in different regions.

It is observed from the works reviewed that the studies were primarily conducted in just one location and, in most cases, did not account for losses accrued in PV systems. This study has determined the technical performance of grid-connected rooftop solar PV systems in five areas with disparate climatic conditions in Ghana by measuring the values of key performance parameters using PVSyst. Physical roof suitability and shading studies are also done on the roofs found in the various locations to determine the available and suitable rooftop areas for PV module installation.

II. Theory

II.1. Grid-Connected Rooftop Solar PV System

A grid-connected solar PV system consists of solar PV modules (which form an array), one or more inverters, and an energy meter. For the aim of producing electricity from stored solar energy and supplying it to loads, these components are assembled and connected in the order shown. The grid receives the excess energy.

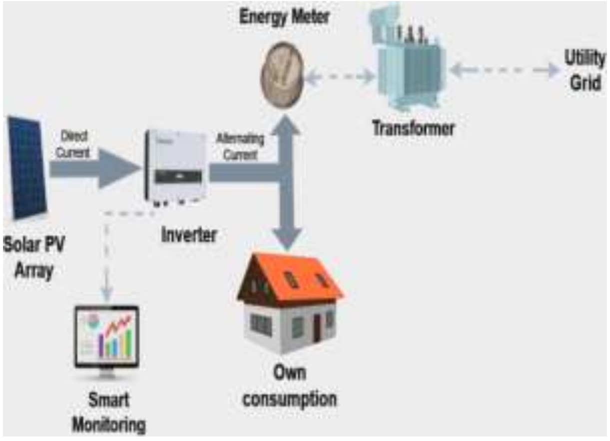

Figure 1. Grid-Connected Rooftop Solar PV System

II.2. *PV Array and Inverter Configurations*

The Solar PV array consists of a collection of modules. The modules contain solar cells that harness DC solar energy to be changed into AC energy. The PV array size and inverter for gid-connected PV systems using the available area are determined using the following mathematical equations. The total power of the PV array is given by (1)

$$\mathrm{P(array)} = \mathrm{A} \times \mathrm{I} \times \eta \tag{1}$$

where P(array) is PV Array Power, A is Total Area, I is Solar Irradiance, and η is conversion efficiency.

The number of modules in a PV string is calculated using eq (2).

$$\text{No. of modules in a string} = \frac{V_{max}}{V_{oc}} \tag{2}$$

where V_{max} is Max. Inverter System Voltage and V_{oc} is Open Circuit Voltage of Module Used

The number of strings in parallel is determined by (3):

$$\text{No. of strings} = \frac{\mathrm{P(array)}}{\mathrm{P(string)}} \tag{3}$$

where, P(array) is the PV Array Power and P(string) is the PV string power

The total number of modules is given by (4).

$$\text{Total no. of modules} = \mathrm{N(module)} \times \mathrm{N(string)} \tag{4}$$

where, N(modules) = Number of modules in strings and N(string) = Number of strings in parallel

The inverter is an electronic device that converts the harnessed DC energy by the PV modules into AC energy. The inverters' rating is determined using (5).

$$\mathrm{P(inverter)} = \frac{\mathrm{P(array)}}{\text{DC}-\text{to}-\text{AC ratio}} \tag{5}$$

where, P(inverter) is Inverter Power, P(array) is PV Array Power and DC-to-AC ratio is a ratio usually between 1.1 and 1.3.

The number of inverters that are used per location is calculated using (6).

$$\text{No. of inverters} = \frac{\mathrm{P(array)}}{\mathrm{P(inverter)}} \tag{6}$$

where P(inverter) is the power rating of the inverter.

II.3. *Performance Metrics*

Per the standards set by the International Electrotechnical Commission (IEC) and the International Energy Agency (IEA), the assessment of solar PV system performance can be conducted through various parameters, including energy yield, final system yield, reference yield, performance ratio, losses, and capacity factor [9], [12]. These performance parameters enable the comprehensive evaluation of the grid-connected PV system's overall efficiency, facilitating comparisons between different PV installations [7].

II.3.1. *Energy/ Array Yield (Y_a)*

This ratio, referred to as the energy yield or energy/array yield, represents the DC energy (E_{DC}) generated by the PV array over a given period (such as a day, month, or year) in relation to the peak power of the PV plant ($P_{PV\ rated}$) at standard test conditions (STC) [13]. The energy/array yield expresses the energy output of the PV array per installed kilowatt (kW) of the PV array, providing a measure of the energy output independent of the size of the plant [10]. It can also be defined as the DC energy produced by the PV solar array divided by the nominal (rated) power of the PV solar system [7], [8], [12], [14]. It has a unit of kWh/kWp.

$$Y_a = \frac{E_{dc}}{P_{pv(rated)}} \tag{7}$$

where, E_{dc} = DC energy (E_{DC}) produced by the PV array over a period and $P_{PV\ rated}$ = Peak power of the PV plant

II.3.2. *Final System Yield (Y_f)*

The final system yield is a metric that determines the efficiency of a PV plant. It is calculated as the ratio of the net AC-generated energy output of the PV plant to the plant's rated power according to (7) [10], [12]. Alternatively, it can be expressed as the ratio of the final energy yield to the nominal power installation of the solar PV at standard test conditions (STC) [9], [13]. This metric represents the useful energy the system generates and signifies how long the PV array needs to operate at its rated power to produce the same energy from sunlight [11], [15]. The final system yield considers factors like the angle at which the PV array is tilted and the structure used for mounting the PV panels, and when Y_f is close to 1, it indicates the use of appropriate technology [10].

$$Y_f = \frac{E_{dc}}{P_{pv(rated)}} \tag{8}$$

where, E_{ac} is AC generated energy output and $P_{PV\ rated}$ is peak power of the PV plant.

II.3.3. Reference Yield (Y_r)

The reference yield is calculated as a ratio of the total horizontal irradiance received by the PV array to the global irradiance at STC according to (8) [9], [10], [14]. It represents the entire amount of solar insolation on the surface of the PV array divided by the array's reference irradiance, which is typically set at 1 kW/m² [12], [13]. This metric signifies the theoretical energy that can be harnessed from the sun and is influenced by factors such as the geographical location, the orientation of the PV array, and variations in weather conditions over a given period, whether a month or a year [11].

$$Y_r = \frac{H_t}{G_o} \tag{9}$$

where, H_t represents the Total horizontal irradiance on the array and G_o is the Global irradiance at standard test conditions.

II.3.4. Performance Ratio (PR)

The performance ratio (PR) measures a PV plant's effectiveness in delivering energy to the grid in relation to the energy it could generate under standard test conditions. This is calculated according to (9). This dimensionless parameter is a crucial indicator for assessing the performance of PV systems, regardless of their installation location or method [10]. PR is considered the most significant parameter when evaluating the performance of any PV plant [10]. It evaluates the efficiency of a solar PV system by considering environmental variables such as irradiance, temperature, and climate fluctuations [11]. This metric reflects the energy sent to the grid in relation to the received irradiation and is expressed as the ratio of the final system yield to the reference yield [6].

$$PR = \frac{Y_f}{Y_r} \tag{10}$$

where, Y_f is the Final yield and Y_r is the Reference yield.

II.3.5. Capacity Factor (CF)

The capacity factor is a metric that quantifies the efficiency of a PV system. It is calculated as the ratio of the actual annual energy generated by the PV system (E_a) to the amount of energy the PV system would produce if it operated at its full rated power 24 hours a day for an entire year, according to (10) [6], [16]. It can also be expressed as the percentage of energy generated annually divided by 8760 hours, divided by the installed capacity of the PV module [11]. When a system continuously delivers its full rated power, its Capacity Factor (CF) equals 1, or 100%. The system's location influences the CF; a higher capacity factor indicates a more efficient PV system [17].

$$CF = \frac{E_{ac}}{P_{pv(rated)\times 8760}} \tag{11}$$

where, E_{ac} = AC generated energy output and $P_{PV\ rated}$ = Peak power of the PV plant.

II.3.6. Losses

The losses incurred in the grid-connected solar PV system can be categorised into system and array losses.

- System Losses (L_s)

These are losses resulting from the conversion of DC energy to AC power via the inverter. It is expressed mathematically as the difference between the energy/array yield and the final yield [12] - [14] according to (11)

$$L_s = Y_a - Y_f \tag{12}$$

- Array Losses (L_a)

These losses result from the operation of the PV array and signify the array's inability to completely convert the available solar insolation into electricity. In simpler terms, they represent the portion of total irradiation that the PV modules are unable to capture [13]. These losses can be attributed to factors such as wiring, module quality, mismatch, thermal losses, shading, dirt, and other sources of inefficiency [14]. They are quantified as the difference between the reference yield and the array yield according to (12) [12], [13], [17].

$$L_a = Y_r - Y_a \tag{13}$$

II.4. PVSyst Software

PVSyst is computer software designed for the simulation of solar photovoltaic systems. By using PVSyst, data on complete grid-connected or stand-alone solar PV systems may be found, organised, and analysed. This simulation tool contains a large database of different brands of solar PV modules and inverters, which provides a flexibility in designing PV systems, all the while obtaining high accurate results for key design parameters that can be translated into building real-life systems. The software is also very user-friendly with an easy-to-operate interface [18]

III. Methodology

Tables the project was sectioned into three: Feasibility Study, System Specifications, and Performance Analysis phases.

III.1. Feasibility Study

In this phase, five sites along the solar belt of Ghana are selected based on their disparate solar potential and climate data (temperature and humidity). The selected sites are Sakumono (Greater-Accra Region), Wa (Upper-West Region), Bolgatanga (Upper-East Region), Kumasi (Ashanti Region) and Kintampo (Bono East Region). Again, physical suitability studies of the rooftops of five buildings at each of the selected sites are conducted by measuring and summing their roof areas for each orientation: North, South, East and West. The measurement is done using the ruler tool found in the Google Earth Pro software. The total measured roof areas are represented in Table 1.

Table 1. Total Measured Roof Areas for the Five sites

Site	Total Measured Roof Area (m^2)			
	North	South	East	West
Sakumono	538.43	583.74	492.09	551.74
Wa	872.41	718.74	676.68	768.95
Bolgatanga	141.43	176.64	240.71	385.32
Kumasi	437.12	577.77	508.60	368.02
Kintampo	593.79	428.98	360.64	383.56

To account for solar setback, which is a security factor for safety concerns and to avoid obstruction of sunlight to neighbouring buildings, the roof areas are multiplied by a factor of 0.75 to obtain the recommended roof areas for PV modules installation [19]. The recommended total roof areas are shown in Table 2.

Table 2. Recommended Roof Areas for PV Installation

Site	Recommended Total Roof Area (m^2)			
	North	South	East	West
Sakumono	403.82	437.81	369.06	413.86
Wa	654.30	539.01	507.51	576.71
Bolgatanga	106.07	132.50	180.53	288.99
Kumasi	327.88	433.33	381.45	276.02
Kintampo	445.34	321.74	270.48	287.67

After determining the suitable roof area, the next stage was finding the optimum tilt angles for the study sites. Using the Solar GIS Prospect platform, the different sites are found as shown in the Table 3:

Table 3. Optimum Tilt Angles for the Five Sites

Site	Optimum Tilt Angle (˚)
Sakumono	7
Wa	13
Bolgatanga	14
Kumasi	8
Kintampo	10

The optimum orientation for all the study sites was determined using PVSyst. This is determined by comparing the tilted global irradiations of the different orientations at the different sites. The tilted global irradiations are found by accessing the Monthly Meteo Computation under the Tools option in PVSyst, then selecting the Tilt Global Irradiation under the list of variables that could be drawn and taking into account Transposition of tilted plane. The optimum tilt angles for the various sites are inputted, together with the corresponding azimuth angle for the various orientations which are all in the northern hemisphere (North: 180˚, South: 0˚, East: -90˚, West: 90˚). The values for the tilted global orientation are then generated by the software. The result is shown in Figure 2.

From Figure 2, the South is the best orientation for solar PV installations for all the locations as it yields the optimum tilted global irradiation. Thus, south-facing roof areas were employed for further studies.

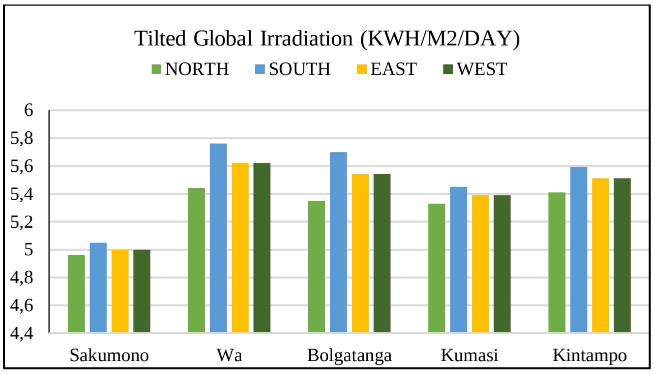

Figure 2. Tilted Global Irradiations for the five sites

III.2. System Specification Phase

This section determines the electrical and mounting specifications for the PV modules, the electrical specifications for the inverter, and the system power size for various locations. The SunPower brand of PV modules is considered for this project, as it is one of the market's most reliable, durable and efficient brands of PV modules [20]. The monocrystalline PV modules are used for the work since it is the type of PV module that yields the highest efficiency in terms of solar energy harnessing [21,22]. This module type can also be found in PVSyst, which helps in simulation.

Table 4. Specifications of PV Module Used

Brand	**SunPower**
Model	SPR-X21-345-COM
Technology	Silicon-monocrystalline
Nominal Power at STC	345-Wp
Nominal Voltage Output	50-V
Module Area	1.631-m^2
Weight	18.60-kg
Short-circuit Current	6.16-A
Open-circuit Voltage	70.0-V
Efficiency	23.03%

Due to the varying south-facing roof areas, Table 2, for the different sites, the number of PV modules that could be mounted also varies. Using (1) – (4), the number of PV modules in series, the number of strings in parallel, and the total number of modules required for installation on the rooftops at the various sites were computed in Table 5.

Table 5. PV Modules Configuration

Site	**Modules In Series**	**Number Of Strings**	**Number Of Modules**	**Roof Area Occupied in m^2**
Sakumono	11	24	264	431
Wa	11	30	330	538
Bolgatanga	10	8	80	130
Kumasi	11	24	264	431
Kintampo	12	16	192	313

Inverters from Huawei Technologies were used in this study because of their high efficiency, reliability, and durability [23]. The power rating and the number of inverters used are found using (5) and (6), respectively.

Table 6. Specifications of Inverters Used

Site	Model	Specifications	Number Of Inverters
Sakumono	SUN2000-75KTL-C1	75-kW, 200-1000V, 50/60-Hz, 99.00% efficiency	1
Wa	SUN2000-50KTL-ZHM3-380V	50-kW, 200-1000V, 50/60-Hz, 98.42% efficiency	2
Bolgatanga	SUN600-25KTL-ZHM0-380V	25-kW, 200-1000V, 50/60-Hz, 98.44% efficiency	1
Kumasi	SUN2000-75KTL-C1	75-kW, 200-1000V, 50/60-Hz, 99.00% efficiency	1
Kintampo	SUN2000-29.9KTL	29.9-kW, 200-1000V, 50/60-Hz, 98.64% efficiency	2

The total planned peak power rating for each site is obtained using data from Table 5.

Table 7. Planned PV System Sizing for the Five Sites

Site	**Planned Power Size (kWp)**
Sakumono	91.08
Wa	113.85
Bolgatanga	27.60
Kumasi	91.08
Kintampo	66.24

III.3. Performance Analysis Phase

The imulation work is done using PVSyst to measure/estimate the technical performance metrics to obtain results, which help determine the feasibility of PV installation at the various locations. The meteorological data for the sites are obtained from the Meteonorm 8.1 database found in the PVSyst software. Some of the important meteorological data observed are shown in Table 8. The average horizontal global irradiation was transposed to tilted global irradiation using the optimum tilt angles, obtained in Table 3, in determining the performance metrics.

Table 8. Some Meteorological Data for the five sites

Site	Avg. Horizontal Global Irradiation (kWh/m^2/day)	Avg. Annual Temperature (° C)
Sakumono	5.01	27.5
Wa	5.66	27.6
Bolgatanga	5.60	28.8
Kumasi	5.40	27.3
Kintampo	5.52	26.6

The optimum tilt angle and the azimuth angle for the South orientation are inputted into the PVSyst software under the orientation parameter. Under the System parameter, the recommended rooftop area is entered into the software. The solar PV and inverter brands are selected from the list of brands. The solar PV module and the inverter with the required specifications are selected from the list available in the software's database. The system is sized by selecting the appropriate PV array and the inverter configurations to match the available roof area. The simulation of the designed system is run, and the results are obtained.

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IV. Results and Discussions

Based on the six mentioned performance metrics, the simulation results for PV systems at various south-oriented sites are analyzed. These parameters are normalized, allowing conclusions to be drawn about the performance across different locations.

IV.1. Results for the Performance Metrics in the Different Sites

IV.1.1. Reference Yield

Reference Yield, which characterizes solar energy incident on the PV panels per unit area, varies across the selected sites as shown in Figure 3.

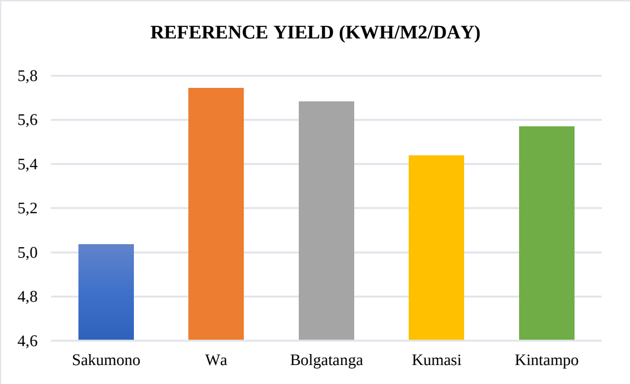

Figure 3. Reference Yield Results from Simulation

The highest reference yield was observed in Wa (5.74 kWh/m^2/day), attributed to the relatively elevated solar irradiance in the northern parts of Ghana. In contrast, Sakumono exhibited the lowest reference yield (5.04 kWh/m^2/day), indicative of comparatively subdued solar irradiance levels in the southern locale.

IV.1.2. *Energy Yield*

The energy yield in each location, which denotes the actual electrical energy produced in each location, is compared in Figure 4.

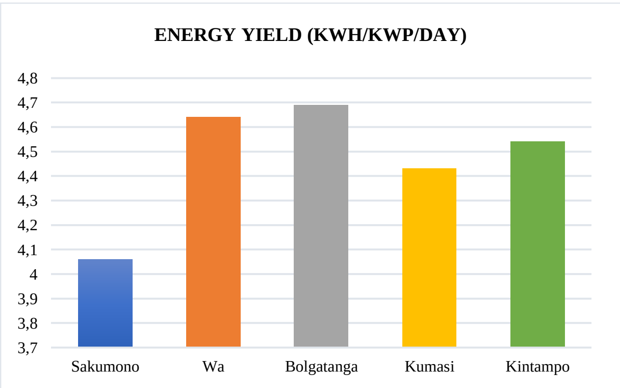

Figure 4. Energy Yield Results from Simulation

Regarding actual electrical energy production per installed PV capacity, the Energy Yield metric showed that Bolgatanga produced the most energy (4.69 kWh/kWp/day), followed closely by Wa (4.64 kWh/kWp/day). Sakumono, on the other hand, demonstrated the lowest energy output (4.06 kWh/kWp/day), highlighting the relationship between solar irradiance and efficient energy generation.

IV.1.3. *Final Yield*

The final yield for each location is also compared in Figure 5.

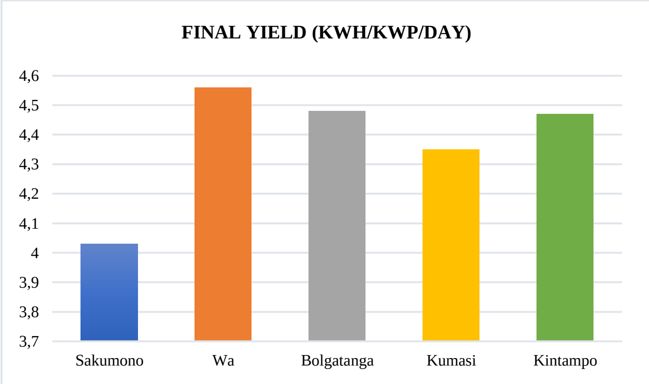

Figure 5. Final Yield Results from Simulation

In terms of Final System Yield, Wa had the highest yield (4.56 kWh/kWp/day), followed closely by Bolgatanga (4.48 kWh/kWp/day). Sakumono had the lowest final system yield (4.03 kWh/kWp/day), demonstrating the significant impact of solar irradiation and related system losses on overall system efficiency. Therefore, the amount of AC energy fed into the grid will be highest in Wa and lowest in Sakumono per the results obtained.

IV.1.4. *Performance Ratio*

The performance ratio of the PV system in each location is compared Figure 6.

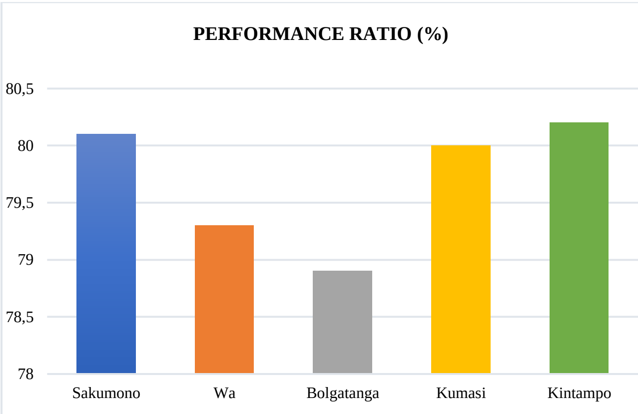

Figure 6. Performance Ratio Results from Simulation

The Performance Ratio (PR) showed that Kintampo (80.2%) and Sakumono (80.1%) were the two locations with the greatest PR values. Bolgatanga and Wa showed PR values below 80%, indicating reasonably efficient solar energy-to-power conversion. These lower values are due to high temperatures in those areas, which decrease output voltage and, consequently, power output.

IV.1.5. *Capacity Factor*

The efficiency of the PV system measured in terms of capacity factor for each location is compared in Figure 7.

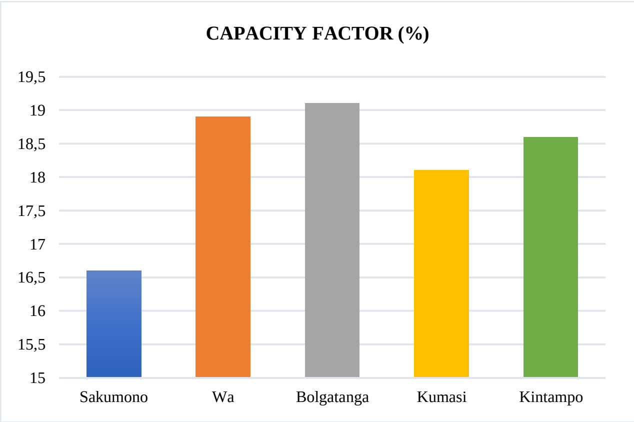

Figure 7. Capacity Factor Results from Simulation

Bolgatanga had the highest value of the capacity factor (19.1%), which measures actual output concerning maximum potential output over a year, whereas Sakumono had the lowest value (16.6%). This can be attributed to Sakumono having lower solar irradiation than Bolgatanga, which is more arid.

IV.1.6. Losses

The results show losses, which are inevitable in PV systems due to components, shade, temperature, and soiling as shown in Table 9. The most enormous system losses (0.09 kWh/kWp/day) and array losses (1.09 kWh/kWp/day) accounted for a loss of 1.18 kWh/kWp/day were observed in Wa. In contrast, Sakumono had the lowest overall losses (1.00 kWh/kWp/day) due to reasonably low temperatures in this region.

Table 9. Losses Results from Simulation (in kWh/kWp/day)

Site	Array Losses	System Losses	Total Losses
Sakumono	0.93	0.07	1.00
Wa	1.09	0.09	1.18
Bolgatanga	1.10	0.18	1.28
Kumasi	1.01	0.08	1.09
Kintampo	1.04	0.07	1.11

IV.2. Summary

These findings demonstrate that the location for solar panel installation is essential. Energy production is typically higher in areas with greater solar energy, as observed from the energy and final yield values obtained for the sites Wa and Bolgatanga, where high solar irradiance is prevalent. However, good design and maintenance, such as the introduction of ventilation and cooling systems, also play a significant part in the efficiency of electricity generation from solar energy in these sites. Kintampo, Sakumono, and Kumasi produced relatively higher average PR values than Wa and Bolgatanga, where final yield values are seen to be high. This is attributed to the lower temperatures in Kintampo, Sakumono, and Kumasi compared to temperatures experienced in Wa and Bolgatanga. Overall, solar energy has potential for Ghana's energy requirements, mainly if how these systems are installed and maintained is improved.

IV.3. Comparison of Study with Existing Literature

This study is compared with related studies published in the literature from around the world in Figure 8. The comparison is based on the performance ratio metric since it may be used to assess the performance of a PV system quickly. Turkey, India, Iraq, and Nepal are the nations under consideration. These countries were selected because their solar irradiance capacity is comparable to Ghana's.

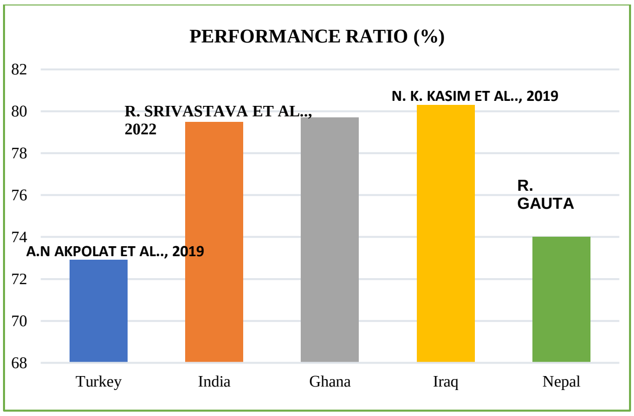

Figure 8. Acomparison of the study with existing literature

Observations Made from the Comparison

- All the countries have performance ratio values falling between 72 and 80% due to high solar irradiation in these areas.
- Iraq and Ghana have two weather seasons per year: summer and winter and dry and wet seasons, respectively. However, Iraq has a higher PR than Ghana because it has better combined climatic conditions such as irradiance, temperature and humidity, which are favourable for improved solar energy harnessing.
- Turkey, Nepal and India experience four seasons (Winter, Autumn, Spring and Summer) compared to Ghana, which has two seasons. Due to the change in seasonality throughout the year, PV systems in those countries cannot effectively run all year long, hence a lower PR.

V. Conclusion

This research presents a comprehensive technical evaluation of the performance of grid-connected rooftop solar PV systems across five locations within Ghana's solar belt. It meticulously measures key performance indicators such as Energy/Array Yield, Final System Yield, Reference Yield, Performance Ratio, Losses, and Capacity Factor. To assess the viability of installing rooftop PV systems, the study includes roof suitability analyses across the chosen locations, using SolarGIS and PVSyst's tilted global irradiation data to ascertain the optimal tilt angles and orientations for PV module installation. Additionally, the study defines system requirements encompassing electrical and mounting specifications for PVs and electrical specifications for inverters to maximize solar energy capture. Simulations of the PV systems for the different locations were carried out using PVSyst software.

The study found an average Reference Yield of 5.49 kWh/m^2/day and an Energy/Array Yield of 4.47 kWh/kWp/day. The Final System Yield was 4.38 kWh/kWp/day, with a Performance Ratio of 79.7%, a Capacity Factor of 18.26%, and Total Losses amounting to 1.13 kWh/kWp/day. It was noted that southern orientations favoured PV system installations. Simulation results confirmed the feasibility of installations in all locations, as evidenced by high-performance ratio values. Notably, northern sites in Ghana showed higher values for reference yield, energy yield, final system yield, and capacity factor attributed to the region's intense solar irradiation. However, these sites also experienced higher losses due to elevated temperatures, suggesting that incorporating efficient cooling and ventilation in PV systems could render northern locations highly suitable for installations. In conclusion, the installation of PV systems in the evaluated locations is not only feasible but would also substantially contribute to the national electrical grid's energy output.

Declaration

- The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.
- The authors declare that this article has not been published before and is not in the process of being published in any other journal.
- The authors confirmed that the paper was free of plagiarism.

References

[1] Intenational Energy Agency, “Defying expectations, CO2 emissions from global fossil fuel combustion are set to grow in 2022 by only a fraction of last year’s big increase,” https://www.iea.org/news/defying-expectations-co2-emissions-from-global-fossil-fuel-combustion-are-set-to-grow-in-2022-by-only-a-fraction-of-last-year-s-big-increase.

[2] A. Afful-Dadzie, S. K. Mensah, E. Afful-Dadzie, “Ghana renewable energy master plan: The benefits of private sector participation,” Sci Afr, Vol. 17, 2022, doi: 10.1016/j.sciaf. 2022.e01353.

[3] Alternative Energy Tutorials, “Grid Connected PV System,” https://www.alternative-energy-tutorials.com/solar-power/grid-connected-pv-system.html#:~:text=The%20main%20advantage%20of%20a,required%20amount%20of%20excess%20power.

[4] SolarTech, “Solar Ground Mounts vs. Solar Roof Mounts,” https://solartechonline.com/blog/ground-vs-roof-solar/.

[5] K. V Vidyanandan, “An Overview of Factors Affecting the Performance of Solar PV Systems,” 2017. https://www.researchgate.net/publication/319165448

[6] N. Anang, S. N. A. Syd Nur Azman, W. M. W. Muda, A. N. Dagang, M. Z. Daud, “Performance analysis of a grid-connected rooftop solar PV system in Kuala Terengganu, Malaysia,” Energy and Buildings, vol. 248. Elsevier Ltd, Oct. 01, 2021. doi: 10.1016/j.enbuild.2021.111182.

[7] D. A. Quansah, M. S. Adaramola, G. K. Appiah, I. A. Edwin, “Performance analysis of different grid-connected solar photovoltaic (PV) system technologies with combined capacity of 20 kW located in humid tropical climate,” Int J Hydrogen Energy, Vol. 42, no. 7, pp. 4626–4635, 2017, doi: 10.1016/j.ijhydene.2016.10.119.

[8] A. K. Saxena, S. Saxena, K. Sudhakar, “Energy, economic and environmental performance assessment of a grid-tied rooftop system in different cities of India based on 3E analysis,” Clean Energy, Vol. 5, no. 2, pp. 288–301, Jun. 2021, doi: 10.1093/ce/zkab008.

[9] R. Gautam, H. Bahadur Darlami, “Technical analysis of grid connected 1 kwp rooftop solar pv for residential consumer at urban areas of lalitpur, nepal.”

[10] R. Srivastava, M. Amir, F. Ahmad, S. K. Agrawal, A. Dwivedi, A. K. Yadav, “Performance evaluation of grid connected solar powered microgrid: A case study,” Front Energy Res, Vol. 10, Nov. 2022, doi: 10.3389/fenrg.2022.1044651.

[11] M. Fakrie, M. Ali, M. N. Abdullah, “Journal of Electronic Voltage and Application Feasibility Study of the Technical and Economic Performance of Grid-Connected PV System for Selected Rooftops in UTHM,” Journal of electronic voltage and application, Vol., no. 2, pp. 45–56, 2021, doi: 10.30880/jeva.2021.02.02.005.

[12] N. Kasim, H. Hussain, A. NAbed, “Performance Analysis of Grid-Connected CIGS PV Solar System and Comparison with PVsyst Simulation Program,” 2019.

[13] A. Murat Ates, H. Singh, "Rooftop solar Photovoltaic (PV) plant – One year measured performance and simulations," J King Saud Univ Sci, Vol. 33, no. 3, May 2021, doi: 10.1016/j.jksus.2021.101361.
[14] V.M. Phap, N.T. Nga NT "Feasibility Study Of Rooftop Photovoltaic Power System For A Research Institute Towards Green Building In Vietnam". EAI Endorsed Transactions on Energy Web. doi: 10.4108/eai.7-1-2020.162825, 2020.
[15] S. Thotakura, S. C. Kondamudi, J. F. Xavier, Ma Quanjin, G. R. Reddy, P. Gangwar, S.L.Davuluri, "Operational performance of megawatt-scale grid integrated rooftop solar PV system in tropical wet and dry climates of India," Case Studies in Thermal Engineering, Vol. 18, 2020, doi: 10.1016/j.csite.2020.100602.
[16] I. Ibrik, F. Hashaika, "Techno-economic impact of grid-connected rooftop solar photovoltaic system for schools in palestine: A case study of three schools," International Journal of Energy Economics and Policy, Vol. 9, no. 3, pp. 291–300, 2019, doi: 10.32479/ijeep.7593.
[17] R. Sharma, S. Goel, "Performance analysis of a 11.2 kWp roof top grid-connected PV system in Eastern India," Energy Reports, Vol. 3, pp. 76–84, Nov. 2017, doi: 10.1016/j.egyr.2017.05.001.
[18] PV Syst, "General description of the PVsyst Software," https://www.pvsyst.com/help/index.html?overview.htm.
[19] The Green Watt, "Solar Rooftop Calculator: How Many Solar Panels Can Fit On Roof? kW?," https://thegreenwatt.com/solar-rooftop-calculator-how-many-solar-panels-can-fit-on-roof-kw/.
[20] Sun Power Corporation, "Home solar panels and residential solar systems," https://us.sunpower.com/home-solar/better-solar-panels.
[21] Y. Sawle, M. Thirunavukkarasu, "Chapter 9 - Techno-economic comparative assessment of an off-grid hybrid renewable energy system for electrification of remote area," in Design, Analysis, Applications of Renewable Energy Systems, A. T. Azar , N. A. Kamal, Eds., in Advances in Nonlinear Dynamics, Chaos (ANDC). , Academic Press, 2021, pp. 199–247. doi: https://doi.org/10.1016/B978-0-12-824555-2.00027-7.
[22] A. Ameur, A. Berrada, K. Loudiyi, R. Adomatis, "Chapter 6 - Performance and energetic modeling of hybrid PV systems coupled with battery energy storage," in Hybrid Energy System Models, A. Berrada and R. El Mrabet, Eds., Academic Press, 2021, pp. 195–238. doi: https://doi.org/10.1016/B978-0-12-821403-9.00008-1.
[23] L. Huawei Technologies Co., "Six Reasons to Choose Huawei Inverters for C&I," https://solar.huawei.com/au/news-room/au/2018/news-20181112.