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Impact of Meteorological Conditions on Photovoltaic Production in Guinea Using MATLAB Simulink Modeling of an 886 Watt System

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Abstract

Solar photovoltaic energy represents a promising alternative for Republic of Guinea, where access to electricity is limited. This study analyzes the impact of climatic conditions on an 885.5 W PV installation, modeled in MATLAB/Simulink with photovoltaic modules, a booster converter, and a Perturbation & Observation type MPPT to maximize power. The objective is to identify the regions of Republic of Guinea that are most favorable for these installations, regardless of climate. RETScreen and PVsyst software were used to obtain temperature and solar radiation data. In April, the KINDIA region has the highest average daily solar radiation (6.89 kWh/m²/day), while FARANAH has the highest annual solar radiation (5.6 kWh/m²/day). The careful analysis of the collected data made it possible to identify the optimal sites for photovoltaic energy production. The simulations achieved average monthly energy yields of 42.6%, 42.3%, 45.6%, 44.7%, 43.9%, 44.5%, 43.9%, and 41.0% for BOKE, CONAKRY, FARANAH, KANKAN, KINDIA, LABE, MAMOU, and N'ZEREKORE, respectively. These values show that Guinea's solar photovoltaic potential offers the Guinean government the opportunity to significantly reduce its dependence on fossils energy. Its exploitation will contribute to the reduction of greenhouse gases.

Keywords: Solar photovoltaic**,** Solar irradiation**,** Weather impact, Republic of Guinea**,** Renewable energy potential

1. INTRODUCTION

Energy has become essential in our modern society, because without it the world would be plunged into darkness. Over the last four decades, its demand has increased sharply due to the increase in the world population and the growth of means of transport and industries. [1], [2]. While the use of fossil fuels continues to worry the world because of greenhouse gas emissions [3, 4, 5]. This is why renewable energy sources occupy an increasingly important place in state policies. The best known are solar, wind, hydraulic and geothermal. Among these energies, solar photovoltaic (SPV), in certain localities, stands out for its reliability, availability and use [6], [7]. For a decade, solar photovoltaic energy installations have been increasing considerably worldwide [8, 9]. In 2023, China had a solar capacity of 610 GW [10]. From 2008 to the end of 2019, the power of PV installations connected to the European Union electricity grid increased from 11.3 GW to more than 134 GW [11]. In 2020, the global solar energy capacity is estimated at 707.5 GW [12]. The solar PV capacity, in 2023, is 1,412.093 GW worldwide, including 12.394 GW in Africa [13]. This shows that PV is increasing in an increasing way.

In 2016, several African countries committed to invest $1 million to boost solar PV development in Africa [14]. The solar energy potential in Sub-Saharan Africa (SSA) is estimated at 525 GW for solar PV and 475 GW for solar thermal. Among all renewable energy sources, solar potential is most abundant in SSA with 38%, followed by natural gas with 21% [15]. In West Africa, the potential for solar PV is far superior to other types of renewable energy [15]. This means that solar PV energy is promising in this area. While until 2021, the electrification rate in the Economic Community of West African States (ECOWAS) area did not exceed 60% [16]. ECOWAS has planned to reach 25% electrification rate in rural areas by 2030. It has proposed that the installations be made by solar PV and by isolated and autonomous Micro-Electrical Grids [17].

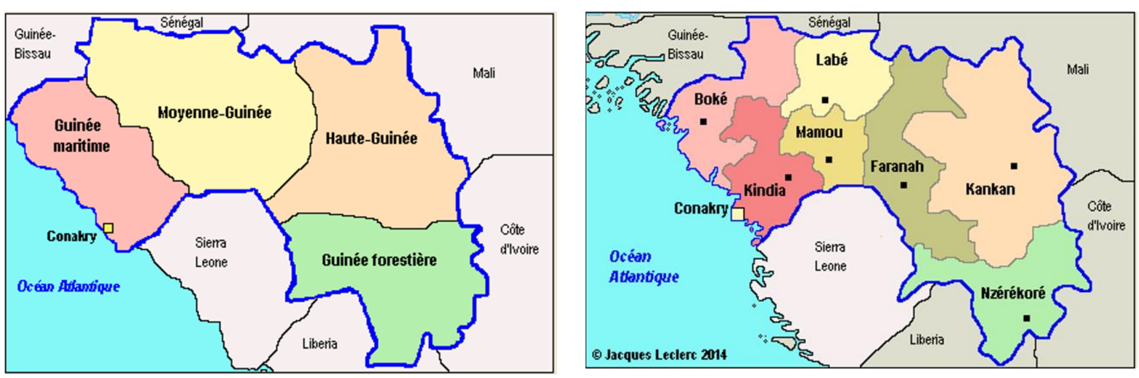
Photovoltaic solar energy is the energy obtained by converting sunlight into electricity [18], [19] by a device called a generator or photovoltaic module or panel. The photovoltaic generator is a set of solar cells connected in series and/or

in parallel. Its operation is influenced by the climatic conditions and the geographical position of the installation site [9], [20]–[23]. The efficiency of a PV module depends on its operating temperature and the irradiation of the site [2], [24], [25]. The operating temperature of a PV module depends on the irradiation, the ambient temperature and the wind speed [26]–[29]. The higher the irradiation of a given site, the more favourable it is for a solar system [24, 30]. On the other hand, temperature has a negative effect on solar photovoltaic production [30], [31].
In view of all the above, this present work focuses on the impact of weather conditions on photovoltaic production of a capacity of 885.5 W in Guinea using MATLAB/Simulink, PVsyst and RETScreen software. It exploits the solar PV potential of all 8 administrative regions of the Republic of Guinea, namely BOKE, CONAKRY, FARANAH, KANKAN, KINDIA, LABE, MAMOU and N'ZEREKORE. This study highlights the SPV potential in Guinea that can be exploited by the Guinean government and independent producers and incorporated into their energy portfolios to select the most favorable sites and months for the PV system. This study provides answers to the following questions: Which regions of Guinea benefit from significant solar radiation? What is the expected average energy production (measured in W per month) in each region for the proposed PV system example? Which locations in Guinea are best suited to the installation of solar PV systems?
This paper is organized into several detailed sections. Section 2 presents the localities. The description of the materials and methods are developed in Section 3, and the meteorological data of the sites are detailed in Section 4. The simulation results are presented and discussed in Section 5. The paper ends in Section 6 with a conclusion.

2. METHOD

2.1. STUDY SITES

The Republic of Guinea is located between 7° 30' and 12° 30' north latitude, 8° and 15° west longitude; halfway between the equator and the Tropic of Cancer. It is located in West Africa and borders Senegal and Mali to the north, Guinea Bissau to the northwest, the Atlantic Ocean to the west, Sierra Leone and Liberia to the south, and Côte d'Ivoire and Mali to the east (see Figure 1). Its total area is 245,857 km². It is made up of 4 natural regions (Figure 1 (a)) and 8 administrative regions (Figure 1 (b)): CONAKRY (9.55° N, -13.67° E), BOKE (10.94° N, 14.30° E), FARANAH (10.04° N, -10.75° E), KANKAN (10.38° N, -9.30° E), KINDIA (10.06° N, -12.87° E), LABE (11.32° N, -12.30° E), MAMOU (10.69° N, -12.29° E) and N'ZEREKORE (7.76° N, -8.83° E).



(a) (b)

Figure 1. Map of the natural and administrative regions of Guinea.
https://www.axl.cefan.ulaval.ca/afrique/guinee_fr-carteregionale.htm

2.2. MATERIALS AND METHODS

In order to evaluate the potential of SPV in Guinea, a stand-alone PV system with a capacity of 885.6 W is proposed in this study in each region. Table 1 represents the characteristics of the PV module used.

Table 1. PV module characteristics.

Parameter	Values
Maximum Power (W)	44.28
Cells per module (N_{cell})	36
Open circuit voltage V_{oc} (V)	20

Short-circuit current I_{sc} (A)	3
Voltage at maximum power point V_{mp} (V)	16.4
Current at maximum power point Imp (A)	2.7
Temperature coefficient of V_{OC} (%/deg.C)	-0.36099
Temperature coefficient of I_{sc} (%/deg.C)	0.002
Light-generated current I_L (A)	3.0149
Diode saturation current I_0 (A)	$9.4362*10^{-11}$
Diode ideality factor	0.89655
Shunt resistance R_{sh} (ohms)	98.1851
Series resistance R_s (ohms)	0.40738

The proposed system is composed of 20 photovoltaic modules, 5 in series and 4 in parallel, a booster chopper to force the PV to operate properly, and an electrical load. These two components allow us to perform the simulation under Matlab/Simulink. Figure 2 represents the scientific block diagram of the proposed system. The major problem with these types of systems is the intermittency of its source, which is the sun. In addition, the temperature has a negative influence on production. Those who make that the production of energy with PV systems is accompanied by considerable power losses. To solve these problems, power optimization commands are used [32] – [35]. These are methods of tracking the Maximum Power Point (MPP) of a PV, the most used of which is the Perturbation and Observation (P&O) method [34], [36]. The P&O MPPT technique is one of the classic methods used to extract the maximum power from a PV module by controlling an inverter via a duty cycle. It is simple to implement. This is chosen in this study in order to extract the maximum power of the PV modules. The P&O method consists of a ΔV perturbation of the system by varying the operating voltage or current of the PV module and then observing its effect on the PV output power and comparing the previously obtained power with the new power after perturbation.

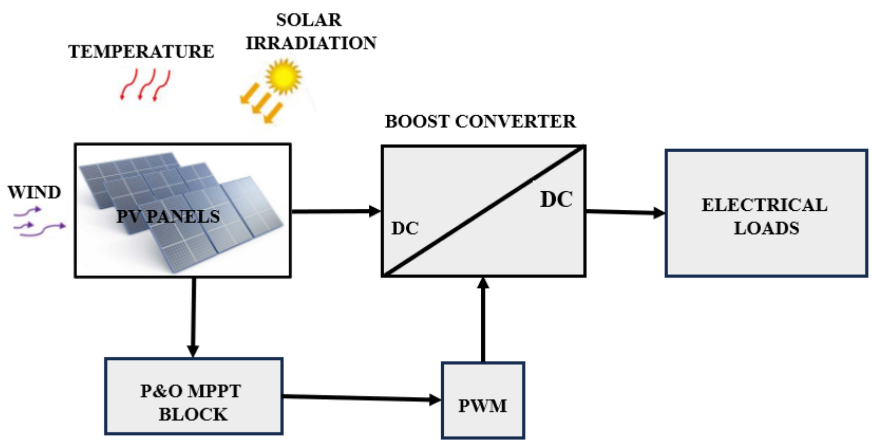


Figure 2: Scientific block diagram representation of the proposed system.

National Resource Canada's RETScreen and PVsyst software are used to obtain monthly mean values of global solar radiation on the horizontal surface and monthly mean temperature for all locations.

1.2. METEOROLOGICAL DATA FROM THE STUDY SITES

To make a good analysis or forecast of the solar PV potential of a given location, it is very important to have the meteorological data of the study area. In this work, temperature and irradiation are used. Because, the literature has shown that they affect the production of the power produced by the PV. These meteorological data (temperature and irradiation) were extracted from the RETScreen software developed by the Government of Canada. They are NASA data, monthly averages from satellites, calculated over 30 years (1991-2020).

Figure 3 shows the monthly average temperatures of the different localities. It shows the regions of BOKE, CONAKRY, FARANAH, KANKAN, KINDIA and LABE recording their highest temperatures in April respectively 29.4°C, 27.9°C, 28.9°C, 30.1°C, 29.5°C and 28.4°C. For MAMOU and N'ZEREKORE, it is the month of February with an average temperature of 28.6°C and 26.2°C respectively. While the lowest temperatures are noted in the month of August for BOKE, CONAKRY, KINDIA, MAMOU and N'ZEREKORE which are 25.0°C, 25.3°C, 23.5°C, 22.8°C and 22.6°C respectively. FARANAH and KANKAN record their lowest temperatures in December. As for LABE, it is August and December with 22.1°C. From this figure 3, we conclude that it is the region of KANKAN which records the highest monthly average temperature (30.1°C in April) and that of LABE the lowest monthly average temperature (22.1°C in August and December).

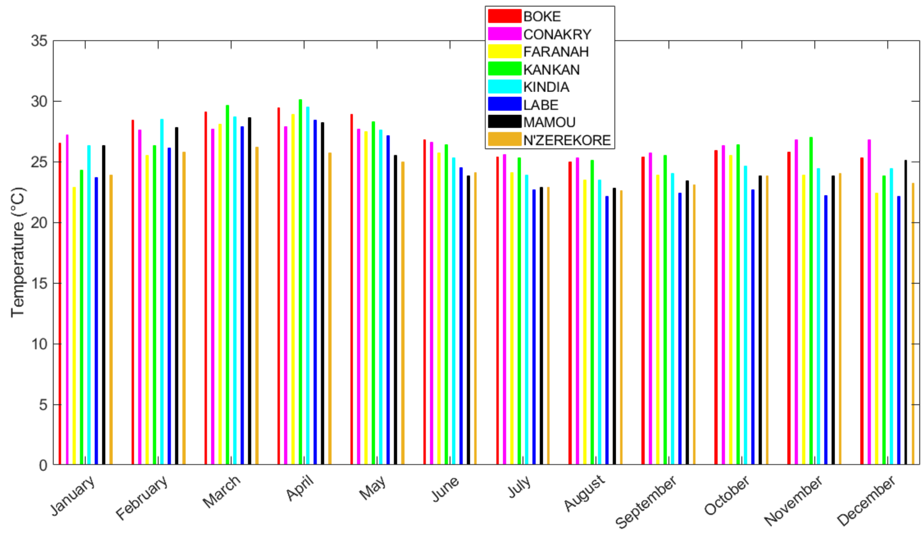


Figure 3. Average monthly temperatures of different locations.

The average annual temperatures are shown in Figure 4, which shows that BOKE and CONAKRY record the highest average annual temperatures and MAMOU and N'ZEREKORE have an average value below 25°C.

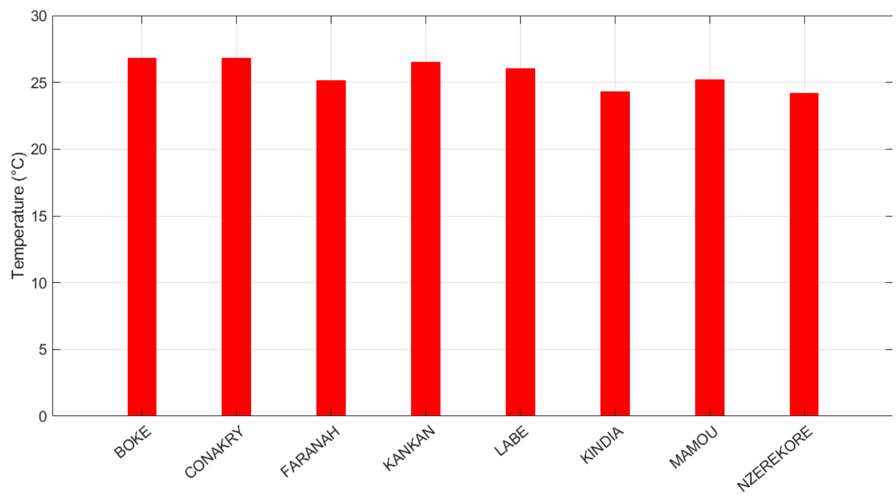


Figure 4. Average annual temperatures.

Figure 5 represents the monthly average irradiation of the study sites. It shows that the highest monthly average irradiation is recorded in March for BOKE, CONAKRY and KANKAN (6.59 kWh/m^2/d, 6.59 kWh/m^2/d and 6.03 kWh/m^2/d respectively). For KINDIA, LABE and MAMOU, it is in April with 6.89 kWh/m^2/d, 6.76 kWh/m^2/d and 6.59 kWh/m^2/d respectively. As for FARANAH and N'ZEREKORE, they record their highest values in December and February respectively 6.6 kWh/m^2/d and 5.73 kWh/m^2/d. The lowest monthly average irradiation is noted in August for all Guinean regions except N'ZEREKORE, which records it in July. From this figure 5, we conclude that it is in KINDIA and N'ZEREKORE, where the highest and lowest monthly irradiation are noted respectively.

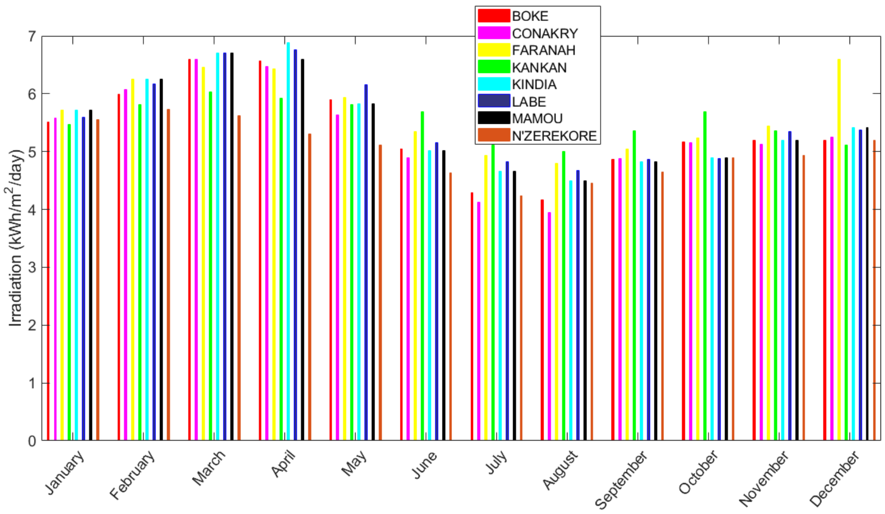


Figure 5. Average monthly irradiations of different localities.

Figure 6 shows the average values of the average annual irradiation of the Guinean regions obtained from the RETScreen software. In this figure, we see that FARANAH has the highest average annual irradiation and N'ZEREKORE the lowest. These data make it possible to estimate the average annual irradiation of Guinea at 5.53 kWh/m^2/d. We conclude that Guinea has a strong solar potential.

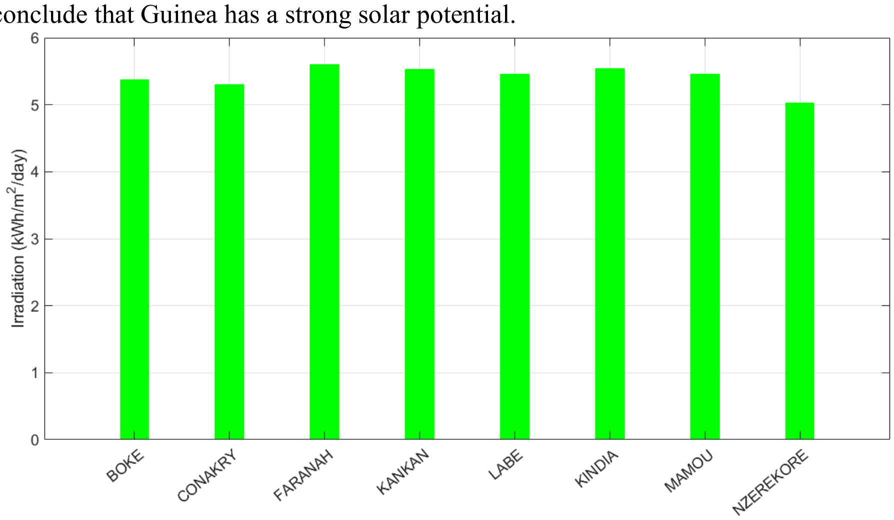


Figure 6. Average annual irradiation.

We point out that these meteorological data are obtained from the RETScreen software except those of MAMOU, which are obtained, with the PVsyst software. Because, MAMOU does not appear in RETScreen.

3. RESULTS AND DISCUSSION (10 PT)

Before studying the operation of the photovoltaic system in the different sites, we subjected the system to standard conditions. That is to say, at a temperature of 25°C, sunshine of 1000 W/m^2 and air mass of 1.5. After the simulation under MATLAB/Simulink, Figure 7 is obtained which shows a huge gap between the power produced with and without the MPPT control. MPPT control extracts the maximum possible power. This helps reduce production losses. This figure shows that without MPPT control, there will be a very large loss of output power even under standard test conditions. In addition, this could distort our analysis. These results justify the choice of MPPT control.

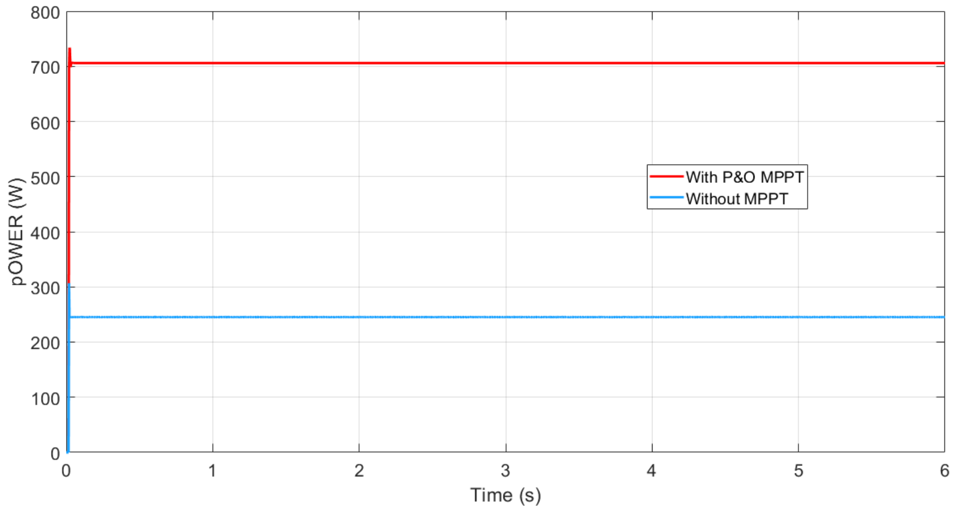


Figure 7. Power obtained with and without MPPT control.

Figure 8 represents the block diagrams of all the Guinean regions. Each block is implemented in MATLAB/Simulink and subjected to the climatic parameters, namely the temperature and the irradiation of its area.

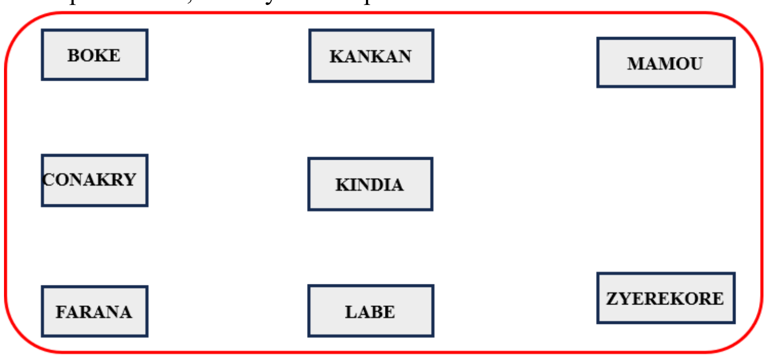


Figure 8. Block diagram of the 8 administrative regions of the Republic of Guinea.

Taking into account the annual average values of temperature and irradiation, the powers shown in Table 2 are obtained after implementation and simulation of each block in Figure 8 under MATLAB/Simulink. It can be seen that the FARANAH region which has irradiation (5.6 kWh/m2/d) higher than the national annual average (5.41 kWh/m^2/d) and an average temperature of 25.1 °C produces the highest power (397.55W) or more than 17.46 W of the average value of all installations (388.79 W).

Table 2. Power obtained with annual average meteorological data.

Installed power (W)	Regions	Average annual temperature (°C)	Average annual irradiation (kWh/m^2/d)	Power produced (W)	Average power produced (W)
	BOKE	26,8	5,37	372,29	
	CONAKRY	26,8	5,30	370,41	
	FARANAH	25,1	5,60	397,55	
	KANKAN	26,5	5,53	374,50	380,09
885,6	KINDIA	26,0	5,46	384,14	
	LABE	24,3	5,54	387,96	
	MAMOU	25,2	5,46	383,61	
	N'ZEREKORE	24,2	5,02	370,31	

- Correlation between temperature and power produced:
    - Temperatures vary between 24.2°C and 26.8°C,

- Regions with higher temperatures, such as Boké (26.8°C) and Conakry (26.8°C), have a lower power produced (~372 W),
- On the other hand, regions such as Faranah (25.1°C) and Labé (24.3°C), which have a lower temperature, show a higher power produced (~397 W).

Interpretation: Higher temperature can reduce the power produced, which is consistent with the effect of high temperatures on the efficiency of solar panels (thermal losses) [30, 31].

- Correlation between irradiation and power produced
  - Irradiation varies between 5.02 kWh/m²/day (N'Zérékoré) and 5.60 kWh/m²/day (Faranah),
  - Regions with higher irradiation, such as Faranah (5.60) and Labé (5.54), also have higher production (~397 W and ~388 W),
  - On the other hand, N'Zérékoré (5.02) has a lower power produced (370 W).

Interpretation: Higher power is directly related to stronger irradiation, which confirms that available solar energy positively influences electricity production [30], [31].
Table 3 shows the impact ratio of temperature and irradiation on the power produced. This table compares the regions of BOKE vs FARANAH and between KINDIA and LABE in order to calculate the impact ratio.

Table 3. Impact ratio of temperature and irradiation on the solar PV power.

Regions	Temperature impact ratio on power (IR_{temp})	Temperature impact ratio on power (IR_{irrad})
BOKE vs FARANAH	-14.858824	109.826087
KINDIA vs LABE	-2.247059	47.750000

A negative RI_{temp}shows that an increase in temperature reduces the power output. A positive IR_{irrad} shows that an increase in irradiation increases the power output. The BOKE vs FARANAH region shows a stronger impact of irradiation on power than temperature. The impact of temperature on power is lower in the case of KINDIA vs LABE compared to the impact of irradiation. Irradiation has a dominant effect on solar production, while temperature has a negative but lower impact.

Figure 9 shows MATLAB/Simulink simulation results of the power produced by a photovoltaic array over 12 months of the year, taking into account temperature and solar irradiance for eight Guinean localities. These results clearly illustrate the decisive influence of local climatic conditions on photovoltaic production, in coherence with observations in the scientific literature. Analysis of the curves in Figure 9 illustrates several important regional trends:

- BOKE, KINDIA, LABE, MAMOU and CONAKRY show a gradual increase in PV field output power from January to March, reaching a high and relatively stable plateau between March and May. From May onwards, a sharp drop in output power is observed, lasting until August, before a gradual recovery towards the end of the year. This high variability reflects the impact of the rainy season, during which solar irradiation drops sharply and temperatures can become unfavourable for PV module performance.
- In the KANKAN region, the power generated is relatively constant between February and June, reflecting favourable and regular climatic conditions over this period. A slight drop is observed in July, followed by a recovery, suggesting less sensitivity to seasonal variability than in other regions.
- At FARANAH, power output remains almost constant from January to April, and then gradually decreases until August. This stability is explained by constant moderate irradiation and temperature, before the rainy season affects production.
- Finally, at N'ZEREKORE, the power generated decreased steadily from February to July, and then began to rise again. This trend indicates a particularly strong impact of the wet season on PV production in this locality.

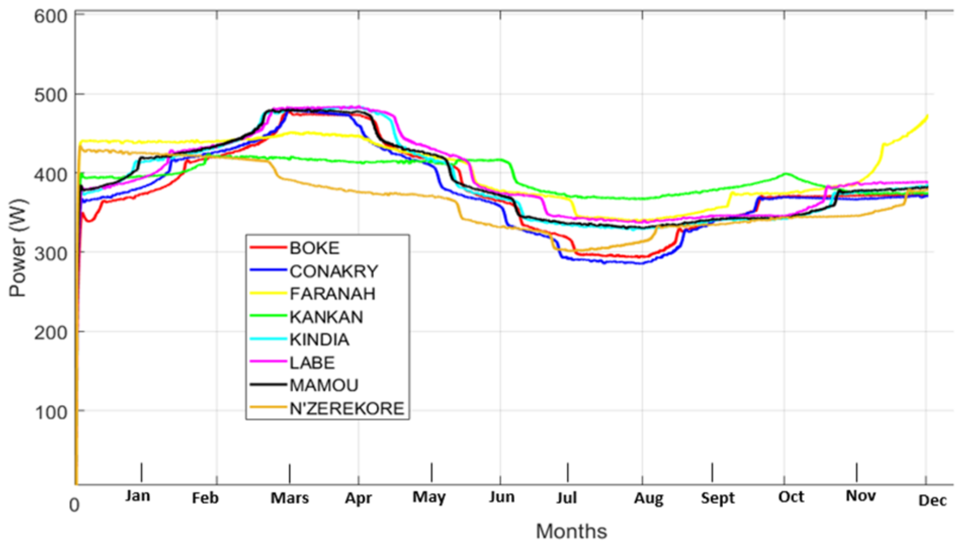


Figure 9: Evolution of the power produced with the monthly average meteorological data.

FARANAH and KANKAN show better resistance to the drop in power output observed during the least favorable period, which is explained by more advantageous local climatic conditions: more stable or higher solar irradiation and/or less extreme temperatures during the rainy season. These factors enable these two localities to maintain a higher level of production than other regions.

This analysis highlights the crucial importance of solar irradiation and ambient temperature in the performance of PV systems, and the need to adapt installations to the specific climatic conditions of each locality.

Table 4 gives the average monthly production and the month in which the production is highest, i.e. the Peak power. For the same installed PV capacity, the study regions are ranked in ascending order, in terms of average monthly production (second column of Table 4), as follows: FARANAK, KANKAN, LABE, MAMOU, KINDIA, BOKE, CONOKRY and N'ZEREKORE.

This table 4 shows that March is more favourable for the regions of BOKE and CONAKRY and April for those of KINDIA, LABE and MAMOU. For FARANAH, it is in December when the power produced is maximum. As for KANKAN, it is in February and N'ZEREKORE, the month of January.

Table 4. Average monthly power and most productive month.

Regions	Average power (W)	Maximum power (W)	Month
BOKE	377,4	477,0	March
CONAKRY	374,7	480,5	March
FARANAH	403,8	509,1	December
KANKAN	395,7	424,3	February
KINDIA	388,5	484,1	April
LABE	394,5	485,1	April
MAMOU	388,7	480,8	April
N'ZEREKORE	363,2	435,0	January

4. CONCLUSION

In this work, the evolution of photovoltaic solar energy in the world was described and the factors influencing solar energy production were developed. The main objective of this paper was to analyse the photovoltaic solar potential of all Guinean regions in order to select the most optimal sites for PV solar energy. Simulation results in MATLAB/Simulink of a proposed PV system subjected to meteorological parameters have identified that the FARANAH, KANKAN and LABE regions are the most favourable sites for PV solar energy production and N'ZEREKORE is the most unfavourable for hosting a PV solar installation. The most favourable period for solar PV in the Republic of Guinea, for all regions, is from November to May. The unfavourable period is August. The results show that the irradiation influences the production of a PV system more than the temperature.

Only temperature and irradiation were taken into account in this study, although relative humidity and wind speed also influence the operation of the PV module. Therefore, in future studies, we plan to take into account all factors affecting the PV output power.

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