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Characterization of Parameters and Risk Indicators Related to Climate Change for a High-Power Photovoltaic Field Installed on ABECHE Site in the Republic of Chad

Idriss Atouniss Yakoub[1], Macaire Agbomahéna[1, 2], Wilfrid Coffi Adihou[3], Irénée Vianou Madogni[1, *], Basile Bruno Kounouhéwa[1]

[1]Radiation Physics Laboratory (LPR), FAST-UAC, Cotonou, Benin

[2]Laboratory of Applied Energetic and Mechanics (LEMA), Polytechnic School of Abomey Calavi, University of Abomey Calavi, Abomey Calavi, Benin

[3]Laboratory of Engineering Sciences and Applied Mathematics (LSIMA) of the National University of Sciences, Technology Engineering and Mathematics, Abomey, Benin

Email address:

madognimadogni@gmail.com (Irénée Vianou Madogni)

[*]Corresponding author

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Abstract: Our objective is to carry out a depth study of the site of 5 MW photovoltaic solar power plant installed in Mabrouka in the ABECHE town, in order to better identify potential risks related to climate change, and elaborate strategies for a better choice of (PV)-modules best adapted to the Chadian climate. We characterized in this study the meteorological parameters (temperature, sunshine, wind speed and relative humidity). Important parameters allowing evaluating the energy potential of the ABECHE site. Global warming and its consequences on the production of photovoltaic solar energy have been listed. Impact of the parameters and risk indicators susceptible to reducing the (PV)-modules performance has been discussed. Finally, the defects and anomalies detected in the (PV)-modules due to climatic factors have been highlighted. Ours investigations showed that: (i) the temperatures are sufficiently high throughout the year, so that it is very difficult to distinguish the seasons. (ii) The parameters and risk indicators would cause a failure and performance reduction of the (PV)-cells/modules on the site.

Keywords: (PV)-Module Technology, Meteorological Parameters, Energy Potential, Defects and Anomalies, Parameters and Risk Indicators

1. Introduction

Of all the renewable energies, solar photovoltaic presents a very particular interest for Africa, since it has disposed of a propitious solar deposit to the development of this energy source. For example, in Tchad only one person out of twenty has access to electricity. The Country knows the difficulties of supplying and accessing electrical energy which are slowing its development. At the national scale, 96.5% of the energy consumed is produced from ligneous fuels (wood fuels), with serious consequences for the environment, in particular on the forest resources and on the air quality.

Renewable energies are still very little developed and exploited. Though, this Central African country benefits from the extremely favorable and exceptional sunshine conditions allowing the development of sustainable electricity production systems, reducing deforestation and thus improving the energy performance of the country. It possesses vast free spaces and can receive the photovoltaic electricity production capacity of great power and large size.

In October 2015, the company (InnoVent Tchad) signed a memorandum of understanding with the Renewable Energies Development Agency (ADER). This concession agreement with the Chadian Government has allowed the construction and the setting operation of a 5 MW photovoltaic solar power plant using crystalline silicon/thin layers (fixed or tracker) at Mabrouka in the ABECHE town (North-Eastern of Tchad). This environmental and social project aimed to:

1. Identify the great environmental challenges on the site;
2. Present the alternative technologies with the variants available on the Chadian market;
3. Identify and evaluate the impacts and the mitigation measures, in particular those taking into account in the design and the implementation of the solar projects in Tchad;
4. Identify an environmental management plan of the project;
5. The increase in production capacities of the ABECHE city and the satisfaction of the domestic consumption;
6. Dependence reduction and the risks bound with the massive recourse to fossil energies.

To promote potentially the renewable energies (mainly photovoltaic solar), by facilitating the access of these energies for all housekeeping, and liberalize the energy sector, the company DJERMAYA CDEN ENERGY in 2019 has put in exploitation a photovoltaic solar power plant of 32MWc (polycrystalline silicon) near the Djermaya city, about 30 km northwest the capital N'Djamena and covers an area of nearly 100 ha. This project aimed a double objective:

1. Increase the electricity production capacity of the country so durable and environmentally respectful;
2. Modernize the electricity transmission system renovating the line connecting Djermaya to N'Djamena

General objective:

In front of climate change, study the risk parameters and indicators for a great power photovoltaic power plant installed in the Chadian environment.

Specific objectives:

Four specific objectives have been enumerated in this study:

1. Literature review of all parameters and risk indicators owing to climate change (temperature, humidity, cloudiness, solar flux, etc.) on the efficiency of the electricity production for a great power photovoltaic field installed on the ABECHE site;
2. Analyze and study based on Data come from Chadian weather conditions, the impact of parameters and risk indicators on the performances of the (PV)-modules installed, using the appropriate analytical and numerical models;
3. Evaluate the energy performance of these (PV)-modules using the performance ratio (PR) model and performance indicators (IP), in order to identify the types of (PV)-modules best adapted to the Chadian climate;
4. The overall effect of the aerosols on the radiation must be quantified, using various sources of information on the aerosol concentrations in the air. Finally, this study will avoid the modules-(PV) poor choices, leading to the project failures in the field of solar photovoltaic on the Chadian market.

The first specific objective has been the essential point put into account in this literature review and widely developed. It has been potentially devoted to the site of the 5 MW photovoltaic solar power plant of Mabrouka in the ABECHE town (North-East of TCHAD). Subsequently, TCHAD geographical location and that of the ABECHE city have been presented. The characteristics of meteorological parameters (temperature, sunshine, wind speed, relative humidity) which are the parameters allowed evaluating the energy potential of ABECHE site. Global warming and its consequences on the production of photovoltaic solar energy have been listed. Then, the impact of the parameters and risk indicators on the performance of the (PV)-modules has been discussed. Finally, the defects and anomalies detected in the (PV) modules due to climatic factors have been highlighted. These different parameters have already been studied and have been the subject of several research works in other countries, but very little studied in TCHAD or even non-existent.

2. Materials and Methods

Several studies have been carried out in Europe, America and Asia, to identify the photovoltaic technologies adapted to their climates [1-9]. Studies carried out in South Africa in 2011 showed that monocrystalline (AP-7105) and amorphous (US-42-001416) silicon modules have been high-performance on their site and can be used indifferently [10]. In Egypt, under a desert climate, the studies recommended the use of polycrystalline silicon which presents better performances [11]. During the months of December, January and February (months of high heat) in Algeria, the amorphous silicon modules presented a better performance ratio estimated at 99.76% compared to the other technologies [12-14]. Recently [15] compared the energy performance of four (PV) - technologies (monocrystalline (sc-Si/VIC003/A), polycrystalline (pc-Si/VIC006/A); polycrystalline (pc-Si/SUN011/B) and micromorph (aSi:H/mc-Si:H/SHA017/CSHA017/C), in order to determine energetically, the most adapted to the different climatic zones of West Africa (Mali, Niger, Burkina Faso and Ivory Coast), using neural networks (PMC) for numerical simulations. The results obtained clearly indicate that the micromorph module (aSi: H/mc-Si:H/SHA017/CSHA017/C) presents the better performance, with a performance ratio evaluated at 92%. The (sc-Si/VIC003/A) and (pc-Si/VIC006/A) modules came from the same manufacturer have an average performance rate of 84%. The (pc-Si/SUN011/B) module came from another manufacturer, gives a performance ratio of 80%, due to its large series resistance, and its high maximum power temperature coefficient under real operating conditions. There is very little work in Central Africa, particularly in TCHAD on (PV)-technologies, which at present is increasing its electricity production capacity from photovoltaic solar energy, in order to reduce the risks associated with the massive recourse of the fossil fuels in the country.

2.1. Presentation

TCHAD covers 1.284 million km^2 areas and localized between the longitudes 14° and 24° East and latitudes 7° and 24° North Figure 1. As a function of the precipitation regime, the seasons succession and the thermal regime, the Chadian territory undergoes a Saharan climate between latitudes 14 and 24° North, Sahelian between 10° and 14°North and Sudanese at latitudes 7° and 10° North. The climate is similar to one of West African countries, generated by the moving of the intertropical convergence zone with a period of great heat from March to June, characterized by the temperatures that could reach 45°C. A rainy season from May to October, with average rainfall between 50 and 1350 mm, and a relatively dry and cold period from November to February. The precipitations in TCHAD are generally characterized by a very irregular spatial and temporal distribution from one station to another [16, 17].

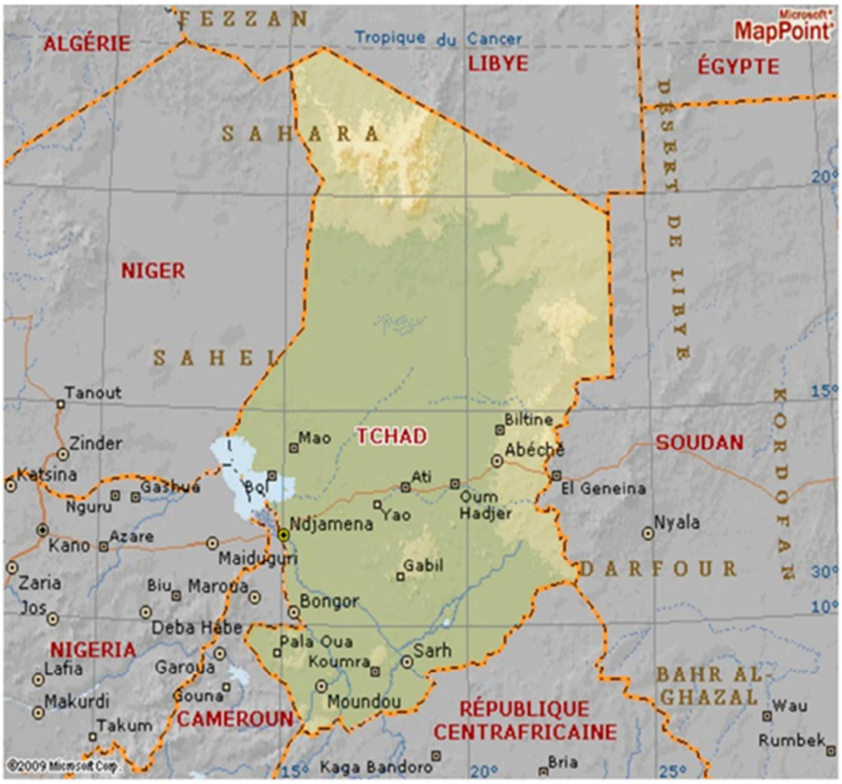

Figure 1. *Geographical location of Tchad.*

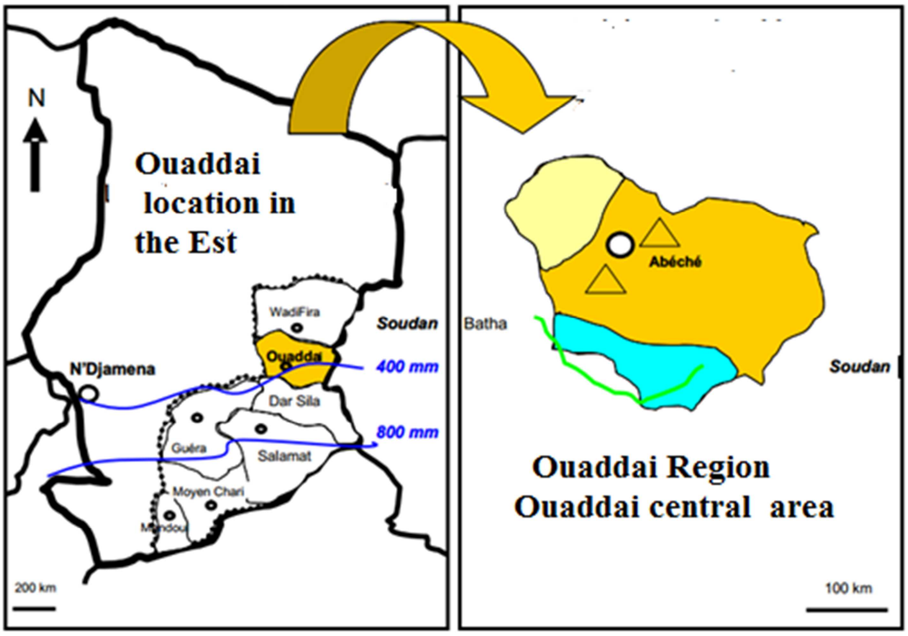

Figure 2. *Study site: Ouaddai Region (Source: INSEED, RGPH2, 2009) (CEDRE. BP: 1822 N'Djamena – Tchad).*

ABECHE town is located between 13th and 14th degrees North latitude and 20th and 21th degrees East latitude. It is located 900 km from the capital N'Djamena. Hinge town on the road to the East towards Sudan and North-East towards Biltine (80 km) and Fada (nearly 1000 km). The plant site (PV) is located in the Mabrouka town located about 5 km west of the ABECHE town [17].

2.2. Characteristics of Meteorological Parameters

Tchad has a low-density meteorological observation network. It is made of synoptic, climatologically, agro-meteorological stations and rainfall stations. The network is jointly managed by the National Directorate of Water Resources and Meteorology (DREM), the Representation of the Agency for Air Safety and Navigation (ASECNA) and the Delegation of National Aeronautical Activities.

The Meteorological variables measurements are carried out in synoptic stations and pluviometric or hydro-climatic stations (N'Djamena, Moundou, Am-Timan, ABECHE). They have been installed by the Overseas Scientific Research Organization (ORSTOM) in the aerodromes and the data are generally transferred to ASECNA. The national climatological database is managed by the National management of Water Resources and Meteorology (DREM). The data series come from ABECHE synoptic station [16, 17]. These data have been treated and corrected in-situ by the mobile station of the Radiation Physics Laboratory (LPR/FAST/UAC) using MATLAB Software.

2.2.1. Temperature Variation

We have identified that March, April, May and June are the hottest months (30.3°C to 32.8°C and 31.6°C on average), and the least hot months are December and January (around 25°C and 24.9°C on average). May is the hottest month of the year in ABECHE, with an average maximum temperature of 39°C and minimum of 25°C. January is the least sunny and least hot month, with an average minimum temperature of 15°C and maximum of 34°C.

Table 1. *Temperature variation (annual average) on the ABECHE site.*

Time / Years	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean temperature (°C)	24.9	27.6	30.3	32.7	32.8	31.6	28.7	27	28.2	29.8	27.9	25.4
Average minimum temperature (°C)	16.2	18.7	21.9	24.7	25.2	4.6	23.1	21.7	21.5	21.9	19.9	16.7
Average maximum temperature (°C)	33.7	36.5	38.8	40.5	40.8	38.6	34.4	32.3	35	37.7	36	34.2

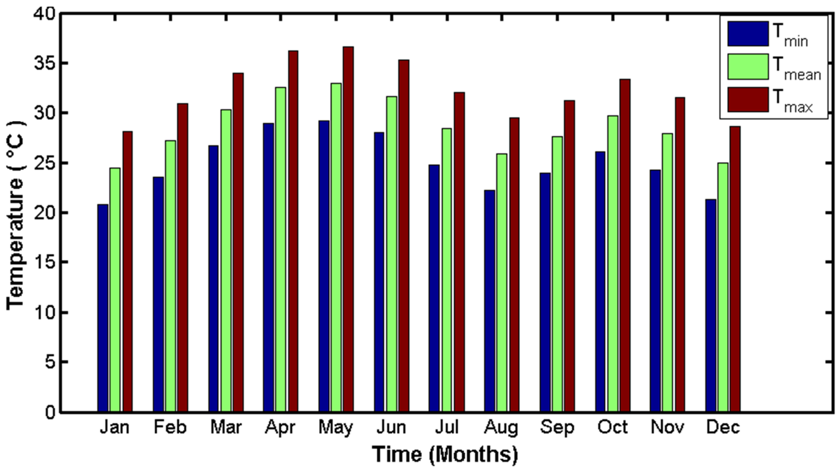

Figure 3. *Temperature variation (annual average) on the ABECHE site.*

The temperatures in ABECHE are sufficiently high throughout the year, so that it is very difficult to distinguish the seasons.

2.2.2. Sunshine

The maximum values of sunshine are registered in March, April, May and June. The Minimum values are recorded in November, December-January table 2. The relatively low values observed in July-August September are due to the rainy period. High values of insolation correspond to very high temperatures and low values to low temperatures and vice versa table 2.

Table 2. *Variation in sunshine (annual average) on the ABECHE site.*

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Global Horizontal Irradiance (KWh/m^2)	171,1	177,0	212,7	212,1	211,7	198,0	184,8	181,7	170,0	183,2	167,7	161,2
Global irradiance at the cell surface (KWh/m^2)	225.1	233.2	281.1	277.1	273.3	253.8	234.0	228.4	230.9	211.1	224.1	214.1
Ambient temperature (°C)	24,20	26,20	29.60	31.50	30.70	29.10	26.20	25.60	27.40	29.40	27.70	24.99
Annual energy production (KWc)	342	349	331	405	403	375.6	356.2	348.2	347.6	358.2	335.8	325.2

2.2.3. Wind Speed

The quietest period of the year lasts five months, from May to October. September is the calmest month of the year in ABECHE, with an average hourly wind speed of 8.4 kilometers per hour or 2.33m/s. The predominant average hourly wind direction in ABECHE varies during the year. The wind most often comes from the south for four months, from the end of May to September 30, with a maximum percentage of 54% on July 14. The wind most often comes from the East for eight months, from September 30 to May 27, with a maximum percentage of 58% in January.

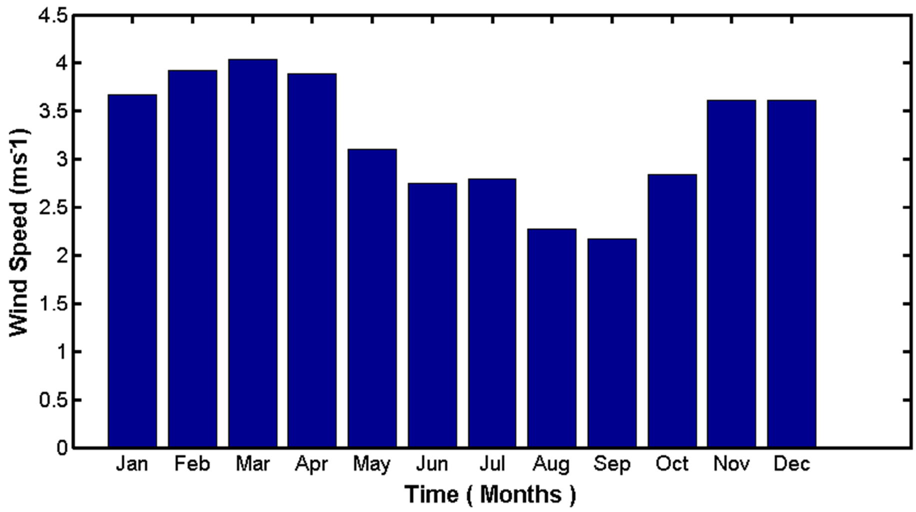

Figure 4. *Variation of wind speed on the ABECHE site.*

The maximum relative humidity reaches its lowest values between November and April and is associated with the presence of the easterly flow. From April the values increase to reach the maximum in August with the presence of the westerly flow. The minimum is noted between January and May. The minimum relative humidity follows the same evolution with a minimum in March and a maximum in August.

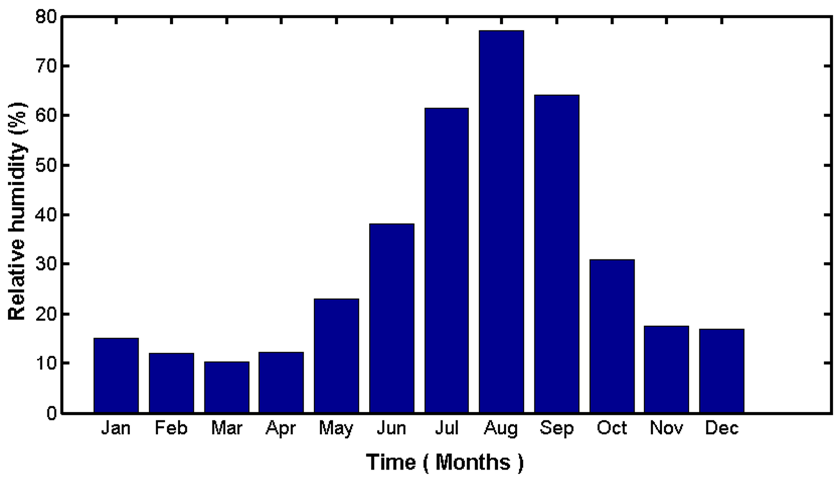

Figure 5. *Variation of relative humidity on the ABECHE site.*

2.3. Global Warming Effect on the Photovoltaic Solar Energy Production

The rise in temperature due to global warming directly impacts the solar energy production, and weakens the (PV)-modules performance. First of all, global warming induces the formation of frequent cloud covers due to the increase in air humidity, the effects of water evaporation on the surface, thus making the control of general electricity generation more difficult and less predictable. Then, the high heats is harmful to the (PV) - modules. Indeed, a rise in average temperatures directly affects the (PV) - module efficiencies, since an excess heat reduces the efficiency and efficacy of these (PV) - photovoltaic modules beyond the ideal operating temperature. It is considered that beyond 25°C, an increase of 1°C would induce a drop in production of 0.45%. [13] Modeled the effects of a global warming of 1.8°C, the (PV)-modules efficiency should drop by 15 kWh on average per kW installed. Moreover, even if the consequences of global warming on solar energy production will be global, some regions will however be more affected than others. In particular the case of South America, South Africa, Central Africa, Central Asia, where we will note the drops in efficiency of up to 50 kWh. Burkina Faso, Niger and all the Sahel will not be spared. Faced with this threat, one of the possible responses would be to find new materials for the (PV)-modules/cells, so that they are more efficient and less sensitive to rising temperatures.

In addition, the (PV)-cells do not support high heat. When the photons migrate in the conduction band of these cells, they lift electrons from the silicon atoms thus creating a "hole" in the semiconductor material. An important factor in the (PV)-cell efficiency is the rate at which the electrons recombine with holes. However, this recombination rate is very sensitive to the temperature. The increase in temperature reduces the band gap and therefore the (PV)-cell performance. It has been proved that the (PV)-modules conversion efficiency progressively decreases as dust accumulates on the (PV)-modules surface in the simultaneous presence of high temperatures [18]. Beyond 25°C, an increase of 1°C due to global warming results in a drop in production of 0.45%. Under ambient temperatures of 35°C, the cells can reach a temperature of 80°C on the surface and lose up to 30% of their efficiency [13, 19, 20].

2.3.1. Impact of Parameters and Risk Indicators on (PV)-Module Performance

Table 3. *Parameters and risk indicators on (PV)-module performance.*

Parameters (Factors of stress)	Risk indicators	Impacts	Performance loss
1) Humidity 2) UV 3) Thermal cycle 4) High Voltage 5) Mechanical shocks	Degradation of Packaging materials	1) Glass breakage 2) Dielectric breakdown 3) Bypass diode failure 4) Encapsulant (discoloration, loss of elasticity) 5) Backsheet cracking/delamination	1) Current leakage 2) Electrical shock 3) Electrochemical corrosion 4) Efficiency loss
1) High Temperature 2) Thermal Cycle 3) Mechanical shocks	Degradation of cells / modules interconnected	1) Solder bond failure 2) Thermomechanical fatigue 3) Change in joint geometry	1) Increased heating 2) Increased series resistance 3) Localized hot spots 4) Burns (solder joints, backsheet, encapsulant) 5) Arcing due to open - circuit
1) Humidity 2) UV 3) Thermal cycle 4) High Temperature 5) High Voltage 6) Mechanical shocks	Loss of adhesion	1) Delamination: 2) Glass-to-encapsulant 3) Cell-to-encapsulant 4) Encapsulant-to-backsheet	1) Optical decoupling (reduced light transmission) 2) Inefficient heat dissipation 3) Hot spot formation 4) Higher operating temperatures 5) Reverse bias cell heating

Table 3. *Continued.*

Parameters (Factors of stress)	Risk indicators	Impacts	Performance loss
1) Humidity 2) High Temperature 3) High Voltage	Degradation caused by moisture intrusion	1) Delamination 2) Corrosion of metallization	1) Failled gridline-to-cell adhesion 2) Increased electrical conductivity of materials 3) Increased current leakage 4) PID
1) Thermal cycle 2) Mechanical shocks	Degradation of semiconductor devices	1) Diffusion of dopant to cell surface 2) Cracks in cell	Electrical isolation

In addition, these parameters and risk indicators cause a failure and performance reduction of the (PV)-cells/modules.

However, solar radiation is subject to constant changes throughout the day, due to climatic variability. It also depends on the geographical location of the site, the angle of the sun, the cloudiness and the month of the year, etc. An increase in solar radiation improves the power output of the module, but also increases its temperature, which reduces its efficiency and intrinsic performance [18].

As a result, when water vapor interacts with solar radiation, light can be reflected, refracted or diffracted. This affects the non-linearity of the irradiance and at the same time causes small non-linear variations in the open-circuit voltage (V_{OC}) and large variations in short-circuit current density (J_{SC}) [18].

The wind drops the module temperature and contributes to a reduction or even a decrease in the temperature at the cell level, which is crucial to maintain the (PV)-conversion efficiency [21, 22].

Atmospheric pressure is a combination of moving air molecules and aerosols. The change in this air pressure causes the change in air flow at the surface of the (PV)-modules, which affects heat dissipation and causes temperature fluctuation at the (PV)-modules [13, 18-23]. Aerosols have a cooling effect, as they darken the atmosphere and reduce the effect of solar radiation arriving on the surface of the (PV)-modules. This influences the photovoltaic conversion and therefore reduces the (PV)-modules energy production [24, 25].

2.3.2. Synthesis

We indexed here, in addition to climatic factors, other intrinsic and extrinsic factors that contribute to and/or favour the loss of the (PV)-modules performance, and therefore reduce the photovoltaic energy production.

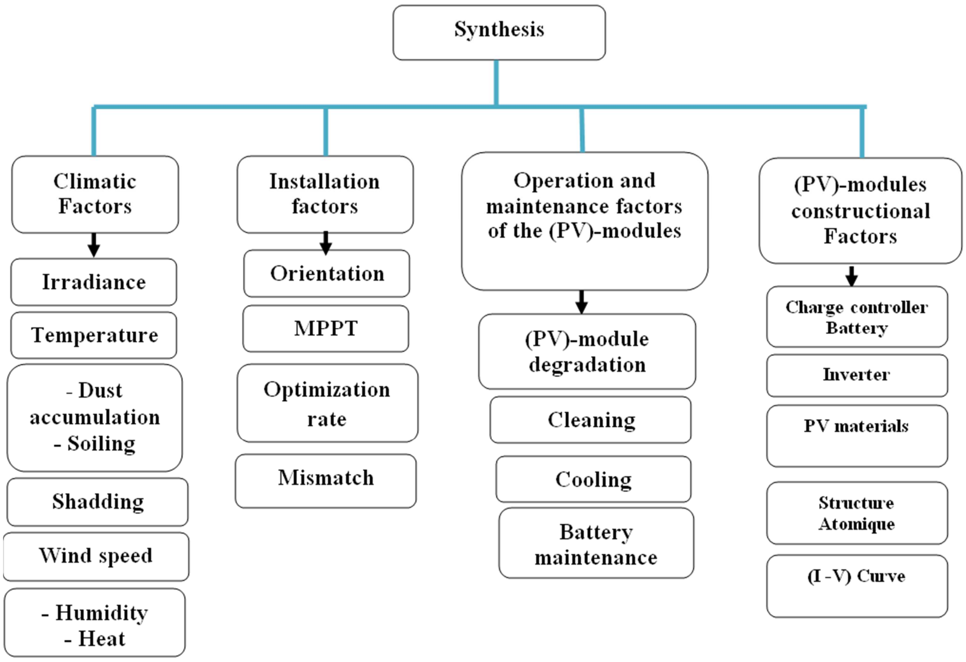

Figure 6. *Intrinsic and extrinsic factors that contribute to the loss of the (PV)-modules performance.*

Under the effect of climatic factors (PV)-modules can be subjected during its operation to various defects and anomalies causing a drop in system performance, even to total unavailability of the modules. All these unfavorable effects (factors) will obviously reduce the productivity of the installation and therefore reduce the profit of the installation without counting the cost of maintenance to put back the system to normal condition. Defects and anomalies that appear vary from one installation to another depending on the locality, of its design, the quality of the installation, operation and maintenance table 4.

Table 4. *Defects and anomalies encountered in a (PV)-module due to climatic factors.*

Module elements	Origins of defects and anomalies
(PV)-module	1) Cells damaged, crack, cell heating 2) Moisture intrusion, interconnections degradation, corrosion of connections between cells 3) Different performance modules 4) Module snatch or broken 5) shorted modules, inverted modules
Junction box	1) Electrical circuit break 2) Electrical circuit short circuit 3) Link breaking 4) Corrosion of connections
Wiring and connector	1) Open circuit 2) short circuit 3) bad wiring 4) Contact corrosion 5) Electrical circuit break
Protective diode (bypass diode, anti-return diode)	1) Diodes destruction 2) Diodes failure 3) Inversion of the diodes polarity, badly connected diode

3. Conclusion

We characterized in this work, the temperature, sunshine, wind speed and relative humidity that allow evaluating the energy potential on the ABECHE site. Impact of the parameters and risk indicators susceptible to reducing the (PV)-modules performance during their real operation conditions. We noted:

1. Intense variability of solar resources throughout the year;
2. The temperatures are sufficiently high throughout the year which can give back the (PV)-modules operating conditions very difficult;
3. A potential impact of sand and dust storms on (PV)-modules;
4. Risks of premature deterioration of equipments due to climatic conditions

For future work, we will evaluate in the second paper, the energy performance of these (PV)-modules using the performance ratio (PR) model and performance indicators (IP), in order to following their behaviour during the real operation conditions on the site. This stage will allow to identify the types of (PV)-modules best adapted to the Chadian climate.

References

[1] Bashir M A, Ali H M, Ali M, Siddiqui A M. An experimental investigation of performance of photovoltaic modules in Pakistan. Thermal Science. (2013) 134-134.

[2] Sharma V, Kumar A, Sastry O S, Chandel S S. Performance assessment of different solar photovoltaic technologies under similar outdoor conditions. Energy 58 (2013) 511-518.

[3] Carr A, Pryor T. A comparison of the performance of different PV module types in temperate climates. Solar Energy 76 (2004) 285-294.

[4] Cañete C, Carretero J, Sidrach-de-Cardona M. Energy performance of different photovoltaic module technologies under outdoor conditions. Energy 65 (2014) 295-302.

[5] Akhmad K, Kitamura A, Yamamoto F, Okamoto H, Takakura H, Hamakawa Y. Outdoor performance of amorphous silicon and polycrystalline silicon PV modules. Solar Energy Materials and Solar Cells 46 (1997) 209-218.

[6] Poissant Y. Field Assessment of Novel (PV) Module Technologies in Canada, in Proc. 4th Canadian Solar Buildings Conference, June 2009.

[7] Nishioka K, Hatayama T, Uraoka Y, Fuyuki T, Hagihara R, Watanabe M. Field-test analysis of PV system output characteristics focusing on module temperature. Solar Energy Materials and Solar Cells. 75 (2003) 665-671.

[8] Minemoto T et al., Effect of spectral irradiance distribution on the outdoor performance of amorphous Si//thin-film crystalline Si stacked photovoltaic modules. Solar Energy Materials and Solar Cells. 91 (2007) 120-122

[9] Aste N, Del Pero C, Leonforte F. PV technologies performance comparison in temperate climates. Solar Energy. 109 (2014) 1-10.

[10] INSEED, RGPH2, 2009 CEDRE. BP: 1822 N'Djamena-Tchad

[11] Aguilar E, Aziz Barry A, Brunet M, Ekang L, Fernandes A, Massoukina M, Zhang X. Changes in temperature and precipitation extremes in western central Africa, Guinea Conakry, and Zimbabwe. Journal of Geophysical Research: Atmospheres (2009) 1955-2006.

[12] Abdoulaye B, Clobite B B, Bell Jean P, Issak A, Robert M, Baohoutou L. Évolution des indices des extrêmes climatiques en République du Tchad de 1960 à 2008. Atmosphère-Océan 55 (1) (2017) 42-56.

[13] Bassam A, Tzuc O M, Soberanis M E, Ricalde L J, Cruz B. Temperature Estimation for Photovoltaic Array Using an Adaptive Neuro Fuzzy Inference System. Sustainability (2017) 1-16.

[14] Ian M, Kantareddy S N, Tonio Buonassisi, Ian Peters M. Technology and market perspective for indoor photovoltaic cells. Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA. Octobre 2019.

[15] Quansah D A, Adaramola M S. Assessment of early degradation and performance loss in five co-located solar photovoltaic module technologies installed in Ghana using performance ratio time-series regression. Renewable Energy 131 (2019) 900-910.

[16] Başoğlu M E, Kazdaloğlu A, Erfidan T, Bilgin M Z, Çakir B. Performance analyzes of different photovoltaic module technologies underİzmit, Kocaeli climatic conditions. Renewable and Sustainable Energy and Reviews 52 (2015) 357-365.

[17] Rosaura C M, Paul Andrés M C, Javier M R H, Francisco J R M, Gabriel G P. (PV)-Energy Performance in a Sustainable Campus. Electronics 9 (2020) 1874.

[18] Abiola O A, Hangan H, Siddiqui K. Experimental investigation of wind effects on a standalone photovoltaic (PV) module. Renewable Energy 78 (2015) 657-665.

[19] Mekhilef S, Saidur R, Kamalisarvestani M. Effect of dust, humidity and air velocity on efficiency of photovoltaic cells. Renewable and Sustainable Energy 16 (2012) 2920-2925.

[20] Cheng X, Chen F, Yu B, Zhang X. The method for photovoltaic module temperature ultra-short-term forecasting based on RBF neural network. In Proceedings of the China International Conference on Electricity Distribution (CICED), Xi'an, China, August (2016) 10-13.

[21] Long B. Détection et localisation de défauts dans un système photovoltaïque. Thèse de Doctorat, Université de GRENOBLE 2011.

[22] Rajput P, Sastry O S, Tiwari G N. Effect of irradiance, temperature exposure and an Arrhenius approach to estimating weathering acceleration factor of Glass, EVA and Tedlar in a composite climate of India. Solar Energy 144 (2017) 267-277.

[23] Bana S, Saini R P. Experimental investigation on power output of different photovoltaic array configurations under uniform and partial shading scenarios. Energy 127 (2017) 438-453.

[24] Ahmad R, Murtaza A F, Ahmed S H, Tabrez S U, Olalekan S. An analytical approach to study partial shading effects on (PV) array supported by literature. Renewable and Sustainable Energy 74 (2017) 721-732.

[25] Kafui A D, István S, István F. Efficiency comparison of Different photovoltaic modules. Acta Technologica Agriculturae 1 (2019) 5-11.