A GIS Approach of Potential Photovoltaic Power Sites in Niamey, Niger

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Abstract—**Nowadays, the daily conversations at summits and conferences are mainly about energy, climate change, and environmental issues. Fossil fuels are the main causes of global warming due to the release of greenhouse gases (GHG) into the atmosphere, leading to a change in the climate. Niger, as an emerging nation, has significant energy potential that is weakly exploited due to socio-economic factors. Multi-criteria analysis and satellite imagery were utilized to generate the potential photovoltaic (PV) energy maps. Three sites were selected as the most suitable places: 1) Site A with 22.5% or 12.154km^2; Site B with 53.33% or 28.82 km^2; and Site C with 10.23% or 5.53 km^2. The average annual energy potential of the selected sites was found to be 45.13 GWh. This energy potential was based on the: 1) calculated average annual solar radiation per unit surface area; 2) total suitable areas; and 3) efficiency of the PV panels.**

Keyword: Niamey, GIS, Solar farm, Suitability, Weighted Linear Combination (WLC).

I. INTRODUCTION

One of the planetary environmental challenges nowadays evolves alongside the nexus between food production, water supply, energy, and health. More than ever, climate change draws global attention, ranging from media and government entities to academia. Climate change refers to any change in climate over time due to natural variabilities or because of human activities [1].

Scientists have unanimously agreed that the primary factor contributing to global warming is the combustion of fossil fuels [2]. It is also worth mentioning that energy and transportation sectors are the major contributors of greenhouse gas emissions into the atmosphere, thus rendering the latter unhealthy [3].

According to the 2018 renewable capacity statistics conducted by the International Renewable Energy Agency (IRENA), the worldwide renewable energy (RE) capacity in 2017 was 2.2 TW [4]. It follows that 18 % of the aforementioned global RE capacity was solar. As of the year 2017, the African share of the global solar energy capacity was 3.6 GW.

Unfortunately, with an average daily insolation of 6.3 KWh/m^2 [5], Niger generated only 9 MW of green power in 2017 [4] even though renewable energy technologies are soaring at a much faster rate in Africa. This RE growth will contribute to: 1) enhance electricity production; 2) eradicate poverty; 3) supply remote areas; and 4) ensure energy security and reliability. To date, not a single study was carried out on solar suitability in Niamey and the vicinity. Conversely, many studies have been done at a continental scale. As an example, the study conducted in Iran by [6] considered the technical, environmental, geographical, and GIS factors. The authors found that 14.7% of Iran's land has an excellent suitability level, 17.2% are good, 19.2% are fair, 11.3% are low, and 1.8% are of a poor-quality level.

This study used a GIS-based multi-criteria method to identify various sites suitable for implementing solar PV projects in Niamey. With the proper PV technology, the identified sites would help meet the growing energy demand in Niamey by taking into account the following parameters: 1) real-time solar insolation; 2) environmental factors, such as land cover and digital elevation model (DEM); and 3) socio-economic variables like protected area, population density, transmission lines, and road network.

II. METHODOLOGY

Monthly solar radiation over a period of eight (8) years was recorded by the "Centre National de l'Energie Solaire, (CNES)." The CNES is located in Niamey, the capital city of Niger. The DEM of Niamey was utilized for the analysis throughout the city to see how the local topography influences the solar radiation distribution in conjunction with the images from "Landsat 8." The latter is an American Earth observation satellite launched on February 11, 2013.

A. Data preparation and analysis

With the help of the daily solar radiation data obtained from the CNES in the course of eight years, the monthly and annual solar radiation measurements were computed. The monthly insolation measurements were then used for the purposes of this study. In fact, the distribution of the aforementioned monthly electromagnetic waves can be utilized to examine the seasonal energy variations. It is worth pointing out that solar radiations are much more stable compared to other climate variables, such as temperature, humidity, and winds.

B. GIS modelling

The mapping and analysis of suitable land use for any study is the most helpful application in GIS [3]. The Weighted Linear Combination (WLC) and Boolean overlay operations, such as intersection (AND) and union (OR), are the simplest and most widely used operations in the GIS environment. Therefore, based on preferences, specific requirements, and predictors of some activities, land use suitability analysis is defined as the most relevant spatial pattern for future land usage [7]. This method was employed for optimal solar park site selection [8]. The flow chart, shown in Fig. 1, shows the process followed to determine suitable places for the implementation of a solar PV power plant in Niamey and the vicinity.

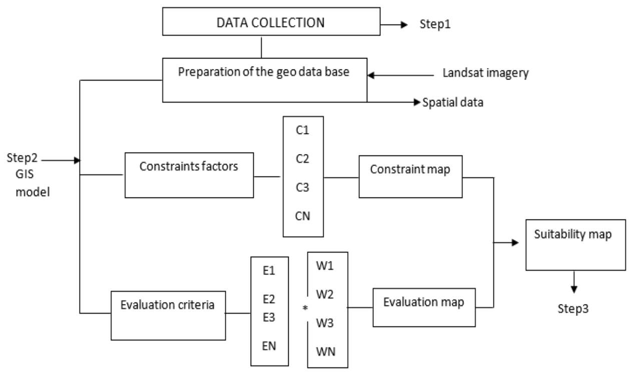

Fig. 1. Flow chart for suitable place in Niamey.

C. Criteria Identification

A sound knowledge of the environmental characteristics of an area is paramount before implementing a solar PV project. Hence, identification of key criteria is a necessary step. The criteria of solar PV implementation are a set of features, such as economic feasibility, severe and unpredictable environmental issues, and physical aspects.

D. Boolean Overlay

The above-mentioned Boolean variables serve to delineate area that is not suitable for consideration or helpful to use as constraints [9]. Based on Boolean logic, the buffer zones were employed and the CON tools were used to assign a true (or 1) or false (or 0) value to the selected criteria. The criteria used in this study for forbidden zones are: 1) Build up area to avoid the proximity to inhabitants; 2) Vegetation area to avoid deforestation; and 3) Agricultural land to avoid a reduction in productivity.

III. RESULTS AND DISCUSSIONS

The ARCGIS software was used to calculate the monthly suitable areas for solar PV projects for several years. ARCGIS is comprised of data-driven software and analysis tools, which are reliable for working with maps and geographic information.

A. Mean Solar Radiation, Niamey

Fig. 2 depicts the monthly mean solar radiation pattern collected from the CNES. For simplicity purposes, only one-year of data is shown. The remaining seven years exhibit a similar trend. From March to May, the aerosol in the atmosphere is very low due to hot and dry weather conditions. This is one possible reason why the highest irradiance value of 7.4 kWh/m^2 (*Blue line*) over Niamey occurred in April. It can also be seen that the yearly mean solar irradiance was about 6 kWh/m^2/day (*Red line*). In contrast, it can be observed that the minimum insolation of 4.6 kWh/m^2 occurred in August, which was due to the significance of rainfall and cloud coverage over the city. The implication is that the whole city, irrespective of the season, has a high solar suitability potential.

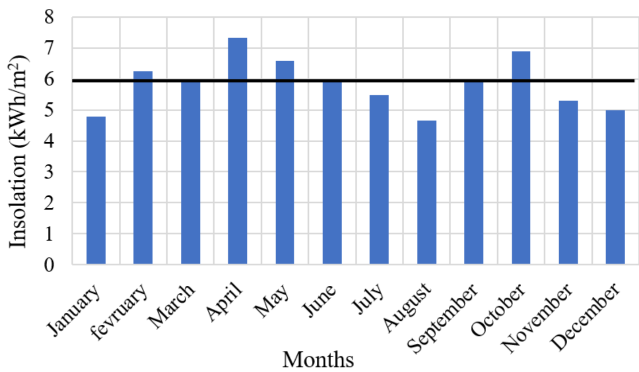

Fig. 2. Monthly mean solar radiation from 2007 to 2014.

B. Monthly Solar Radiation, Niamey

Fig. 3 portrays the monthly solar radiation for 2016. According to the graphs represented by Fig. 3, there is no significant variation between the monthly radiations. This fact is in perfect accordance with the graph shown in Fig. 2. The incoming solar radiation is modified as it travels through the atmosphere. The annual average solar insolation from the selected region was 6.841 kWh/m^2/day, yet it is different for each month, as can be seen in Fig. 3. These observed monthly discrepancies were solely linked to weather variables, such as relative humidity, wind speed and direction, and other unknown climatic parameters. It appeared that April had the highest insolation with a maximum mean of 7.340 kWh/m^2/day and a minimum of 5.760 kwh/m^2/day. The second sunniest month was March, with a maximum of 7.134 kWh/m^2/day and 3.368 kWh/m^2/day as its minimum. The lowest insolation occurs in August with a minimum of 2.53

kWh/m²/day. The second lowest irradiance happened in December with a minimum of 3.67 kWh/m²/day. This phenomenon is attributable to intense cloud coverage and fog formation, respectively in August and December.

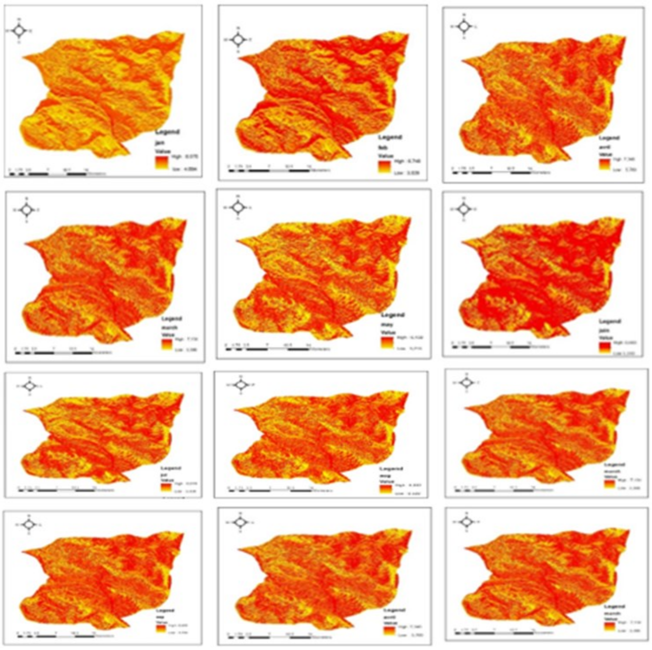

Fig. 3. Monthly Solar Insolation

C. Suitability Mapping

The constraint suitability solar PV map of Niamey is shown in Fig. 4. The latter also shows the total area of solar radiation in 2016. The constraint map used in this study took into account the water bodies, build-up areas, farmland, and vegetation. A constraint layer, comprising of all the unsuitable areas, was then created. The constraint areas represented by the red color occupy about 23.17%, which is equivalent to 246.23 km² of the study area, as shown in Fig. 4. Consequently, the remaining area denotes the best site for implementing solar PV plants.

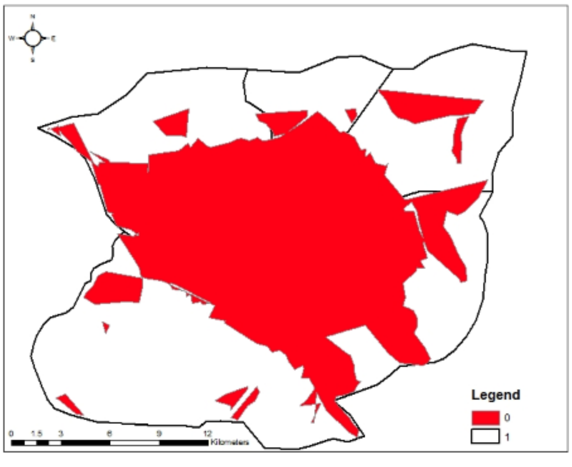

Fig. 4. Constraint map for suitability solar PV, Niamey

The criteria taken into account in this study, including proximity to the grid (*Upper Left, a*), proximity to major roads (*Upper Right, b*), slope factor (*Bottom Left, c*), and solar radiations (*Bottom Right, d*), are presented in Fig. 5. These constraints are the Fuzzy Membership (FM) layers. FM is an effective way of combining subjective geographical knowledge with empirical data in a neural network approach of mapping. Road accessibility layer values range from 0.9 to 1. It was found that the layer value of 57% of the land in Niamey was 1. This range of fuzzy value showed that all Niamey's area has great accessibility to roads. In terms of access to transmission lines, 58% of all selected areas had a fuzzy value of 1. In contrast, the minimum value of grid accessibility was 0.64. It was also observed that most of the city is flat, where 97.25% of the land has a slope of less than 5%, *i.e.*, an FM value of 1. Solar irradiance, the last criterion, was sub-divided by nine evenly distributed categories ranging from 4.32 to 7 kWh/m²/day.

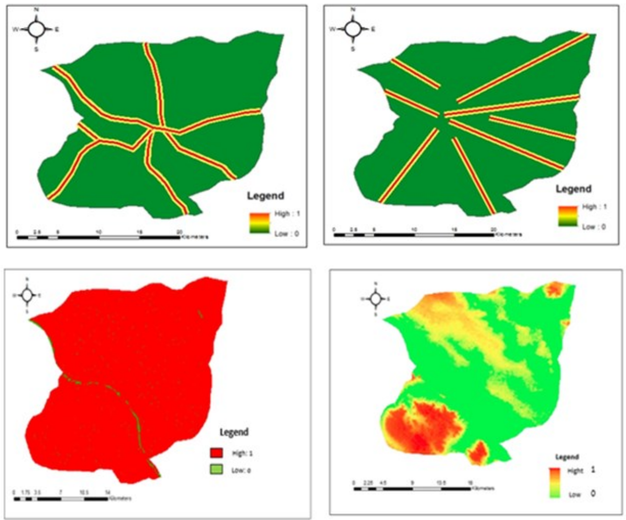

Fig. 5. Standardized factor of road network (a), Transmission line (b), Slope (c), and Solar radiation (d).

As a result, it was discovered that 65.27 % (693.42 km²) of the study area has low suitability, 3.68 % (39.13 km²) has moderate suitability, 2.78 % (29.55 km²) has high suitability, and 5.08 % (54.04 km²) has very high suitability for solar energy applications.

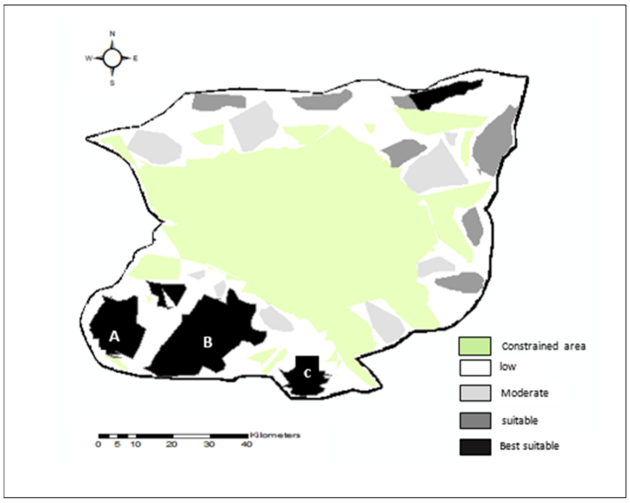

Fig. 6. Suitability niches for PV projects, Niamey.

Then three sites were selected among the very high suitability niches. The total area for sites A, B, and C is 22.5% (12.2 km^2), 53.33% (28.82 km^2), and 10.23% (5.53 km^2), respectively, as given by Fig. 6.

D. Model Validation

Before validating the model, a site visit was conducted. It was discovered that the plateau was composed of three types of soils: rocky soil, sandy (or light) soil, and shrub area, as portrayed, in that order, in Fig. 7.

Fig. 7. Rocky soil (1), sandy soil (2), shrub (3) for PV implementation

E. Energy Potential per Suitable Site

The electric power generation potential per day for the selected sites can be estimated through Eq. (1). This estimation is based on the: 1) calculated average annual solar radiation per unit area per day, 2) total suitable area, 3) efficiency of the PV panel, and 4) area factor. Therefore, the yearly solar electric power generation potential, as reported in [9], is

$$GP = SR \cdot CA \cdot AF \cdot \eta \quad (1)$$

where, GP is the electric power generation potential per year (kWh/day); SR is the annual solar radiation received per unit horizontal area (kWh/m^2); CA is the calculated total area of suitable land in m^2; AF is the Area Factor, indicating what fraction of the calculated areas can be covered by solar panels; and η is the PV system's efficiency.

The potential generation capacities (kWh/day) for the selected sites with different PV technologies are presented in Fig. 8. An AF of 70% was selected based on the maximum land occupancy of PV panels with the minimum shading effect.

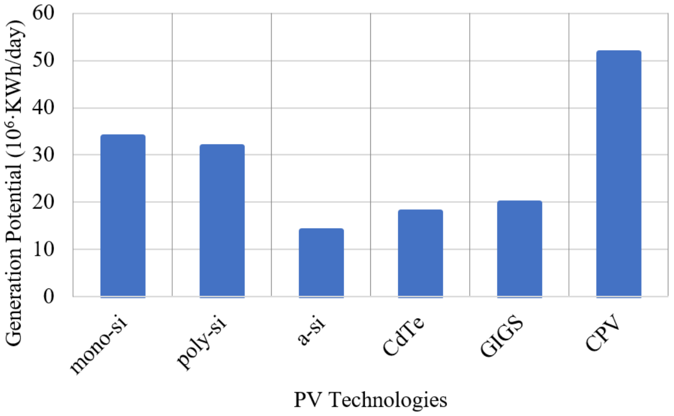

Fig. 8. Annual generation potential by technology

IV. CONCLUSION

In spite of its enormous renewable energy resources potential, Africa continues to struggle with the growing energy per capita demand. This continent is lagging way behind with intermittent power-cuts, especially in the Sub-Saharan nations, which hinder any real economic achievements. Unfortunately, Niger, as a landlocked country is no exception. The energy issue is most felt in Niger despite its huge energy potential composed of Uranium, Coal, Oil, Natural Gas, Hydroelectricity, and extensive sunshine. Regrettably, this energy issue is increasing due to fast population growth. The way out is that Niger has to strengthen its energy sector by becoming more independent by not only diversifying its energy sources, but also by cutting down its energy import from neighboring countries.

During this study, satellite Landsat 8 images were used for differentiating the categories of land use in Niamey and the vicinity, thus allowing for the identification of the suitable sites for solar PV implementations. The study also combined the GIS and remote sensing techniques for spatial analysis, modelling, and visualization purposes. Hence, the suitability maps were generated by taking into account the distance from transmission lines, distance from the roads, and the most isolated areas. Results showed that the plateaus, located in the southern part of Niamey, were the best places for any viable solar PV project. The overlay results of the resultant maps showed that about 22% of Niamey demonstrates very high suitability for PV farm implementation. Finally, three sites were identified with a total area of 46.51 km^2.

ACKNOWLEDGMENT

We would like to express our special gratitude to: (1) the West African Science Service Centre on Climate Change and Adapted Land Use program (WASCAL) and (2) the Bundesministerium Für Bildung und Forschung (BMBF), equivalent to the German Federal Ministry of Education and Research.

REFERENCES

[1] Edenhofer Ottmar, "Special Report on Renewable Energy Sources and Climate Change Mitigation," 2012.

[2] K. Dai, A. Bergot, C. Liang, W. N. Xiang, and Z. Huang, "Environmental issues associated with wind energy - A review," *Renew. Energy*, vol. 75, pp. 911–921, 2015.

[3] M. G. Collins, F. R. Steiner, and M. J. Rushman, "Land-use suitability analysis in the United States: Historical development and promising technological achievements," *Environ. Manage.*, vol. 28, no. 5, pp. 611–621, 2001.

[4] IRENA, *Renewable Capacity Statistics 2018 Statistiques De Capacité Renouvelable 2018 Estadísticas De Capacidad*. 2018.

[5] C. de Cigogne, "Potentiel énergétique du Niger," 2008. .

[6] Y. Charabi and A. Gastli, "PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation," *Renew. Energy*, vol. 36, no. 9, pp. 2554–2561, 2011.

[7] J. Malczewski, "GIS-based multicriteria decision analysis: A survey of the literature," *Int. J. Geogr. Inf. Sci.*, vol. 20, no. 7, pp. 703–726, 2006.

[8] A. Georgiou, H. Polatidis, and D. Haralambopoulos, "Wind energy resource assessment and development: Decision analysis for site evaluation and application," *Energy Sources, Part A Recover. Util. Environ. Eff.*, vol. 34, no. 19, pp. 1759–1767, 2012.

[9] J. Eastman, "Multi-criteria evaluation and GIS," *Geogr. Inf. Syst.*, pp. 493–502, 1999.