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Assessment of the Potentials of Solar and Wind Resources for Sustainable Energy Transition in Northern Bauchi State, Nigeria

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Abstract **Original Research Article**

The study assessed the potentials of solar and wind resources for sustainable energy transition in Northern Bauchi State, Nigeria. The study utilized remotely sensed climatic data of the area for the study. ArcGIS 10.3 was used to perform the geospatial analysis. The software allows mapping the spatial distribution renewable energy resources. Interpolation method (Inverse distance weighted) was adopted to produce maps of the distribution of renewable resources. The study found enormous potentials of solar and low intermittent wind energy in the study area; the result revealed that generally all the nine LGAs of the study area have high solar radiation incidence 6.28-6.48kwh (21.99-22.67 mega joules) daily which is potentially enough generation electricity. It is further revealed that wind speeds in the study area range from 2.1 - 2.5m/s. and LGAs like Gamawa, Zaki and Dambam have high wind velocity of between 2.6 and 2.4 m/s which is suitable for generation of electricity. The study concludes that there is enormous potential and availability of renewable energy resources, in particular solar and wind energy, which can be harnessed for small and large-scale electricity generation. The study therefore recommended that the Federal and State Governments as well as Private Companies as the matter of urgency should explore and harnessed the enormous and abundant renewable energy resources. The policymakers and NGOs should pay more attention to provision and installation of the community based off-grid renewable infrastructures such as hybrid solar/wind powered systems.

Keywords:Assessment, Potentials, Renewable EnergyResources, Sustainable Energy Transition, Northern Bauchi State.

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INTRODUCTION

Globally sustainable energy is considered as a critical and essential factor for achieving social, economic and environmental development. Adequate energy supply is generally considered the backbone for any meaningful development of a country. Chukwu *et al.,* (2014) argued that tracking the success towards realizing the objectives of modern energy requires the assessment of a broad range of relevant and interrelated issues that need to be analysed with quantitative energy parameters or energy indicators, this involves both installation of established technologies and research and development to create modern based technologies with the aid of renewable sources. Nigeria has huge amount of renewable natural resources for sustainable energy transition. But no doubt the country also has been also blessed with fossil fuel deposits, its potentials in the renewable energy resources can be used for power generation. Several studies reported that northern part of the country has enormous and adequate solar radiation and medium winds for permanent and sustainable power generation.

Renewable Energy Resources

Renewable energy it refer to energy that is environmental friendly and less polluting derived from resources that are constantly replenished usually through the natural processes, these include solar, wind, hydropower and biomass. Renewable energy sources generally occur in sustainable forms without depletion (UNCTAD, 2010; Nadabo, 2010). Renewable energy which basically occurring naturally provides an unlimited and sustainable energy supply without making serious damage to our fragile environment, renewable energy is regarded as the future and energy that we can use today. Globally energy from renewable sources is considered to

be environmental friendly then the conventional sources from fossil fuel. Being an environmental common, renewable energy can used to achieve sustainable development agenda of access to modern and sustainable energy.

Solar Energy

Solar energy is a form of green energy obtained from the Sun. It's occurring naturally, inexhaustible and pollution free. Solar energy is the ultimate and most abundant cheapest source of energy in the global earth, but its intensity on the earth surface varies spatially and temporally from one place to another at a global level (Tekle, 2013).

Wind Energy

It's an energy blowing from the movement of the wind on the surface of the earth. This is a natural movement of air masses cause by the variation of solar radiation heating surface of the earth (Agbetuyi *et al.*, 2012). Energy from the wind energy can be converted to electricity and serve as a promising source of power in the areas where it is available and adequate. But the only limitation is it intermittent nature and the movement or speed may vary from time to time, day, season, and even year to year (Ajayi *et al.*, 2008).

Solar and Wind Resources Potentials in Nigeria

Potentials of Solar Energy in Nigeria

Nigeria is country located in the tropic and blessed with adequate solar radiation that can be harnessed to meet its today and future energy requirements. Being a country that is located within the regions with more solar radiation that is fairly well distributed, studies have shown that the annual average irradiation varies from about 12.6 MJ/m2/day (3.5 kWh/m2-day) in the coastal latitudes to about 25.2 MJ/m2-day (7.0 kWh/m2-day) in particular in the extreme north (Johnson and Ogunseye, 2017, Charles 2014, Olelakan *et al.*, 2012, Chineke *et al.*, 2010, Ogunleye and Awogbemi 2010). Energy from sunlight is regarded as one of the focal point of the country sustainable energy transition due to its availability and abundance (Ilenikhena and Ezemonye, 2010; Newsom, 2012, Charles, 2014). Various studies reported that the country has average sunshine hours of about 6 hours, 3.5 hours in the coastal areas of Niger Delta and 7-9.0 hours in the extreme North of the country (Ohunakin *et al.*, 2014, Charles, 2014, Oseni, 2012 and Sambo 2009). These statistics reflect the availability and potentials to generate adequate and sustainable electricity using solar radiation (Oghogho, *et al.*, 2014).

Despite the fact that country is blessed with abundance and enormous solar radiation but only about 0.005% is converted into electricity and if 1% of the total land area will be covered with solar energy collectors, the electricity deficit of the country could be solve (Chendo, 2002; ECN and UNDP 2005; Sambo, 2008; Onyema, 2010; Uzoma, *et al.*, 2011; Chukwu and Kwajaffa, 2013; Charles, 2014). Furthermore, other studies pointed out that the energy from the sun is available at about 26% per day (Bala, *et al*, 2001 in Nadabo, 2010; Akintola and Alamu, 2010). This is supported by IEA (2011) that argued that in about one and half hour, the radiation from sun that hits the surface can be enough to meet the annual global energy needs.

Wind Energy Potentials in Nigeria

Although, electricity generated from wind is not the most widely used in Nigeria. This has prompted the government, independent researchers and industries find out about the potentials of wind energy solving the electric power challenge of the country. Furthermore, studies of wind resources also revealed that the North, Central and South-East possesses appreciable potential for harvesting wind energy, with wind speeds reaching as high as 8.70 m/sin some place in the north (Ajayi, 2007). At present, the total consumption of wind energy has very minimal with only a few number of stand-alone wind power plants were installed over the decades mainly in the northern states to power wind pumps and a 5 kW wind electricity conversion system for village electrification installed at Sayyan Gidan Gada, in Sokoto State (Nnaji,; Uzoma and Chukwu, 2010). Nigeria can used the wind speed in some states with the highest potentials like Sokoto, Jos, Bauchi and Kebbi States to provide substantial electricity from wind.

Establishing the availability and potential of renewable resources in study area, centered mainly on solar, wind and bio-energy resources. One of the major problems regarding the renewable energy resources is the lack spatial data that would clearly show availability of these natural resources in the study area. The area is though blessed with renewable energy resources which may be used to meet household's energy demand. Field observations identified three (3) major form renewable energy resources that may be useful for sustainable energy generation for household and productive uses in the area, these resources are solar, wind and biomass energy. This study attempted to map the spatial distribution of renewable resources with a view of understanding the resources availability as it may vary from one location to another within the study area.

STUDY AREA AND RESEARCH METHOD

Location and Size of the Study Area

The study area lies within Latitudes $11^0$12'N to $12^0$45'N and Longitudes $9^0$37'E and $10^0$58'E, with a total landmass of about 12508 square kilometers; and shares a border with Yobe state to the north and north-east, Jigawa to the north-west part, and Darazo Local Government of Bauchi State to the south. The area has three (3) emirates (Katagum, Misau, and Jama'are) and nine (9) Local Government Areas including Katagum, Shira, Gamawa, Itas-Gadau, Giade, Zaki, Misau, Dambam, and Jama'are (Figure 1).

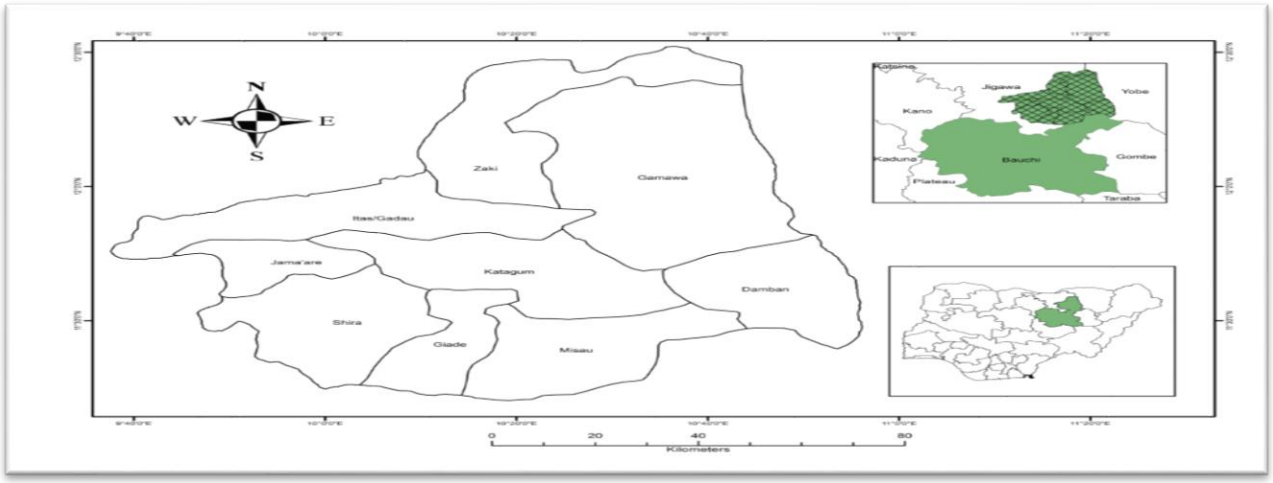

Figure 1: The Study Area
Source: Geographical Information System Unit FUDMA

Climatic Condition

The climatic condition of the study area is tropical wet and dry characterized by two main seasons i.e. rainy or wet season starting from June-October and a dry season which occupies the rest of the year which caused by the movement of Inter Tropical Convergence Zone (ITCZ) or Inter Tropical Discontinuity (ITD) which separates the two major air masses. The rainy season begins late in the Northern part of the State, June and July records the highest amount of 800mm per annum. While it is humidly hot during the early part of the rainy season in the south, the hot, dry, and dusty weather lingers up north. The area has a mean daily maximum temperature of 23.4˚C with a mean daily minimum being 13.5˚C. Maximum temperature occurs between March and August with extreme values of 24.3˚C in April (Bauchi State Diary 2008; Chadi, 2018). The climatic data from the study area indicated relatively high solar irradiation and a low annual average of wind speed. This shows the potential of off-grid electrification using solar photovoltaic panels in rural communities of the area. According to Ajayi, (2008); Akpan and Ishak, (2012), the study area has annual average of solar irradiation of about 5.96kWh/m2/day with mean daily wind speeds of between 2.0 to 4.0 m/s at 10 m height.

Vegetation Characteristics

The study area lies mainly in the Sudano-Sahelian Savannah region. The study area is mainly characterized by scattered trees, shrubs and grasses. The vegetation is made of encroached forest and grazing reserves, plantation and parklands as well as riparian vegetation. The vegetation is conditioned by the amount of rainfall received in the area of about 500-800 mm per annum (Bauchi State Diary 2008). The most widely tree species found in the study area include *Parkiabiglobosa, Adansoniadigitata, Khayasenegalensis, Fadherbiaalbida, Tamarindusindica*, *Ceibapentendra, Diospyrosmespiliformis, Proposisafricana,Balaniteaegyptiaca, Acacia nilotica, Acacia seyel, Acacia Senegal, Combretumglutinosum, Combretummicranthum, etc.* there also found some exotic plant species such as *Azadirachtaindica and Eucalyptus cameldulensis.* In addition, fruit trees are grown on the farm lands such as *Magniferaindica, Moringaoleifera*, and *CajanusCajan* among others.

Population and Socio-Economic Activities

The study area has an estimated population of 2,093,537 people in the 9 L.G.As based on the 2018 population projection. The ethno-linguistic groups include Hausa, Fulani, Karekare, and Kanuri (Sule, 2017). This accounts for the differences in dialects, settlements, customs, festivals, historical backgrounds, and occupational patterns in the study area. There are similarities in term of cultural attributes of languages, occupational practices, festivals, and mode of dressing with a high degree of ethnic interaction especially in marital and means of livelihood (Bauchi State Diary 2008). The area has a population density of 1-199 persons per square kilometer (Sule, 2017; Sule 2017b). The study area is predominantly rural with few towns like Azare, Misau, Jama'are, and Gamawa. Agriculture is the main economic activity in the rural areas with millet, guinea corn, groundnut, beans, and sesame seed being the predominant crops cultivated. Furthermore, about 97.0% of the household energy needs for cooking in the study area mainly is obtained from traditional biomass such as wood fuel (NBS, 2009 in Akpan and Ishak, 2009). Biomass such as trees, shrubs and other woody plants remain one of the important energy sources for cooking and heating services, it also play an important role to the socio-economy and livelihood as wood fuel extraction offers many benefits such as jobs opportunities in the study area. This study observed that in the study area various fuels and technologies were used for lighting services such as electricity from the national grid,

disposable batteries flashlight and solar home systems, etc. Other fuels used cooking and heating are crop residues, animal dung, wood fuel, charcoal, other woody biomass and Liquefied Petroleum Gas.

Data Sources and Types

The data used for this study comprised of climatic, which was obtained from Global Weather Data for SWAT (Climate Forecast Systems for Reanalysis) 2014. These data include 15 years daily solar radiation and wind speed was updated and correlated with the U.S. National Aeronautics and Space Administration (NASA), these satellite climate data of the study area were updated up to 2019 and correlated at 95% level of significance. Others include the satellite imagery of the study area obtained from United State Geological Survey (USGS).

Data Collection Technique

The documented data made up of daily solar insolation and wind speed were generated from Global weather data for SWAT (Climate forecast system for reanalysis) 2021and these archival data were updated and validated with climatic data (solar radiation and wind speed) obtained from one of meteorological station in the area.

Method of Data Analysis

Arc GIS 10.3 was used to perform the geospatial analysis. The software allows mapping the spatial distribution renewable energy resources. Interpolation method (Inverse distance weighted) {IDW} was used to produce maps of the spatial distribution of renewable resources. Each map was generated was generated by interpolating attribute values using IDW. Mohammed *et al.* (2017) argued that the IDW implement explicitly the assumption of any phenomena close to one another. To find out a value for an unmeasured location, IDW considers the measured values of the surrounding area for the prediction of location. Furthermore, all the datasets reclassified were overlaid using the fuzzy tool in Arc GIS 10.3. It is important to note that elevation affect the amount of incoming solar radiation and wind speed of an area. These spatial datasets used for the mapping of available renewable energy potentials include climate data which were generated for 20-year period from 2000-2019, in addition to Landsat 8 NDVI and elevation map of the study area. These datasets were generated from various sources such as SWAT, NASA and USGS and processed using Arc GIS 10.3 software. Moreover, various spatial datasets such as solar radiation, wind speed, and elevation were utilized and processed using multiple GIS tools for the purpose of mapping and analysis renewable energy resources potentials.

RESULT AND DISCUSSION

Spatial Variations of Solar and Wind Energy Resources Potentials

Table 1 and field observations identified three (2) major form renewable energy resources that may be harnessed and useful for sustainable energy generation for household and productive uses in the area, these resources are solar, and wind energy. It is evident from the Table below that the area is blessed with these green energy resources which may be used to meet energy demand.

Table 1: Solar Radiation and Wind Speed Parameters of Northern Bauchi State

LGA/Location	Latitude	Longitude	Average solar radiation in mj/m2/day	Average wind speed in m/s	Elevation in meters
Shira	11.08409977	9.6875	22.11	1.97	445
	11.39640045	9.6875	22.35	2.15	419
Jamaare	11.70860004	9.6875	22.3	2.31	389
Giade	11.08409977	10	22.19	2.07	592
	11.08409977	10.3125	22.29	2.3	428
	11.08409977	10.625	22.42	2.33	422
Misau	11.08409977	10.9375	22.41	2.38	346
	11.39640045	10	22.36	2.21	416
	11.39640045	10.3125	22.33	2.34	420
Dambam	11.70860004	10	22.32	2.36	403

	11.70860004	10.3125	22.16	2.45	405
	11.70860004	10.625	21.99	2.54	360
	11.70860004	10.9375	21.71	2.61	451
Zaki	12.02079964	9.6875	22.25	2.44	400
	12.33300018	9.6875	22.58	2.48	362
	12.02079964	10	22.31	2.48	371
Gamawa	12.02079964	10.3125	22.23	2.53	385
	12.02079964	10.625	22.14	2.6	363
	12.02079964	10.9375	21.81	2.66	329
Zaki	12.33300018	10	22.68	2.51	362
	12.33300018	10.3125	22.64	2.5	333
Gamawa	12.33300018	10.625	22.59	2.53	370
	12.33300018	10.9375	22.4	2.58	342
Misau	11.39640045	10.625	22.25	2.43	417
	11.39640045	10.9375	22.07	2.49	462

Source: Global Weather Data for SWAT (Climate Forecast System Reanalysis) (2022)

It is important to find out these energy resources because the utilization of renewable fuels must be dwelling on understanding the resources availability; the resources vary from one location to another over time and thus the potentials in the study area.

Spatial Distribution of the Potential of Solar Radiation in Northern Bauchi State

In an attempt to analyze the spatial distribution of solar energy resource, the daily solar radiation was examined for different locations in the study area (Table 1). The daily solar radiation is the solar energy that falls on the earth surface and is expressed as kilowatt-hours (kWh) on a square meter area while the daily solar hour is the number of sunshine hours in a year for a given location on earth (Zhu, 2017). The result in Figure 2 shows that the study area has an average daily radiation of 6.28-6.48 kWh/m^2/day (21.99-22.67 mega joules) with sunshine of eight (8) hours per day. Though the energy intensity is low in the early and late hours of the day and it can be very suitable for large scale electricity generation. This implies that the area is abundantly blessed with enormous solar radiation which may be used to meet both small to large scale sustainable electricity generation. This was also observed and reported by Burari, (2001); Akpan and Ishiak, (2012); Ohunakin *et al.*,(2014) and Sule (2017) on studies conducted on solar energy in Nigeria, North East Geo-Political Zone and Bauchi State.

In addition, the solar energy distribution map identifies areas with solar energy potentials, generally all the nine LGAs of the study area, have high solar radiation incidence 6.28-6.48kwh (21.99-22.67 mega joules) daily which is potentially enough for both solar home system and large scale solar photovoltaic (PV) generation. In this regard, given the large barren land surface in the area, Kvarner (2012) claimed that solar farms with land area of 110 hectares, about 200 standard football fields, would produce 40 million kWh of electricity annually saving 25.000 tonnes of CO_2 and cost about 130 million €.

Moreover, the result of the analysis shown in Figure 2 indicated that solar radiation increases as one moves from the southern to the northern part of the area. The study further classified into three (3) zones of solar radiation as (low, moderate and high) based on the geographical differences of solar radiation incidence (Figure 2). Some parts of Gamawa and Zaki LGAs fell within the high solar radiation zone whereas Itas/Gadau, Jama'are, Shira, Giade and Misau are within the moderate solar radiation zone, while Katagum, Dambam and some parts of Gamawa fell on the low zone. This implies an adequate solar radiation that can be converted using appropriate technology for sustainable energy generation in the area. Akpan and Ishak (2012) and Ohunakin *et al.*, (2014) argued that North-East geopolitical region of the country has the lowest electricity access level with a relatively high solar irradiation level can perhaps be used for decision support in energy planning. This indicated the potentials for mini off-grid systems in rural and remote

communities in the study area as stressed by Ohunakin *et al*. (2014) that pointed out states like Bauchi, Borno, Yobe, Jigawa, Kano, Kaduna, Gombe, Adamawa, Plateau and Katsina have an average of 5.7–6.5 kWh/m², 6.0 hours/day and 2186 kWh/m²/year, with greater potentials for using solar photovoltaic panels for off-grid electrification in rural communities.

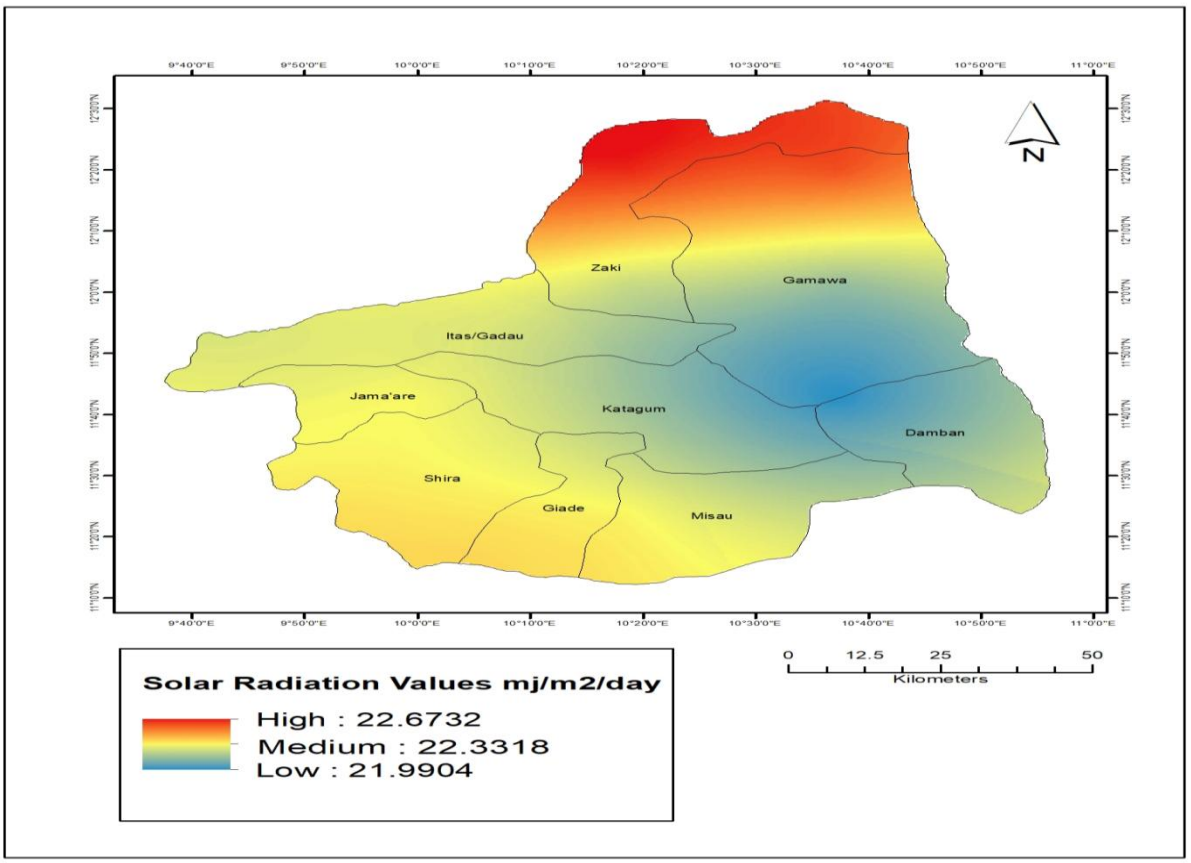

Figure 2: Solar Radiation Map of Northern Bauchi state
Source: Data Analysis (2022)

Thus, this study observed that solar PV is currently used for micro-grid, refrigeration, water pumping, and other productive activities in the study area. This shows the need for more adoption of solar PV for mini-grid and integration into the national grid. This will go along with the global effort of cutting down the rate of carbon footprint within the rural communities. This study strongly agrees with Ohunakin *et al.* (2014) who argued that solar PV applications will reduce carbon footprint, thereby mitigating climate change in Nigeria as well as improving rural water supply. It is further observed that despite the abundant solar radiation in the study area, there is no existing solar PV mini grid providing electricity to any rural community. This shows the need for policies and concerted efforts from all level of governance that would support off-grid electrification for rural communities using solar PV in the area.

Spatial Distribution of Wind Energy Potentials in Northern Bauchi State

Many studies have for long concluded that there is enormous potentials of wind energy especially in the semi-arid and high land areas of Northern Nigeria (Ajayi, *et al.*, 2010: Ohunakin, 2011; Ajayi, *et al.*, 2011: Charles, 2014). The result of study shows that the study area is generally characterized with low wind speed. The result indicated Table 1 and Figure 3 shows that the wind speeds in the study area range from 2.1 -2.5m/s. From Figure 3, Local Government Areas like Gamawa, Zaki and Dambam have high wind velocity of between 2.6 and 2.4 m/s, and then followed by Katagum and Itas/Gadau with moderate wind speed of between 2.3 and 2.2 m/s whereas the southern and western part of the study area which include Jama'are, Shira, Giade and Misau LGAs is characterized by low wind speed of between 2.19 and 1.97 m/s despite the fact that these LGAs have the highest elevation. Thus, considering the intermittent and low daily wind speed in the study area, it is concluded that there is no area to be very suitable for wind electricity generation, except with the aid of a tall tower and can only be used for mechanical applications such as water pumping. This study agrees with Ohunakin *et al.*, (2011) who observed similar situation in North Central part of Nigeria. However, the study disagrees with Ajayi *et al.* (2010 and 2011) and Charles (2014) that

reported enormous wind speed in the core north of the country, with the possibility of wind speeds reaching as high as 7.5 to8.70 m/sat 10 m/s and very suitable for electricity generation.

Generally the wind speed in the study locations is less than 5 m/s, and this is not enough and lacks much suitability for wind energy generation. This implies wind speed across various locations is the not suitable for harnessing electricity via wind energy. Contrary to this study, Ramachandra and. Shruthi (2005) reported high wind speed of greater than 5 m/s during most of the months in Chikkodi, Horti, Kahanderayanahalli, Kamkarhatti, Raichur and Bidar of India and hence suggested for construction of wind energy farms in these locations. This study therefore, considering the high solar and low wind speed in most locations of the study area, suggests for possible combination of wind and solar energy (hybrid wind/solar design) for electricity generation in the area. Although it is observed, despite the low wind speed there are currently few wind powered boreholes operating at the height of more than 10 m/s in the study area.

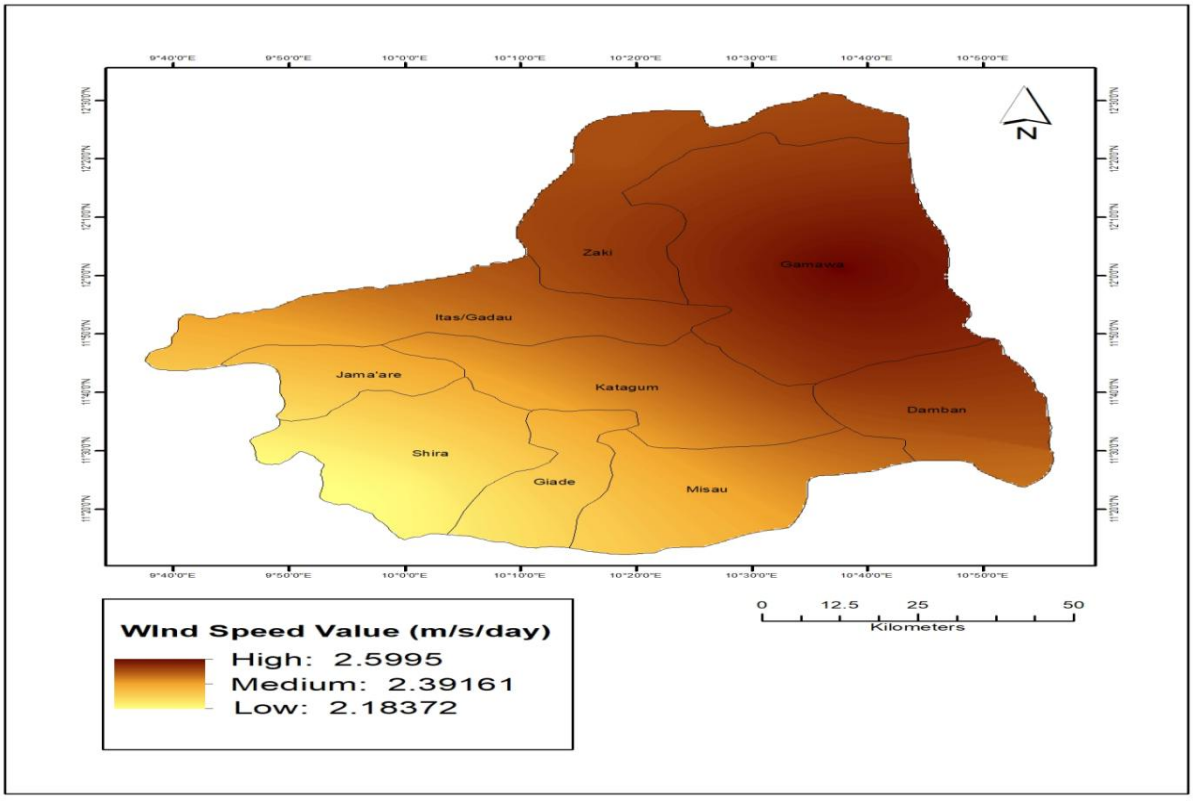

Figure 3: Spatial Distribution of Wind Speed in Northern Bauchi State
Source: Data Analysis (2022)

Mapping of Renewable Resource Potentials in Northern Bauchi State

The geographic location of the study determines the available potentials for renewable energy generation. The available renewable energy potential of the area provides a great for opportunity sustainable energy generation (Sule, 2022). The results of this study showed significant variability in the spatial distribution of renewable energy potentials in the study area. Generally based on the result in Figure 4, the study area was classified in five (5) classes based on potentials of renewable energy resources; this is range from very low, low, moderate, high and very high areas of renewable energy potentials. According to the result in figure 5, the northern part of the study area is relatively have very high renewable energy potentials for hybrid large-scale (solar and wind installations). This study disagreed with Tekle (2014) who reported that the eastern part of Ethiopia is having high solar energy and relatively suitable for large-scale solar farms.

Furthermore, this study found that the middle and southern parts of the study area have relatively very low and low renewable energy potentials. Conversely, the south-west part of study area such as Jama'are, Shira, Giade, and Misau LGAs have low renewable energy potentials for hybrid (solar and wind) energy generation when compared northern part such as Gamawa and Zaki LGAs with high and very renewable energy potentials for large scale installation of solar and wind farms. The result of this study shows the strength of combining the spatial variables such as solar, wind and biomass energies in providing results oriented maps which would be useful for decision makers and energy planners in both local and regional scale.

This study demonstrated the potentials of renewable energy especially solar and wind energies in the extreme northern part of the study area. It is believed that the policy and decision makers will take advantage these clean and renewable energy resources to resolve the acute shortage of sustainable energy in the area, and this will facilitate a platform for achieving sustainable development goals (SDG7) in the study area. However, there is no doubt that the study area needs to expand her horizon for sustainable energy provision. Despite the abundance of renewable energy such as solar energy the current state of sustainable energy provision depicts a very unfortunate situation; this condition shows clearly the need for sustainable energy access from renewable and smart sources by upscale the exploitation of enormous green energy sources such as solar energy in the study area. This shows the need for more commitment and political will towards prompt implementation of policies such as Renewable Electricity Policy Guidelines (REPG), Renewable Electricity Action Programme (REAP), Renewable Energy Master Plan (REMP), National Renewable Energy and Energy Efficiency Policy (NREEEP) and the provision of Sustainable Development Goal Seven (SDG7), these policies when fully and judiciously implemented would no doubt upscale renewable energy access and use in the area and the country at large.

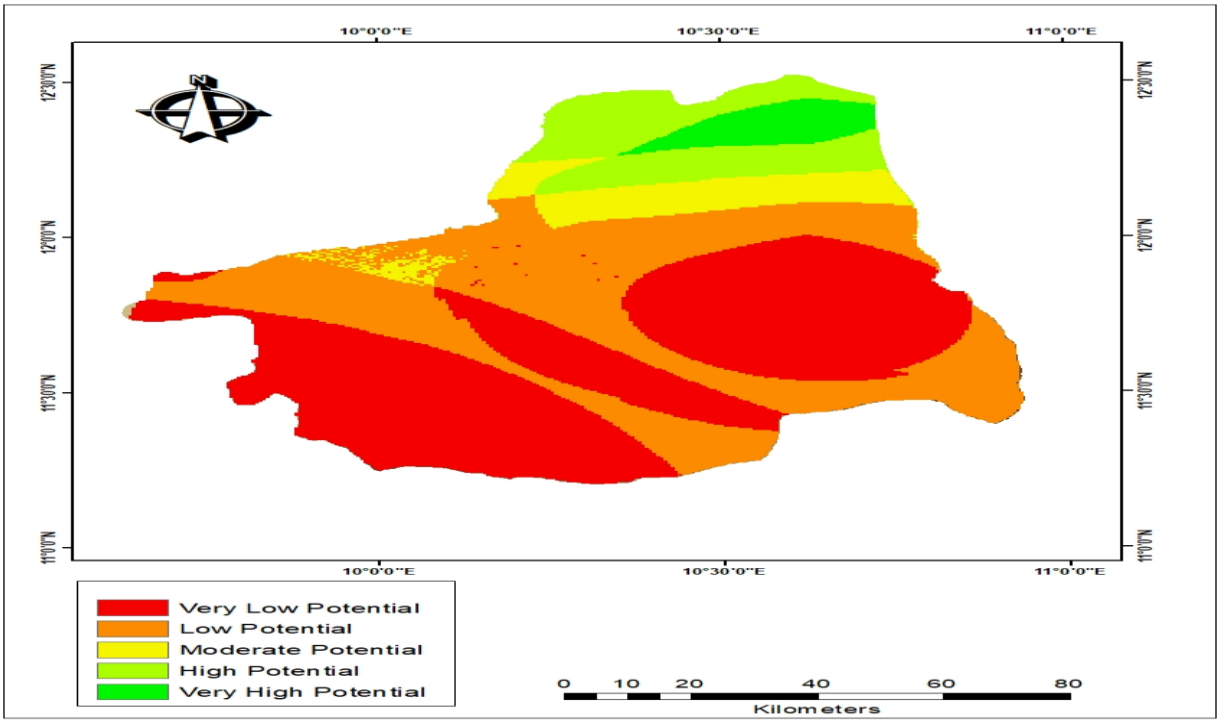

Figure 4: Spatial Distribution of Renewable Resources Potentials in Northern Bauchi State
Source: Data analysis 2022

CONCLUSION

This study concludes that there is enormous potential and availability of green energy resources, in particular solar and to some extent wind energy in some location using tall towers, which can be harnessed for small and large-scale electricity generation. Although, the study discovered that wind energy unlike solar radiation is not enormous but can combined together using appropriate technology to be harnessed as a hybrid solar/wind design option.

RECOMMENDATIONS

The study offers the following recommendations in order to improve access to clean, affordable, reliable, sustainable and modern energy in the study area.

i. Federal and State Governments as well as Private Companies as the matter of urgency should explore and harnessed the enormous and abundant solar and wind energy resources.
ii. The policymakers and NGOs should pay more attention to provision and installation of the community based off-grid renewable infrastructures such as solar and windpowered systems.
iii. It is recommended for the adoption of hybrid sola/wind off-grid design systems that may combine the utilization of solar and wind energy for modern and sustainable energy transition.

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