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RENEWABLE ENERGY SOURCES FOR SUSTAINABLE OFF-GRID ELECTRIFICATION IN MOKWA LGA CASE STUDY OF EDAN RURAL COMMUNITY

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Abstract: **Utilizing renewable energy sources for off-grid electrification has emerged as a viable solution in the pursuit of sustainable development, particularly for rural communities where conventional grid extension is challenging. The focus of this research is Edan, an isolated community within Mokwa Local Government Area (LGA) that faces significant economic and technical hurdles with traditional power options. This study aims to assess whether solar or wind could supply consistent and steady electricity to meet their needs sustainably. The methodology involves assessing renewable resources available within Edan through feasibility analyses on several different off-grid systems. Taking into account the high levels of solar irradiance experienced in the region, photovoltaic (PV) systems appear promising due to suitability; however data surrounding wind speed yield results less favorable than PVs. Hybrid solutions combining both options may offer stability while remaining cost-effective when put forth accordingly. Successful implementation depend heavily upon involvement from local leaders capable of upholding ownership over system maintenance by equipping them with capacity building tools imperative project success at all stages until completion along continuing usage thereafter. By highlighting tailored strategies utilized during remote area electrification processes such as found here provides helpful insights useful applyable elsewhere even across Nigerian borders beyond set limitations encountered en route implementing grassroots endeavors towards cleaner sourced self-sustainable developed communities worldwide.**

Keywords: **Hybrid, Edan, Sustainable, PV, Solar, Irradiance.**

I. INTRODUCTION

Mokwa Local Government Area (LGA) in Niger State, Nigeria, like many rural regions in Sub-Saharan Africa, faces significant challenges related to energy access. The absence of reliable electricity infrastructure hampers socio-economic development, exacerbating issues such as poverty, lack of healthcare, and educational deficits. In response to these challenges, the integration of renewable energy sources presents a viable solution for sustainable off-grid electrification. This approach aligns with global efforts to achieve the United Nations Sustainable Development Goal 7 (SDG 7), which aims to ensure access to affordable, reliable, sustainable, and modern energy for all by 2030. Mokwa LGA is endowed with substantial renewable energy resources, including solar, wind, biomass, and small-scale hydropower. These resources provide a unique opportunity to implement decentralized renewable energy (DRE) systems, which can operate independently of the national grid. The high solar irradiance in the region makes solar photovoltaic (PV) systems particularly promising. Studies have shown that areas in Northern Nigeria, including Mokwa, receive an average of 5.5 to 7.0 kWh/m²/day of solar radiation, which is adequate for solar energy generation (IRENA, 2023). To maximize the reliability and efficiency of off-grid electrification, integrating multiple renewable energy sources into hybrid systems is essential. Hybrid systems combine different types of renewable energy technologies, such as solar PV, wind turbines, and biomass generators, with energy storage solutions like batteries. This integration mitigates the intermittency issues associated with single-source renewable energy systems and ensures a more stable and continuous power supply. For instance, a solar-wind hybrid system can leverage the complementary nature of these resources solar power during the day and wind power at night. Additionally, integrating biomass energy, derived from agricultural residues, can provide a continuous energy supply, especially during periods of low solar or wind activity. Global economic growth has relied heavily on energy, particularly in the sub-Saharan African region where achieving universal access to this resource is still an outstanding goal (International Energy Agency, 2019). Seeing significant growth in its energy demands, as predicted by the International Energy Agency, Africa countries will not achieve full energy accessibility by 2030 if current trends persist. This means that around 530 million people across Africa may remain without electricity. Moreover, at present approximately 600 million and 900 million individuals lack access to clean cooking solutions and electricity correspondingly (International Energy Agency, 2019). Not all individuals benefit from grid-connected electricity for power delivery, particularly those who reside in remote villages and rural areas. To meet their energy needs, they must rely on autonomous power supply systems that predominantly utilize fossil fuels (Rinaldi et al., 2021). A major drawback of these systems is the increase in greenhouse gas emissions which consequently lead to air pollution (Ahmed et al., 2022). Utilizing renewable energy sources like solar, wind or biofuel amongst others can aid in reducing the emission of GHG's. Electrifying poorly connected regions plays a key role in enhancing economic and social wellbeing of people living here while also contributing towards overall country development objectives (Awopone et al., 2021; Rashid et al., 2021). Most Nigerians reside in isolated rural areas that lack access to grid energy, and expanding it is not feasible. Even those remote sites with connections receive a limited supply only every six to nine hours. Diesel generators are also impractical due to fuel costs, maintenance fees, operational expenses and their emission of greenhouse gases. On top of this, Nigeria's government endeavors to promote renewable energy sources by providing various programs and incentives among other things. Nigeria potentially possesses the ability and resources necessary for combining two or more renewable energy sources including those mentioned above towards meeting national demand levels effectively. The Nigerian government's sustainable development objectives mandate that the current generation meet their own requirements without jeopardizing future generations' potential (WCED, 1987). Despite possessing plentiful renewable energy resources, Nigeria has not fully exploited them to make a significant contribution to power production. Nevertheless, in various sectors of the economy, the Nigerian administration has taken some initiatives toward promoting alternative and renewable energies' adoption.

II. LITERATURE REVIEW

With the rising demand for power, governments and industries are under constant pressure to ensure efficient energy use. As a result, many companies are searching for ways to improve their processes. These include methods like reducing energy consumption or improving quality control in order to reduce wasted resources during repair procedures. Additionally, concerns about global warming and an impending shortage of fossil fuels have made it even more essential for sustainable energy sources that can meet increasing demands to be developed . This has led researchers such as Al-Ghussain (2020), Calise (2016), Esteban (2018), and Leal et al.(2019) to explore viable options accordingly. To address this issue, clean fuel alternatives (Huang, 2018; Bontempo et al., 2019) and renewable resources such as solar power (Li,19), wind turbines [Li.20], and Budiyanto et al.,(2020) are being employed. In line with the Paris climate accord signed in 2016 by several nations including Jordan to minimize greenhouse gas emissions, there's a call for more inclusion of renewable energy into their grids. It goes without saying that energy plays an integral role in driving economic growth and national development. Abdalah et al. (2015) explain that the growth of development and human prosperity relies heavily on energy supply, security, and efficiency. Additionally, Lior (2011) argues that there is a relationship between energy resources/consumption and environmental quality as well as other crucial resources like water and food. For this reason, developing Africa's energy infrastructure would not only improve the standard of living for its citizens but also open up opportunities to export renewable energies globally while reducing reliance on fossil fuels in response to global warming concerns caused by their continued use during an ongoing worldwide crisis related to energy availability. Adefela and Agbroko (2020) emphasis on abulecentric method of renewable energy as a way towards nation’s development where mini and small energy system can be build in clusters. They further mentioned that energy renewability and sustainability is of great importance to overall nation’s development. Due to their dependence on non-renewable energy sources and lack of capacity for stable energy stock and costly mix, developing economies exhibit volatility in response to

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fluctuations in the energy market. Nonetheless, many such countries possess substantial untapped reserves of renewable resources that could serve multiple purposes (Orisaleye et al., 2018). According to Piebalgs (2017), these same nations are uniquely positioned with abundant wind, solar, geothermal, biomass and hydro power potential suitable for driving increased use of renewables. Nevertheless, financial and political aid may be necessary to achieve this. Research has proven that renewable energy plays an essential role in the promotion of growth and economic development by creating job opportunities (Tum et al., 2017).

Sometime in 2016 it was heard that the Ogun State government were looking into biomass conversion which is a positive move and a method to solve improper waste disposal in the state. If all states in Nigeria could develop its own source of power, and then the work load on the Kanji dam would reduce potential for failure (Emetere, 2016). A typical example of a biomass conversion process is demonstrated in Figure 1.

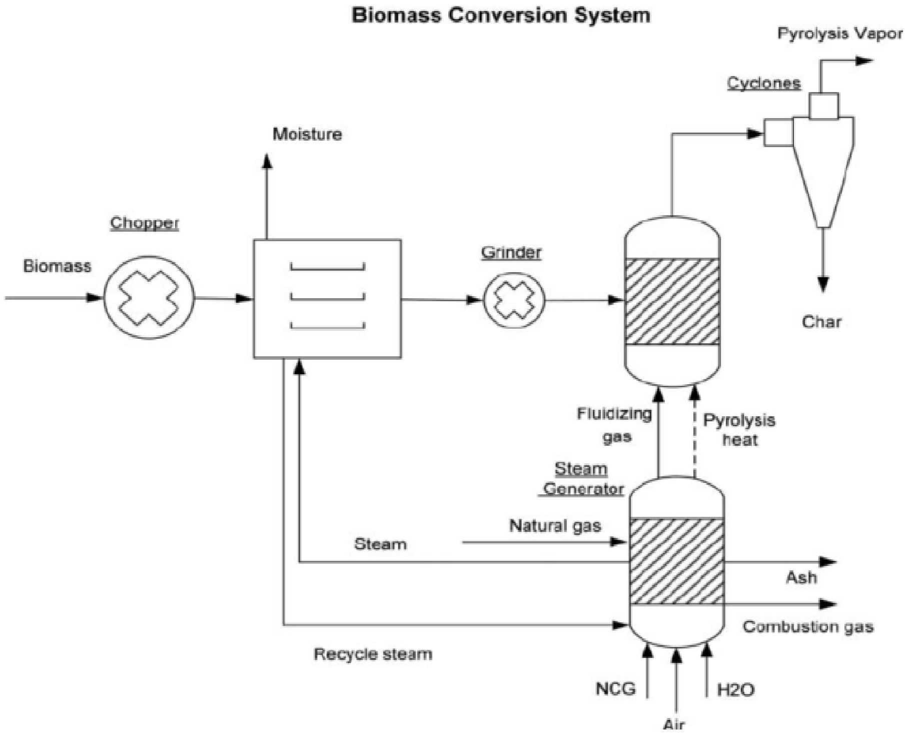

Figure 1: Complete Biomass System (Guiping et al., 2015)

Urbanization, economic expansion, and population growth all result in waste (Kaza et al. 2018). Global trash production is anticipated to 2.59 billion tons in 2030 and reach 3.4 billion tons by 2050, double from 2016 and treble by 2100 (AbdollahiSaadatlu et al. 2022). Numerous categorization standards exist for garbage, which may be material-based, state-oriented or source-focused. Garbage can be classified into three main categories based on its origin: municipal solid waste, agricultural solid waste and industrial solid waste. One of the most important consequences of living in an urban environment is municipal solid trash, which is increasing more quickly than urbanization (Tun and Juchelkova 2018; Tawfik et al. 2022). Similar garbage from homes, enterprises and commerce, office buildings, institutions, and small industries is usually included in municipal solid waste (Sipra et al. 2018). By 2025, there will be over 4.3 billion people living in cities, creating 1.42 kg of municipal solid waste per person day, according to Mandal (2019). According to Azam et al. (2019), disposing of household garbage in the atmosphere might have detrimental effects on both the ecosystem and human health.

Furthermore, food production will confront significant hurdles in the upcoming years due to a sharp rise in population (Myers et al. 2017). With intensive raising and cultivation methods, livestock and agricultural output have expanded dramatically to fulfill the food demands of millions of people. But this has also resulted in a significant volume of agricultural waste (Tripathi et al. 2019). According to Akinrinmade (2020), agricultural leftovers, hazardous garbage, and spoilt food waste from farms, orchards, vineyards, dairies, feedlots, and crops are the primary types of agricultural solid waste. If agricultural waste is not appropriately disposed of, it can pose a threat to both the environment and human beings by emitting greenhouse gases such as carbon dioxide, nitrous oxide, and

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methane (Kaab et al. 2019). The radiant rate of the sun's energy is about 3.8 x 1023 kW per second, this makes solar energy the most promising form of the renewable energy sources as it is potentially limitless. (Ohunakin et al., 2015) We have two basic forms of solar energy; the Photovoltaic (PV) which are commonly found on the roof top of houses and the Concentrated Solar Power (CSP). Figure 2.6 shows the solar intensity distribution in Nigeria with a conspicuous demarcation between areas of high intensity, medium and low intensity. The CSP is an array of solar concentrator with large number of curved panels, they look like PVs but they use mirror system to draw in concentrated beam of sunlight. According to Osueke (2011), the average daily sunshine in Nigeria is about 6.25hrs which range between 3.5hrs at the coastal areas and 9.0hrs at the far northern boundary with an average annual solar daily radiation of 5.25kW/m2 per day and 7.0kW/m2 per day at the coastal and northern area respectively. The energy radiation from the sun is about 4.85×1012kWh of energy per day in Nigeria. The underutilization of this abundant energy has laid much dependency of the economic driving force on a standby. If this energy can be harnessed into PVs or CSP in our homes and industries, the country’s dependence on hydro and fuel would be reduced and put into other research program. (Ohunakin et al., 2014).

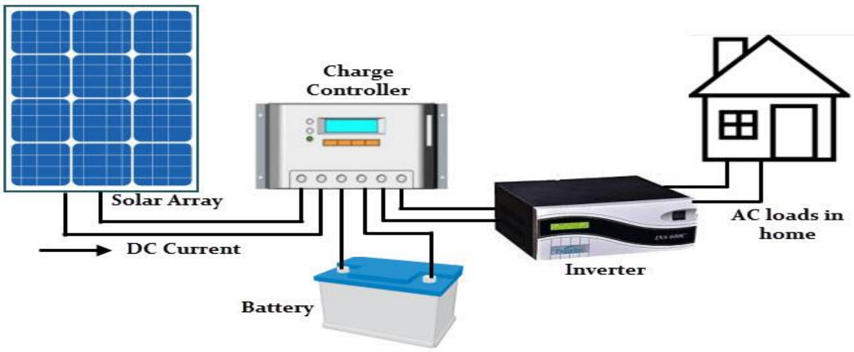

Figure 2: Electricity generation using solar photovoltaic cell (Electronics Hub)

The atmospheric pressure difference due to the disparity in temperature is the cause of wind. This process is catalyzed by the sun. The sun produced uneven heating effect on the earth at different temperature and at different times and at different places. This uneven distribution of heat thus creates warm air in form of wind which rises and while cooler air descends to occupy the void and generate wind which in the movement of air. Wind power system utilizes benefits of the power of wind in their functionality. Wind energy resource is available everywhere on the earth without restriction, both on the sea and land. Due to the absent of topography to act as wind breaker near the sea, the levels of wind energy at sea than the land. Hence greater energy potential is obtained in riverine environment. (Oyedepo, 2012).

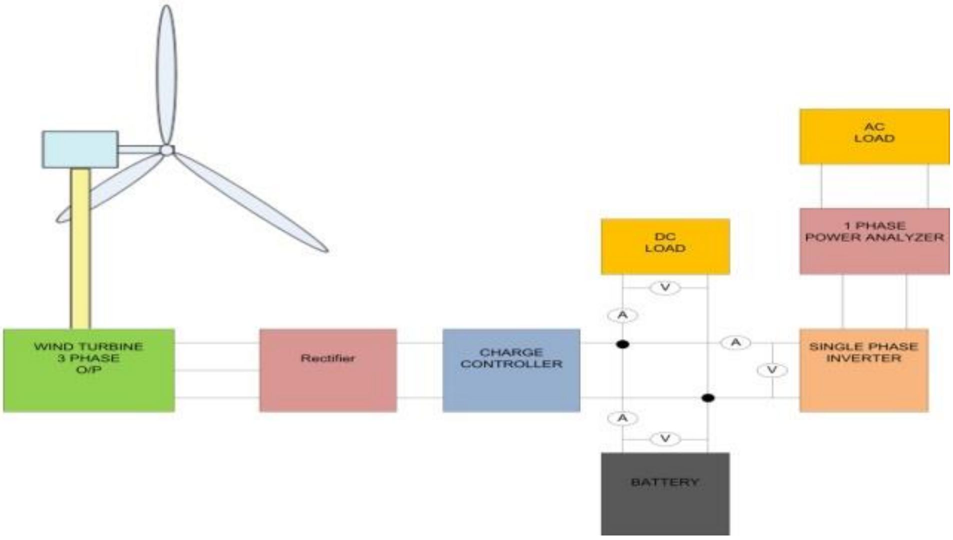

Figure 3: Energy generation using wind.

Hydro energy is one of the largest forms of renewable energy. Nigeria's abundant rivers, waterfalls and streams present a vast potential for hydro power. This source of energy has been the country's primary power source for many years. A 2017 study conducted across twelve states and four river basins identified over 278 untapped Small Hydropower (SHP) sites with a total capacity of 734.3 MW in Nigeria; additional SHP opportunities are evident throughout the nation, presenting an estimated average capacity of about 3,500 MW. Currently harnessing only up to maximum output of 960MW at Kanji Dam barely meets demand while severely lacking coverage elsewhere nationwide is not sufficient enough adaptable measure against electricity shortages within communities that require alternative renewable sources such as wind or solar according to Figure 4 presented alternatives (Adom et al., 2018).

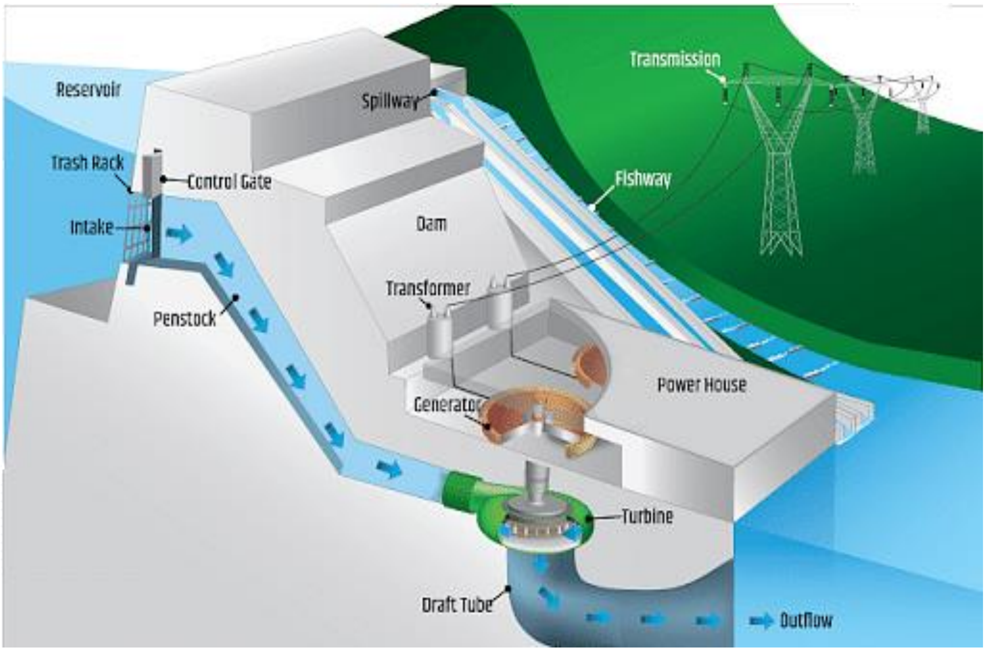

Figure 4: Hydropower system (Bayar and Gavriletea, 2019; Maji et al., 2019).

III. METHODOLOGY

Mokwa Local Government Area has its administrative headquarters in the town of Mokwa and this area council consists the districts of Mokwa, Rabba, Ndayoko, Muregi, Kudu, Takuma, Kpaki, Ja'agi, Bokani, Muwo, Gbajibo, Gbara, Jebba North and Labozhi. Mokwa is a town in Niger state with an estimated population of 244,937 (2006). It has an area of 4,338 km^2. Mokwa is on latitude 9° 12' North and longitude 5° 20' east, and on elevation 152.9 meters above the mean sea level. The long southern border of the LGA is formed by the Niger River from in the west beyond the confluence of the Kaduna River in the east. Kwara State and Kogi State are across the Niger from the LGA. This research work develops an integrated approach to off-grid renewable energy systems for improving modern energy access in the context of rural area. This integrated approach is to utilize solar technologies to meet the electricity demands of rural households in Edan. In order to evaluate the RESs, this study has solar energy potentials at the local level. The solar energy potential was determined calculated using solar radiation data obtained from NASA metrological database station. Data obtained include the All Sky Insolation Clearness Index, All Sky Surface Shortwave Downward Flux, All Sky Surface Albedo which determine solar system functionality and this data span between 10 years (2012-2022). This approach also represents an advanced methodology for local potential calculation at a regional level. The methodology developed in this study provides an improved approach for potential estimations at the local scale. Furthermore, it can be applied in other regions as well. The energy potential calculation was carried out at a local level to consider sustainable use and the necessity of achieving decentralized energy generation and a higher level of local energy independence. For solar home systems, annual solar radiation and annual solar hours were examined for the selected area. Annual solar radiation is the solar energy on the earth surface that is expressed as the average kilowatt-hours (kWh) of thermal energy incident on a square meter of horizontal area and annual solar hour is the number of sunshine hours in a year for a given location on earth. Solar radiation and annual solar hours data retrieved from Meteorological Administration were used as primary sources for data collection analysis of solar energy potential in Edan. Majorly the Albedo and the All Sky Surface Shortwave Downward Flux was the major focus in this context. Basically this approach are in three phases.

i. Assessment using metrological data focusing on the albedo

This helps to identify regions/areas with high solar potential, therefore these areas can be considered as the potential candidates for solar home system implementation

ii. The second phase was analyzing the energy performances of off-grid renewable energy systems (a sample solar home system of array capacity of 3kWp was determined through energy and power Audit. This is based on the examination of the resource potential in Edan in Mokwa. The solar house system in Edan, solar electricity generation was calculated using the solar atlas model tool. A data input module, a calculation engine, and an output module make up this system. It automatically determines the hourly solar electricity output from the solar system when resource data and system data are input. Following the estimation of hourly energy output numbers, solar atlas adds up the hourly values to get daily, monthly, and yearly values. Moreover, by figuring out the daily electricity output.

From the energy Audit, the following equations are used to determine the overall load consumption as well as the total energy required.

Total load consumption of a single appliance in watt $= (A \times B) = AB\ Watts$ 3.1

Where A= Appliances Rating in Watt or kiloWatt, B = Quantity

For the energy required for on appliance for a certain number of hours of operation

Total Energy require for a single appliance is given as = $(A \times B \times C)$= ABC Watthr 3.2

Where A= Appliances Rating in Watt or KiloWatt, B = Quantity and C is the hours of Operation.

The effective Watt hour required is given as $(A \times B \times C) \times 1.25$ 3.3

1.25 is the energy correction factor.

Solar Panel Sizing

To determine the number of solar panel requires we use the formula below

Number of Solar Panel = $\left(\frac{(A \times B \times C) \times 1.25}{PANEL\ WATTAGE \times PSH}\right)$ 3.4

Where PSH is the peak Sun Hour of the location

iii. The third phase is modelling the energy required of an average home in Edan.

IV. RESULTS

4.1 Solar Features

4.1.1 All Sky Surface Albedo

No clear pattern is observed across months, but variations across years highlight changing surface reflectivity. Lower albedo values in certain years may enhance solar energy absorption, influencing the overall solar potential for the region.

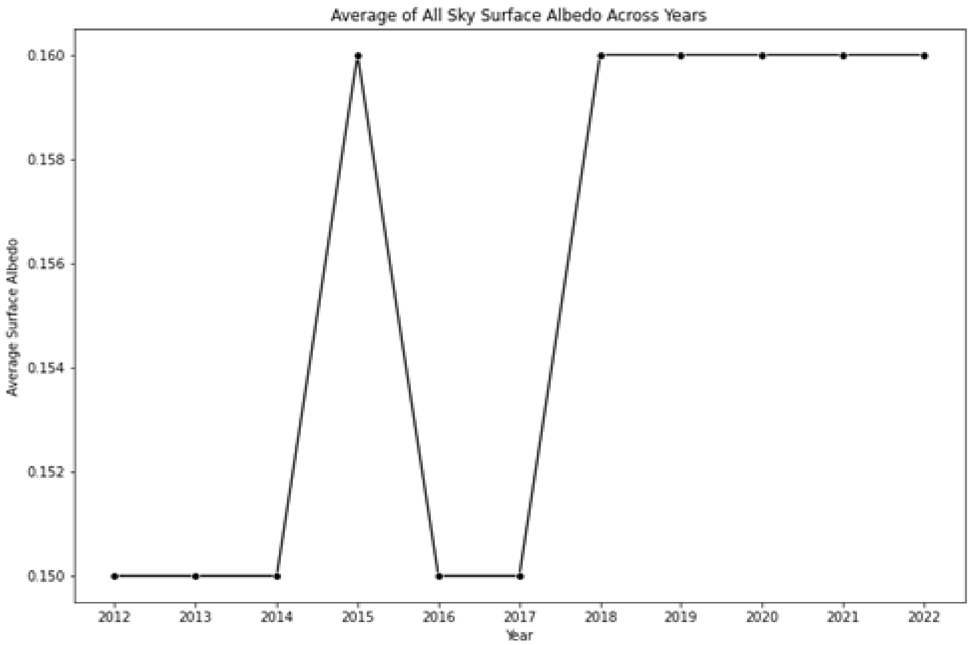

Figure 5: All Sky Surface Albedo across and Years

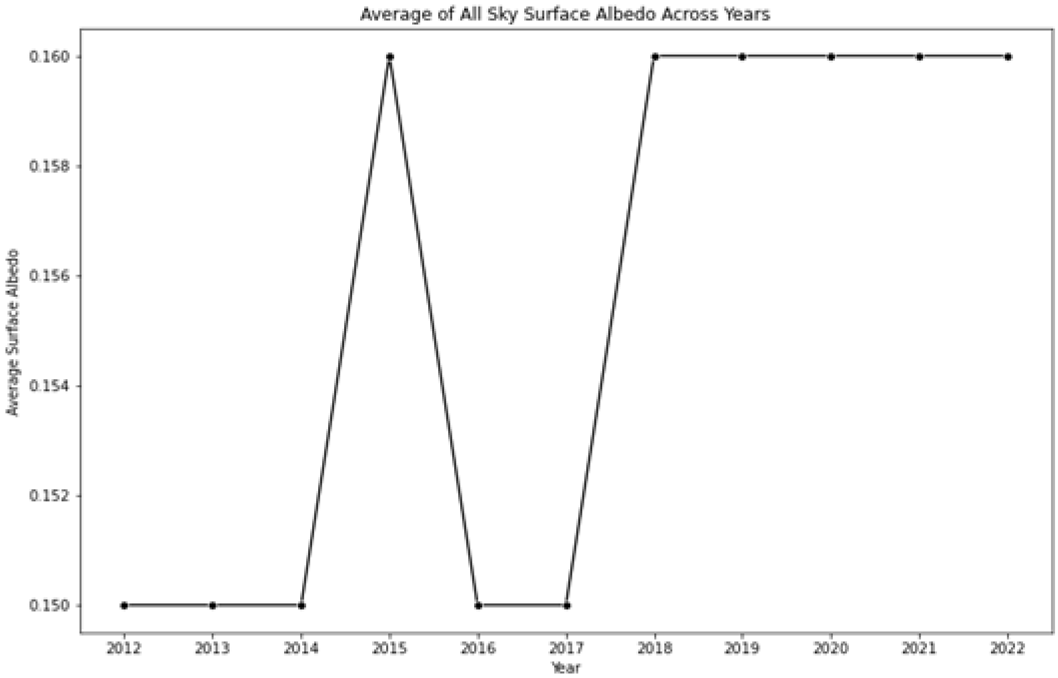

Figure 6: Average of All Sky Surface Albedo across Years

4.1.2. All Sky Surface Shortwave Downward Flux
The observed high range around January to May suggests peak solar radiation, impacting potential solar energy generation. The dip in August and September indicates a period of reduced solar radiation, affecting energy production during these months.

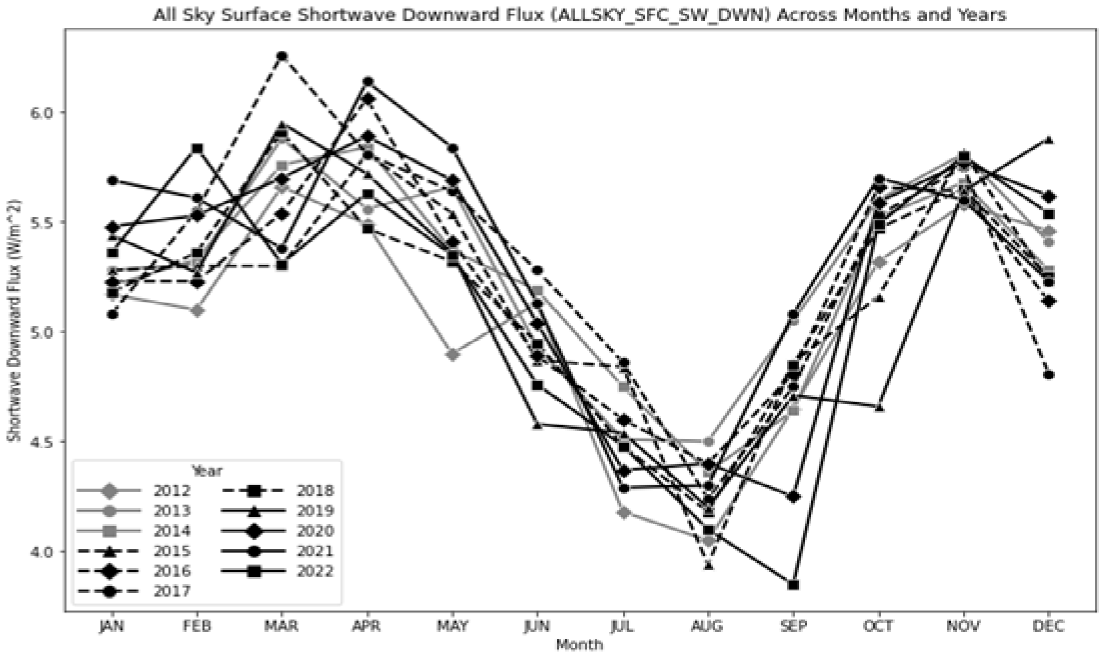

Figure 7: All Sky Surface Shortwave Downward Flux

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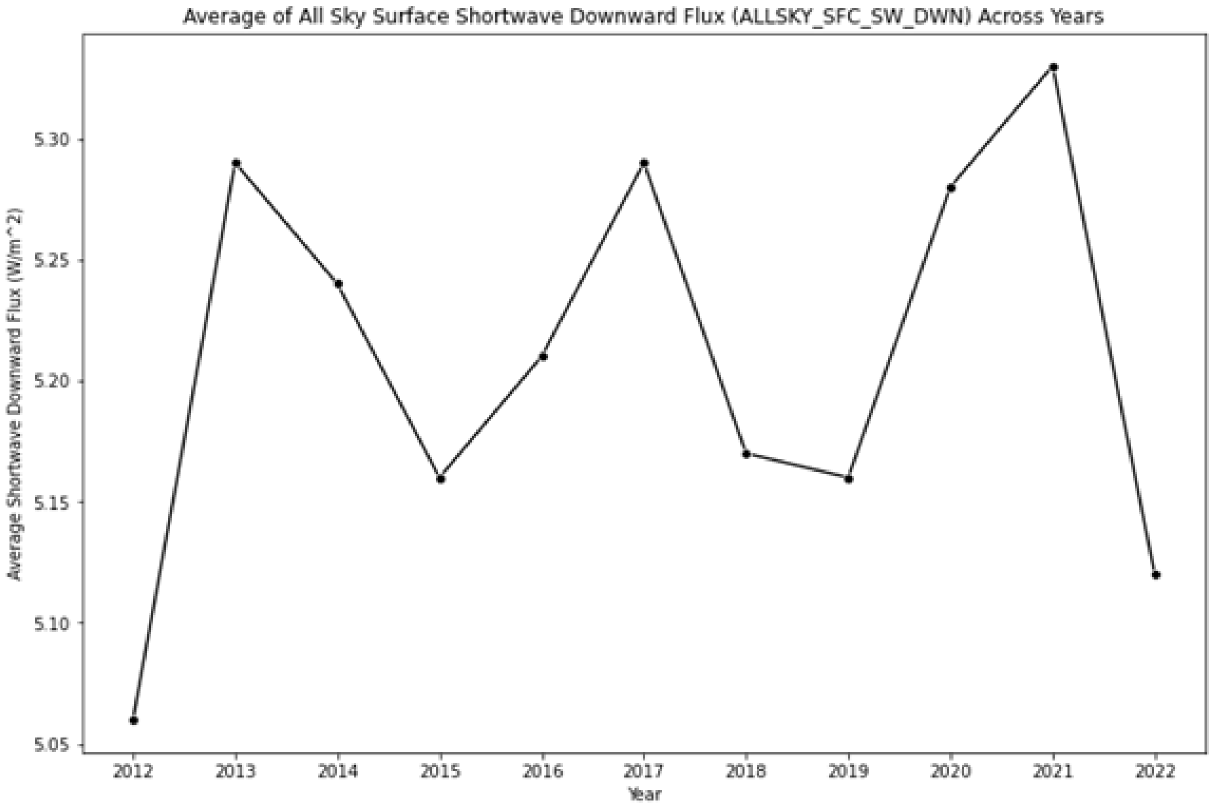

Figure 8: Average of All Sky Surface Shortwave Downward Flux

The observed patterns and variations in meteorological parameters highlight the dynamic nature of solar. Effective harnessing of solar energy in Mokwa hinges on a nuanced understanding of the observed patterns. For solar energy, aligning photovoltaic installations with periods of higher insolation and lower albedo values is critical.

4.1.3 Energy Performance Analysis (Energy Audit)

The aim of building energy performance analysis is to enhance the efficiency of a structure by identifying its primary sources of energy consumption and suggesting measures for conservation. This investigation focuses on examining homes in EDAN within Mokwa local government area located in Niger State. During initial planning stages, poor design lead to inefficient use of power resulting in uncomfortable temperature control conditions. The research determined the optimal method for assigning an appropriate system that satisfies individual households' necessities while analyzing their overall usage using survey forms. Results indicated that homeowners consumed more than 3kWh per household daily using generators while the Agricultural area consumes over 5kWh; therefore it was recommended that they explore suitable approaches toward managing their electrical resources efficiently if solar system is to be implemented. From the energy Audit for the following equations are used to determine the overall load consumption as well as the total energy required.

4.1.4: Energy Modelling of Edan in Mokwa Nigeria

Modeling the energy demand structure involves analyzing and representing the patterns and characteristics of energy consumption across various sectors, end uses, and geographic regions. In modelling the calculated energy demand for an average home in Edan real time online solar modelling software was use for the design.

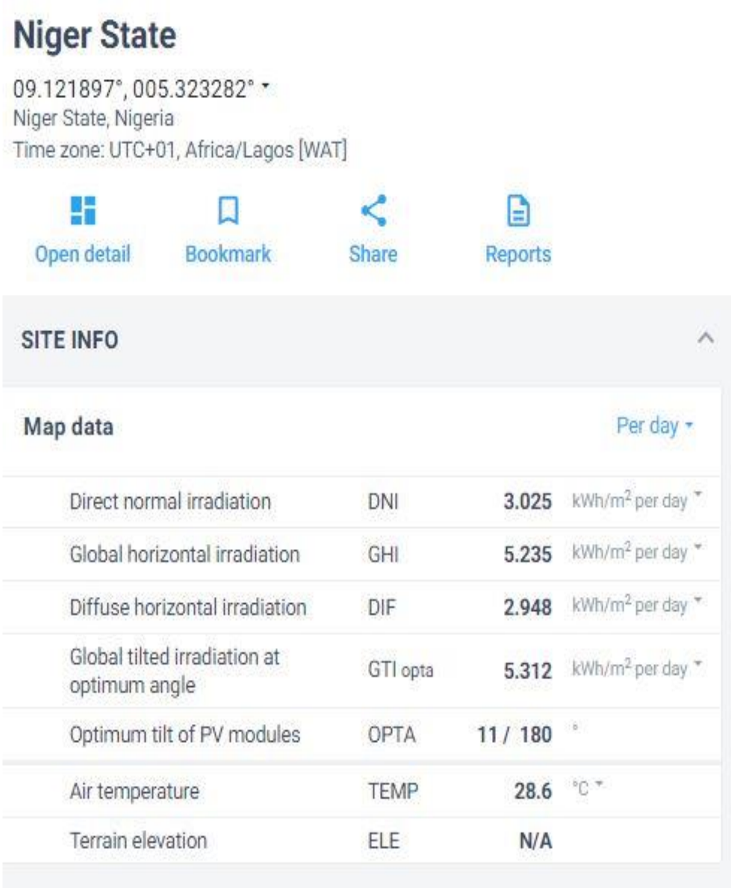

Figure 9: Study Location Irradiance Data

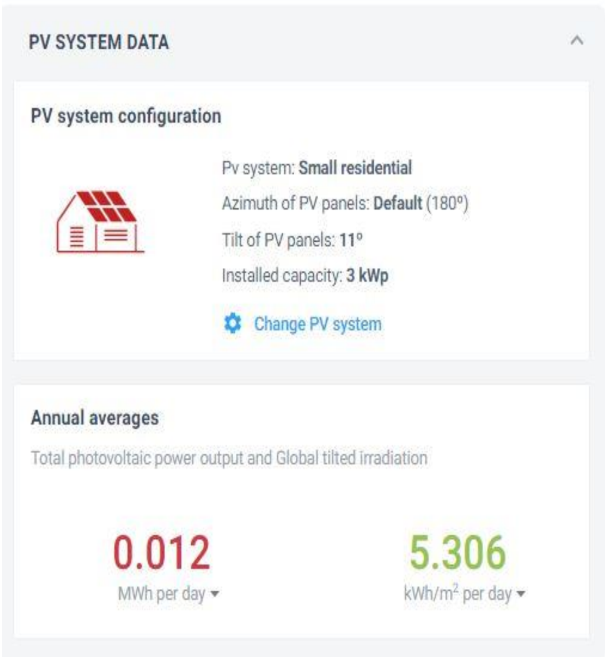

Figure 10: PV System Configuration

Figure 11: Monthly Average Photovoltaic power Output

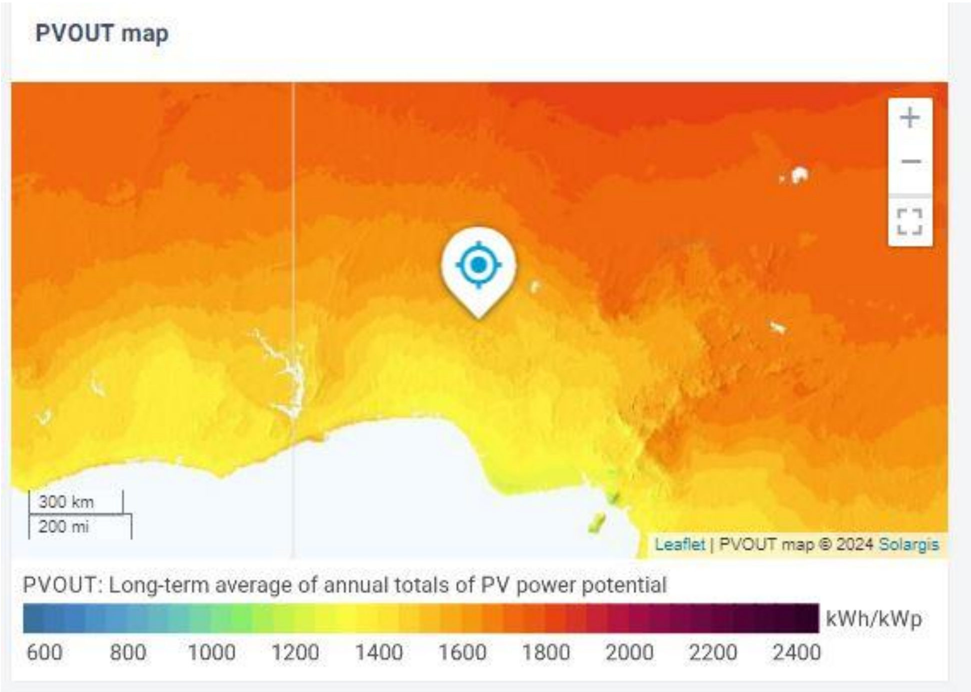

Figure 12: PV out Map

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Average hourly profiles

Total photovoltaic power output [kWh]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5												
5 - 6				0.001	0.007	0.011	0.007	0.004	0.008	0.008		
6 - 7	0.055	0.059	0.098	0.194	0.229	0.221	0.197	0.186	0.234	0.293	0.286	0.133
7 - 8	0.496	0.474	0.514	0.606	0.629	0.570	0.537	0.509	0.622	0.766	0.843	0.691
8 - 9	0.987	0.968	0.980	1.044	1.024	0.920	0.843	0.806	0.986	1.190	1.336	1.195
9 - 10	1.409	1.403	1.398	1.419	1.354	1.213	1.091	1.029	1.240	1.540	1.723	1.593
10 - 11	1.694	1.701	1.686	1.665	1.574	1.418	1.275	1.210	1.464	1.800	1.954	1.836
11 - 12	1.810	1.836	1.807	1.754	1.680	1.534	1.456	1.345	1.619	1.882	2.002	1.916
12 - 13	1.759	1.799	1.758	1.697	1.604	1.497	1.411	1.374	1.636	1.804	1.893	1.829
13 - 14	1.554	1.595	1.538	1.480	1.424	1.361	1.314	1.260	1.443	1.576	1.633	1.588
14 - 15	1.201	1.252	1.185	1.150	1.141	1.115	1.070	1.053	1.151	1.209	1.236	1.213
15 - 16	0.746	0.804	0.749	0.746	0.759	0.763	0.770	0.765	0.791	0.751	0.725	0.732
16 - 17	0.254	0.328	0.309	0.315	0.338	0.363	0.386	0.377	0.325	0.232	0.151	0.221
17 - 18	0.001	0.020	0.022	0.024	0.029	0.047	0.066	0.045	0.015			
18 - 19												
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	12	12	12	12	12	11	10	10	12	13	14	13

Show details

Figure 13: Average Hourly Energy profile

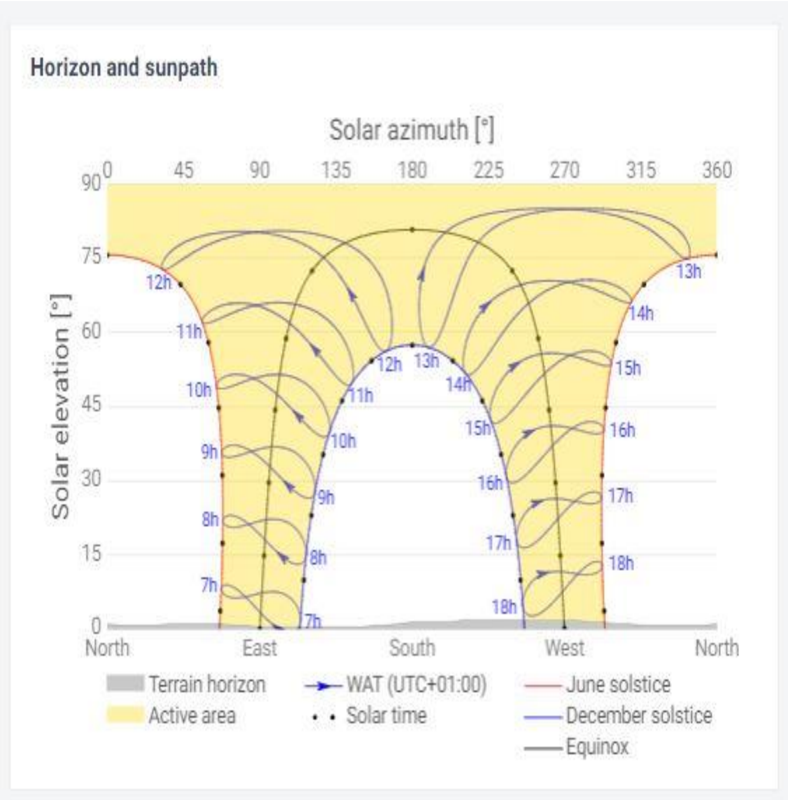

Figure 14: Horizon and Sun path

V. CONCLUSION

Based on the research objectives, the following conclusions have been drawn related to the Status of Solar Energy sources in Mokwa, Niger State. The Local Government Area (LGA) of Mokwa holds significant potential for renewable energy development, particularly solar. While solar energy infrastructure is still in its infancy, there is a growing interest in utilizing these resources to meet the energy demands of the local population. The vast land, ample sunlight of the region is a strong foundation for harnessing solar energy**.** Potential for Energy Generation from Solar sources having solar energy has the greatest potential for energy generation due to the region's favorable climate, which includes long hours of sunlight throughout the year. However, combined with solar energy with other renewable energy sources, a hybrid system could provide a reliable and sustainable energy solution for rural communities. The varying climate of Mokwa, particularly in the dry and wet seasons, influences the availability of solar irradiance making it essential to optimize these resources accordingly. The study also reveals that the energy output from solar systems vary significantly throughout the year. Solar energy is more consistent, with high energy production during the dry season, while in the wet season its low as a result of variation in the value of the surface albedo. Changes in surface albedo have notable impact on solar energy production, particularly in areas like Mokwa Local Government, where solar energy potential is relevant. Albedo which refers to the reflectivity of Earth's surface, where a higher albedo means more sunlight is reflected, and less energy is absorbed by the ground. Conversely, lower albedo surfaces absorb more sunlight, making them beneficial for solar energy systems that rely on absorbing sunlight for conversion into electricity. Changes in surface albedo and global horizontal irradiance (GHI) can significantly impact solar energy production in Mokwa Local Government.

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