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Renewable Energy for Sustainable Rural Development in Sub-Saharan Africa: Case Study on the Accessibilty of Solar Photovoltaic Systems for Electrification in Bengbis-Cameroon

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Abstract:- Endowed with huge energy resources, Africa is a major player in the global energy markets. Although much attention has been given to the exploitation of fossils and uranium for electrification and global industrialization processes, energy security remains a predominant and contemporary phenomenon, especially in rural Sub-Saharan Africa. With the highest potential of solar radiation globally, Africa remains resourceful in sustainable energy production and transition. Despite these potentials, Sub-Saharan Africa remains the least electrified globally, with electrification rates lowest in the rural areas. Using semi-structured interviews, this study qualitatively investigates the accessibility of solar photovoltaic systems for sustainable rural electrification of Bengbis Municipality in the southern region of Cameroon. Findings established energy stacking as an empirical reality with policy gaps, physical and infrastructural factors hindering accessibility. The study recommends the introduction of a renewable energy act, revision of rural energy programs and prioritizing the decentralization of solar photovoltaics for sustainable rural electrification.

Keywords:- Solar Photovoltaics, sustainable rural development, sustainable rural electrification and Bengbis.

I. INTRODUCTION

Global energy supply is reliant on 83% of fossil fuels, 12.6% of renewable (primarily hydro, wind and solar) and 6.3% of nuclear energy in 2020 (Holechek , 2022). With the projection that fossils reserves shall be exhausted by the end of the 21st century, it is an urgent need to developed alternative energy resources (Makarieva et al., 2008; Fahmi et al., 2014). High energy demand and over reliance on fossils has aggravated environmental degradation and climate change (Jean-Baptiste & Ducroux, 2003; Bos & Gupta, 2018).

Developing countries have over 80% of the world's population but consumes only 30% of global commercial energy (Rena, 2012). Over 3.3 billion people live in rural areas in the world, 91.7% (3.1 billion) of them are found in developing and least developed countries accounting for about 70% of developing world's poor people (Field & Barros, 2014; Chinongwa, 2024). Rural electrification remains a contemporary challenge to policy makers (Pellegrini & Tasciotti, 2013). Access to energy is very vital for social, economic and environmental progress of rural areas (Kaygusuz, 2011; Reddy, et al., 2000). Energy constitutes one of the main determinants of economic development as it is a requirement for the fulfilment of almost all basic goods and commodities such as water, food, health education and clothing (Shah, et al., 2020; Khan, et al., 2022).

The quest for energy security to power economic growth without environmental considerations has led to global warming (Chichilnisky & Eisenberger, 2009; Ziankova, et al., 2020). The issue of energy use and ecological conservation has attracted much attention and enhanced a global debate on sustainable development and particularly on climate change and the reduction of emission of greenhouse gasses. Ecological safety and the mitigation of climate change can be achieved through drastic cuts in the use of fossil fuels, clean technological transfer and the vigorous harnessing of abundant renewable resources (Uzoma, et al., 2011). Although global warming and climate change is said to be caused by rapid industrialisation and economic growth in the northern hemisphere, the impact is highly felt in developing and least developed countries in the global south with rural areas most affected.

Energy transition is at the centre of global politics where states are tasked with the regulation of production, distribution and consumption of energy through legislative and policy frameworks while taking into consideration its implication on social, economic and environmental sustainability (Newell, 2021; Hafner & Tagliapietra, 2020). In recent years, rural areas have become significant battlegrounds for the implementation of energy transitions (Clausen & Rudolph, 2020). Introduction of renewable energy and advancement in technological development of solar photovoltaic systems was perceived as a game changer in the rural electrification domain. Multiple evidences have proven that of all renewable energy technologies, solar

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photovoltaic systems have the most penetration rate in rural areas (Raman, et al., 2012; Bhandari & Stadler, 2011). Advancement in research and development in solar photovoltaic technology alone cannot independently determine access to sustainable energy as its dissemination depends on a mix of legislative and policies options which enhances accessibility through the elimination of barriers.

Rural areas in developing countries are often agricultural and inaccessible leading to difficulty in the distribution of basic commodities (Ajiboye & Afolayan, 2009). Being vulnerable and poverty prone, rural areas are often qualified by small clusters of energy demand with low quality supplies. Often surviving with distributed generations (Mini grid and Auto generation), rural electricity is characterized by low quality and distorted supplies.

Likewise other sub-Saharan countries, universal access to electricity has been a long-term challenge to policy makers in Cameroon despite the creation of Rural Electrification Agency in 1998 (Law nº 98/022). Focusing mostly on grid extension and isolated thermal generation through international development assistance with little or insignificant resources deployed towards the exploitation of renewable resources, national electrification rates stand at 65.4% while rural rates stand at 24.8% (World-Bank, 2024).

Described as Africa miniature and strategically situated in sub-Saharan Africa, feasibility studies have shown that the Cameroon’s territory possesses solar radiation with the potential of solar energy exploitation for both commercial and private purposes with the rate of solar radiation decreasing from north to south (MINEE & KOICA, 2017)

Bengbis is one of the nine municipalities in the in Dja et Lobo Prefecture situated in the southern fringes of Cameroon. Located deep in the Dja reserve, Bengbis consist of 60 villages and five pigmy camps (PDC, 2014). The municipality is a melting point of numerous economic activities such as mining, agriculture, forestry, fishing, hunting and tourism. The municipality is characterised by low electrification rates powered by thermal generation into a mini grid, grid and solar Photovoltaics. With the challenges of sustainable supplies, the inhabitants are left with no choice but to resort to energy stacking to meet their needs as a grater chunk of them are among the 75.2 % of rural population in Cameroon living without access to electricity (World-Bank, 2024). Changing the status-quo of grid extension and thermal generation preferences to the adoption of wider solar photovoltaic generation is gaining momentum both at individual, local and national levels.

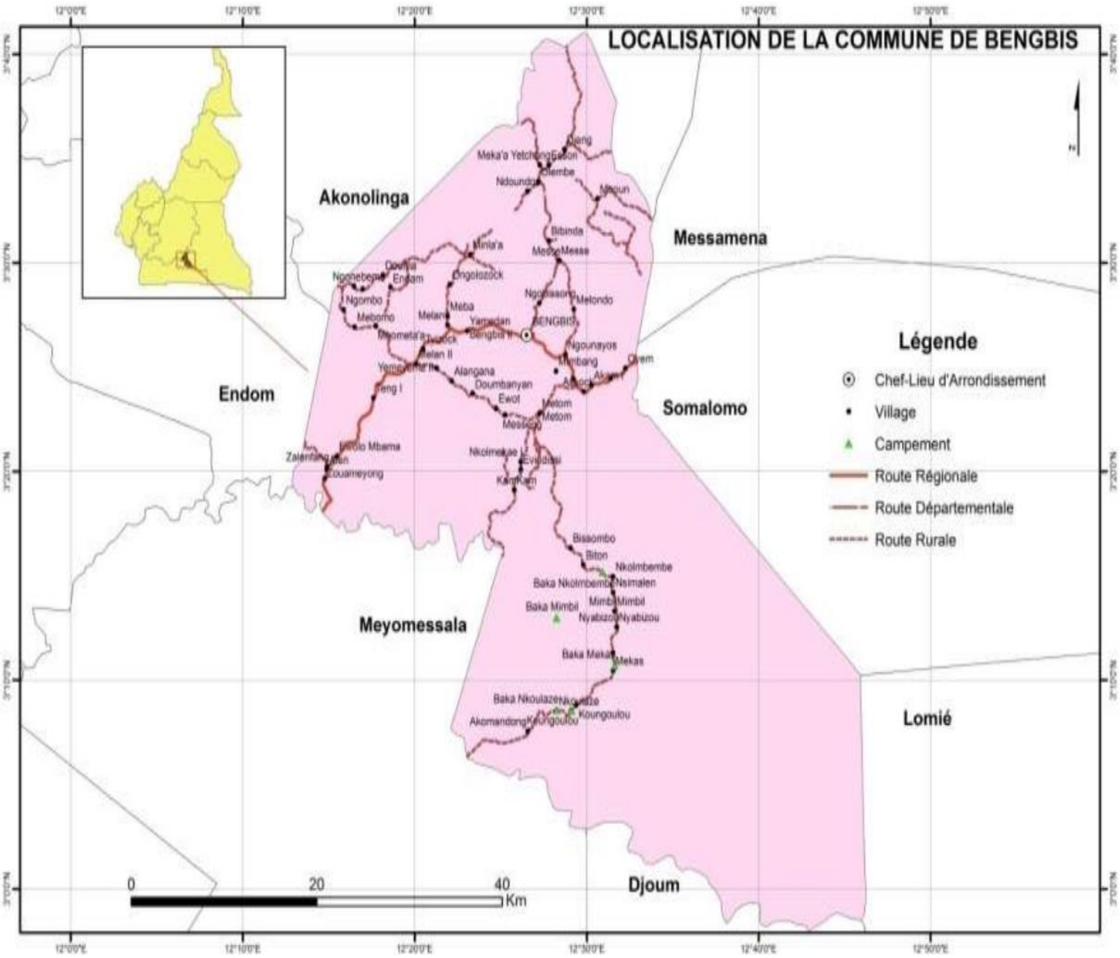

Fig 1: Map of Bengbis Municipality (source: PCD, 2014)

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II. LITERATURE REVIEW

A. Renewable Energy and Sustainable Rural Development

Renewable energy-led energy transition is a top priority at the global discourse on emission reduction and climate change which is not just a political but also a socio-technical, economic and a spatial process (Matthias & David, 2020). Energy transition through the decentralisation of renewable energy is crucial for the economic development of rural areas although the underlying link has been taken for granted rather than been conceptually and practically cultivated (Clausen & Rudolph, 2020; Albrecht, 2021). With most developing countries still to attain 100% of electricity access, rural areas are experiencing very low rates. Energy insecurity in the rural milieu provides avenues for energy transition through the adoption of renewable and low carbon standalone energy systems for sparsely populated and mini-grids for densely populated areas (Babayomi, et al., 2023).

Rural spaces are prerequisites and battle grounds for energy transition as they are a melting point of renewable and low carbon energy resources which remain the fundamental drivers of sustainable rural development. The growth in renewable and low-carbon energy is a policy process with the aim of improving energy security, protecting climate change and improving economic development (Benedek, et al., 2018). However, governments worldwide are enacting frameworks promoting renewable and low-carbon energy infrastructural development and generation such as wind farms, solar stations, Biofuels, geothermal and small hydro stations through the decentralisation of both technical and financial resources (Susana, 2020). Despite these efforts, the deployment of renewable and low-carbon energy remains uneven (Eicke & Goldthau, 2021).

Although decentralised development promised to bring opportunities to rural areas, factors of economic and political inequalities render those opportunities socially and spatially segregated (O'Sullivan, et al., 2020). Most countries have developed policies and strategies that envisions renewable energy-led rural development but it remains unclear how these policies are reasoned, realised and how they are related to the political economy of energy transition.

B. Solar Photovoltaics and Rural Electrification

Rural electrification remains an integral component of national development and poverty alleviation strategy as it encompasses all aspects of rural life (Sharif & Mithila, 2013; Adjoa, 2014). Renewable energy processes often occur in rural areas where there is an abondance of water, solar radiation, biomass, wind and geothermal except for anaerobic resource from sewage or urban waste which present a very small proportion of total renewable energy production (Bryden, 2010). Renewable energy deployment to rural areas requires an approach of rural development that is adapted to the local conditions with the objective of enhancing sustainable development and competitiveness in rural communities.

The exploitation of solar energy resource has drastically increased globally. Solar photovoltaic technologies are having a high penetration rate due to advancement in its technological development and market attractiveness. Solar photovoltaic systems have gain prominence in rural electrification projects especially solar home system (Williams, et al., 2015; Boamah & Rothfuß, 2018). As solar photovoltaic systems have become more affordable, they are being used for a variety of applications, including social and communal services, agriculture, and other productive activities. This has the potential to significantly impact income generation and quality of life of the rural poor (Ahammed & Taufiq, 2008). The flexible nature and financial attractiveness of solar photovoltaics provides a unique opportunity for the energy sector to provide electricity packages to rural and remote areas in the domain of health, education, agriculture, communication, lighting and water supply while converting rural communities into more environmentally sustainable spaces (Ibrik, 2020).

Governments are considering solar energy options as an ultimate solution for breaching the gap between demand and supply of grid electrification. Standalone solar photovoltaics systems are most recommended for rural and remote areas due its adaptability, economic and financial sustainability (Mazur, et al., 2019). In so doing, frameworks regulating the processes of production, distribution and consumption of renewable energy are mostly solar photovoltaics centered.

C. Solar Photovoltaics Access in Rural Sub-Saharan Africa

Solar insolation levels in Africa ranges from 4 to 7 kW h/m2 /day (Fadare, et al., 2010). Africa receives more solar radiation than the rest of the world making her economically attractive for investments in electricity generation from solar sources (Baurzhan & Jenkins, 2016). Solar photovoltaic systems remain a viable alternative to fossil fuel although it is yet to make a meaningful contribution in Sub-Saharan Africa (Okoye & Oranekwu-Okoye, 2018).

Rural areas are a home to a majority of the people living in Sub-Saharan Africa (Akinyemi, et al., 2016). The importance of providing them with modern energy cannot be overemphasised. Despite government and donors' efforts to provide solar photovoltaics through clean rural electrification programmes, access to modern energy remains painfully low in rural Sub-Saharan Africa. The fall in price and improved market attractiveness of solar photovoltaics remains unaffordable and expensive in Sub-Saharan Africa compared to other regions in the world (Karekezi & Kithyoma, 2002).

Based on variation in resource potential and diverse political choices, different Sub-Saran countries pursue different renewable energy agendas for rural electrification. This can be a point of difference in the dissemination and growth of solar photovoltaics consumption across the sub-region.

- *Kenya*

Although in Kenya, electricity generation was dependent on fossil technologies due to relatively low oil prices in the 1980s and 1990s, increase in oil prices in the 2000s saw Kenya's policies drifted towards sustainable generation through the adoption of geothermal, wind and solar technologies (Moner-Girona, et al., 2019). Despite the abondance of solar energy resource across the national territory, Kenya's policies are more geared towards geothermal and wind technologies for the exploitation of distributed resources with less significant interest on the dissemination of solar energy technologies (Boliko & Ialnazov, 2019). With distributed resource-based generation been grid-tied, the slow progress of grid extension hinders universal access with the rural and remote areas mostly affected. With the constant increase in demand of solar photovoltaic devices, it is now considered to be a crucial determinant of clean energy access especially in the rural Kenya. It is no doubt that a large segment of the population is left out especially the rural poor, forced to rely on counterfeit devices due to the high cost of quality solar energy solutions (Muok & Makokha, 2017).

- *South Africa*

Committed to energy transition in 1998 and 2003 White Paper on Energy and Renewable Energy, South Africa's has experienced an impressive rural electrification from 49.2% in 2002 to 75.3% by 2020 (World Bank, 2022). These policies details instruments needed to enhance the valorization of renewable energy resources to mitigate over-dependence on fossils and enhance energy access and efficiency (Sebitosi & Pillay, 2008). Committed to Paris Climate Agreement and SDG7, sustainable rural electrification is crucial to the fulfillment of this commitment with off-grid solar energy solutions for rural areas considered to be more sustainable and financially feasible than grid extension (Meyer & Overen, 2021).

In 2003 the Free Basic Electricity policy was initiated with prioritization of solar home systems and the distribution of 5kwh electricity to low-income rural areas free of charge and the subsidization of solid and liquid fuels to remote areas that are not connected to the electricity network (Kambule et al., 2019; Meyer & Overen, 2021). This policy was decentralized to municipal authorities and the national utility company funded by the Special National Treasury Budget (Adam, 2010).

Solar Home System initiative was also initiated and managed by Integrated National Electricity Program which laid down the framework for concessions and implementation of solar home system program in rural areas (Meyer & Overen, 2021). This program is very essential for social, economic, and cultural transformation of the rural milieu and has an objective of installing solar home systems to 300 000 homes with beneficiaries mandated to pay $5.3 in connection fee and $5.36 in monthly running cost (DOE/SA, 2015). Although this program faced operations and concessions challenges, it was very vital in the enhancement of access to clean energy in the rural areas (Wlokas, 2010)

- *Cameroon*

Likewise other Sub-Saharan countries, there is a wide gap in energy access between urban and rural areas in Cameroon. With urban access rate at 94%, the rural areas are dwindling at 25%. Electricity production from hydropower stands at 75%, fossils at 23.5 % and renewables at less than 2% (World Bank 2022). Liberalisation of the electricity sector in early 2000s with the creation of Electricity Regulation Agency (ARSEL) and the Rural Electrification Agency (AER), tasked with the enhancement of rural electrification depended solely on grid extension and diesel-powered mini grids. This mode of electrification mostly financed by international development assistance face multiple challenges such as financial, technical, political and spatial (Chapel, 2022). Until the implementation of Vision 2035 in 2010, the adoption of renewable energy for rural electrification was neglected.

The adoption of Law Governing electricity in 2011 emphasised on the importance of renewable energy in animating rural areas and sales of energy from independent producers to the national utility company (Tamasang, et al., 2021). This law was applauded but failed to elaborated on the sales modalities for independent producers. The Intended Nationally Determined Contributions (INDC) of Cameroon at the Paris Climatic Accord emphasized on Cameroon's commitment to attain 25% of renewable energy in her energy mix by 2035. This led to the formulation of a Rural Electrification Master Plan 2016 (REMP) which has prioritized solar energy systems for rural electrification attracting foreign investors for investments in sustainable rural electrification.

Solar photovoltaic has been very pivotal in rural electrification in recent years in Cameroon. While the AER has been involved in the development of Micro grids for densely populated rural communities, most rural residents are dependent on Pico solar for electrification.

III. METHOD

Qualitative case study research design was deployed in this study as it requires the understanding of relations between human and social systems in a holistic approach, not only describing events and situations but also a deep understanding of subjects involved, their experiences and interaction with one another (Gagnon, 2010). The instrument used for data collection was a semi-structured questionnaire. The questions were sourced and modified from "Energy Policies and Multi topic Household Surveys: Guidelines for Questionnaire Design in Living Standards Measurement Studies (O'Sullivan & Barnes, 2007)." Interview was the technique used for data collection. The interview procedure consisted of 25 participants from households across the area under study. The rational for the selection of participants are;

- Participant must be above 18 years old,
- Participant must contribute to household income generation and
- Participant must be resident in the area studied for not less than 2 years.

The questionnaire consists of three major sections; letter of consent to participants, demographic information and the questions. Upon review of data collected, three explanatories (themes) emerged from the questions (Akinyode & Khan, 2018); Current energy access, availability/affordability and sustainability of solar photovoltaic supply and the electricity generated. These were the themes of analyses of data throughout the research.

Theme one assesses current energy access in an effort to identify whether or not solar photovoltaic system is among household energy choices. This theme also investigates the empirical reality of energy ladder and stacking. This also provides us with the information on the adoption of sustainable practice within the rural milieu.

Theme two elucidates on the availability and affordability of solar photovoltaic systems within the municipality (this theme provides and empirical evidence on rational distribution). This further investigates the purchasing power, time spent to commute to the sales point and payment methods made available to facilitate access to solar technology.

Theme three investigates on the sustainability of supply of solar photovoltaic systems and the electricity generated. it also elaborates on the effects of seasonal changes on the supply chain as well as the implications of seasonal changes on solar radiation and electricity generation.

IV. RESULTS

A. Explanatory one: Energy Sources for Electrification

Energy Stacking is an empirical reality among all respondents (100%) as they stack multiple sources of energy for electricity generation (Yadav et al., 2021). Transition to cleaner and more reliable energy sources remains income dependent (Ai et al., 2021).

Nine of the respondents (36%) have solar photovoltaic systems of different categories in their energy mix with four (16%) respondents using them as main source of electrification whereas five other respondents (20%) use them as back-up sources. It remains evident that most respondents are under the grid network but are mostly disconnected to the grid system directing their preference to other reliable sources of energy for electrification and lighting. Most respondents with access to more advanced solar photovoltaic systems are at the center of the municipality while access diminishes as you move towards the periphery.

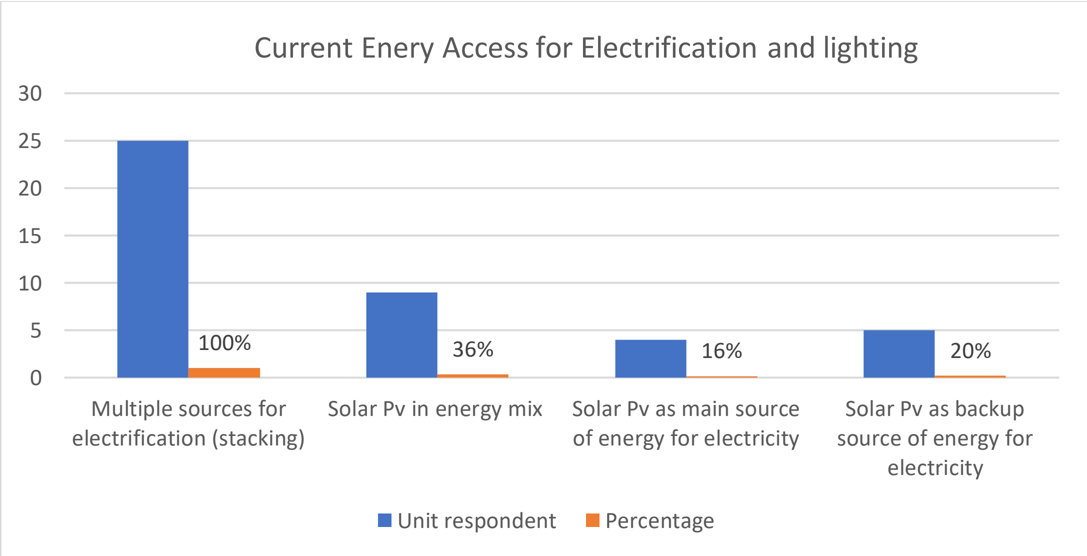

Fig. 2: Energy access for Electrification and lighting.

Of the four respondents (16%) using a variety of solar photovoltaic system as their main sources of energy for electrification and lighting alongside other unclean and less reliable sources as backup systems, two respondents preferred Solar Home System with one of them having a big system (1.5kw) and a genset although under the Mini grid network while the other with a smaller system (40watts) remains vulnerable to lower solar radiation and reliant on candles, genset and kerosene lamp. The last two respondents depend on Pico solar system (Solar Lamp) with more reliance on kerosene lamps, candles and dry cell.

Three respondents (12%) depend on the grid as their main source of electrification and lighting. The low quality, frequent and long blackouts often shift their reliance to gensets, solar lamps, mobile phones, candles and dry cells (Bensch et al., 2017). Six respondents (24%) depend on gensets with similar backup system like kerosene lamps, candles and solar lamps while twelve respondents (48%) rely on kerosene lamps with dry cells and solar touches as their backup systems.

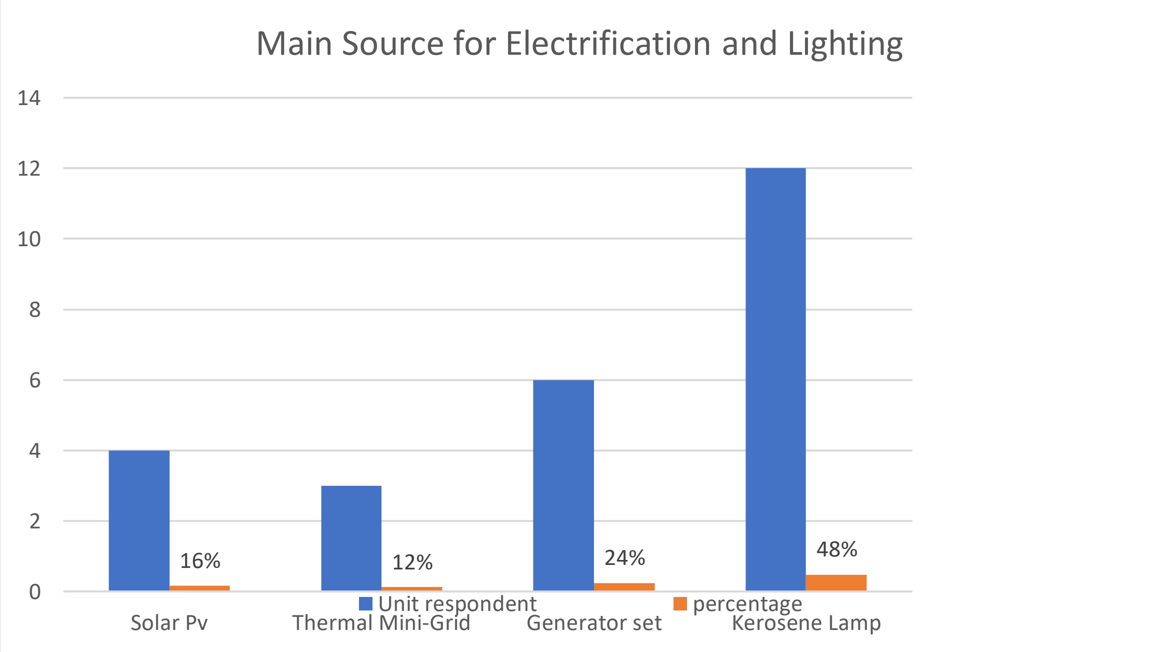

Fig. 3: Main sources of energy for Electrification

B. Explanatory Two: Accessibility and Affordability of Solar Photovoltaic Systems

The access and affordability of the systems portrays an understanding of the level of rational distribution of vital commodities across the country. This reflects the empirical reality of rural-urban divide and the irrational distribution of goods and services across rural areas.

Participants (36%) with solar photovoltaic systems in their energy mix as a main or back-up system share differences in experiences on both means of accessibility and affordability. The difference in their experience is dependent on the place of acquisition and cost variation. A very great proportion of respondents (28%) with solar photovoltaic in their energy mix uses solar lamps with just two participants (8%) using solar home system.

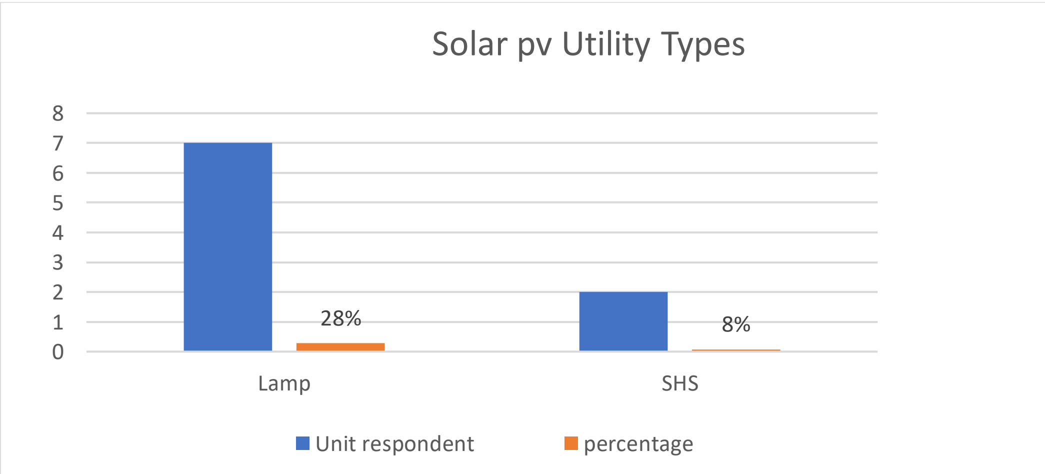

Fig. 4: Solar photovoltaic systems used

Five of the respondents (20%) acquired their solar photovoltaic systems from the central municipal headquarter Bengbis which are all Pico Solar Systems whereas four respondents (16%) acquired their systems consisting of two solar lamps and two solar home systems from Yaoundé (280 kms away from the municipality). It was also evident that same systems have different cost at different locations. For instance, acquisition of systems from Yaoundé (city) are cheaper than in the municipality and the total cost accrued to same systems are more expensive for residents in remote areas who have to commute to the municipal headquarter to acquire a system.

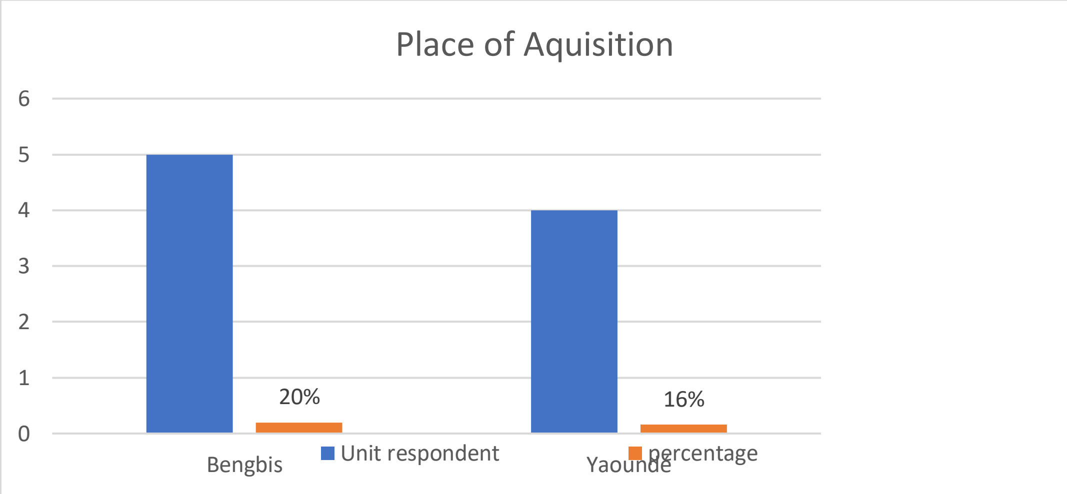

Fig. 5: Place of Acquisition of Solar Photovoltaic Systems

The means of payment for the systems also differ amongst respondents as 32% of them could only access the systems through cash payments except for one respondent (4%) who had to make a bank transfer for the acquisition of 1.5kw solar system.

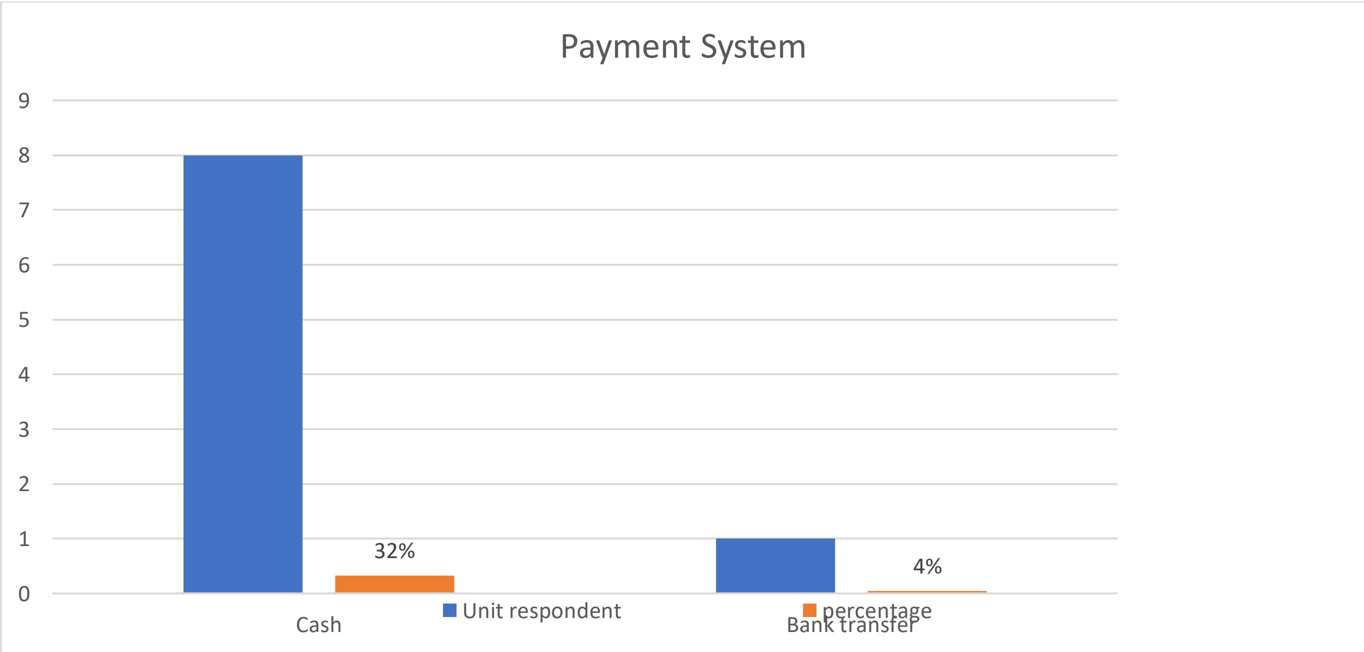

Fig. 6: System of payment

C. Explanatory Three: Sustainability of Supply and Use of Solar Photovoltaic systems

Located deep in the equatorial rainforest, geographical factors play a significant role in the dissemination and electricity generation of solar photovoltaic systems. Physical factors affect the dissemination whereas seasonal changes affect electricity generation.

Eight respondents (32%) are not satisfied with the use of their solar photovoltaic systems because they own smaller systems (either Pico or small Solar home systems) which can only provide shorter hours of lighting except for one respondent (4%) who owns a 1.5kw Solar home system.

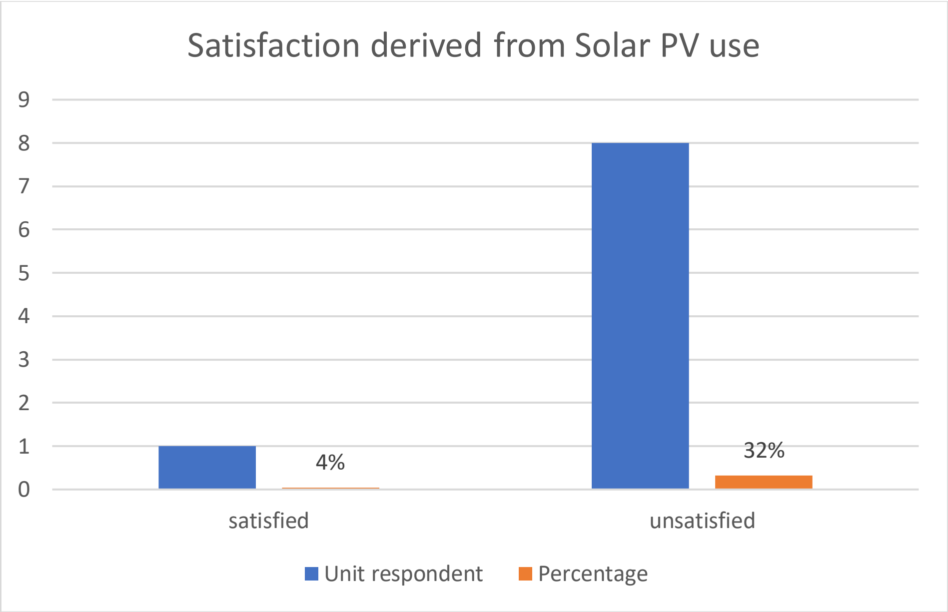

Fig. 7: Satisfaction derived from the use of Solar photovoltaic systems

The supply of electricity of one respondent (4%) is not altered by seasonal changes as his 1.5 kw solar home system consist of large panels that can capture enough solar radiation to keep his household afloat with electricity supply even at the heart of the wet season. Although satisfied with household electricity supply, the respondent still interns to increase his clean generation capacity for business purpose.

All other eight respondents (32%) own smaller systems that cannot satisfy their entire energy needs for electrification and they are bound to depend on them because even with the potential to acquire bigger systems, there are not available at dealer's shops in the municipality. So, they struggle through the wet season with limited lighting hours as their systems are too small to capture enough solar radiation to enable them function efficiently.

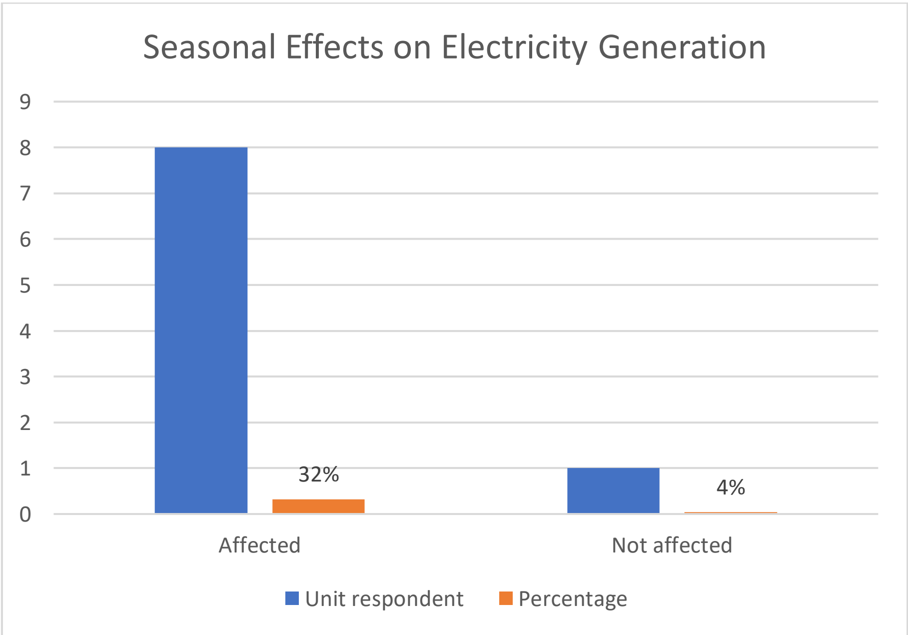

Fig. 8: Seasonal Effects on Electricity generation

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All respondents confirmed on the effects of seasonal changes on the supply of solar photovoltaic technologies to the municipality as heavy rains during the wet seasons renders the roads linking the municipality to the entire nation inaccessible often leading to scarcity and price hikes of solar photovoltaic technology.

V. DISCUSSIONS

Energy stacking for electricity generation is an empirical truth in Bengbis municipality. Located deep in the Dja forest, accessing adequate solar photovoltaic systems for sustainable electrification has been a daunting task (Streimikiene, et al., 2021). Consisting of 60 villages and five pigmy camps, the is a very low rate of grid electrification in Bengbis (PDC, 2015). Dominated by sparse settlements, the municipality possess a great market potential for standalone solar photovoltaic system as grid connections might seem economically and environmentally unsustainable (Akikur et al., 2013).

Although there is a high penetration rate of Solar photovoltaic systems, Pico solar is more visible in the electrification process but the electricity generated cannot fully satisfy entire household energy needs (Kapoor, 2013).

Accessibility of solar photovoltaic systems revolves around three factors which depend on each other; availability, affordability, and seasonal changes.

The wet season is very crucial to both availability and affordability of solar photovoltaic system as the two major roads connecting the municipality to the entire nation and major supply points are rendered inaccessible by heavy rains (Yaqoot et al., 2016). During these periods, mostly motorcycles are used for transportation as cars cannot easily access the roads. This leads to hike in transportation cost, creates scarcity and price hikes limiting accessibility.

The wet season is also crucial for consumers of Pico solar which is the most visible solar technology in the municipality as heavy rains are accompanied by limited solar radiation (Bloomfield et al., 2022). Having few solar cells, Pico solar systems can’t capture enough solar radiation to efficiently provide electricity for household (Nderitu, 2018). Limited lighting hours leaves the consumers with no choices but resort to other available sources to satisfy their electricity needs.

Accessibility of solar home system is the greatest challenge to residents of the municipality regardless of seasonal changes. Despite their willingness and financial capability to purchase small, medium or large systems, stocks are not visible at dealers’ shops in the municipality. Hence acquisition of these systems requires a trip to Yaoundé and the dislocation of a technician to the municipality for installations. This is often financially unsustainable to the locals who are left with no choice but depend on pico systems for their electrification and lighting needs.

VI. CONCLUSION

This study adds to empirical evidence that lack of regulation and administrative prioritization are impeding deployment and accessibility of solar photovoltaic systems in rural and remote areas. Information gathered from the field have also proven that infrastructural development in various dimensions is crucial to deployment and accessibility of solar photovoltaic system in Bengbis municipality (Barrios, 2008; Cook, 2011).

Many studies have emerged with evidence of physical factors being a major barrier to the electrification of rural and remote areas (Chaurey, Ranganathan, & Mohanty, 2004). Grid extension which has been the conventional means of rural electrification in developing countries remains economically unsustainable to rural areas far from the grid (Alqahtani & Patino-Echeverri, 2023). Fossil powered mini-grids are popular in the electrification of densely populated rural areas in sub-Saharan Africa but remain economically and environmentally unsustainable. Informed policies of sustainable rural electrification have turn to substitute fossil powered mini-grids with solar Micro-grids (Ponde, 2021).

Lack of an explicit regulation and policy framework has much impacted access to solar photovoltaic systems in area under study as price fluctuations of fossils coupled with a variety of technical issues hampered the smooth functioning of fossil powered mini grid (Kabeyi & Olanrewaju, 2022). Although the mini grid has been replaced with a solar micro grid, centralization of management will lead to eventual operational failures.

Likewise, all other economic sectors, renewable energy sector requires a robust communication and financial services to enhance its development (Yu et al., 2023). Multiple evidence has proven the significance of financial services in the dissemination of renewable energy (Ncube, 2007; Klapper & Singer, 2015)). The emergence of internet or mobile banking has also enhanced access to good and services in rural areas as it provides them with remote banking and payment services (Dermish et al., 2011). Low coverage and low-quality communication network impede access to communication, internet banking and other banking services that could enhance savings and payment for solar photovoltaic systems in Bengbis.

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