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Escuela de Doctorado

TESIS DOCTORAL

TOWARDS SELF-SUFFICIENCY IN ELECTRICITYPLANNING FOR INFORMAL SETTLEMENTS THROUGH THE FRAMEWORK OF URBAN METABOLISM.

(HACIA LA AUTOSUFICIENCIA EN LA PLANIFICACIÓN ELÉCTRICA DE ASENTAMIENTOS MARGINALES A TRAVÉ SDEL MARCO DEL METABOLISMO)

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Towards self-sufficiency in electricity planning for informal settlements through the framework of urban metabolism

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ABSTRACT.

Informal settlers are an integral part of the energy demand mix; they are responsible for contributing a significant amount of CO_2 emissions through the use of fossil fuels to meet their energy requirements. Thesesettlers are found in the urban fringes and inner cores of cities and in the wake of rapid urbanization trendsacross the globe, research findings reveal that there will be a significant rise in the number of the world's population living in informal settlements and slums. The figures are expected to rise from over 1 billion people in the year 2020 to 3 billion in 2030. With this monumental increase, there is a consensus from world leaders and stakeholders in the energy industry to ensure that the current global energy model,undergoes a full transition to a sustainable type that supports these growth changes. Obtaining an energy model that is resilient to withstand the pressure, which emerges from the alarming population growth, involves the use of renewable energy sources to provide much-needed energy security.

The selection of renewable energy resources as a replacement for fossil fuel usage has been carried out in previous research, where renewable energy resources are chosen based on their suitability to technical, social, environmental, and economic factors in cities and municipalities, which fall under a formal scope. These studies make use of the urban metabolism concept to diagnose the energy requirements of cities and municipalities to quantify the amount of renewable energy that can be utilized for energy consumption purposes; however, little attention has been given to the informal settlements, which are equallyas important and also in close proximity to the informal settlements of cities and municipalities in general.

This research work applies the concept of urban metabolism extensively to the informal settlements, whererenewable energy resources are analyzed and selected with the use of multi-criteria selection tools to matchthe direct energy consumption of these informal settlements.

The methodology is applied to four informal settlements: New Nyanya, Orozo, Ado (One man village) and Uke, which are conurbations situated in the Greater Karu Urban Area of Nasarawa State in Nigeria.

The bottom-up energy planning model is applied and community energy indicators are obtained from the result of the participation of energy agents in the decision-making process. The community energy indicators and the energy scenarios reveal the consolidation of different factors which determine if self-sufficiency can be reached in these settlements.

DEDICATION.

This research work is dedicated to all the inhabitants of informal settlements and slums around the World, who are constantly overwhelmed with low access to electricity and other infrastructural facilities that are deemed necessary to live comfortably and certainly above the poverty threshold. The findings from this research work will go a long way to bringing lasting solutions for the improvements of lives and personal well-being of informal and slum settlements.

SUMMARY.

The energy metabolism for the informal settlements of New-Nyanya, Orozo, One-man village and Uke, which are situated in the Greater Karu Urban Area of Nasarawa state of Nigeria are diagnosed to reveal the energy requirements.

Six renewable technologies were identified, and the multi-criteria technique is used to select the most appropriate technology.

Fourteen sub-criteria have their weights assessed by expert opinion and with the use of the Analytical HierarchyProcess methodology.

The PROMETHEE-GAIA software (Preference Ranking Organization Method for Enrichment Evaluation) is used to prioritize and select the most preferred renewable energy technology**.**

Six community energy indicators were also identified from the inclusion of community agents in the decision-making process. A comparison is carried out with the opinion of experts in the renewable energy field and community agents with regards to the weights and usefulness of the technical, environmental, economic, and social criteria in the decision-making process.

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RESUMEN.

El metabolismo energético de los barrios marginales de New-Nyanya, Orozo, Ado (one man village) y Uke, situados en la gran área urbana de Karu del estado de Nasarawa de Nigeria, se analiza con el fin de revelar los requisitos energéticos que son necesarios para su desarrollo.

Son identificadas seis tecnologías renovables y la técnica multicriterio utilizada a la hora de seleccionar la tecnología en energía renovable más adecuada para dicho propósito.

Catorce subcriterios tienen una evaluación de peso por parte de expertos en la materia junto con el uso del proceso de jerarquía analítica.

El software PROMETHEE-GAIA (método de organización de clasificación de preferencias para la evaluación del enriquecimiento) se utiliza para priorizar y seleccionar la tecnología de energía renovable más adecuada.

También se procede a la identificación de seis indicadores de energía comunitaria mediante la inclusión de agentes locales en el proceso de toma de decisiones. De esta manera se lleva a cabo una comparación con la opinión de expertos en el campo de las energías renovables y agentes comunitarios en relación con el peso y la utilidad de los criterios técnicos, ambientales, económicos y sociales en el proceso de toma de decisiones.

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Abbreviation.

LCOE	Levelized Cost of Electricity.
REA	Rural Electrification Authority.
WACC	The weighted average cost of capital.
DISCOS	Distribution companies.
GENCOS	Generation Companies.
AHP	Analytical Hierarchy Process.
MCDM	Multi-Criteria Decision Making.
MUSIASEM	Multi-scale integrated analysis of societal and ecosystem.
PROMETHEE	Preference ranking organization method for enrichment evaluation.
ELECTREE	Eliminating and Choice Translating Reality Method.
MADM	Multiple Attribute Decision Making.
TOPSIS	Technique for Order Preference Greater Karu Urban Area.
IEA	International Energy Agency.
IRENA	International Renewable Energy Agency.
IPCC	Intergovernmental Panel on Climate Change.
NREL	National Renewable Energy Laboratory.
MYTO	Multi-Year Tariff Order.
NERC	Nigerian Electricity Regulatory Commission.
NBET	Nigerian Bulk Electricity Trading Company.
NREMP	Nigerian Renewable Energy Master Plan.
NREEEP	Nigerian Renewable Energy and Energy Efficiency Policy.
PPTA	Petroleum Profit Tax.
CITA	Companies Income Tax Act.
GWPI	Global Energy Poverty Index.
GDI	Gender Development Index.
GEM	Gender Empowerment Measure.

1 INTRODUCTION & OBJECTIVES.

This research work analyses the possibility of replacing the direct energy used in informal settlements with the use of renewable energy resources available. The concept of urban metabolism develops this proposal because it analyses energy flow within the informal settlements. However, certain factors determine the extent to which the application of urban metabolism can facilitate the change in the energy model.

The factors emerge as a result of the participation of community agents in the decision-making and the selection process of renewable energy sources.

Six renewable technologies were identified, and the multi-criteria technique is used to select the most appropriate technology.

Fourteen sub-criteria have their weights assessed by expert opinion and with the use of the Analytical Hierarchy Process.

PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation GAIA software and the Analytical Hierarchy Process is used to prioritize and select the most preferred renewable energy option for the replacement energy for electricity production.

The informal settlements of New-Nyanya, Orozo, Ado settlement and Uke, which are situated in the Greater Karu Urban Area of Nasarawa state of Nigeria are characterized by different typologies of households and productive enterprises with the use of a community energy model. Five household typologies and three productive enterprise typologies were identified. In addition, the household sector is disintegrated to include five sub-sectors: cooking, lighting, air-conditioning, water heating and refrigerating, while the productive usage sector is disintegrated into three sub-sectors: Agriculture, Local Commerce and Local Manufacturing.

The Sankey diagram establishes the energy balance in the informal settlements and the useful intensity for each sub-sector was determined from the use of the appliance approach method in the absence of adequate energy consumption data. The potential of the renewable energy resources selected is determined and included in the scenarios to assess the impacts in line with the Nigerian renewable energy policy.

Three scenarios were established, which depict Nigeria's energy policy plan from the short term, middle, and long term. Six community energy indicators were also identified from the inclusion of community agents in the decision-making process. A comparison is carried out with the opinion of experts in the renewable energy field and community agents with regards to the weights and usefulness of the technical, environmental, economic, and social criteria in the decision-making process. The results obtained are a consolidation of different factors in determiningthe possibility of achieving a self-sufficient energy model.

The difference with previous studies on urban metabolism is the inclusion of informality and the bottom-up approach, which involves the wholesome participation of community agents in the selection of the appropriate renewable energy technology.

1.1. Introduction.

The climate change proposal under the Paris agreement is to plan toward replacing fossil fuel usage – a high emitter of CO2, with the use of renewable energy technologies, thereby symbolizing a paradigm shift in the energy outlook (UNFCCC, 2015; Savaresi, 2015).

In the context of energy planning, poorer countries often encounter difficulties in setting up a planning framework to achieve their goals on climate change, which is a result of the lack of willpower by their respective governments and the presence of weak institutions that are responsible for enforcing and implementing these energy policies and strategies. The challenges become more complex when there is a need to integrate informal settlements into the general planning framework (Tsenkova, 2012, Tsenkova 2019; Samper et al, 2020; Niva et al, 2019).

The United Nations records show that about 80% of the world's informal settlers are domiciled in developing countries: 370 million in South-Eastern Asia; 238 million in sub-Saharan Africa and 227 million in Central and Southern Asia (UN,2020). In developing countries, urban settlements are characterized by better livelihood, higher levels of education, job opportunities, and access to social amenities and infrastructure. These provide attractive options for rural dwellers to relocate from their base. Rural migration poses a great challenge to energy poverty, as the amount of pressure on social amenities increases, thereby posing a huge challenge for city planners (Singh et al, 2014).

Generally, informal settlements consist of sparsely and densely populated areas where quite a considerable number of rural-urban migrants find a place of solace in unplanned residential areas on urban fringes or inner cities and slums (Brown, 1996), These settlements are now characterizedas the rural-urban interface and the subsequent emergence of a peri-urban system of living. Peri-Urban areas are characterized by low access to services such as energy, infrastructural facilities, and basic amenities. The challenge of providing peri- urban residents with a wide variety of electricity services presents the face of energy poverty (Smith et al 2019).

The populace comprises artisans, traders, food vendors, carpenters, and low-income workers who throng the big cities in search of better means of livelihood. As a result of their low-income status, they are unable to afford the living and accommodation expenses of these major cities, so they resort to setting up illegal structures that serve the purpose of alternative housing for themselves and their families at large. This illegal way of living constitutes a big challenge to urban planning. Recent urban planning experiences exhibit the growing challenge of the legalization and integration of informal areas into the overall planning process. (Tsenkova,2012). The essential characteristics of informal settlements are an aberration to the conditions of urban planning that are required under the scope of formality.

Urban planners rely on official data, which in most cases includes the accurate population of people in the city, after a nationwide/ city census is duly conducted. The data obtained from the census reveals household details such as: household occupants, the structure of the household, the income of the households, and the energy consumption profile on a wider scope. The feedback obtained from the headcount exercise conducted through the census, enables urban planners to apply different codes that represent the data captured for the different households in the city. On the other hand, informal settlements are not accounted for in this census, which has come to symbolize irregularities in building structures, income profile, household size, employment, education, and energy consumption profile (Tsenkova, 2012, Tsenkova 2019; Samper et al, 2020;Niva et al, 2019).

The data for the energy consumption profiles of different households is an important parameter, which is used by energy planners to determine the immediate energy demand of the city and also make necessary projections to accommodate future energy requirements. The exclusion of informal settlements in formal data capture is responsible for impeding the operation and performance of the energy sector, especially in developing economies. The situation is easily seen when electricity distribution companies (DISCOS) experience a drop in revenue as a result of huge collection losses that occur from the inability to distinguish between legally and illegally connected electricity customers. The inability of the distribution companies to maximize their ATC&C losses has a ripple effect on the electricity value chain as a whole. It happens such that when the distribution companies experience dwindling revenues from electricity sales, it becomes difficult to meet up with their operation and maintenance cost and also affects their financial commitmentto the electricity generation companies (GENCOS).The GENCOS in return cannot fulfillment to their contractual agreement with the energy suppliers, thereby creating a huge backlog of payments and a creation of a liquidity crisis, which is capable of crippling the progress of the electricity sector.

Sub-Sahara Africa is the fastest growing urbanization in the world at 4.5% per annum, and it is projected that in 2030 urban population will exceed the rural population. Sub-Saharan Africa has oneof the highest rates of urban poverty in the world. 40% of people living in Sub-Saharan cities lackaccess to electricity (Putti, 2011).

A practical example is in Nigeria, a country in the western region of sub-Saharan Africa where there are over 180 million people with about 60% of the populace having access to electricity, andthe remaining 40% fall into the category of persons who are underserved or unserved. (REA, 2020). Informal areas are a particular challenge to Discos due to the high losses that result from low collection rates. Commercial losses are highest in informal areas, where about 30% of losses are a result of unmetered connections. and consequently, energy theft through meter bypass, thereby costing the DISCO an average of $22,000 dollars per community per year in losses (Graber et al,2018). In the year 2019, the electricity distribution companies in Nigeria are indebted to a tuneof about US 2 million dollars (NBET, 2020).

The concept of urban metabolism highlights the metabolic flow of energy, food, nutrients, and materials into a system. The application of the underlying principle of urban metabolism to the informal settlements in the Greater Karu Urban Area of Nasarawa state in Nigeria, is the focus of this research work.

The methodology of urban metabolism is applied to seek a change in the current energy model from a linear to a circular model, which involves the promotion of renewable energy usage for the informal settlers in order to achieve self–sufficiency. The planning towards self-sufficiency, in this instance, encompasses the integration of informality into the formal framework of energy planning for cities thereby introducing a paradigm shift in the way urban planning is carried out and reshaping the concepts and theories behind informal planning in general.

Cities are man-made creations with a huge requirement for materials in the form of food, water, nutrients, and energy. Continuous consumption of these resources exerts pressure on the environment as a result of its exploitation and the release of waste/emissions. (Barragan et al, 2018). It is against this background that as cities undergo rapid urbanization, the dire need to adapt to urban resilience is of utmost priority. In this regard, city planners have to implement a circular model that affects the ability of a city to withstand shocks, stress and threats whilst adapting to social, political, economic, and environmental change and still able to retain its original identity Deriving a circular model to uphold the sustainable development discourse is contingent on the urban metabolism pathways that are inherent to the cities. The metabolism of a city grows in synchrony with the population size precipitated by the migration of people from rural areas. (Smit et al, 2017).

1.2. Objectives of Thesis.

This research work analyses the possibility of replacing the direct energy used in the informal settlements with the use of renewable energy resources available. The aim is to:

- Identify the renewable energy sources that are deemed appropriate for the replacement of fossil fuelenergy and fuel carriers for the production of electricity.
- Project electricity demand beyond the year 2030.
- Adopt a multi-criteria weighting method, which determines the usefulness and importance of criteria used in selecting the renewable energy sources.
- Identify the different typologies of informal settlements, thereby revealing the different characteristics and energy consumption profile that is particular to each of them.
- Disaggregate household and productive use sectors into sub-sectors to determine their respective contribution to energy consumption.
- Analyze the Nigerian renewable energy policy scenarios.
- Involve the participation of community members in the decision-making process of electricity planning for the informal settlements.

1.3. Specific objectives.

The main focus of this research work is to diagnose the energy flow pattern of informal settlements in order to determine the fuel and energy carriers from fossil fuel sources and replace them with the use of the most appropriate renewable energy sources.

Subsequently, this research focuses on the bottom-up planning approach methodology in order to determine the level of contribution of community agents in the overall electricity planning framework.

The hypothesis is that self-sufficiency is achieved through the adoption of a circular energy model.

1.4. Content and Structure of Thesis.

1. Introduction: This thesis comprises eight chapters. The first chapter is an introduction to the research problem and its objectives.

2. Urban Metabolism: Refers to the application of the urban metabolism concept. A literature review is carried out on previous studies by defining the characteristics and importance of the urban metabolism discourse, firstly within cities and municipalities before including the analysis within the scope of informality. Subsequently, the discussion is extended to include the current trends in urban metabolism, which highlights the planning approach that is appropriate for policy recommendation.

3.Overview of the Nigerian electricity industry: Depicts the problems inherent in the Nigerian electricity industry in a chronological order. The chapter elucidates the several attempts by the government in increasing the capacity to supply electricity to both rural and urban areas. It includes the policy changes and implementation strategy and also the setbacks that have accompanied these efforts.
The chapter finally concludes with the inclusion of electricity planning for informal settlements especially the ones in the inner cities and the fringes that are classified as underserved and unserved communities.

4. Methodology: This is a starting point to refer to the methodological proposal for the selection ofthe most appropriate renewable energy technology in the urban metabolism of the informal settlements in view. The methodology is divided into two sections, which include the selection process and the community agent participation.

Firstly, the selection process involves the use of multi-criteria decision-making methods which includes the PROMETHEE GAIA software and the Analytical Hierarchy Process to select the most appropriate renewable energy technology in the informal settlements.

Fourteen qualitative and quantitative criteria are established to enable the selection. The criteria weights are allocated through the combination of expert opinion and the Analytical hierarchy process.

Secondly, the community agent participation involves the sampling of data from the informal settlements through a survey and semi structured interviews of focus groups. Six community energy indicators are established, which determine the impact of a bottom-up approach to the entire planning process.

The metabolic flow pattern of the direct energy in the informal settlements is created through a community energy model and the energy balance is represented with the use of Sankey Diagrams. In addition, the use of the appliance method for the determination of useful energy intensity is included in the methodological approach.

5. Case Study: This section conducts a case study of the Greater Karu Urban Area, Nasarawa State in Nigeria.

The diagnosis of four informal settlements is carried out to include the typologies of household and productive usage of energy.

The energy situation of the established typologies is established, which includes the sectors and subsectors within the Greater Karu Urban Area. The results are benchmarked with what is obtained on the Regional and National level to provide some level of consistency.

The application of PROMETHEE- Gaia software in the criteria analysis and the weight selection of criteria with the use of experts and the analytical hierarchy process, provide a hybrid analysis for the selection of the most appropriate renewable energy technologies in the four informal settlements.

The energy potential for the four renewable technologies considered appropriate for the provision of electricity in the informal settlements are -also obtained and included in the community energy model.

Three scenarios are established and together with the response from the community energy participation and the community energy indicators obtained for the informal settlements, a determination of self-sufficiency is assessed and the analysis is extended into the final chapter for a detailed discussion.

6. Community energy participation: This chapter concludes with the results obtained from the research analysis and recommends areas for future studies. It contributes to the argument about the effect of renewable energy technologies in altering the energy model from linear to a circular type. It also examines other factors that need to be considered from a bottom-up approach.

7. Policy case scenarios: The effect of the different policy proposals on renewable energy uptake is discussed in this section, three scenarios are analyzed and the energy requirement is projected into the future.

8. Discussion and Conclusion: This section summarizes the findings from this research work and proposes a future study on grey areas concerning the uptake of renewable energy sources through the urban metabolism framework.

INTRODUCCIÓN.

Este trabajo de investigación analiza la posibilidad de sustituir la energía directa que se usa en asentamientos marginales por los recursos disponibles de diferentes energías renovables. El concepto de urbanismo metabólico es el responsable de desarrollar esta propuesta porque analiza el flujo de energía dentro de los asentamientos marginales. Sin embargo, hay ciertos factores que determinan la extensión por la cual la aplicación del urbanismo metabólico facilita el cambio en el modelo energético.

Los factores emergen como resultado de la participación de los agentes comunitarios en la toma de decisiones y la selección de las fuentes de energías renovables.

Se identificaron seis tecnologías renovables y la técnica multicriterio utilizada a la hora de seleccionar la tecnología en energía renovable más adecuada para dicho propósito

Catorce subcriterios tienen una evaluación de peso por parte de una opinión experta junto con el uso del proceso de jerarquía analítica.

El software PROMETHEE-GAIA (Método de organización de clasificación de preferencias para la evaluación del enriquecimiento) se utiliza para priorizar y seleccionar la tecnología de energía renovable más adecuada.

Los asentamientos marginales de New-Nyanya, Orozo, Ado y Uke situados en el área urbana de Greater Karu del estado de Nasarawa se dividen en dos tipos de hogar y empresas productivas con respecto al uso del modelo comunitario de energía. Fueron identificadas cinco tipologías de hogares y tres tipologías de empresas productivas. Además, el sector de la vivienda se divide en cinco subcategorías: los aspectos relacionados con la preparación de alimentos, el alumbramiento, el aire acondicionado, el calentamiento de agua y la refrigeración, mientras que el uso productivo del sector se divide en tres subcategorías: agricultura, comercio y fabricación local.

El diagrama de Sankey establece que el balance energético en los asentamientos marginales, así como la intensidad útil para cada uno de los sub sectores se determinan a partir del uso del método de aproximación ante la ausencia de datos adecuados de consumo de energía. El potencial de los recursos de energía renovable seleccionados se determina y se incluye en los escenarios para evaluar los impactos de acuerdo con la política de energía renovable de Nigeria.

Se establecieron tres escenarios que representan el plan energético de Nigeria a corto, medio y largo plazo.

También se identificaron seis indicadores de energía comunitaria mediante la inclusión de agentes locales en el proceso de toma de decisiones. De esta manera se lleva a cabo una comparación con la opinión de expertos en el campo de las energías renovables y agentes comunitarios en relación con el peso y la utilidad de los criterios técnicos, ambientales, económicos y sociales en el proceso de toma de decisiones.

El resultado obtenido es la consolidación de diferentes factores que determinan la posibilidad de conseguir un modelo de autosuficiencia energética.
La diferencia con estudios previos sobre metabolismo urbano es la inclusión de la marginalidad y enfoque que se ejecuta desde abajo hacia arriba. Esto involucra la participación de todos los agentes comunitarios en la selección de una tecnología renovable que sea apropiada.

2. URBAN METABOLISM.

This subsection reviews the literature on the concept of urban Metabolism.

The contextual approach to understanding urban metabolism is to create a comparison with the biological description of the word “metabolism”. Metabolism is the sum of the chemical reactions that take place in a living cell (Zhang et al 2015). Living cells synthesize new organic material that spurs growth and development. The determinant of the growth processes is related to the amount of input extracted from the environment and the comparison of living organisms with the nature of cities, is not done out of proportion, as cities exhibit the very nature and characteristics of a living organism and in this regard, the city will depend on the extracts or imports from the environment to ensure its existence. The concept was first highlighted with the process of supplying materials, energy and food to a hypothetical city, as well as its respective output in the form of products or waste (Musango et al, 2017). The output in the form of waste was analyzed by chemists in the 19thcentury who were concerned with wastewater and fertilizer use in agriculture production (Barles et al, 2019). Other studies e.g. Wolman (1965);Baccini &Brunner (2012) define urban metabolism explicitly laying emphasis on the essential components of an urban system, with an inclination towards the ecological relationship that exist within. It recognizes it as an industrial ecology relating it to the collection of complex sociotechnical and socio – ecological processes (Musango, 2017).

This narrative is broadly consistent with the work of Kennedy et al (2007) that equates cities with ecological systems. He defines the word urban metabolism as the “sum of the technical and social-economic processes that occur within the cities, resulting in growth, production of energy, and the elimination of waste” (Kennedy et al, 2007). Ecosystems depict the level of interactions between living organisms and the non- living component of the environment. The relationships of these components are result of the energy and nutrient cycle that support the metabolic processes. Cities are fabricated by the amount of energy, people and information present. In cities, the human populace interacts with the social, economic and environmental factors in order to maintain their existence. Socio-economic factors such as income, health, employment and education which characterize a city inadvertently supports human activities such as transportation and economic production, which are indicators of the growth performance of the city brought to the fore. On this premise, the energy required to consolidate this symbiotic relationship between human activities and the environment, creates the possibility of applicable measures to be instituted to maintain its continuous supply from across the globe.

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In the work of Zhang et al., (2015) an attempt is made to quantify the amount of energy required to support the metabolic processes that are attributed to a city with regards to upholding the sustainable energy discourse, The work of Zhang indicates that in order to achieve security of supply to a metabolic system, the use of renewable energy should surpass the use of conventional energy. This concept is depicted in the equation as shown below:

$$UF=RE+N+IMP \tag{1}$$

Where (UF) is the flow of urban energy and (RE) symbolizes the renewable energy, (N) is the non –renewable energy sources and (IMP) denotes the imports. This work concludes that provided energy efficiency measures are not applicable, the city's requirement for energy is met by reducing the use of non –renewable imports (Zhang et al, 2015). This fundamental approach supports the production of energy within the boundaries of a metabolic system. Necessitating a switch from a linear to a circular model upholding the sustainable development discourse (Brown, 2017). This will require an assessment of metabolic pathways of systems to determine the inputs and outputs and what components of the outputs require recycling. Several urban assessment studies have been carried out to determine the metabolic pathways of systems, which includes; accounting approaches that make use of the thermodynamic laws of the conservation of mass and energy to audit energy inflows and outflow. Mostafavi et al., (2014) proposes an integrated metabolism analysis tool (IUMAT), which considers social, environmental and environmental criteria that determine the input into an urban eco system. Input- output analysis creates a different approach to the urban metabolism assessment by determining the drivers of urban systems i.e., human activities, with the drivers compartmentalized to sectors of the system (Musango,2017). Assessment methods such as life cycle analysis defines the flow of direct and indirect energy (Ferrao and Nhambiu, 2009). Other notable methods are the simulation method which appreciates the impact of socio-economic factors as energy flow determinants (Dooley, 2005), however no method of assessment is considered the best to the urban metabolism approach. Suggestions so far from literature point towards the direction of a hybrid model to outweigh the disadvantage or advantages of the various methods already proposed.

Several investigations that applied the concept of urban metabolism in cities can be sighted in the work of (Zhang et al, 2011). Energy analysis was investigated by determining a unified method to evaluate a systems metabolism in the city of Beijing. The environmental and economic values were measured with Energy indices i.e., environmental ratio, energy used per person, etc. to determine the relationship that exists between the system and its environment. Findings from this work suggest that based on the energy indices, Beijing depends on its energy from external resources, which was done in sharp comparison between 5 cities. Wenyi et al., (2018), investigatedurban metabolism in Shanghai, Tokyo, London and Paris to inform low carbon and sustainable development ways. The work indicates that Shanghai's labor productivity and its energy efficiencyare the lowest, while Tokyo's labor productivity was the highest and Paris has the best social welfare. Thework involved the use of multiscale integrated analysis of societal and ecosystem metabolism (MULSIASEM) to analyze the metabolic characters of the four cities. Barles, (2009) supports theuse of MFA (material flow analysis to investigate urban metabolism in Paris and its region. The study identifies the impact of exported waste on material flow on a local scale and national scale. The findings suggest that Paris has a lower direct material input (DMI) than the rest part of the country, which results from less extraction, production and transformation of material than the rest parts of the country. Rosado et al., (2017) also analysis material flow in the city of Sweden, the aim was to determine the driving force of material flows in urban areas. Three cities: Stockholm; Gothenburg and Malmo were analyzed based on their urban metabolism characteristics framework. The finding indicates that Gothenburg has the most resource-intensive metabolism, requiring several times larger material input and produces larger outputs. The findings from the work is consistent with Barles (2009), where cities in Paris which are more denser usually requirea larger input and are often characterized with the release of more CO_2 emissions. Malmo is seen to have more affinity for materials needed in construction, in other words the determinant of inflow of energy to the city should target the construction industry where the city major contributor to high consumption rates is easily discovered. However, Malmo is less dependent on external flows as it derives its energy source from non-metallic minerals and biomass within its system boundaries. Resource consumption in cities was highlighted in the work of (Currie & Musango, 2017). The objective of this investigation, was to determine the quantity and quality of resources consumed and what fuel choice is required in Cape Town, in order to highlight the prospects of sustainability. Key findings from the assessment indicate that annual energy consumption showed a decline in 2007 and 2011 respectively, thereby suggesting that in order to reduce energy consumption in the city there is a need to completely reduce private car usage. The work of Barragan (2018), highlights sustainable measures to be included in the city of Cuenca in Ecuador. The work identified conventional energy carriers i.e., fuel and electricity and also six renewable energy sources as energy inflow.

The urban metabolism assessment carried out in Cuenca also determined the consumption patterns in the intermediate city, to include different sectors of the economy i.e., transport, housing etc. With the aim of determining the amount of energy the conventional carriers contribute to the demand, and to replace them with the use of renewable energy sources. The work takes a step further in the study of urban metabolism assessment in cities þy determining the potential of renewable energy sources that were selected. However, gaps in literature still exist as no research work has applied the concept of urban metabolism to informal settlements at large. Generally, the application of urban metabolism in modelling a cities energy status, provides the necessary information with regards to energy efficiency, recycling of waste and the quantification of resource flows and their impacts in determining the fabric of a city.

In the context of informal settlements of a city, 30 research findings over the years are being categorized accordingly in three dimensions emerging from the major principles of urban metabolism namely:

System dynamics analysis (Pickett et al 2001).
Formalization strategy and policy integration, Guibrunet et al (2017). Material flow analysis (Baoet al,2010).
Sector wide/input-output analysis, (Beloin-Saint-Pierre et al,2017).

System dynamics analysis: This analysis recognizes the socio ecological and socio-economic attributes of a system entirely. It determines the causal relationship between components by capturing real world behavior without the use of empirical data.

(Kovacic et al, 2016) assesses the levels of uncertainty that affects informal settlements in South Africa. Findings from this work, highlights the effects of technical uncertainty on socio political challenges of informal settlements. (SMIT et al, 2018) applies a multi scale integrated analysis of social and ecosystem metabolism (MUSIASEM) to Enkanini informal settlement in South Africa. The work investigates the use of Time, Money and Energy variables to validate the link between socio ecological relationship within the informal settlement and the surrounding city. Similar work on MUSIASEM methodology was the application to hybrid/multi- structured urban informal settlements (Makinde, 2018). Other research in these categories includes:(Song & Robinson, 2018; Sharlene & Hermans, 2018), which examines the behavioral response to environmental changes in Bangladesh. Attia and Khalil, (2015) investigates the quality of life measured by the consumptive behavior of water resources by informal residents in the city of Cairo. The paper concludes that identifying points of leakages in water supply inadvertently improves the life quality of residents.

Formalization strategy and policy integration: This dimension involves the concept of formalizing the informality, it involves a hybrid approach of integrating the input/output analysis into system dynamics.

Guibrunet et al (2017) explore the link between institutional laws and waste management in urban areas in Mexico City and Santiago in Chile. Nissing and Blottnitz, (2007) investigate the material flows of wood and paper in Capetown. The objective is to redirect flows from the informal to the formal sector for renewable energy usage, thereby strengthening the argument for formalizing the informal sector. Findings from this work suggest that 70% of renewable energy sources can be derived from the redirection of material flows. Tsenkova, (2012) shows how urban metabolism in 5 capital cities of eastern Europe transform informal planning. Wilson et al., (2006) investigate the role of informal sector recycling in waste management in developing countries. It finds how best to work with informal sector waste. It proposes the integration of informal waste into formal waste. Other works include (Kleeman,et al 2017; Djist et al 2018;Nassar& Elsayed,2017) citing instances of informal land use and its connection to urban metabolism.

Accounting Approach (material flow Analysis): this quantifies resource flows by applying the principle of conservation of mass and energy. It involves the analysis of inputs by extraction and changes to physical stock and outputs through emissions without considering the grey boxes of the economy. Barles, (2009) work on Paris and its hinterland determine where the feasibility of material flows is used to determine consumption levels in urban sprawls and the inner city.Maione & Morello (2016) investigate the reduction of urban metabolism in informal settlements in the city of Nairobi. Galan and Perrotti, (2019) focus on the metabolic study of the metropolitan area of Valencia, Sierra and Calderona. The objective of this work is to increase sustainable levels by optimizing the flowof material and energy. Krausmann, (2013) conducts the energy metabolism of the city of Vienna and its Hinterland. Meyer et al, (2020), monitor urban metabolism drivers in the metropolitan area of Ho Chi Minh by assessing the metabolic flows. Wu, (2008) investigates growth patterns and sustainable development per urbanization of shanghai. It links sustainable development and urban growth by examining foreign direct investment to the area. Kombe, (2005) determines the impact of urban growth of peri urban settlement in Tanzania. Wotjer, (2012) focus on drivers for peri urban development.

Miranda et al.,(2016) analyze the metabolic growth pattern in the favela in Rio de Janeiro. Narain et al., (2013) investigate peri-urbanization in India. Butera et al.,(2016) review energy access and energy efficiency in slums.

Input-output analysis flow: This involves flow analysis of the grey boxes of the economy. Input and Output analysis involves accessing the grey areas of the economy. It involves the determination of consumption drivers on a sector-wide basis. Four studies on African metabolism depict the failure of African economies to indicate a positive correlation with economic growth measured in GDP terms. Ravaillion, (2007) indicates that the proportion of in flow into sub-Saharan countries must be lesser than outflows if the countries are to achieve any significant economic progress. Kessides, (2007) advocates for the adequate management of resources in the wake of rapid urbanization in the region. The work suggests the inclusion of institutional support systems on a local and national level, which are capable of measuring and controlling the input and output flows into the economy. The work of Bouare, (2006); Khanna & Bloom (2007), depict a picture of the difference in metabolic flow pattern between richer and poorer countries, whilst advocating for efficient consumption of resources in poorer countries in order to maximize their GDP. Currie and Musango, (2016) applies the concept of sustainable development and urban metabolism in the African context by determining the consumption profiles of 54 African countries. Currie and Musango, (2010) profile consumption data for 120 African cities. The work of Appies, (2016) examines the popular usage of energy carriers in informal households in South Africa and found that electricity and paraffin are most commonly used for energy services in households.

In summary, findings from the review reveal an existing gap in the literature of the informal planning of energy using the concept of urban metabolism. Amongst the 30-research reviewed only the work of (Appies, 2016) makes reference to sector wide analysis. However, the work is restricted to one sector of the informal economy i.e., the household/ residential sector. The work fails to analyse the local commercial sector which is important to peri-urban electrification. In addition to this, the productive use of energy in peri urban areas is not highlighted, which is of great importance to the livelihood of informal settlements in developing countries. Perusing through the remaining 29 research papers, there is little emphasis on the role and functionality of informal settlements. The findings suggest that the trend in informality is embodied within the context of formalization of the formalization of informality and the importance of their metabolic flow patterns.

This research work focuses on creating sustainability within the informal settlements, by identifying the metabolic flow pathway.

2.1 The importance of informality

The Sustainability discourse concerning informal settlements is underpinned by the UN sustainable development goal 11. It states that; “Cities and human settlements should be made inclusive, safe, resilient and sustainable” (UNDP, 2010). Making cities safe and sustainable implies that adequate access to safe housing and upgrading of slum settlements should be affected. The process of slum upgrading, involves the improvement of both the physical and social environment, (Sticzay et al, 2015). With regards to creating resilience, Arefi, (2011); Pickett et al, (2004) argue that resilience is preferred to mean the pursuit of an alternative rather than reverting to the original state. Community resilience in a broader perspective, represents the ability for a community to respond and influence change, by developing personal and collective capacities (Davoudi et al.,2003). Renewable energycan play a vital role in ensuring the resilience of the electric supply coupled with the collective capacities for energy storage (Mclaren, 2010). Numerous cases of electricity theft in slums and informal settlements can be resolved by renewable energy usage, (Sharifi& Yamagata, 2015). Similarly, the continuous threat of climate change and volatile prices of fossil fuel commodities puts in jeopardy the reliability of the system to resist shock in the disruption of energy supply (Delucchi & Jacobson, 2011).

The directive for the necessary inclusion of informal human settlements as integral parts of any city around the world is provided in the UN sustainable development goal 11(UNDP, 2010). This directive poses a major challenge in the rudiments of urban planning. Jones, (2017) states that informal settlements suffer social, economic and spatial exclusion from urban benefits compared to the rest of the urban populace.

The planning of energy for informal settlements involves understanding the attributes that support their existence and the necessary impacts on global and regional policy frameworks. There are misconceptions that emerge from the historical literature on informality. The general notion provided from the review of literature, generalizes informal areas as homogeneous systems, characterized by poverty and exclusion from the services obtained in formal settlements.

UN Habitat, (2003) depicts informality as settlements for migrants that are often characterized by vulnerability and bereft of governance processes.

Archer & Bezdecny (2016), defines the informal economy as the group of people or businesses who avoid taxes. The definition of informality provided by literature depicts a negative image, the authors are strongly opined to view informal planning as inconsequential, because of the inability to get documented evidence in the form of data to affect a sustainable urban design. The research conducted by Schneider et al., (2010) support this narrative by defining informality as productive activities that are “deliberately concealed”.

This has been the reason for its exclusion in sustainable urban practices posing a major challenge with regards to the UN sustainable cities directive, highlighting the need for cities and informal settlements to be unidirectional. However, conventional planning methods in cities occur in two dimensions i.e., formal and informal, in lieu of the fact that they are both aspects of the same city, which display different levels of interdependence and close economic relationship.

Urban planning over the years underpins the importance of accountability of resource flows that provide the details for an effective urban plan (Kennedy et al 2012). This implies that resource flow accountability should traverse the inner-city boundaries to the informal. More so, there has been growing support for the need for planners to recognize the positive role of informal actors in the city, and to work toward a positive response such as regularization and upgrading, to be negotiated on a case-by-case basis (Patel, 2013). Several research works have challenged the notion of the simplified understanding of informality as a distinct and homogenous entity in the city. In that regard, show that informality is not quintessentially poverty-ridden, marginalized, and unsustainable and should not be treated with exclusivity. Turner (1968), argues that informality characterizes a majority of urban processes. He asserts that informal areas are responsible for contributing to the economic development of inner cities, and as such should be formalized into the entire system. Findings from this work, suggests that informality’s usefulness to urbanism cannot be overlooked and necessary support needs to be given by adapting contemporary planning framework to informal processes. Turner (1968), thus advocates that the government should accompany self- construction of housing by providing legal, technical and financial support. That means adapting the planning framework to informal processes, rather than attempting to fit these processes to a rigid planning framework. In terms of national and international policy, this means focusing efforts on slum upgrading and incremental improvement of livelihood.

In Mexico, informal economies represent 31% of the GDP (Schneider, Buehn & Montenegro 2010). They assert that Informal economies are suppliers of essential services for the city as they complement the formal sector of the economy. Giglia, (2014) cited an example to support the argument of Turner (1968) and (Schneider et al., 2010). The work asserts that in the formal sector where workers do not earn high salaries to afford expensive meals, informal food vendors become a substitute. Informality provides the resilience the cities need because informality provides the services that are lacking in the formal sector (Simone, 2004). This is in contrast to the rationalethat informality is insignificant to urban development.

"Informality" appeared as a concept in the early 1970s as a means to characterize a growing proportion of insecure urban employment, usually ignored by statistical and employment studies. The term is applied to three sectors of a city's economy, i.e., housing, employment and provision of services. Informal housing refers to buildings not permitted by planning agencies and deprived of basic services (electricity, water and sewage). Informal economy refers to activities not regulated by the state i.e. unregistered businesses, (Moser, 1994).

(Moser 1970), mentions that the occupants of informal settlements are predominantly migrants, engaging in illegal activities to support their existence. Hart (1973), found the term useful in describing non-wage-earning jobs in Accra. The urban poor, in particular migrants engage in informal employment such as food vendors, mechanics, street traders, bar attendants, as well as cloth merchants among others.

(Hart 1973), advocates for the development of new typology of employment for informal settlers. Another notable contribution of informality to formal sectors is the presence of informal elements becoming drivers of the formal social, political and planning process. The active participation of informal settlers with donor organizations, and community ad hoc committees, whose role serves as a mediator, between workers and the state, in the form of informal leadership and other socialist groups, ensure that their voices are granted in the planning process. Examples are trade unions, socialist groups etc. Chakraborty et al (2015), suggest that informal planning is sacrosanct to the functioning of cities and thus argue that planning policies have been too rigid and advocate for the adaptation of the planning framework to informal processes to include the upgrade of slums and shanty settlements rather than primarily focusing on the issues that border on legality i.e., land dispute settlement.

The use of renewable energy in the informal settlements creates access to clean and affordable energy thereby supporting the sustainable energy discourse that unifies the uptake of renewable options in one dimension.

2.1.1 Sustainable cities and Informal settlements.

This section establishes the importance of cities as energy producers and the level of support to city dwellers. It also describes what energy in the cities is used for and suggests effective ways to ensure its sustainable supply. It also describes the importance of informal settlements and howto meet up with the requirement for sustainability by careful review of the literature.

2.1.2 Towards a sustainable city.

Cities are open systems that depend on the outside world to provide raw materials and assimilate wastes to sustain their functions as defined by (Bai 2007). The responsibility of cities is to take necessary actions to meet the rising needs of their populations. City dwellers use energy to meet their daily needs cut across the broad spectrum of industrial, residential and transportation sectors of the city (Guibrunet 2015), Cities are responsible for 70% of global emissions (UN-Habitat 2011). The generalized rationale behind achieving sustainability in cities is the ability to provide for the present without jeopardizing the future.

A sustainable city should be able to power itself with renewable sources of energy without jeopardizing the future (Kammen & Sunter 2016). Solar, Wind, Biomass e.tc replenish themselves naturally without being depleted. Most renewable energy sources produce little to no global warming emissions (Owusu & Sarkodie 2016), because cities are a key contributor to climate change, resulting from the urban activities being major pollutants. This necessitates the assimilation of renewable energy to meet the the energy requirements of its dwellers. Cities need to adapt to climate change and this can be achieved by sustainable energy planning. Many cities struggle with environmental degradation, traffic congestion, inadequate urban infrastructure and a lack of basic services such as water supply, sanitation and waste management culminating from improper planning.

Yigitcanlar & Dizdaroglu (2015), identify environmental, social and economic factors as the threemain challenges that have considerable impact on the existence of a city. Planning for cities involves working on the tension generated amongst the three fundamental factors.

Campbell (1996), integrates social theory with environmental ideologies to confront economic and environmental injustice. Social relationships and material aspects of human science are considered normative ecological parameters in determining the impact of ecology on cities in Hong Kong (Boyden et al, 1981). The analogy that links cities to living organisms is provided in the framework of urban metabolism studies.

In this work, cities are depicted as ecosystems. The model of a natural ecosystem is the objective of developing sustainable cities, (Kennedy et al, 2010). The ecosystem depicts the interaction between the natural environment and human activities thereby identifying the environmental effects of the interaction, and highlighting the importance of urban ecological planning in achieving sustainable cities. The urban metabolism analyzes the relationship with cities and their environment to determine green-house gas emissions and energy requirements. The objective of sustainability is to alter the current energy model in cities from a linear to an urban model with the use of renewable energy. (Barraghan, 2018).

2.1.3 Renewable Energy and Informal Settlements.

This subsection discusses about the importance of renewable energy and its application to informal settlements. It introduces planning using the concept of urban metabolism.

Energy consumption in informal settlements is recorded in the residential, commercial and transportation sectors of the informal economy. Arefi, & Triantafillou,(2005); Pickett et al, (2003) allude to the resilience of an informal settlement as characterized by the adaptive mechanism put in place to find alternative options to energy to meet the residential, commercial and transportation demand, in the event of supply disruptions. This is an integral part of the sustainable energy discourse (UN, 2010).

Informal settlers rely on electricity, LPG, natural gas, Kerosene, Coal, Biomass, Firewood and Charcoal as base energy carriers in various households (Butera & Faccini, 2016). Household requirements for energy involve cooking, lighting and heating and powering electrical appliances. The commercial sector attributes energy consumption to the productive use of energy for the enhancement of income and welfare (Terrapon-Pfaff et al, 2018). Frozen food storage in refrigerators, powering of farm tools, and electrification of shops that provide local services are identified as drivers of commercial consumption (Butera & Faccini 2016).

In the transportation sector, informal settlement consumption is as a result of those who commute to inner towns for employment and income progression by accessing public transportation and other means such as motorcycles, bicycles and walking. These scenarios are contigent on the delineating factor of proximity to inner cities and the status of residency in the informal settlements. In developing countries such as Nigeria, diesel and gasoline are the predominant energy carriers (Oyedepo, 2012). In major sub- Saharan countries, which experience rapid urbanization growth, kerosene and fuel oil are the secondary source of lighting (Putti 2011). This growing evidence suggests that the current energy model should be altered to include the replacement of fossil fuel sources with renewable energy. Unlike energy based on fossil fuels, renewable energy is considered sustainable, thereby providing informal settlements resilience to mitigate against disruption of supply.

Barraghan & Espinoza (2015), assert that renewable energy can be used in distributed applications to promote sovereignty and the use of endogenous resources to fuel local economies. In developing countries where cities are planned with more consideration for resource equity than efficiency, planning for creating access to renewable energy resources can be done with the urban metabolism tool (Currie et al 2015). The urban metabolism tool can analyze the flow of energy and other materials in cities through metabolic pathways (Kennedy & Hoornweg, 2012).

Possible usage of the urban metabolism tool with informal settlements includes: identifying energy flows (fuel, electric power); defining study sector (commercial and transportation); sectoral analysis, and identifying energy that can be substituted with the renewable energy technology that is applicable (Barraghan, 2018). The flow drivers in the residential, commercial and transportation sector of informal settlements, can be analyzed, to determine where fossil fuel imports can be replaced by renewable energy sources.

2.1.4 Energy Planning in Informal Settlements.

This subsection discusses literature research on planning perspectives from the global south and global north and includes informality in the discourse.

The Urban metabolism tool has recently begun to influence urban planning and policy. (Bancheva 2014), gives information on analyzing city resources, by providing a perspective on planning. It integrates the urban metabolism practice into public policies,requiring its full implementation in order to support the sustainability discourse, (Musango et al, 2017). In the contextual planning framework, implementation of urban metabolism practices into public policies differ between the global-north and south divide. Most countries of the Global North are highly rated in effective policy implementation, however in the Global-Souththe reverse is the case (Robinson 2013). The global south is characterized by informality and implementing public policies are constrained by the presence of a bureaucratic and centralized planning framework. Curristine et al, (2007) argue that the efficiency of a public policy is contingent on the access to decentralized power. However, the work of (Devas 2005), highlights decentralization as being problematic, when multiple decisions are made unilaterally.

Contemporary methodologies of urban metabolism are not designed to look at the informal settlements, because of the limitation of data. (Musango et al, 2017). Belone-Saint- Pierre (2006) argues that the top–down planning methodology does not account for the relationship between urban activities and the metabolic flows, an essential requirement for the balanced relationship between cities and their ecosystem The social dimension of the relationship between urban activities and resource flow is leveraged in the bottom –up approach because it derives data from platforms and people interactions. The Bottom-up approach puts into consideration activities and flows not monitored by the state official statistics and reports. This is an advantage of planning informally without the use of empirical data.

According to the literature, there has been a growing debate bordering on the general planning procedure that should be adopted by cities across the world. There is a general notion that applying the parochial experience of Euro American cities is a useful theoretical model for all cities. Roy (2009), argues that this approach is narrow and limiting. Watson (2013), supportsthis argument by advocating for more experiences from the global south invariably recalibrating the conceptualized urban theory. Cities of the global north are often described through formal knowledge while cities of the global south are often described through ethnography, detailing attributes such as culture, customs, habits and mutual differences (Robinson 2013).

Another dimension to the difference in integrating planning concepts of urban metabolism practices between informal and formal flows borders on the social, economic and political aspects of resource distribution respectively (Ringo & Broto 2021).

In cities of the global north and south these attributes that are inherent and occur in different dimensions, understanding these differences provides clarity on how the cities are shaped, which affects the implementation of urban metabolism practices to sustainable planning.

Firstly, the social attributes i.e., landscape, culture, politics, and likeability noticeably differ for global north and south cities. Cities in Africa that are characterized by informality exhibit a social landscape of post- colonial configuration depicting the existence of high levels of urban primacy.

In this setup, the capital city superintends the political and economic decisions of a country (Robinson 2013). Urban primacy appears in autocratic leadership where the central city is a lot larger than the next city. This is in sharp comparison with a closer size in democratic set ups obtained in global north cities. The implication of centralization brings to the fore the issues of social inequality and resource equity. Wolman (1965), argues that a system bereft of adequate service supply is due to the lapses in management alluding that decentralized energy systems are more efficient. Secondly, the political attributes pose more of a problem for African/developing cities by upholding the urban political ecology discourse. Heynen (2006), identifies the city as not being black- boxed alluding to the urban actors that control metabolic flows. In the African context, centralization means control over -flows is uniformly experienced. More so, a critical lookat the sustainable agenda in both the global north and south country policies, reveals that the different goals and objectives are profound. The policies differ respectively with mitigation being attributedto north/formal countries (Hawken et al 1999; Korhonen,2008) and resource equity as the agenda for southern/informal countries. Simon and Leck (2014) simply put it that those African countries do not have enough access to energy, so more effort is focused on creating adequate energy options through adaptability. In the global north, the agenda is focused on reducing consumption levels through the adoption of efficiency in all ramifications. The underlying political issue in African/informal economies is further exacerbated by the ineptness of their political leaders who are in constant denial about the effect of urbanization on economic growth prompting more focus on the reduction of migration, other than the inclusion of urban growth and including development in policy plans.despite the varying needs of the global South, (Robinson 2013).Watson, (2013) alludes to the fact that urban planning in the south is influenced by planning practices from the north. Further to this the north can broaden its planning scope by learning fromthe experiences from the southern/informal countries.

The summary of the planning experiences from both informal and formal perspectives portrayed in the global-north and south divide informs on the need for more interactions of a city with its environment. Urban political ecology studies conceptualize cities as a socio ecological process, with various actors and stakeholders being responsible for determining the framework of a city (Heynen, 2006). The planning experience in informal countries implies that in order to integrate urban metabolism practices into public policies, there must be political will from institutions, leaders and decision makers to ensure a successful implementation of urban metabolism practices in both formal and informal economies.

3 OVERVIEWS OF THE NIGERIAN ELECTRICITY INDUSTRY.

This chapter identifies and analysis the major problems in the Nigerian Electricity Industry.

It further discusses informal electricity planning in Nigeria, describing the several efforts from the government in improving the electrification process in the country.

The limitation in the Federal Government electrification strategy is highlighted and a connection is created between the strategy and the objective of this research work.

3.1 The problem inherent in the Nigerian Energy Industry.

Nigeria is a country in the western part of the African continent that shares borders with Cameroon to the east, Niger to the north, Benin Republic to the west, and the southern border stretching into the Atlantic Ocean. It occupies the latitudinal and longitudinal region within 9.08200 N,8.67530E

It occupies a land area of about 924,000 km² with a population size of about 190 million inhabitants based on the census carried out by the National Population Commission in the year 2006 (Shaaban & Petinrin, 2014).

Nigeria has an abundance of various energy resources, such as crude oil, natural gas, coal and some renewable sources. The United States department for energy information administration (EIA 2020), ranks Nigeria as the largest crude oil producer in Africa. In addition to having the largest natural gas reserves in the continent. These fossil energy resources have provided a main stay to the economy, where it derives 90% of its total revenue from. The production level of crude oil resources suffers major setbacks with disruptions that emerge from the inadequate maintenance of the country's refineries, insufficient policies to improve on production quotas and the incessant social and political unrest in the Niger Delta Region, that result from the illegal activities of militants and oil bunkers (Oluwaniyi, 2010).On the global scale, Nigeria is ranked as the 10th country with the largest oil reserve, with estimate reserve of about 37 million barrels (OPEC,2020). The natural gas reserves supersede the level of has an estimated value of 200 trillion S.C.F in the year 2020 (EIA,2020). This includes the amount of associated and non-associated reserves in the country.

The country is also richly blessed with renewable energy resources such as wind, solar, biomass and hydropower. Nigeria has a hydropower potential of 14,750 MW and 3500MW for large and smallhydro respectively, according to the Energy commission of Nigeria (ECN, 2005).

14% of the large power potential is being utilized, providing about 1950 MW of electricity to the national grid, and on the other hand 3500 MW of small hydro potential which represents 23% of the nation's hydro power potential is yet to be harnessed as it is still in its infancy stage (Ohunakin et al,2011). Nigeria equally has a wind potential of 150,000 terajoule with an average speed of 2.0-4.0 m/s (Dioha 2018; Ajayi, 2010; Shaaban & Petinrin 2014; Idris et al 2020). According to the renewable energy master plan (2005), the potential for Biomass resources in Nigeria is estimated to be 61 million tonnes/year of animal waste and 83 million tonne/year of crop residue (Akuru & Okoro,2010). Nigeria also has adequate solar radiation that ranges between 3.5 -7.0 kWh/m2. Despite the availability of these energy resources, Nigeria is still categorized as a capacity short system with most of the capacity being underutilized. This has come to symbolize that the country is only able to generate a low amount of energy, which is inadequate to meet up with its energy demand. This inadequacy is linked to the problems that are inherent in the production of fuel and electricity that represent the direct energy forms in the country.

3.1.1 Access to Electricity.

One of the major sustainable development goals is to ensure access to affordable, reliable, sustainable and modern energy for all, according to the UN (2019), " Ensure access to affordable, reliable, sustainable and modern energy for all"(Goal 7).The organization for economic cooperation and development (OECD), which consists of 37 member countries spanning the globe from North and South America to Europe and Asia-pacific, includes countries such as: Turkey, United Kingdom, Japan, Australia, Spain, Germany, Norway, United States of America, Israel, Columbia, and Switzerland. These countries aforementioned, have been able to live up to the expectations of the United Nations sustainable development Goal 7, however most countries in the continent of Africa still fall below the threshold. Prior to the year 2019, about 1.2 billion people, which represents 16 % of the world's population were without electricity access, this number reduced drastically to 770 million.17% of the total number of 770 million people reside in sub-Saharan Africa. (IEA, 2020)

It is expected that with the current COVID-19 pandemic, there will be a drastic reversal of this trend due to the reason that the energy supply chain in these countries will be distorted, preventing the implementation of strategic roll out plans, which have been put inplace to improve the access rates by their respective governments.

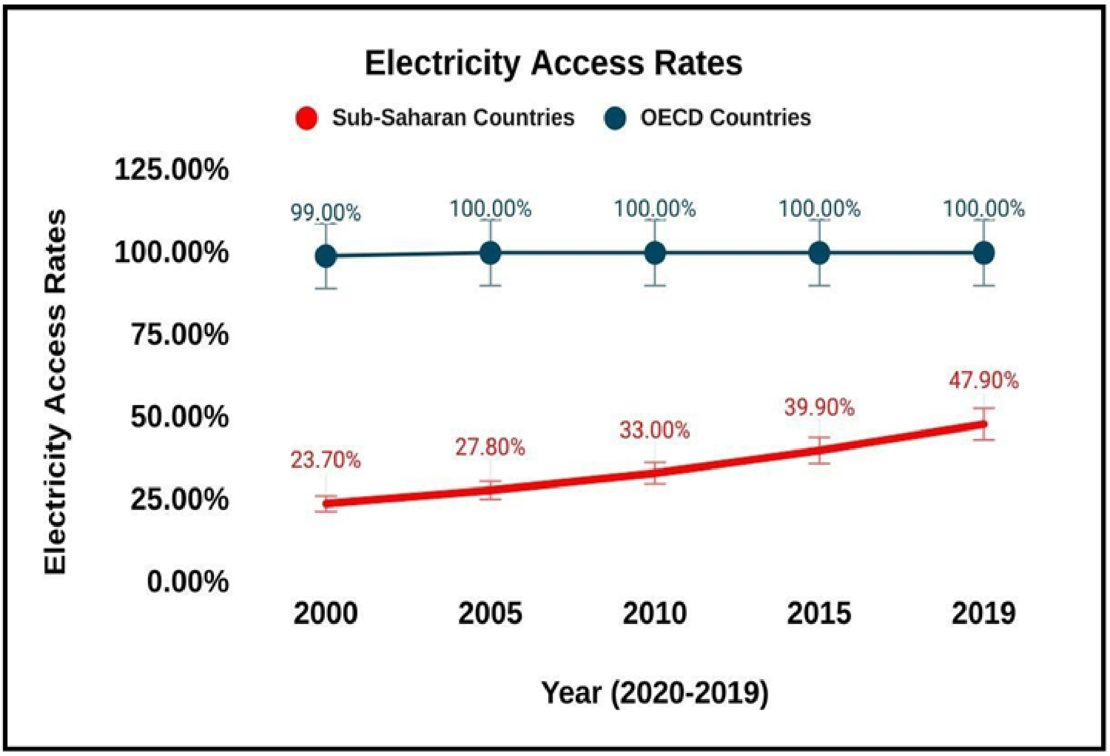

Figure 1. Electricity access rate. Source: IEA 2019.

Other countries who are not part of the OECD countries such as China and India have achieved electricity access rates of 100% and 95.2 % respectively (World Bank, 2018). The growing trends in electricity accessibility is being recorded in other regions across the World. The improvement can be seen in countries of South and Central America, the Northern region of the African continent and some developing economies in the Middle East and East Asia.

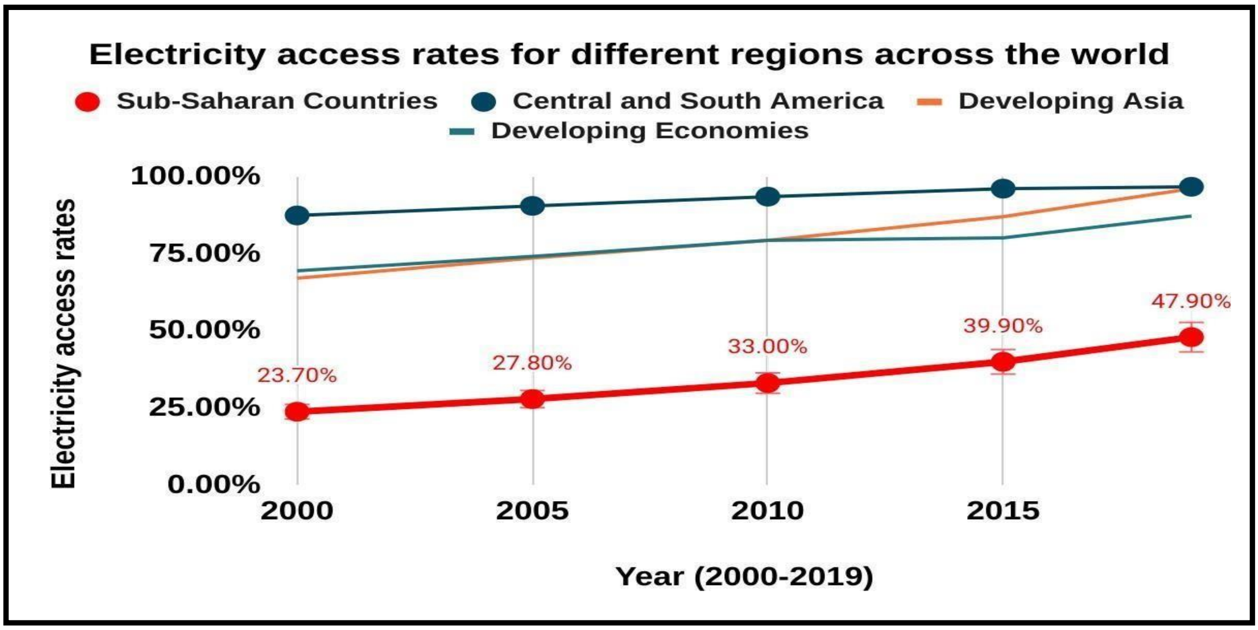

Figure 2. Electricity access for different regions across the world. Source: IEA, 2018.

In the year 2019, the average electricity rate of the world's population peaks at 90.0% which in sharp comparison to 47.9% across the sub-Saharan region of Africa, depicting a huge difference which requires addressing the situation of energy outlook.

More interestingly are the energy access rates that are observed within the countries that occupy the sub-Saharan region of Africa. Several countries such as South Africa and Kenya record a significant improvement in energy access from the year 2000 to 2019. In the year 2019, South Africa electricity access rate, peaked at 94.3%. Towards the eastern part of the sub-Saharan region, some countries such as Kenya and Seychelles record a peak in level of electricity access rates at 84.5% and 100%respectively. While countries such as Uganda and Tanzania, which are also included in the eastern part of the sub-Saharan region record low rates at 28.9% and 39.5% respectively.

The chart below (see Figure 3), shows countries in the eastern, southern and western part of the sub- Saharan region showing the sharp comparisons of electricity access rates. The electricity access rates of Nigeria still remain low in comparison with other developing economies around the World like India, South Africa and Egypt. These countries have future prospects and capability to compete on a global stage with western and developed economies.

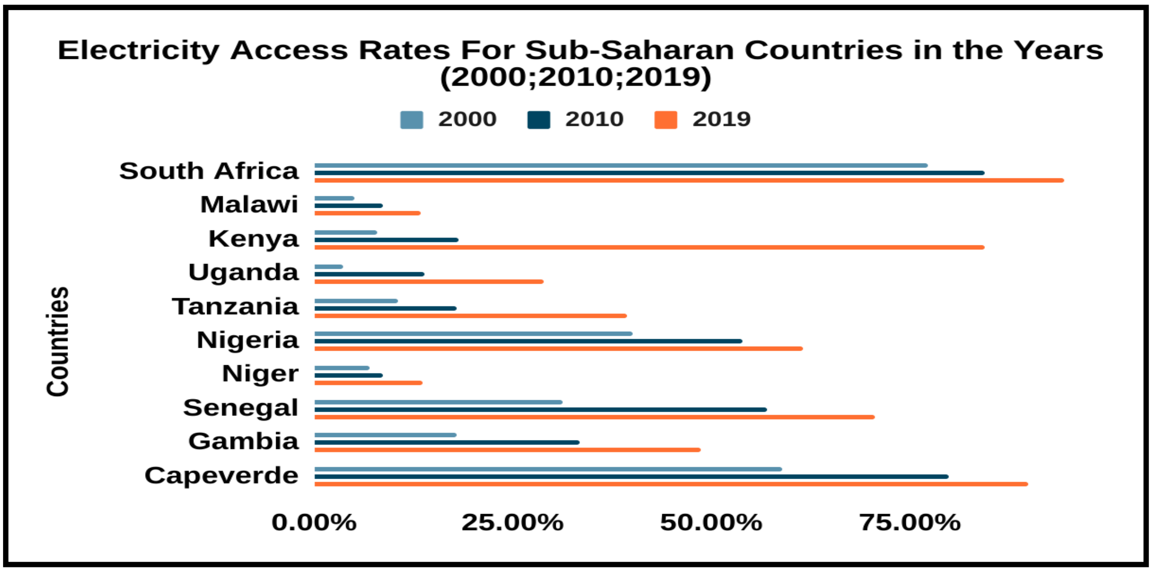

Figure 3. Electricity access for Sub- Saharan African Countries.
Source: IEA 2018.

3.1.2 Funding and Credit facilities.

The annual financial commitments in the energy industry are relatively lower than other regions of the world, in 2018; the sub - Saharan region received 9.91 billion dollars in financial commitments in renewable energy, while western Europe received 56, 79 billion USD. The region of Latin America & the Caribbean received 15,457 USD, and the region of East Asia and pacific 84, 24 billion USD. The region of south Asia received 14, 62 billion, USD. The OECD Oceana countries received 9,54 billion USD (Australia and New Zealand), OECD 81,61 billion USD, the Middle East and North Africa received 6,00 billion USD, Latin America & the Caribbean 15,47 billion USD. The Sub- Saharan region of Africa still lags behind in investment funding which is necessary to cover the capital cost and the cost of the operation and maintenance of renewable energy infrastructures. (IRENA, 2018).

The production costs of electricity vary across different countries and the implication financing options cannot be underestimated. The current financial practices in countries within the sub-Saharan region are a disadvantage to achieve the full deployment of renewable energy technologies.

Investors and foreign donors are not given enough incentives to attract their financial commitment. Sweerts et al, (2019), advocates for financial de risking to improve on investors' confidence after undergoing a study of renewable energy finance options for 46 African countries. The financing mechanism involves disaggregating the LCOE into the individual debt, equity, fuel, depreciation of the asset and the fixed and variable operating expenses. This is carried out to determine the causal link between the availability of finance options on the cost of generation. In these countries the weighted average cost of capital (WACC) varies across different technologies selected. Consequently, the renewable energy technologies with considerable higher risk reflect an increase in the value of WACC, the competitiveness of a renewable energy source in comparison to another will determine how the financing mechanism can be restructured, In most countries of the sub-Saharan region, the finance mechanism involves allocating a large portion of equity to investors, followed by the drastic reduction of debt, which on a long term drives the value of the WACC to an unprecedented level posing a threat to more investments. What this symbolizes is that there is a high level of volatility of returns in the sector and a high cost of debt servicing (Njiddah et al 2015).

The value of WACC and LCOE varies across several renewable energy and fossil fuel technologies. The energy technologies with high upfront investments consequently leads to a rise in the debt and equity portion of the WACC (Sweerts et al, 2019). Renewable energy technologies have a higher upfront investment cost, however non -renewable energy technologies have much of their generation cost influenced by the rise in the value of their fuel expenses, this is notable in natural gas and diesel. Solar and Wind technologies are competitive in comparison with natural gas and diesel when the absence of fuel cost is considered, but at a higher WACC value they become more expensive because of the capital cost component of equity and debt that is factored into the derivation of the WACC. The upfront capital cost of renewable energy technologies, wind and solar is higher thangas or diesel.

Generally renewable energy technologies are in good competition with fossil fuel technologies at lower values of WACC. Other renewable energy sources, especially small hydro and geothermal plants cost less than diesel and gas plants as a result of their lower operation and maintenance cost.

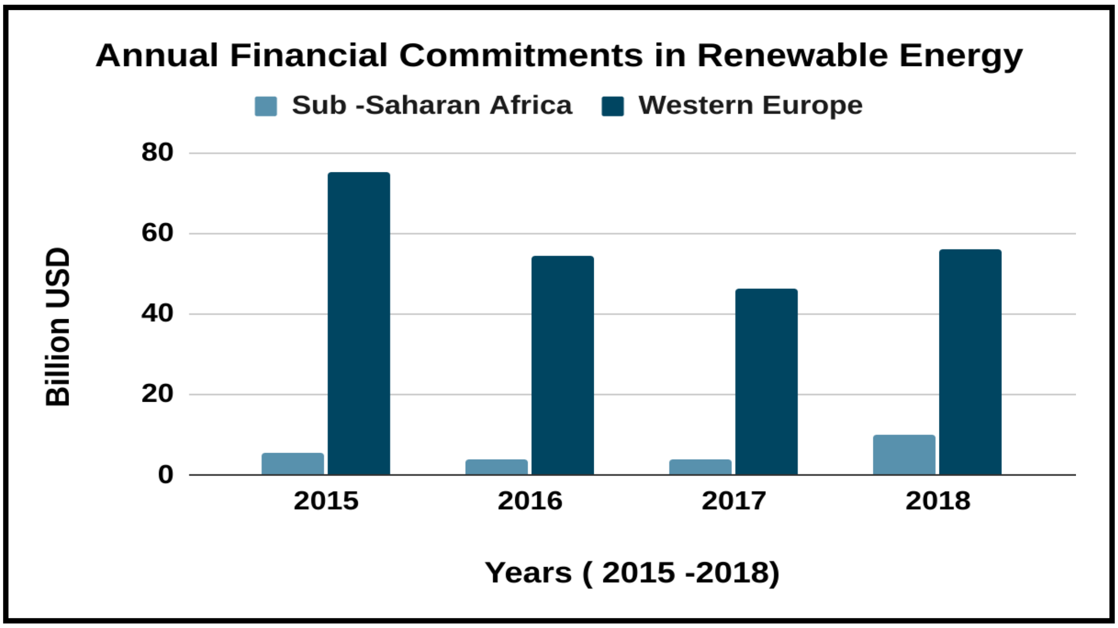

Figure 4. Annual financial commitment to renewable energy for Western Europe and Sub-Saharancountries.

Table 1. Showing the renewable energy sources.

Renewable Energy Sources	Weighted average cost of electricity /USD/kWh)	Change in cost from 2017
Bioenergy	0.06	-14%
Geothermal	0.072	-1%
Hydro	0.047	-11%
Solar PV	0.085	-13%
Concentrated Solar Power	0.185	-26%
Wind offshore	0.127	-1%,
Wind onshore	0.056	-13%
Coal	0.92	-
Natural Gas	0.12	-
Diesel	0.25	-

Table 2. Renewable energy sources with the WACC.

Renewable Energy Sources	Weighted average cost of electricity /USD/kWh)	Change in cost from2017
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		-26%
Wind offshore	0.127	-1%
Wind onshore	0.056	-13%
Coal	0.92	-
Natural Gas	0.12	-
Diesel	0.25	-

Source: IRENA (2018).

The prospects for growth in the level of Investment in renewable energy projects in sub- Saharan Africa is dependent on the risk concerns that emerge from political and financial instability. Most of the countries that occupy the region are engulfed in political conflicts.

An example is the act of terrorism from Islamic militant groups in the Northern region of Nigeria, coupled with the continuous destruction of oil and gas assets such as pipelines and storage facilities in the Niger delta region, which is located in the Southern part of the country (Olusola, 2013). Other countries such as Sierra Leone, The Democratic Republic of Congo, the Republic of Niger and the Republic of Chad are experiencing fairs share of political instability which gives these countries a high level of WACC and thereby reducing investor appetite. Beside from the country risk that stymie the flow of capital to fund renewable energy projects, there is the financial instability component involved as well (Sweerts et al, 2018).

The dimension of financial instability is apparent In the Nigerian electricity industry, since the inception of the privatization process that sold government utilities to private individuals, the electricity sector has been plagued with a liquidity crisis. The liquidity crisis has lingered up until this moment since the inception of the privatization process was completed in the year 2013.

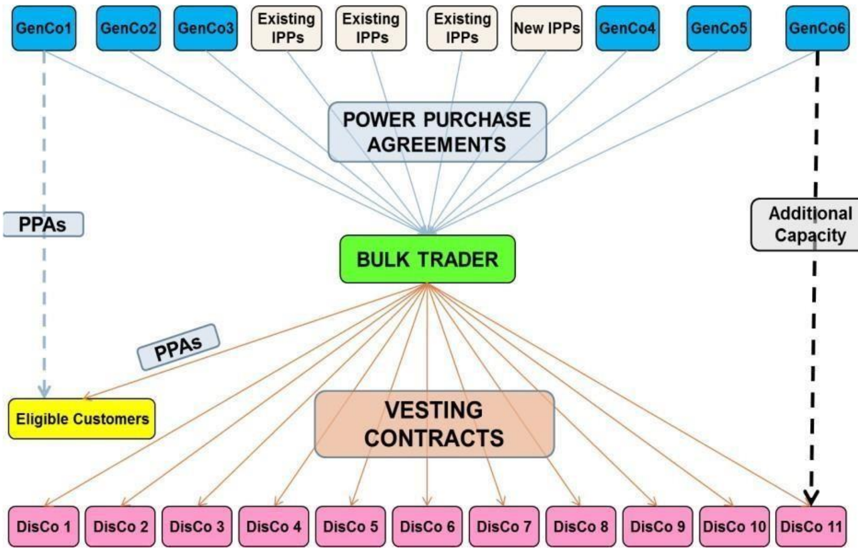

Figure 5. The structure of the electricity industry in Nigeria.

From the perspective of the Nigerian electricity supply industry some challenges contribute to the lack of investor confidence which include; non cost reflective tariff, gas supply constraints in the generation and transmission infrastructures, and a huge amount of aggregate, technical, commercial and collection losses (ATC&C), which is an important component of the electricity tariff (Banwo & Ighodalo, 2018). The creditworthiness of the key players in the supplychain i.e., Gas suppliers to the GENCOS (Generating companies), the electricity bulk trader (NBET) and the Distribution and Metering companies (DISCO and METCOS) respectively, is also a great concern for investor confidence in enabling adequate cash flow into the system see figure 3.5 for the overview of the Nigerian Electricity Industry.

Across the electricity supply chain, the level of trust between key players is determined by creditworthiness. The relationship is strengthened when each side fulfills its obligation in making scheduled payment under the power purchasing agreement and the vesting contracts respectively. The liquidity crisis emerged when parties failed to meet up with their respective financial obligation, consequently distorting the supply chain. The building up of debt overtime culminated into a large deficit of US $ 1,500,000,000 (One Billion Five Hundred Million United States Dollars) in the year 2016 (Banwo &Ighodalo,2018). The tariff shortfall in 2019 -2020 rose to a value of 1.1 tons (One trillion and 1 billion Naira). This credit profile makes soliciting for financial loans from local banks and international donors an almost impossible task. According to the report created on the review of the Nigerian Electricity Supply industry by EMRC (2020), it finds that anincrease in the electricity tariff will address the issue of liquidity.

It all begins from the metering section of the electricity supply chain, where the lack of meters leads to customer dissatisfaction and unwillingness to make payment on the claims of not receiving electricity from their distribution service providers (DISCOS). The absence of meters, make it difficult for electricity customers to determine their actual electricity consumption, which leaves them with huge estimated bills. The DISCOS claim to be owed over N156 billion (410 million USD) in debt from their different customer classes, which includes private residencies, government ministries, departments and agencies (MDA), and the military The GENCOS claim they are owed N155 billion (407 million USD) by the DISCOS, and the Gas supply companies, that sell gas to the GENCO claim to have unpaid receipts of about N110 billion (289 million USD) (Banwo & Ighodalo 2017). All these debts are a result of the inefficiencies experienced in the supply chain as a whole. A total sum of N354bn (931 million USD), is required to meter all the enumerated customers, according to the report on the review of the Nigerian electricity supply industry EMRC (2020). The issue with metering moves up the supply chain distorting the operational efficiency of the distribution companies. The collection efficiencies of the distribution company are drastically reduced by the inability to receive money from the customers, who are under their operating franchise areas.

This problem associated with collection of payment for delivered power, coupled with the technical and commercial losses, constitute the distribution companies aggregate ATC&C losses.

The value of WACC ranges from 10% to 35% in sub-Saharan African countries. In 2018 the average weighted average cost of capital (WACC) in OECD countries is 7.5% and 10% for China and the rest of the world for renewable power generation technologies (IRENA, 2019).

3.1.3 Gender mainstreaming.

The gender situation in Nigeria is far from equal. The Nigerian society is still much characterized by the dominance of patriarchy with more men occupying different positions in the education, administrative, financial and every other sector of the economy.).

Generally, women earn 77% for every dollar that men get for performing the same job, and in the political scenery only 24% of women were among members of parliament. In the energy industry, women represent 13% of the total number of people that qualify for productive use of energy through land ownership.

Empirical literature that touches on gender, development and poverty suggest that electricity is empowering (Pueyo et al, 2018; Pueyo and Maestre 2019; Cecelski 2005). Creating access to sustainable electricity is considered a major challenge for gender equality, as it is generally observed that society is patriarchal and Men generally are mostly favoured, with women, and younger girls usually are at the tail end of inequality, the reason why energy policies are constantly re- evaluated to include empowerment measures (Groot et al, 2017).

The general hypothesis is that gender equality is expected to increase with the subsequent increase in access to electricity. A careful review on household literature on electricity access deduce that women and young girls are primarily responsible for taking up roles of domestic care and cooking, which is a typical situation in the Nigerian household According to (Groot et al, 2017; Pueyo, 2019; Skutsch and Clancy, 2006; Mehta and Kumar, 2016; Yadama, 2013) household activities that involve domestic work and cooking, exposes women and young girls to health hazards from the exposure to poor quality cooking fuels like firewood and charcoal. (Naeher etal, 2007; Muneer et al, 2003) establishes that wood smoke emits significant quantities of NOx (Nitrousoxide) and CO(carbon monoxide) in large proportions, which are carcinogenic compounds. The replacement of traditional biomass (Yadama, 2013; Gyamfi and Urmee, 2014), with modern energy sources like Electricity and LPG have been proven to not only reduce drudgery at home, but also re allocates time spent on tedious task for paid work in the formal sector. This is provided in house-hold literature on the principle of time use. (Kooijman-van Dijk,2012; Mehta and Kumar, 2016). The impact of electricity on labour supply to households is observed in the studies conducted by (Banerjee et al, 2011 and Chowdury, 2010).

The findings include that more women can easily perform several tasks in the household with improved access, however Tanguy and Salmon (2016) argue that electrification has a positive impact on the working time of men, and not women.it concludes that electricity access only improves on the time spent on leisure and unpaid work. Consequently, energy access will need to transition from household usage to productive purpose in order to improve the skills set and earning of women and young girls (Pueyo and Maestre 2018).

Cecelski (2005) establishes the correlation between the income generating attribute of productive usage of electricity and economic growth. Electricity access plays an important role in human development. The author also identifies a correlation between energy consumption and the UN human development indicators; life expectancy and the level of literacy as a means to show the importance of electricity access in eradicating poverty. However, the evidence of the income generating impact of electricity on gender empowerment still remains unclear. Pueyo et al, (2018), argue that electricity access for productive usage is necessary but not sufficient for generating income and reducing poverty by providing evidence of various contributing factors to the progress of gender mainstreaming.

Several authors contributing to the literature of productive use of electricity and gender empowerment include the work of (Groot et al, 2017) where linkages between gender, entrepreneurship and access to energy in the informal food sector are explored. The work reveals that women have access to energy but limited rights of control over their various enterprises, and emphasizes on the need to create an enabling environment to empower women in the future. (Pueyo and Maestre, 2019) follows a similar approach by linking energy access, to gender and poverty, focusing on the impact of productive usage and the intervention on male and female enterprises. This further implies that access to skills and decision-making powers are constraints to gender empowerment. Winther et al, (2020) emphasizes on the decision-making constraint on empowerment in Mahadevsthan (Nepal), Homa Bay (Kenya), Chattisgrah (India). Empowerment is examined on a micro political framework revealing the lapse in energy justice. The work suggests that women’s agency must improve in order to better the chances of women´s participation in decision making. (Sovacool et al 2014; Parikh 1995) also delves into energy justice and equality,and focuses on the provision of an enabling environment for gender equality. Pueyo et al, (2018) uses business performance and energy consumption as dependent variables to determine if female enterprises benefit equally from their male counterparts by conducting a comparative study on empowerment in Ghana, Tanzania and Myanmar. Findings from the study reveal positive changes when gender interventions are implemented. Mahmud et al, (2012) measures women empowerment in rural Bangladesh with the use of 5 indicators and conducted a linear regression to examine the effects of covariates to prove that a woman´s exposure to television predicts three of the five indicators. A previous study was conducted in Bangladesh to assess rural credit programs on women’sempowerment in 1996.

The indicators used in this study include; mobility, economic security, ability to make small and large purchases, involvement in major household decisions, relative freedom of domination and involvement in political campaign. The women were given questionnaires and respondents were given a scores between 1 to 3 to weigh these variables in determine their importance in measuring empowerment (Riley et al,1996).

According to Skutsch, (2005), energy functions as a key player in production and in order to benefit from its income generating attribute, access and control must be equally distributed across disaggregated gender roles. Several authors (Clancy et al a, 2003; March et al 1999; Groot.et al,2017) suggest that this perceptive gender role represents the definition of empowerment, The UN describes empowerment to mean creating the enabling environment for young women and men as partners in achieving gender equality from economic empowerment and skills development (UN, 2017). From a human rights and feminist perspective, empowerment implies creating access for women in decision making in social and political circles. (O'Neil and Domingo, 2015; Krook and Mackay, 2011; Paxton et al, 2007; Waylen et al, 2013). The abstract understanding of empowerment makes it difficult to harness the income generating impact of productive uses on empowerment. Empowerment is contextual and its meaning is interpreted in various ways, Skutsch, (2005) suggests a goal-oriented definition of empowerment that takes into consideration the specific needs of gender. While there is not standard or globally agreed definition of the word empowerment, it can be deduced that any process that creates the opportunity to enlarge the decision-making power of women, the youths and other vulnerable groups by giving them access and control over resources is a starting point. Generally, the standard approach to measuring gender empowerment is provided in the UN human development report 2019 (UN, 2019). The UN uses the gender inequality index as the benchmark for determining observed gender differences. It measures inequality in three important areas of human development; reproductive health measured by mortality ratio and adolescent birth rate; empowerment, measured by the improve in status of female and males aged 25 years and older with some level of education and economic status. Prior to the use of the Gender Inequality Index, GEM index was used to measure the gender equality (UN, 1995). GEM is an integrated measure of four indicators; women's representation in parliament, the percent of women as legislators; senior officials and managers; the proportions of women employed as professionals; and the female-male wage ratio (income), used to measure gender equality.

As a result, the GEM is only a reflection of the inequalities experienced in the developed countries. The GEM has also been criticized for focusing on the income aspect for determining the overall score for GEM. Several authors on gender empowerment have applied the GEM index. Ruppanner, (2010) Cross national reports of housework, investigates the relationship between country level gender empowerment on household working hours. Findings from this work reveals that GEM index has a positive and linear relationship with men’s house work hours. Bardhan and Klasen, (1999) critically reviews GEM andGDI proposed indices in the UNDP human development report in 1995. Identifies the limitations with using them to assess gender gaps of inequality in women. Cecelski, (2005) creates a Gender energy poverty index at global level to address energy vulnerability by drawing on the to compensate the limitation of the GDI (gender development index) and GEM (gender empowerment measure).

In the work of Agarwal (1997), A GEP (Global Energy Poverty Index) was formulated to measure variations in gender-environmental-poverty vulnerability across regions and shifts with respect to time gender-environmental-poverty vulnerability. Findings reveal that rural women perform the worst in regions where all three forms of disadvantage in the nexus; gender bias, environmental risk and poverty. It is without doubt that the success of the energy sustainable agenda in Nigeria is preconditioned on the ability to close the existing gap on gender.

3.1.4 Informal electricity planning and rural electrification in Nigeria.

In order to find solutions to the major problems of the electricity industry; (1) Low Access to Electricity; (2) inadequate financing and credit facilities; (3) Gender Equality and Mainstreaming. These issues are discussed in details below. The Federal Government of Nigeria is currently streamlining strategic plans aimed at improving the process of electrification in the country. This plan is accelerated through its implementing agency, the Rural Electrification Agency (REA).

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The core mandate of the REA is to:

- Co-ordinate rural electrification programs for informal communities which are unserved and underserved in the country
- Administer the Rural Electrification Fund (REF) which promote and support rural electrification through public and private sector participation.

The REA has reached the following milestone in solving the country's electrification problems since its inception in 2006, which include:

(1) Low electricity access rates: Electricity access rates have improved from 47.8% in the year 2006, to 61.6% in 2019 (IEA, 2021). This represents 29% growth rate in electricity access that has been achieved by the REA. The REA under the Nigerian Electrification Program with the support of the World Bank and the African Development Bank, embarked on the proliferation of solar hybrid mini grids and solar stand-alone off- grid solutions in four different components.

The components include:

- Energizing Economies: This is an initiative aimed at supporting the rapid deployment of solar technology to medium and small-scale enterprises in economic clusters (such as markets and agricultural/industrial firms).
- Energizing Education: Which is aimed at providing Solar Off-Grid solutions to universities and institutions of higher learning.
- Solar Hybrid Mini Grid; The mini grid component aims to support 300,000 households and 30,000 productive use enterprises.
- Stand Alone Solar Systems (SHS): This component aims to provide homes that are underserved with solar home systems to power basic appliances.

(2) Inadequate financing and credit facilities: The Rural Electrification Agency with the support of the World Bank and African Development Bank (AFDB) set up the Rural Electrification Fund. The funds amount to a total sum 5.7 million USD of the funds are used to promote electricity expansion using renewable off- grid and on- grid electrification through a subsidies and technical assistance.

The REF funds include components I and II, which includes 63-Mini-grid projects ranging between 30kw and 100kw. 20,000 units of solar standalone home systems, research and innovation.

The funds available for the Solar Mini grid Component of the Nigerian Electrification Program is 150 million USD. This fund is accessed through a minimum subsidy tender and a performance-based grant which is set at 350$ per connection for would be investors.

The funds available for the Solar Home Systems component, comes in the form of an output-based subsidy, where the investor is required to meet a minimum threshold requirement of distributing 150 systems per month, in order to benefit from the financial support.

(3) Gender Mainstreaming: The REA hosted a workshop on Gender in collaboration with USAID and Power Africa in 2019 titled: Amplifying Gender in the Energy Sector. The problem concerninggender inequality is not fully addressed at the moment of this research work.

Secondly, the strategy on gender mainstreaming is still in its infancy stage with no basic blueprint on the way forward.

This research work will apply the multi-criteria decision-making tool to analyze six renewable energy technologies. In section 7 of this research, two policy case scenarios are created, which involves the analysis of the rural electrification plan. The first scenario represents the use of solar as the only renewable energy source available, which represents the current status of the rural electrification plan. This is compared with the outcome of the other policy scenario on the condition that other renewable energy sources are being utilized.

The research work also includes community energy participation from men and women, who are inhabitants of the informal settlements in view. The idea is to have an equal representation of gender, thereby obtaining information that is necessary to conduct a bottom-up planning approach as it relates to the issues affecting the different gender groups respectively.

4 METHODOLOGY.

In this Chapter we propose a combined methodology to analyze the inclusion of renewable energy in four informal settlements under the framework of urban metabolism. The methodology is applied in two stages which includes: the selection of the renewable energy resources and community energy participation.

The selection of the most appropriate renewable energy source is done with the aid of a hybrid multi criteria decision making method. This thesis applies the Analytical Hierarchy Process, to determine the weights of the criteria and the PROMOTHEE GAIA software to prioritize the available alternatives before coming to a conclusion.

The community energy participation involves creating a community energy model from the collation of data of households and productive enterprises and subsequently involving community members as participants in the decision- m a k i n g process, through a semi- structured interview and the creation of focus groups, which includes men and women to represent both gender groups.

Random sampling methodology is selected to achieve the purpose of data collation. This chapter clearly illustrates the procedure involved in obtaining the results from the thesis.

4.1 General Methodology.

The methodology is applied in 6 different stages. The information that is required for the application of the methodology is the bibliographic review on previous research work, with direct interview surveys, questionnaires and scientific data.

For this research work we select a hybrid decision making model, which integrates decision making from expert opinion and community agents.

The hybrid model consists of PROMETHEE/AHP/Entropy decision making method and a community energy model, which is derived from member participation in the decision making at local level.

The methodology also involves the use of scenario analysis in the projection of energy demand in the Greater Karu Urban Area. In order to obtain community level data, a semi structured interview.

In-order to obtain the most appropriate technology, the use of Multi Criteria Decision Analysis (MCDM) is widely considered. These techniques have been applied in various studies for energy planning, most especially in some aspects of informality where there is a lack of adequate data.

The Analytical Hierarchy Process is used to determine the weights of the criteria through the consultation of expert opinion. The criteria weights are defined, for the different renewable energy alternatives, and are given scores based on their level of importance. The criteria weights obtained are then applied to the PROMETHEE – GAIA software for selecting and prioritizing the most preferred option to be included in the direct energy mix of the four informal settlements. The entropy method provides a means of comparing criteria weights in order to improve on the level of accuracy in the selection process.

The community energy model is used for planning in communities, where generation, distribution and storage schemes allow inhabitants to cooperate and manage their local energy needs through demand side management in an efficient way. There is no generic standard for the use of a community energy model, the analysis of a community's energy requirement is specific and tailored to meet its individual as every community is unique in its energy consumption profile.

The community energy model involves the sampling of data through a survey of households and productive enterprises. The households and productive enterprises are classified according to their individual typologies. This is done in order to understand the metabolic pattern of direct energy flow in each prototype.

The estimation of the energy requirement of the typologies of households and productive enterprises in the informal settlements is carried out with the use of the electrical appliance estimating method The results of the community energy model help to determine energy indicators that are community specific, enabling the creation of three scenarios that will determine the effect of the inclusion of renewable energy into the energy mix at different periods. The methodological framework is depicted in Figure 6.

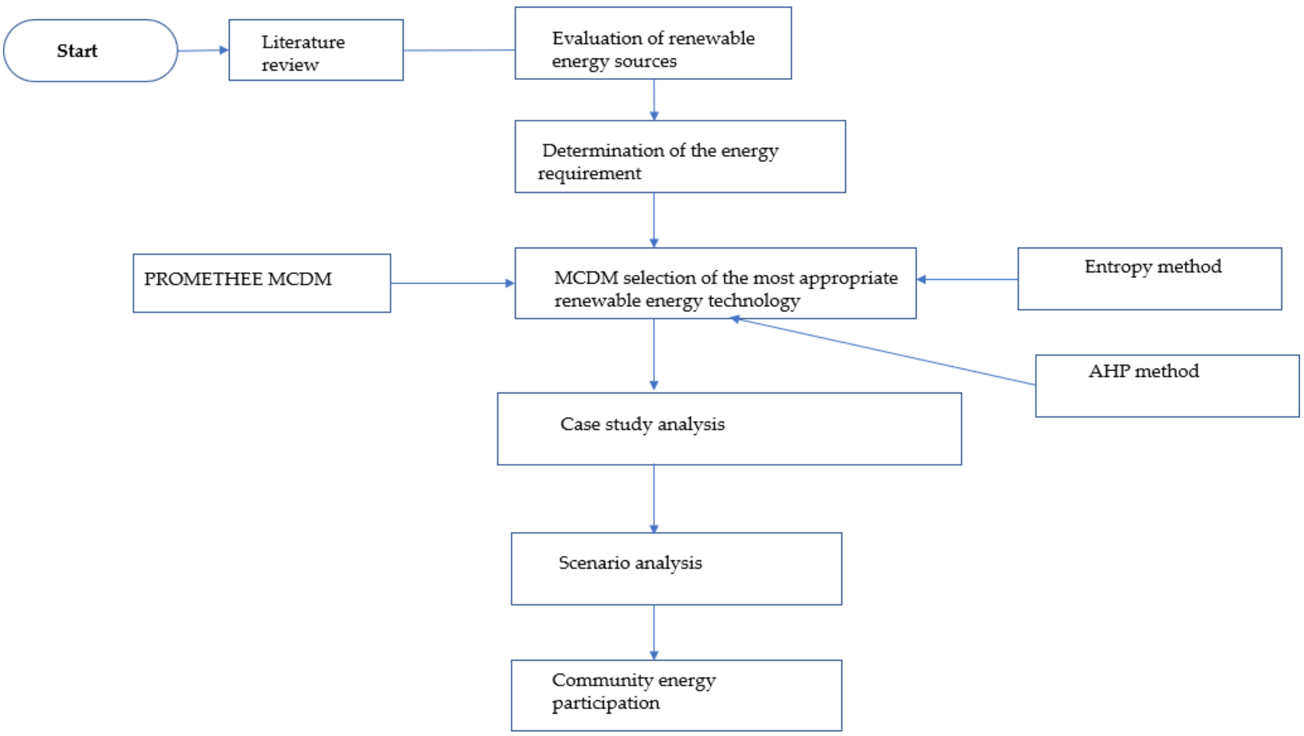

Figure 6. Methodological Framework.

4.1.1 Multicriteria decision making methods.

The importance of renewable energy cannot be overemphasized considering their capability to replace conventional sources of energy in most of their ramification, hence it is imperative to consider the factors and policies that pilot their selection procedures in order to procure the necessary investment.

Selecting alternative energy sources for direct energy consumption purpose is multidimensional; the decision-making process encapsulates the technical (efficiency, primary energy ratio, safety reliability etc.); economical (investment cost, operation and maintenance cost, fuel cost, net presentvalue, service life etc.); social (social acceptability, job creation and social benefits); and environmental (CO_2 emissions, SO_2 emissions, land use, noise etc.), criteria. These criteria are multifaceted, becauseof the complex nature of capturing the socio-economic factors that are often neglected in reality. It is against this back drop that multi criteria analysis becomes an indispensable tool to merge all perspectives concerned with the decision-making process. Demirtas (2013), suggests that the determination of indicators is the first step in sustainable development design and monitoring. The indicators must always reflect the wholeness of the system in order to deal with the complexity of sustainable related issues. These complexities emerge as a result of a large pool of quantifiable and non- quantifiable objectives, which are usually conflicting and therefore the solution is largely dependent on the discretion of the decision maker with the inclusion of a compromise (Loken, 2017 ; Ramachandran &Pohekar, 2003).Various studies on the multi criteria decision methods for renewable energy selection have been published in literature and are consistent with the findings from the work of (Daim, and Taha, 2013).In this published work, the author attempts to generalize multi criteria decision making methods into two categories: Multi -Attribute Decision Making (MADM) and Multi- Objective Decision Making (MODM). In multi attribute decision making, there are a number of alternatives that can be analyzed, while on the other hand, multi order decision making has no defined alternatives. It simply uses optimization techniques for selecting its outcome giving more popularity to MADM. This view ofgranting more preference to MADM in comparison with MODM is supported in the research published by Demirtas, (2013). It highlights AHP as the best method for evaluating renewable energy technology for sustainable energy planning. The main objective of the MADM is to select the alternative, which has the highest score by carefully weighing the different sets of criteria as highlighted in Chawla. (2015), thereby creating a link between weighting schemes and preferences in obtaining results.

Loken (2007), gave priority to AHP and MAUT in deriving suitable multi criteria decision making methods for local energy systems with multiple energy carriers. AHP (Analytical Hierarchical Process) and MAUT (Multi attribute utility theory) fall under the category of multi attribute decision making methods; they are often referred to as value measurement models, where scores are assigned to each criterion. There are other decision-making models, which have similar functions. The Technique for Order. Preference (TOPSIS) and VIse Kriterijuma Optimizacija Kompromiso Resenje (VIKOR), are classified as additional preference models. Eliminating, and Choice Translating Reality Method (ELECTREE) and Preference Ranking Organisation Method for Enrichment Evaluation (PROMOTHEE), are also classified as subsets of MADM. The work also advocates for the use of PROMOTHEE and ELECTREE, which are characterized as outranking in functionality to prioritize alternatives in the decision- making process. The common observation with AHP, PROMOTHEE and ELECTREE method is the use of pair- wise comparison to filter off less important alternatives. In general, MADM applies four basic steps, which are: criteria formation, criteria weight determination, application of value judgement with regards to acceptable evaluationand finally the decision making.

(Ramachandran and Pohekar,(2013);Cajot et al, 2017) conduct an analysis of multi-criteria decision-making methods in urban energy system planning and takes a slight detour from the views upheld by (Daim and Taha, 2013). Findings from the published work suggest there are no best or "most popular models in existence. Applying either an MODM or a MADM to obtain results is largely dependent on the identified problem. This notion is contingent on the fact that decision makers do not accurately quantify theexact weighting of key drivers or indicators before applying them as filters in obtaining the best alternative from the outcome of the decision. This further showcases the existing gap in literatureconcerning the accuracy of multicriteria decision making models in general.

The peculiarity of the multicriteria decision making model in selecting the most preferred renewable energy alternative is in most cases undermined, and couple with the fact that most countries have specific renewable energy targets. The implication is that decision makers will need to combine several methods depending on the context in which the problems are manifested in the decision to be made. In other words, it is not a straightforward process. Other authors in strong support of this point, agree on the need for a hybridized form of decision-making tools.

Cristobal, (2009) applies the VIKOR method combined with AHP to arrive at a compromise ranking method, which is close to an ideal situation to select renewable energy projects in Spain. Tsoutsos et al (2009) apply PROMOTHEE I and II methods to critically analyze sustainable energy planning in Crete.

Kahraman, (2009) applies an integrated Fuzzy-VIKOR and AHP methodology to assess the best renewable energy alternative in Istanbul. Other methods such as SWOT, Delphi techniques, and expert determination, cannot be ruled out as possible methods for assessing renewable energy alternatives, as their importance in identifying stakeholder contribution in the form of socio-economic and environmental impacts cannot be overemphasized (Polatidis et al, 2005).

4.1.2 Renewable Energy Sources in the City.

There are six renewable energy sources majorly present in Nigeria; their sources and their final usage is provided in the table 3 below:

Table 3. Renewable energy technologies in the city.

Renewable Energy	Source	Conversion	Usage
Hydro	Water	Mechanical energy	Electricity production
Solar PV	Solar irradiation	Solar Energy	Electricity production
Solar Thermal	Solar irradiation	Heat exchange	Electricity production
Wind	Wind speed	Mechanical	Electricity production
Biomass	Municipal waste, Agri-foods , Sawdust, Fuel wood, Energy crops	Combustion and Anaerobic	Electricity/Fuel consumption Electricity/Fuel consumption
Geothermal	Earth rocks	Heat exchange	Electricity

These renewable energy sources can be obtained in the cities and its sub urban/ informal areas, the energy released from these sources in the form of their respective calorific values, can be used to replace the energy requirements for electricity and fuel usage. The strategic location of these sources also determine how the Government of Nigeria will enact policies to accelerate their usage.

4.2 Application of MCDM.

The application of multicriteria method is dependent on: real values of the user. The decision-maker is provided with the necessary information in order to carry out its measuring functions (Loken, 2007). The selection of the most appropriate multicriteria method for this research work involves a bibliographic review of the application of different multicriteria methods from previous research work, before determining the most appropriate for this research work. The preferential selection is premised on what is deemed appropriate for the application of renewable energy technologies in informal settlements.

Table 4 depicts previous studies that have used multicriteria methods for the selection of renewable energy technologies. In some cases, there are studies that make use of a hybrid methodological approach carried out on a national and regional level.

Outranking models such as PROMETHEE, TOPSIS, ELECTRE, and VIKOR have been applied in prioritizing and selecting the best choices by attributing scores that represent the level of importance of the alternatives that are under consideration. The selection process is guided with the help of criteria that filter the less desirable alternative.

In the selection of renewable energy sources, the outranking decision-making models are very popular. In this research we employ the use of PROMETHEE software, with the consideration of three systems of criteria values, which include the Equal, Entropy and AHP methods. The peculiar nature of the selection of renewable energy sources in this research work is the consideration of informal contributions in determining the overall selection of the most desirable renewable energy technology. Other decision-making methods such as COPRAS, WAPSAS, and the Fuzzy methods are very popular in the literature of MCDM.

Table 4. Literature revie on MCDM methods.

Technology	MCDA Method	Sources
Wind, Biomass, Solar and Hydropower sources	WSM, VIKOR, TOPSIS &ELECTREE	(Lee & Chang, 2018)
Wind & Solar	PROMETHEE, ELECTRE, FUZZY, ANP& DSS	(Kim et al,2017)
Solar	AHP, TOPSIS, VIKOR	(Abdel-Basset et al,2021)
Solar	Fuzzy AHP	(Saraswat et al,2021)
Wind, Biomass, Solar, Hydropower, Geothermal	GIS, Fuzzy Theory	(Shaw.et al, 2020)
Solar PV	AHP, MULTIMOORA, IVFF	(Seker & Kahraman, 2020)
Biofuel	TOPSI, ARAS, WAPSAS	(Firouzi et al,2021)
Biofuel, Solar, Hydropower, Wind &Geothermal	AHP- CODAS	(Ali et al,2020)
Biofuel, Solar, Hydropower, Wind &Geothermal	Shannon Entropy -EDAS model	(Yazdani-Chamzini et al 2018)
Solar PV, Solar Thermal, Wind Power, Geothermal & Biomass	Shannon Entropy -EDAS model	(Yazdani-Chamzini et al ,2020)
Wind & Solar Energy	Fuzzy MCDM technique	(Jahangiri et al,2020)
Solar PV, Solar Thermal, Wind Power, Geothermal & Biomass	Hesitant Fuzzy Linguistic (HFL), AHP with HFL	(Buyukozhkan et al ,2018)
Wind and Solar PV	Fuzzy numbers (TINS)	(Wu et al,2019)
Biofuel, Solar, Hydropower, Wind &Biomass	Fuzzy Goal Programming	(Hocine et al 2020)
Solar PV, Solar Thermal, Wind Power, Geothermal & Biomass	TOPSIS and Fuzzy	(Rani et al,2020)
Solar PV, Solar Thermal, Wind Power, Geothermal & Biomass	SWOT-Fuzzy AHP	(Wang et al, 2019)
Solar PV, Solar Thermal, Wind Power, Geothermal & Biomass	AHP	(Waewsak et al,2020)

Solar PV, Solar Thermal, Wind Power, Geothermal & Biomass, Hydropower, Tidal wave	Fuzzy entropy based fuzzy COPRASand MULTIMOORA	Alkan & Albayrak,2020)
Solar PV, Solar Thermal, Wind Power, Geothermal & Biomass, Hydropower	MCDA analysis, PROMETHEE	(Terrados et al,2009)
Solar PV, Solar Thermal, Wind Power, Geothermal & Biomass, Hydropower, Tidal wave	MCDM	(Yazdani-Chamzini etal,2020)
Solar PV, Solar Thermal, Wind Power, Geothermal & Biomass, Hydropower	MCDM	(Zhang et al,2015)
Tidal Wave	ANN & MCDM	(Ghosh et al,2016)
Solar PV, Solar Thermal, Wind Power, Geothermal & Biomass, Hydropower	Fuzzy MCDM models	(Colak & Kaya,2017)
Solar PV, Solar Thermal, Wind Power, Geothermal & Biomass, Hydropower	MCDM	(Kumar et al,2016)
Solar PV, Solar Thermal, Wind Power, Geothermal &Biomass, Hydropower	Linguistic Fuzzy Preference relation	(Buyokozkhan &Guleryuz,2017)
Solar PV, Solar Thermal, Wind Power,Geothermal &Biomass,Hydropower	AHP	(Wu et al,2018)
Wind,Solar,Geothermal,Biomass, Hydropower	VIKOR ANP,WSM,TOPSIS,PROMETH EE.ELECTRE	(Li et al,2020)
Solar,Wind, Biomass, Geothermal	ANP	(Alizadeh et al, 2020)

4.2.1 PROMETHEE Method.

In recent years there have been several MCDA methods proposed for the selection of renewable energy, and the PROMETHEE method (Preference Ranking Organization Method for Enrichment Evaluations) is gaining momentum. The PROMETHEE method was developed by Brans, then later advanced by Vincke and Brans, (Vicke &Brans, 1985). Brans proposed PROMETHEE l and PROMETHEE II;a few years later PROMETHEE III,IV,V and VI were developed with Mareschal working alongside with Brans, (Brans & Mareschal, 1992). PROMETHEE is a method that applies the concept of outranking a finite set of alternatives, where their selection is determined by the weights of different criteria (Behzadian et al, 2010).

The preference for the selection of PROMETHEE GAIA software for this research work is the attribute of outranking of alternatives that it provides. This research work will rank therenewable energy alternatives for informal settlements for which the PROMETHEE GAIA software is deemed very appropriate.

PROMETHEE I and II application to a selection process, involves sorting out the alternatives totally or partially, PROMETHEE III on the other hand is used to ranking based on an interval, PROMETHEE IV is applicable for complete and partial ranking, while PROMETHEE V and VI apply to complexities in segmented constraints and human brain classification respectively (Brans & Mareschal, 1992).

The duo of Brans & Mareschal proposed the GAlA method for the pictorial representation of the PROMETHEE outranking (Behzadian et al, 2010). In the case where an alternative (a) is part of a selection of alternatives in a group (A) and a set of criteria (C); the outcome of the selection process is subjected to the environmental, technical, economic and social criteria with both alternatives and criteria represented in the form of matrices.

Max $\{c1(a), g2(a), \ldots\ldots\ldots\ldots gk(a) \text{ t } a \in A\}$……………………….

Where A is a finite set of possible alternatives (a1, a2…...ai…........ an) and

$\{c1(.)\ c2, (.) \qquad ck(-)\}$ a set of evaluation criteria.

The multicriteria denoted in the matrices (c1, c2, cj…) are defined as follows in a dominance relation:

For each alternatives (a,b) $\in A$

$\{\forall j: cj\ (a) \geq cj(b)\ \}$

$\{Ek: (a) > (b)\ \}$ - aPb

$\forall j: cj\ (a) = cj(b)$ - aIb,

$\{Es: (a) > (b)\}$.

$\{Er: (a) < (b)\}$ - aRb

$$E_r:(a) < (b) \rightarrow aRb \tag{2}$$

Where P, I and R respectively stand for preference, indifference and incomparability. Whether an alternative is better in comparison to another is determined if its minimum value is as good as the other with all criteria. For example, if alternative a1 is better on criteria s and a2 is better on criteria j it is impossible to decide which is a better alternative, in that case both alternatives are incomparable, (Brans & Mareschal, 2005). Incomparability is very common in most pairwise comparisons, where the dominance relation in alternatives is very poor in the preference (P) and indifference (I) values.

The pair wise comparison of alternatives in PROMETHEE II is conducted against different criteria in five main steps; and with further information such as the intra criteria and intercriteria, which show therelative importance between different criteria and the expression of each criterion on a scale (Brans & Mareschal, 2005).
The information between inter criteria and intra-criteria are required to run PROMETHEE in order to perform the decision-making analysis. The analysis carried out is subject to the different weights attached to each criterion which represents their relative importance. The heavier the weights the more important is the criteria.

The Analytical Hierarchy Process is used to determine the importance of the criteria weights. The determination of the different weights of the criteria is carried out by allowing the user to include arbitrary numbers, which are then divided by their sum for the weights to be normalized accordingly.
The selection of weights is hinged on the prerogative of the decision-maker, in the case of this research various contributions were given in form of expert opinions in determining the importance of the different criteria used in the selection of the renewable energy technologies

domiciled in the informal settlements of Karu district. The difference in weighted values of the criteria is what constitutes the necessary information between them that is required by the user in coming to a conclusion on the decision-making analysis.

On the other hand, the information within criteria is determined when the deviation of two alternatives on a criterion measured against is put into consideration (Brans &Mareschal, 2005). The significance wherein lies in the preference structure, with small deviations from the normal comes a small preference to the better alternative; much so that if the deviation is very small, the preference becomes negligible, and vice versa when the deviation is larger. The preferences have real numbers that vary between 0 and 1. Vincke & Brans (1985) proposed six types of preference function.

The usual criterion, the U-shape criterion, V- shape criterion, level criterion, V-shape with indifference criterion and Gaussian criterion.

The PROMETHEE II is based on a pair -wise comparison of alternatives ranking procedure occurs in 5 steps.

Step 1: normalization of matrix with the consideration of minimum and maximum criteria with the equations below:

$$R_{IJ} = \left(\frac{X_{ij} - minX_{ij}}{X_{ij} - minX_{IJ}}\right) \tag{3}$$

$$R_{ij} = \left(\frac{max(X_{ij}) - X_{ij}}{max(X_{ij}) - \min{(X_{ij})}}\right) \tag{4}$$

Where $Rij \text{ and } Rij'$ stand for the matrix values for the minimum and maximum criteria.

Step 2. Determination of Criterion Weight: The determination of weights is done through subjective and objective methods. The varying criteria weights are used to determine the deviation during the selection process.

Entropy Ej is the objective weight of the j^{th} criterion and is determined by equation (5), (6) and (7).

$$E_J = h \sum_{i=1}^{n} P_{iJ} \ln P_{ij} \tag{5}$$

$$h = \frac{1}{\ln m} \tag{6}$$

$$w_{j_o} = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{7}$$

$$d_j = 1 - E_j \tag{8}$$

Where dj is the degree of diversification, the weight vector Wj is presented as the ratio of dj and ej.

The AHP is the subjective weight obtained from expert knowledge about hybrid renewable energy systems. It is the subjective weight of the normalized pair wise comparison matrix or eigen vector and it is represented by equation (10).

$$W_C = \frac{\sum normalized\ principal\ eigen\ vector}{n} \tag{9}$$

$$\text{C.I} = \frac{\lambda_{max} - n}{n-1} \tag{10}$$

Where Wc is the criteria weight from the pair wise comparison matrix and n is the number of the criteria.

However, there is a need to check for the consistency of the pair wise matrix with the use of a consistency ratio C.R. The consistency ratio is determined by using equation (11).

$$C{:}R = \frac{C.I}{R.I} \tag{11}$$

Where C.I and R.I are the consistency index and random index. The consistency index is obtained from equation (10) Where λmax is the ratio of the weighted sum value of the criteria and the criteria weight Wc. The general rule of thumb is that the consistency ratio C.I must be < 0.1.

Step 3: Determine the aggregate preference function. The preference index Π (a,b) evaluates the difference in preference for one alternative over another alternative .When Π (a,b) =0, then there is no preference between both alternatives. If Π (a,b) =1 there is a preference for a over b. The aggregate preference function is presented in equation 12.

$$\pi(a, b) = \sum_{j=1}^{k} P(a, b)w_j \tag{12}$$

Where Wj is the subjective or objective weight from the AHP, Equal and Entropy method.

Step 4: Determine the net outranking flow. The preference index is used to quantify the entering and leaving flow of each alternative.

$$\emptyset(a)^{+} = \frac{1}{n-1}\sum_{x\in A} \pi\ (a, x) \tag{13}$$

$$\emptyset(a)^{-} = \frac{1}{n-1}\sum \pi\ (a, x) \tag{14}$$

Step 5: Determine the net outranking flow. The leaving flow ϕ+ determines to what extent alternative a performs better than alternative b. The entering flow ϕ- determines to what extent other alternatives perform better than alternative a. For a complete ranking the net outranking flow is presented below:

$$\emptyset(a) = \emptyset\ \ (a) - \emptyset(a)^{-} \tag{15}$$

The qualitative criteria selected for this study cannot be determined from bibliographic reviews, so a qualitative assessment involving experts in the renewable energy field in Nigeria is carried out in order to compensate for the lack of data.

Experts who are considered knowledgeable in the field of renewable energy technology were invited to participate in a Delphi study to apportion different weights to the already selected criteria; the selection of experts to undergo the qualitative assessment, requires that they meet specific requirements. This is used to filter the less knowledgeable ones.

The following expert criteria are applied to the selection process:

- Years of experience in the field of renewable energy.
- Their respective knowledge about the selection of renewable energy in peri urban/informal areas of cities.
- Educational level.
- Intuition of the experts is being considered.

The questionnaire assesses their knowledge and experience as proposed in (Barraghan, 2018). The experts are asked about the importance of the criteria in selecting renewable energy for informal electricity planning and their responses are guided through the use of the AHP ordinal scale of relative importance. That number from 1 to 9.

The Cronbach's alpha coefficient with a value between 0.7 to 0.99 in value indicates a high level of reliability of the questions that are asked to the experts.

Table 5. Qualification of expert witness.

	High	Medium	Low
(1) Years of experience working in the field of renewable energy	Above 20 years of experience	10 to 20 years of experience	Below 10 years of experience
(2) Educational level attained in the field of renewable energy	PHD in the field of renewable energy	Master's degree in the field of renewable energy	Bachelor's degree in the field of renewable energy
(3) Their respective knowledge about the selection of renewable energy in peri urban/ informal areas of cities.	Analysis of 30 specialized literatures	Analysis of 10 to 20 specialized literatures	Analysis of less than 10 literature
Total Score			

In this work we use descriptive statistics to determine the mean and the median and standard deviation to determine the level of competencies of the experts:

If the total score falls in the range $0.8 < K < 1.0$ the expertise is given a high score. If the total score falls in the range $0.5 < K < 0.8$ the expert is given a medium score.

If the total score of K < 0.5 the expert is given a low score. In this work we apply the average value that is obtained from taking the average scores for the total number of experts involved in the assessment key (Velychko et al,2017).

(Rabieee et al,2021) creates a support system for detecting and handling bias from the expert decision makers, in this research work in order to extract such bias amongst the decision makers, an evaluation system that involves the use of Cronbach’s alpha to test to homogeneity of the responses from the experts is applied to the process.

Criteria Analysis.

According to the review of bibliographical resources, the evaluation criteria for renewable energy selection can be divided into four main categories: Technical, Environmental, Economic and Social respectively. The technical dimension refers to power generation such as (efficiency, technical capacity factor and availability of resource). The financial dimension relates to the aspect of renewable energy cost of technology which are:(investment cost, operational & maintenance cost, levelized cost of electricity). The environmental criteria is related to every renewable energy technology that has a negative impact on the environment such as (e.g .CO_2 emissions and impact on the ecosystem). The social dimension specifies the impact that renewable energy technologies have on the welfare of people, (e.g, job creation, and policy support). (Lee & Chang 2018).

Because of the peculiarity of this research work which focuses on selecting the most favorable renewable energy technologies in informal settlements, this research work takes into consideration factors that explains the reason for their application in order to derive a desirable outcome.

According to previous studies; sub criteria that are not commonly used are discarded for lack of popularity and research clarity (Barraghan,2018).

Wu et al, (2018) identifies those criteria that can be measured qualitatively and quantitative. The quantitative criteria are chosen because of their popularity in previous studies, which are used as reference points and for the reason of availability of information, which deduces the values that correspond to each detailed formula. On the other hand, the qualitative criteria are chosen not because of their popularity, nor their frequency of usage in previous study, but for the reason of data availability at municipal/local/ community level. This is often described as a bottom -top methodological approach that describe characteristics which influence the selection of renewable energy technologies, from structured interviews and responses from questionnaires distributed to stakeholders across the value chain.

Table 6. Quantitative and Qualitative criteria.

Criteria		Sub-criteria	Measurement
Technical	C1	Efficiency	Quantitative
	C2	Availability of source	Qualitative
	C3	Maturity of technology	Qualitative
	C4	Urban obstacle;	Qualitative
	C5	Capacity factor	Quantitative
Economic	C6	Levelized cost of electricity	Quantitative
	C7	Operation cost &maintenance	Quantitative
	C8	Investment cost	Quantitative
Environment	C9	CO_2 emissions	Quantitative
	C10	Land usage	Quantitative
	C11	Water consumption	Quantitative
	C12	Acidification	Qualitative
Social	C13	Jobs	Quantitative
	C14	Government support	Qualitative

Technical Subcriteria: The sub -criteria are denoted as C1, C2, C3 C4 and C5, are qualitative and quantitative measures of the ability to assess the technology.

Efficiency (C1):

This is a technical criterion used to evaluate energy systems. In general efficiency is defined by how much useful energy can be obtained from a renewable energy source. The efficiency coefficient used as a yardstick for measuring the efficiency of a system is given as the ratio of the output energy to the input energy. Previous studies that use efficiency as a technical criterion to select renewable energy sources include; (Lee & Chang, 2000), (Ali et al, 2020), (Wu et al, 2018), (Saraswat et al, 2021), (Li et al, 2020), in these studies, Efficiency is measured with the use of the efficiency coefficient. In the work of Wu et al, (2018). It is used in evaluating renewable energy power sources in China. The efficiency for solar PV modules is calculated as:

$$\eta_t = (P_{max}|G * S_t) \times 100\% \tag{16}$$

W$here$ St is the efficiency, Pmax is the maximum power value of a module in W (Watts), G denotes the irradiance where the unit of G is expressed in (W.m-2).

St denotes the total area of the module with the unit measured in (m2). It can be assessed quantitatively from previous studies. The greater the value of efficiency, denotes a greater amount of energy that can be produced from each renewable energy source, henceforth it is given a maximum value. (Barragan, 2018).

Availability of primary sources (C2):

This sub criteria shows the availability of renewable energy technology to generate energy, it measures renewable energy source flows such as sun irradiation, wind speed and river flow rate for hydroelectricity generation e.t.c. It can be assessed quantitatively through the measurement of renewable energy potential from previous studies, (Li et al, 2020; Wu et al 2020), while in the work of (Seker & Kahraman, 2020; M.Shao et al,2020; and Rani et al, 2020) the focus on available sites for renewable energy technology is carried out.

Each potential site in view is unique to the area of study seeing those characteristics such as topography and slope vary accordingly. This criterion is given a maximum value, the more availability of sources, denotes a favorable selection preference.

Maturity of Technology (C3):

This sub criteria indicates how the renewable energy technology is distributed at local, regional and international levels. It indicates different levels of advancement in renewable energy technology. Level (C) denoting the commercial viability of the technology, which reflects its readiness for consumption on a commercial scale. At level (R&D), the technology is at the level of research and development. Previous work such as (Wu et al, 2018, Colak & Kaya, 2017; Lee & Chang, 2018), measure this sub criteria qualitatively. In Barraghan, (2018), the sub criterion is given a scale from numbers 1 to 5 to reflect the levels of advancement in the technology in view. The number 5 is assigned to commercial maturity, and 1 to researchand development=, where the number 5 represents the highest level of maturity that can be achieved on the qualitative scale. It is given a maximum value.

Urban obstacles (C4):

This sub criteria are used to determine whether there is available space for the construction of renewable energy technologies, it is not to be confused with the availability of land. The difference is the contribution of any renewable energy technology to the obstruction of movement of goods and services in the urban area, whilst availability of land solely informs the adequacy of land mass for the construction of renewable energy technologies. In some cases, this criterion seeks to determine if the architectural design of a renewable energy technology can fit into an urban energy plan and gain subsequent approval. This criterion is given a minimum value, because the more obstruction a renewable energy technology constitutes to the urban metabolic flow, the less favorable it is for selection. Barraghan, (2018) applies this sub criteria in determining the possibilityof circular urban metabolism in the intermediate city of Cuenca in Ecuador.

Capacity factor (C5):

The capacity factor sub criteria that make it possible to measure the ability of a renewable energy power plant to produce electricity. It is denoted as the ratio of the electrical energy produced by a power plant for the period of time to the full power that could have been produced continuously over the same period (Wu et al, 2018).

The capacity factor is affected by weather: wind power plants are affected by wind speed; solar power plants are affected by the sun's radiation, which means that during summer or hot weather conditions, solar plants operate at maximum capacity factor. On the other hand, Geothermal and Biomass energy operate 24hrs a day.

$$CF_i = \frac{Annual\ Total\ Generation}{Installed\ capacity\ \times 365 \times 24h/days} \times 100\% \qquad (17)$$

For a base load power plant with an installed capacity of 1000MW might produce 500,000 megawatt-hours (MW.h) in a 30 day- month. The amount of megawatt hours that would have been produced if the plant is operating at full capacity can be obtained by multiplying the plants maximum capacity by the number of hours in the time period.

l.e 1,000 MW × 30 $days$ × 24 $hours$ /day, which results in the value 720,000MW.h. The capacity factor is determined by dividing the actual output with the maximum possible output.

For example, three gorges dam consists of 26 main generator units @ 700MW, which includes two auxiliary generators units at 50MW and a total installed capacity of 18,300MW. The total generation for that year was about 79.47TW.h. By applying equation 17 we obtain a capacity factor of 49.4% (Gleick, 2009).

Economic sub criteria: These criteria measure cost related parameters that are associated with the selection of renewable energy technologies that include: operation and maintenance cost; levelized cost of electricity; investment cost and the return on investment. All sub criteria are quantitative and their values are derived from previous work (Li et al, 2020; Alizadeh et al, 2020; Abdel-Bassetet al, 2021; Ali et al, 2018).

Levelized cost of electricity (C6):

This economic sub criteria describes the cost of the power produced by a renewable energy source over a period of time. Typically, the lifetime of the system is in unit currency per kWh rate. The cost presented is used to generate the average revenue per unit of electricity generated that is required to recover the capital investment less the operational expenses. The general inputs needed to complete the calculation of LCOE of renewable energy systems include; cost of capital, fuel costs, fixed and variable operations and maintenance costs, financing costs and decommissioning cost (Abdel- Basset et al, 2021; Ali et al,2020; Jahangir et al,2020; Wu et al, 2018; Colak & Kaya, 2017). The LCOE calculated in previous studies by some authors includes other factors such as the depreciation of the power producing asset over its lifetime (Jenkin et al, 2019). So the formular for the LCOE consists of several parameters as depicted in equation 18.

The general inputs needed to complete the calculation of LCOE of renewable energy systems include; cost of capital, fuel costs, fixed and variable operations and maintenance costs, financing costs and decommissioning cost, Where the overnight capital cost is measured in dollars per kilowatt of electricity produced, $/kW.. (Abdel-Basset et al, 2021; Ali et al,2020; M.Jahangiri et al,2020; Wu et al, 2018; Colak & Kaya, 2017). The LCOE calculated in previous studies by some authors includes other factors such as the depreciation of the power producing asset over its lifetime (Jenkin et al.,2019).

$$LCOE_i = \frac{(overbight\ capital\ cost * capital\ recovery\ factor + fixed\ O\&M\ cost)}{(8760 + capacity\ factor)} + (fuel\ cost * heat\ rate) + (variable\ O\&M\ cost) \tag{18}$$

Where the overnight capital cost is measured in dollars per kilowatt of electricity produced, in \$/kW.
Fixed operation and maintenance costs are in dollars per kilowatt -year (\$/kW-yr) Variable operation and maintenance costs in dollars per kilowatt- hour (\$/kWh). 8760 represents the number of hours in a year.

The capacity factor represents the fraction of the power produced by the plant in a time other than when it operates under its full installed capacity.

The formula for capacity factor is provided above see equation 4-8. (NREL, 2020), The LCOE represents the average cost at which energy must be sold to break even and give a net present value of 0.

The fuel cost is measured in \$/MMBtu and the heat rate is measured in the standard British thermal units per kilowatt-hour (Btu/ kWh).

The LCOE can also be calculated using the formula below:

$$LCOE = \frac{I_o + \sum_{t=1}^{N} \frac{A}{(1+i)^t}}{\sum_{t=1}^{N} \frac{E_t}{(1+i)^t}} \tag{19}$$

In Nigeria, 80 percent of the power plants run on gas supply which is indexed to the price of crude oil. This indexation is reflected in the cost estimation used in the determination of the levelized cost of electricity. The levelized cost of electricity determines the amount of returns on the investment in a renewable power project which is reflected in the cost reflected tariff for electricity

Furthermore, the tariffs are significantly impacted by the amount of ATC& C losses experienced from bills collection andpower losses along the transmission lines. The Nigerian electricity industry is experiencing a majorsetback in the progress of achieving a cost reflected tariff which incentivizes more foreign direct investment to expand on the uptake of renewable energy. This is because of the inefficiency that characterizes the collection of money for the provision of electricity services to the different tiersof customer class by the electricity distribution companies.. It is given a minimum value.

Operation & Maintenance cost (C7):

This sub criterion considers all the cost required for the operation and maintenance of renewable energy producing systems in order to select the most preferred in a particular study area. In the work of Wu et al, (2018), operation & maintenance cost is divided into two parts: operation cost; which includes: employees' salaries, direct labour, fuel and maintenance cost such as service cost. This criteria can be assessed from previous work that include: (Li et al,2020; Alizadeh et al, 2020, Abdel-Basset et al,2021, Ali et al,2020, Yazdani et al, 2018, M.Jahangiri et al, 2020, Buyukozkhan et al,2018,Rani et al, 2020, Barragahan, 2018, Wu et al, 2018, Colak & Kaya, 2017, Lee & Chang, 2018).It is given a minimum value.

Investment Cost (C8):

This sub criteria measures the components that constitute the total amount of money to embark on a renewable energy technology project, which includes: purchase of mechanical equipment, technology installations and the purchase of land for production. The value can be derived from quantitative assessment from the bibliographical review of previous study: (Firouzi et al,2021; Ali er al,2020: Yazdani et al,2018, Rani et al,2020; Wu et al,2018; Colak & Kaya,2017; Lee& Chang,2018).

The equation 20 is used to determine the investment costs by applying the method of extrapolating values for different sizes of plants with total consideration for scaling up expansion in arriving at the cost. It is given a minimum value because the higher the cost of investment the less relevant the sub-criterion will become.

$$\frac{C_{T1}}{C^{T2}} = \left(\frac{S_1}{S_2}\right)^P \tag{20}$$

Where CT1 and CT2 are the costs of the plant with different sizes S1 and S2 (IEA, 2013; IRENA, 2019).

Environmental Sub criteria:

The environmental sub criteria determine the impact of the renewable energy technology on the environment by determining the number of emissions released during the production and manufacturing stages, it is measured quantitatively, as it requires energy flow data through the life cycle of a renewable energy technology from the review of bibliographic sources. It is expected that the use of fossil fuel inthe energy mix of a designated study area, municipality or local community will contribute to the record level of emission of harmful substances to the environment (Barraghan,2018).

GHG emissions (C9):

This sub criterion helps to determine the amount of GHG emissions from a given RE system It is one of the most important environmental criteria that is used in evaluating the sustainability of renewable energy technology. The emissions of GHG gas is measured in equivalent emissions of CO_2 eq/kWh. In the life cycle analysis of the renewable energy produced, the emissions factor is applied to all the stages involved in production from raw materials extraction, processing, transportation, distribution and the operation and maintenance. This criterion is measured quantitatively from the review of bibliographic sources that include: (Li et al,2020; Abdel- basset et al,2021; Saraswat et al,2020; Seker& Jahraman, 2020; M. Jahangiri,2020; Buyokozkhan et al,2018, Wu et al,2018; Lee& Chang,2018). It is given a minimum value.

Land use (C10):

This criterion shows the relationship between the environment and its landscape, and how both are affected by the renewable energy system. The land required for the construction and installation of renewable energy technology is measured in m^2. Land usage for renewable energy projects becomes a great concern when a dispute arises from the ownership of the land. This criterion is measured qualitatively. (Li et al, 2020; Alizadeh et al, 2020; Abdel-Basset et al, 2021, Seker & Kahraman, 2020; M.Jahangiri et al, 2020; Wu et al, 2018; Lee&Chang, 2018).

Water consumption (C11):

This criterion measures the amount of water that each renewable energy technology consumes in the process of providing electricity. The importance of this criteria cannot be underestimated, especially with regards to some informal settlements that are plagued with water shortages. The criteria are given a minimum value because the more water that is consumed by each renewable energy source makes it less preferentially selected. (Huang 2010 &Macknick et al., 2011).

Acidification (C12):

This criterion measures the amount of SO2 released from the use of renewable energy technology during the life cycle. This criterion is used both quantitatively and qualitatively. It is given a minimum value. (Turkoni et al 2013 and Nomura et al 2001).

Social sub criteria:

Social criteria measure the ability of the renewable energy technologies to improve on the livelihood of the communities and people where they are constructed. In general terms it is the measure of the benefits of the renewable energy technology to the welfare of individual.

Job creation (C13):

This sub criteria measures the impact of renewable energy technology in providing jobs for the inhabitants of a study area in view, it is carried out on national, regional and community levels. This criterion is assessed qualitatively through structured questionnaires and interviews bordering on the improvement of quality of life and job creation. (Li et al,2020; Lee &Chang,2018; Seker & Kahraman,2020). The sub criterion is given a maximum value. The formula for calculating the number of jobs created by a renewable energy plant is derived from the job per unit energy measurement (jobs- year/ GWh, the measurement occurs in two stages: (i) Construction installation and manufacturing (ii) Operation and maintenance (OM), both representing the initial number of workers involved in the installation of the technology and throughout the operational life of the renewable energy source.

$$CIM = \frac{\{CIM_i\} \times N_i}{P_i} \quad (21)$$

Where CIM is the number of people measured for the construction, installation and manufacturing of a plant.

N_l is the number of years used for CIMP_l is the size of the power of the facility.

The other component of the job creation formula is depicted in the scenario where the number of jobs required for the operation and maintenance of the renewable energy plant is denoted as OM. The employment indicator Le for renewable energy job -year / GWh is given by the formula.

$$L_e = \left(\frac{CIM}{t}` + O\&M\right) * \frac{1000}{8760 * P_p} \quad (22)$$

Where t is the lifecycle of the renewable energy technology.

Pp is the plant factor of the renewable energy technology.

Social acceptance & Government Support (C14).

The measure of public support of the renewable energy technology is what the social acceptance criteria represents, which is important in determining the implementation of the technology and national/ regional policy target, due to the fact that it cannot be measured directly, it is assessed qualitatively on a scale ranging from 1 indicating strong disagreement and 5 indication strong agreement (Rani et al, 2020; Lee & Chang, 2018).

Policy support (C14): This sub criteria defines if the renewable energy technology is supported by the energy policy either on a regional or national level and in some cases community levels in the case where communities are self-autonomous. It is assessed qualitatively on a scale of 1 to 5. With 1 indicating opposition and 5 indicating strong support, (Wu et al,2018; Lee &Chang,2018).

The impacts of different criteria on the alternatives vary accordingly with the weights assigned to them, there are different methods used to achieve the purpose of apportioning weights to criteria in order to measure their effects in decision making outcomes.

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Wang (2015), applies the use of a simple additive weighting method (SAW), in a multi-criteria decision- m a k i n g model to solve fuzzy multi criteria decision making problems. (Zardari er al 2015), uses the methods of rating, ranking and ratio in a multi criteria decision making model for water resources management. In this work careful review of weighting methods used from (2000-2012) is carried out. (Barragahan, 2018) applies equal weighting method, direct rating method and ordinal ranking method in preferentially selecting different alternatives of renewable energy technology in the City of Cuenca.

In the work of Odu, (,2019) the author makes an attempt to derive the most suitable weighting method for multi criteria decision making technique by proposing two categories of weighting methods. The subjective weighting, which involves deriving information from the decision makerabout a criterion in view, making it a simpler and straight forward process and the objective weighting, where the information about each criterion is obtained by adopting a mathematical formula. The author also proposes an integrated weighting method which involves the combination of the subjective and the objective weighting methods. Consequently, other methods have been used by several authors from previous studies.

Point allocation method: In this method, the decision maker determines the weights based on the priority of the criteria by allocating points to each criterion. The more points a criterion is apportioned, the more significance it reflects. In this case the decision maker is required to allocate 100 points across the criteria under the selective process. (Odu, 2019). What this means is that the total of all the various criterion must sum up to 100 in value. However, the down side to this methodology for deriving weights for criteria is its inefficiency in its functionality, as a result of inputting more than 6 criterion even though the methodology makes normalization very easy.
A typical example is depicted in table 7 for the selection of Solar PV technology components.

Table 7. Showing the criteria for the selection of Solar PV.

N	Criteria	Weights
1	Cost	30
2	Battery Bank	20
3	Charge Controller	25
4	Shape &Size	25
	Total	100

Direct Rating method: The direct rating method involves the decision maker ranking all the criteria according to their level of importance (Arbel,1989; Barragahn,2018). In this method, the decision maker invites participants to give importance to criteria using a scale after which the weights are normalized and evaluated by the decision maker. The advantage of this method is that weights can be given to different criteria from across the world where participants can be selectively chosen to participate in the process. The participants involved in the selective process are experts from the field that is under consideration.

The pairwise comparison/AHP method: This method is a subjective methodology for apportioning weights to criteria with the use of pair wise comparisons of the criterion under consideration to determine the difference in values between each weight, which eventually results in their ranking respectively. The decision maker compares each criterion with the use of an ordinal scale of 1-9, in order to complete their preferentially selection. Where the value of 1 is given to criteria of equal importance and the number 9 given to criteria of the strongest importance. The scale also includes intermediary numbers which are2, 4, 6, and 8 where the level of importance lies between the odd numbers. On the scale 1 represents equal importance,3, 5, 7 ,9 represent moderate importance, strong importance, very strong importance and extreme importance respectively. (Saaty,1980). The even numbers on the scale are compromise values were 2,4,6,8 represent equal to moderate performance -2; moderately to strongly preferred -4; strongly to very strong importance -6; very strong to extremely strong importance-8 respectively. The method of comparison is determined by the formula below.

Table 8. Value of the Random Index number.

Values															
Order	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.5	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.5 4	1.56	1.58	1.59

Where CP is the number of comparisons and n is the number of criteria.

$$C_P = \frac{n\,(n-1)}{2} \tag{23}$$

The random index value of 0.9 is derived from the random index table, see table below:

Source: Saaty (1980).

4.3 Energy Planning.

The purpose of this thesis is to derive an energy planning model for the informal settlements of New- Nyanya, Ado Uke and Orozo in the region of Nasarawa State of Nigeria.

The planning model is necessary to satisfy the energy demand of these areas in the short, medium and long term.

In general, energy planning for cities and regions have previously considered the economic factors, which primarily focused on the amount of funding that an energy project required without paying attention to the social and environmental aspects of it, which to a large extent informs on a holistic approach to the planning narrative. More so, with the inclusion of informality to the energy planning discourse, as it is observed in many developing countries, which have the highest population of slum dwellers, there is a need for a more robust planning structure to accommodate various planning aspects (Nerini et al,2018; Runsten,2018,).

Informal settlements are an integral part of a city that cluster in two types of locations which are: the inner city and the peri urban areas. The importance of these settlements cannot be overemphasized as they contribute immensely to the gross domestic production (GDP) in various developing countries such as: sub-Saharan Africa, Latin America, Asia and some Middle Eastern countries. The gross domestic production of a country, which is often determined in three different ways: income; expenditure and production approaches. is an economic and welfare indicator which measures the market value of all the final goods and services produced in a specific period of time. It is unarguably a yardstick used to determine the wealth of a country (Jacques, 2012). The contribution of the informal economy to the GDP of a country is observed in the form of the level of employment in these settlements and the productive linkage it has to the development of the formal economy. The quantification of the contribution of the informal sector is made for developing countries, which make use of household sector and agriculture enterprises. The employment of informal workers in the formal household sector is noticeable in food vending, house cleaning, babysitting, tailoring, apprentices etc. While in the formal agriculture-based sector, informal workers account for about 80% of the workforce, where they are employed as farmers and fruit pickers (Tsenkhova, 2012).

Table 9. Showing the contribution of the informal sector to GDP.

Countries	Total GDP (USD)	Units	Informal sector GV including agriculture	% Percentage contribution to the to GDP
Benin	11.4	Billion	8.16	71.6%
Burkina Faso	23.9	Billion	13.33	55.8%
Niger	9.299	Billion	5.184	57.6%
Senegal	24.3	Billion	17.641	72.6%
Togo	8.6	Billion	6.2178	72.3%

Source: The percentage of the informal sector GVA including agriculture to the GDP is culled from the work of (Charmes, 2012).

Note: the percentage contribution is assumed to remain the same from the years 2000-2003 and it is assumed that the percentage contributions will not very much in 2021, because of the slow level of policy change with regards to integrating informality to formality.

Table 10. Showing the GDP of other developing countries.

Countries	Total GDP in National Currency	Currency	Informal sector GVA Including agriculture	% Percentage contribution to the total GDP
Algeria	11.4	Billion USD	8.16	37.9%
Egypt	23.9	Billion USD	13.33	27.8%
Iran	9.299	Billion USD	5.184	35.6%
Tunisia	24.3	Billion USD	17.641	41.8%
Palestine	8.6	Billion USD	6.2178	38.1%

Source: The percentage of the informal sector GVA including agriculture to the GDP is culled from the work of (Charmes, 2012).

Note: the percentage contribution is assumed to remain the same from the years 2003 to 2008 and it is assumed that the percentage contributions will not vary much in 2021 because of the slow level of policy change with regards to integrating informality to formality.

Table 11. Showing the GDP of South American countries.

Total GDP in National Currency		Currency	Informal sector GVA including agriculture	% Percentage contribution to the total GDP
Brazil	11.4	Billion USD	8.16	21.6%
Columbia	23.9	Billion USD	13.33	37.5%
Guatemala	9.299	Billion USD	5.184	36.9%
Honduras	24.3	Billion USD	17.641	31.5%
Mexico	8.6	Billion USD	6.2178	30.9%

Source: The percentage of the informal sector GVA including agriculture to the GDP is culled from the work of (Charrmes,2012).

Note: the percentage contribution is assumed to remain the same from the years 2006and it is assumed that the percentage contributions will not vary much in 2021 because of the slow level of policy change with regards to integrating informality to formality.

Table 12. Showing the contribution to the GDP of Asian countries.

Countries	Total GDP in USD		Informal sector GVA including agriculture	% Percentage contribution to the total GDP
Bhutan	11.4	Billion USD	8.16	20.0%
India	23.9	Billion USD	13.33	54.2%
Mongolia	9.299	Billion USD	5.184	29.9%
Sri Lanka	24.3	Billion USD	17.641	16.9%
	8.6	Billion USD	6.2178	12%

Source: The percentage of the informal sector GVA including agriculture to the GDP is culled from the work of Charrmes (2012).

It is because of these immense contributions to the gross domestic production of countries, which make it imperative for national governments, regions and municipalities to accelerate the inclusion of informality to urban energy plans. However, the challenge of integrating informality to urban energy planning still exists, as most developing countries struggle to achieve adequate policy interventions which range from legalization to more ambiguous problems of costing and financing (Tsenkhova,2012). Urban planning plays a pivotal role in developing appropriate strategies for integrating informal settlements. The plans will have to provide the essential framework and roadmap to accelerate its implementation. In the absence of these regulations, issues such as land usage and erecting illegal infrastructures will continue to pose a big challenge for electricity access for informal settlers (Chesto, 2013). The UN has made it clear in its sustainable development goal 11- to make cities inclusive, safe resilient and sustainable (UN, 2019). The alarming growth rate of urban slums situated in inner cities and peri urban areas have come to symbolize a challenge in the quest to meet the energy demand necessary to cushion the growth effect. The drastic increase in the population size in informal areas, has come to symbolize the intensive use of fossil resources to meet up with energy demands, which will contribute to the gradual degradation of the environment from the release ofharmful emissions of CO_2 and other poisonous gases into the atmosphere. The urban energy plan must look for a means to change the current energy model from a linear to a circular, which is a stepping stone to achieving sustainability.

4.3.1 Characteristics and structure of the hybrid decision.

The hybrid decision making model is an intermediate model that is derived from the contribution of a top -bottom model and a bottom to top model, making it possible to consider decision making contributions from stakeholders in the community in the absence of data. It has been recommended as a tool to plan for energy for slums/ informal areas, which are situated in cities and peri urban areas. This can be achieved through the synthesis and analysis of data from the planner, in this case the decision maker with an inclusion of the social economic factors and local energy initiatives through the participation of informal dwellers (Ghorbani et al, 2020). The inclusion of local knowledge and experience in developing solutions appropriate to local contexts thereby improving local institutions for energy production.

For this research work we select a hybrid decision making model, which integrates decision making from expert opinion and community agents.

The hybrid model consists of PROMETHEE/AHP decision making and a community energy model, which is derived from community member's participation in the decision making at community level.

To build the model for this research work, we make use of the existing framework for determiningthe demand for informal settlers proposed by the GIZ and the World Bank on mini griddeployment and rural electrification.This framework outlines the following:

Energy consumption profile for informal dwellers income, size and number of appliances. Energy consumption behavior of informal dwellers, metabolic flow, and energy preferences.
The structure of the model allows us to perform the energy analysis for the informal settlers inthe following steps:

Step 1: Population sampling of local opinion from the household and productive use of energy sectorof New-Nyanya, Ado, Uke and Orozo settlements. The population sampling for local opinion is applied to the and skilled personnel working in the field of renewable energy technology is soughtafter in the first multicriteria decision making process.

Holistically it is done to reflect the application of a hybrid model, by integrating the top down (expert opinion) and bottom-up approach (local opinion) in energy planning for these informal settlements. Unlike the selection of expert panels, we select local opinion by using only one yardstick which is the time spent with renewable energy use. This is measured by determining the year of experience a person contributing to l o c a l opinion has with regards to the use of renewable energy sources as a means to provide energy that meets with the energy demand.

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Table 13. Showing the data of local opinion.

Time Spent	High	Medium	Low
Local opinion participant	85%	10%	5%

- High: More than 10 years of renewable energy use.
- Medium: 5 to 10 years of renewable energy use.
- Low: Less than 5 years of renewable energy use.

Step 2: Multicriteria decision making from the perspective of the informal dwellers We invite community members to participate in the ranking of criteria and the attribution of weights to these criteria is carried out using the analytical hierarchical process. Furthermore, six community energy indicators are selected as yardsticks to determine self-sufficiency at communal level from the direct input of community members.

4.3.2 Research methodology for sampling.

Research methodology for Sampling. In order to answer research questions, it is necessary to be able to collect data from different sources so it is necessary to obtain this information from samples. Taherdoost, (2016) highlights the steps that is necessary to obtain data by using the appropriate technique and method.

The advantages of sampling methods in research technology are: To reduce the number of cases and save time.

To save the cost of studying the whole population size. To improve the reliability of the study through the application of confidence interval in the description statistics.

4.3.3 Outline of the research methodology.

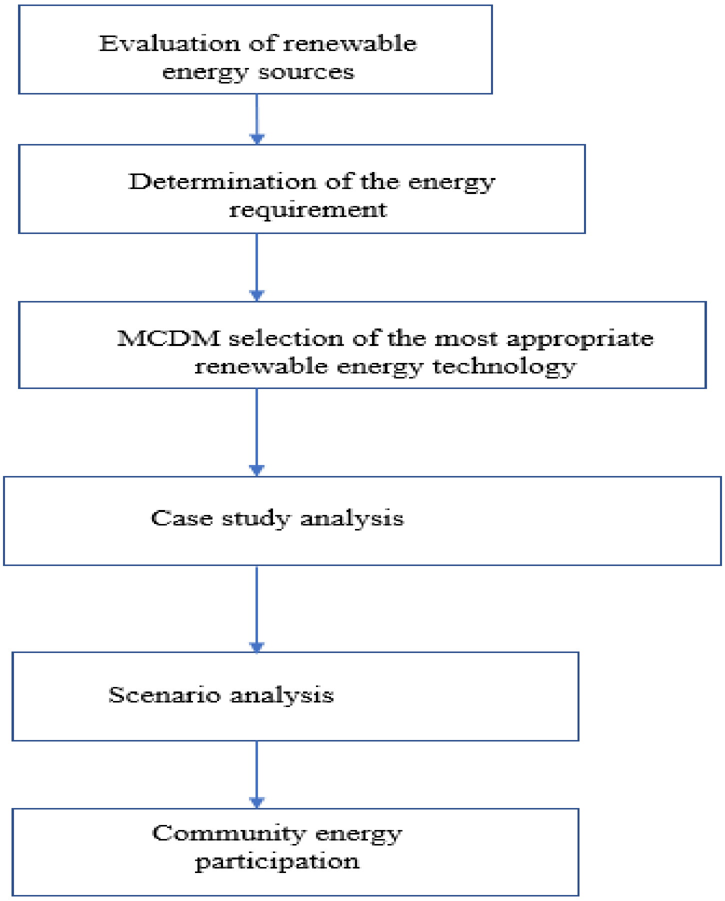

Figure 7. The Sampling methodology.

Clearly define target population: The first stage is to determine the population size of the study in view.

Select sampling frame: This is a representation of the actual case from the population where the sample is conducted from.

Choose sample technique: At this stage the researcher selects a technique that is convenient to the aims and objectives of the study. The derivation of a technique is used to make inferences and observations about a population. e.t.c energy consumption behavior and pattern.

Determine Sample Size: The sample size is determined with the use of several statistical formulas etc. Cochran's formula (Bartlett, 2001; Evans et al, 2000). The Cochran’s formula is represented below:

$$N_O = \frac{Z^2 pq}{e^2} \tag{24}$$

Where e is the desired level of precision, i.e., the margin of error

P is the estimated proportion of the population

Q is given as 1-P

The Z value is obtained from the table of confidence interval. In general, a 5% margin of error is widely accepted in most social science and management research (Tanderhoost,2016; Bartlett et al,2001). At 95% confidence interval, there is a general acceptance of reliability in the value of the samples determined.

Assess response rate: The analysis of the data includes, the response rates of participants, and the mean, median and standard deviation of responses is determined by the application of descriptive statistics**.**

4.3.4 Energy balance and urban metabolism.

For this research work, the energy balance is carried out for New-Nyanya, Orozo, Uke and Ado informal settlements. The energy balance includes the amount of fossil fuel imported, and the amount of the energy consumed in the disaggregated household and productive use sectors. This is carried out in order to quantify the amount of renewable energy technology that is available for the replacement of the fossil fuel imports, which is in accordance with the principles of urban metabolism.

4.3.5 Scenarios.

Scenario planning is used to identify the outcome of different perspectives, when the input or feedstock into a system is altered or modified.

In this research work, the case study on the Greater Karu Urban area, which includes the four informal settlements, makes use of scenarios to justify the need to implement the inclusion of other renewable energy sources in the strategic plan of the Rural Electrification Agency in Nigeria.

The scenarios include: a reference case scenario, which represents the absence of renewable energy sources; policy case scenario I, which includes the current strategic plan of the REA, where only solar energy is utilized and policy case scenario II, which includes other renewable energy sourcesin the long term. The three scenarios are compatible with the Nigerian Renewable Energy PolicyPlan for short, middle and long term.

Energy sustainable indicators are applied to measure the difference in the outcomes of the three scenarios on the four informal settlements of the Greater Karu Urban Area.

4.3.6 Energy Indicators.

The outcome of the three case scenarios are measured with the aid of four sustainable energy indicators. Generally sustainable energy indicators are used to monitor the performance towards sustainable energy. Several assessment criteria are used in the selection of energy indicators. Gunnarsdottir et al (2020), proposes six assessment criteria for the selection of 57 indicators in the review of indicators for sustainable energy development. Findings from this study reveal that the most widely used guideline in literature for the assessment of indicators is the Bellagio STAMP principles. The principles consist of eight good –practice guidelines for assessing the most appropriate indicators, which include:

Guiding vision: Tracking the goal towards sustainable development.

Essential consideration: Taking into cognizance all three dimensions of sustainable development and their interactions, which include the current trends, and drivers of change and impact on decision making.

- **Scope**: Considering the short- and long-term effect generally.
- **Framework and indicators**: Based on standardized measurement methods.
- **Transparency**. Full disclosure of potential conflicts and rifts that may arise in the data.
- **Effective communication**: The use of simple and clear words to explain, with the inclusion of visual tools and graphics.
- **Broad participation**: Involving a wide network of stakeholders and engage with potential users of the assessment.

Continuity and capacity: Allow for continuous re-evaluation of measurements overtime.

It is on this basis, that this research work selects four energy indicators which are deemed appropriate under the Bellagio STAMP principles to be applied in the four informal settlements of Greater Karu Urban Area. The energy indicators used in this research work are listed below:

1. Price of Energy (PES).

$$PE = LCOE * (1 + U_t) * (1 + T) \tag{25}$$

Where PE, price of energy.

LCOE = Levelized cost of energy through the life of the plant (USD/kWh).Ut = business profits T = Applicable taxes.

2. Amount of renewable energy in final energy supply (FES).

$$UR = \sum_{i}^{m} \frac{ERe_i}{OE_i} \tag{26}$$

Where:

UR is the participation of renewable energy in total energy supply. ERei is the Supply of Renewable Energy

OE is the Gross total supply of Energy.

m= number of renewable energy technology.

3. Avoided CO_2 emissions indicator.

   For this research work we estimate the avoided CO_2 emissions from the proposed methodology that is recommended by IRENA for Nigeria.

   IRENA 2018 proposes avoided emissions in two scenarios.

- The first is the inclusion of Solar.
- The second is the inclusion of all renewable energy sources, which include solar, wind and hydro energy.

The methodology is based on estimated calculation by first obtaining the value for the CO_2 emissions from Fossil fuel per country from the industrial, residential, commercial, agriculture and other sectors. Which is in agreement with the data from the International Energy Agency. (IEA,2018).

Then the estimates of the avoided CO_2 emissions for the informal settlements is obtained from the percentage differences in contribution from the first scenario which is the use of Solar, and when all renewable energy sources are applied.

Number of Jobs created.

The values of I_{ei} and the value of Di is determined in chapter 5.

$$E_m = \sum_{i}^{m} D_i * LE_i \tag{27}$$

Where E_m = Jobs per year from the energy industry. Di = energy demand in MWh.

LEi = employment factor (jobs per year/MWh).

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5 CASE STUDY.

This section takes a critical examination of the Energy metabolism of the Greater Karu urban sprawl, which is situated on the outskirts of Abuja, the Capital City of Nigeria. The urban sprawl of Greater Karu is as a result of the conurbation of several informal to Abuja located at the center. The creation of Abuja in 1976, prompted the influx of people from Nasarawa, a neighboring state to the capital city for job opportunities and means of livelihood. The majority of the migrants could not afford the high cost of living in the capital city, it then became a necessity to erect informal settlements on the outskirts and periphery to commute to their workplaces for better means of livelihood.

The objective of this research work is to determine the energy metabolism of the informal settlement that make up the Greater Karu urban sprawl. This will involve the determination of the energy and fuel carriers present in both household and productive end users.

The Greater Karu area consists of the following settlements namely; Mararaba, New Karu, New Nyanya, Masaka, and Uke while the rural areas that have been overtaken by development encroachment include One man Village, Ado, Ado Kasa, Zhenwu,Luvu,Gurku, Kuchikau, and Kodepe. This research will diagnose the energy metabolism of four of these settlements: New Nyanya, Orozo, Ado and Uke. This research only focuses on the household and the productive use of energy sectors of informal settlements. The transportation sector is not considered in this analysis.

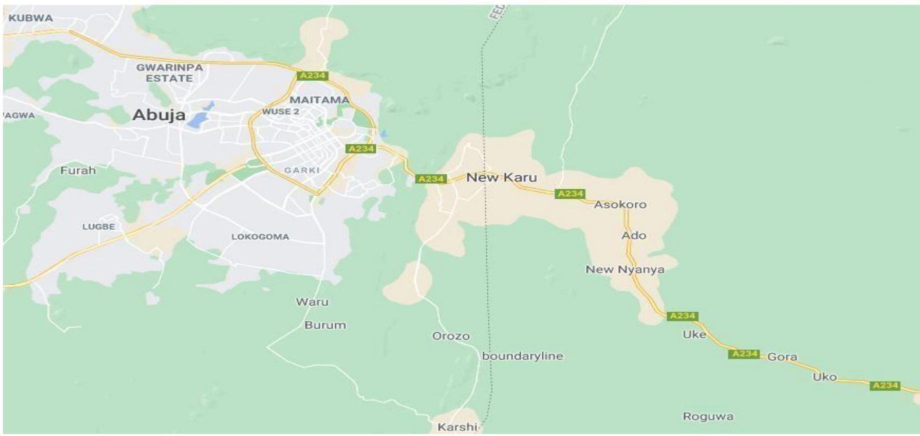

Figure 8. Map of Greater Karu Urban Area.

5.1 Characteristics of case study area.

Greater Karu Urban Area is a town created by the Nasarawa State Government, as a corridor that links the inhabitants of the state with the commercial activities present in Abuja the Federal Capital Territory of Nigeria. It is one of the fastest growing urban areas in the world, it has a notable growth rate of 40 percent making it one of the fastest growing urbanization resulting in urban sprawl from Abuja, Nigeria’s Capital city (Rikko et al, 2019). The area lies between latitudes 8 5”N and 9o 25”E and longitudes 7o 54E and 10o 42 N east of the Greenwich Meridian.(GUK) shares boundaries with Old Nyanya and Old Karu in FCT Abuja to the south west. Jaba local government of Kaduna state to the North. Settlements in the sprawling area consist of Mararaba, New Karu, New Nyanya, Masaka and Ado, which are more urbanized and areas of Uke, Kasa Zhenwu. Luvu, Gurku, Kuchikau identify with a rural setting.

5.1.1 Policy.

The Greater Karu Urban sprawl is administered by Karu local government, which was created in October 1991. Karu Local Government is under the auspices of Nasarawa State. Karu local government is split into three development areas namely; Karu, Karshi and Panda for administrative purposes. The institutional framework for urban governance in the Greater Karu area is complex and cumbersome. There are several layers of authority directly linked to issues of planning and organization of the settlement. The Nasarawa Urban Development Board administers the urban development strategies across the State. The Karu Area Planning and Development Authority is the agency in charge of creating access to basic urban services including waste management and sanitation (UN Habitat, 2012). Nasarawa state ministry of lands survey and town planning oversees the planning and management of land in the state. It confers the rights to issue certificates of occupancy and approves the layout plans before new buildings are constructed. The state ministry of housing, Environment and urban development oversees environmental management creates a double function with the Nasarawa urbandevelopment board.

5.1.2 Climate Characteristics.

Typical of North- Central Nigeria the area has both the raining and dry season. It consists of a mean annual rainfall between 1100 mm to 2000 mm. The plains are undulating with elevation ranging from 300 to 500 meters above the sea level.

The soil type is well drained with high fertility rate. It has run off potential with soil located along the stream beds with a high clay content. The area is covered with natural savannah type vegetation consisting of dense tropical woodland with shrubs and grasses (Ismail et al, 2015).

5.1.3 Water Consumption.

There are only around 5 percent of households in the Greater Karu area with access to adequate water supply from the municipality. About 90% of the residents rely on private boreholes, wells, water tanks and some private vendors in the water trading business (Rikko, 2019).
These private sources are not regulated by Government thereby increasing the risk of exposure to water price hike, disease from untreated water in supply exacerbating the lifestyle of the inhabitants.

The Greater Karu urban sprawl is surrounded with clean and natural water resources from the nearby River Uke, the Karu urban development board has taken strides to utilize the water resources through the creation of storage and reservoirs to the communities’ experiencing shortages but these efforts in form of strategies are often met with a series of challenges with regards to the implementation as a result of the cumbersome administrative structure in place. (UN Habitat,2012).

5.1.4 Emissions.

The overreliance on fossil fuels for consumption in the household, commercial, industrial and transport sectors indicate a high level of emission of greenhouse gases. 85% of Nigeria’s Electricity supply is derived from Natural Gas. In 2017 dry natural gas consumption for the country stood at 609.29 billion cubic feet. (IEA.2018). Nigeria’s CO_2 emissions per capita at 2014 was 0.55 metric tons (Sulaiman,2018).

5.1.5 Solid Waste Production.

The Greater Karu area is inundated with poor waste management disposal mechanisms. Only 4% of the population use improved waste method disposal (Rikko, 2016). There is a huge disregard for managing waste effectively by the local and State government. The Nasarawa urban development board has two refuse disposal vehicles and 250 bins to cover several local government areas. The board has made several attempts to form partnerships with private agencies to manage waste effectively in Karu. The move will see the creation of accessible dumpsites and landfill sites on the outskirts of the town. There are at the moment five dump sites to serve the expanse of land between Karu´s western border and Maraba, which is the next town in proximity to it (UN Habitat, 2012). The Nasarawa urban development board has identified some potential sites for the development of landfill. Private agencies can also provide waste facilities inside the city. Other mitigate measures to tackle waste disposal by the government is to include legal frameworks, for punishing those who dump waste indiscriminately. Nasarawa state board with partnership with the Nigerian police are permitted tocharge illegal dumpers, (Rikko & Laka,2013).

5.1.6 Population.

In 1991 the population stood at about 10,000 people to about 216,000 in 2006 from the census carried out by the National Population Commission (NPC,2006), similarly (Yari et al,2002) estimates that the population of Greater Karu was 500,000 in 2001. (Vilo, 2012) claims the population was about 2 million in 2012.

The Nassarawa state urban development board claims 2 million people at 2016. (NUDB, 2014). The settlements of New Nyanya, Orozo, Uke and Ado, which are under evaluation in this research work have estimated population sizes of 3692, 11286, 343 and 1675 (NUDB, 2014) It has a similar level of population growth with Abuja the capital city of Nigeria because of its close proximity. Abuja has a rapid growth rate of 9% and Karu 4.5% (FIG congress 2014).

5.1.7 Economy.

The economy of Karu is service based with 95% of Karu GDP/Economy earned in the informal sector comprising of self-employed traders, commercial agents and artisans. Karu major economic sectors are agriculture, trade and commerce. (UN Habitat,2012) Agriculture sub sector produces crops used for foodstuff and as an integral part for making other goods, this activity is carried out by farming households and small landowners, as opposed to large scale commercial farming operation. Relatively transport is provided to link residents from the nearby cities such as Keffi and Lafia to Abuja and the city settlements central area that is dominated by informal small businesses. Grains, farm produce, building materials and commercial products.

The extractive industry though not regulated and under government approval operates illegally with the mining of minerals such as clay and granite not fully exploited. 33.33% of the labour force is involved in trading e.g in agricultural products, food products, construction materials and mechanical parts or services. About 10% of the labour force, works in the hospitality and education industries, where their professional services are required in the Capital city of Abuja. 29% of the labour force are involved in the production of small artisan goods and 17% of the remaining work force are involved in the production of more conventional manufactured products the remaining 11% of the labour force work in construction and building sections (UN Habitat, 2012).

5.1.8 Electric Power.

The Greater Karu settlement falls under the auspices of the Abuja Electricity Distribution Company, which provides electricity to four states namely; Abuja (Capital City), Nasarawa, Niger and Kogi state (Abanihi et al, 2018).

The Greater Karu Urban settlement is among the franchise areas allocated to Nasarawa state, where enumerated customers receive electricity supply from the National Grid. These enumerated customers only account for a small fraction of the population in these settlements, with the remaining having to resort to illegal connections as a means of providing solutions to their energy problems.

According to the Nigerian electricity regulator (NERC), Abuja Electricity distribution company received an energy inflow of 460 MWh/h in the month of (Sept-Dec 2020), and it is scheduled to receive: 495 MWh/h, (Jan-June 2021), 495MWh/h (Jul-Dec 2021) and 532 MWh/h in the months of (Jan-Dec 2022). The supply of electricity from the National grid is 4,646 MWh/h in the months of (Sep-Dec 2020), and it is expected that in the forthcoming months 4974 MWh/h (Jan- June 2021), 4974 MWh/h(Jul-Dec 2021) 5325 MWh/h (Jan-Dec 2022), will be recorded. This is the current national electricity supply from the generating companies (GENCOS), that operate on the National Grid (NERC, 2020).

5.1.9 Electricity distribution.

Table 14. Showing the energy inflows into the electricity distribution countries in Nigeria.

Energy Parameter	Sep-Dec 2020(MWh/h)	Jan-Jun 2021 (MWh/h)	Jul-Dec 2022 (MWh/h)	Jan-Dec 2022 (MWh/h)
Energy sent out from GENCOS (National)	4,646MW	4,974MW	4,974MW	5,325MW
Energy delivered to AEDC	460MW	495MW	495MW	532MW
Energy delivered to YEDC	140MW	151MW	151MW	162MW
Energy delivered to PHEDC	260MW	280MW	280MW	301MW
Energy delivered to KEDCO	320MW	344MW	344MW	370MW
Energy delivered to KAEDC	320MW	320MW	320MW	320MW
Energy delivered to JEDC	220MW	237MW	237MW	254MW
Energy delivered to IKEDC	600MW	645MW	645MW	694MW
Energy delivered to EKEDC	440MW	473MW	473MW	509MW
Energy delivered to IBEDC	520 MW	559 MW	559 MW	601 MW
Energy delivered to EEDC	360 MW	387 MW	387 MW	416 MW

Source: (NERC, 2020).

The table 14 depicts the load allocation to Abuja electricity distribution company with an average value of 10% of the National electricity supply. In this research work it is assumed that there is no discrimination in supply of electricity in the franchise areas under the auspices of AEDC which include the states: Nasarawa, Kogi, Niger, Abuja. It is estimated that the energy inflow into these areas is pro rata the total amount of inhabitants captured in the customer enumeration of AEDC. The total number of customers under the auspices of AEDC is 6 million. Where average load share for AEDC is 495.5MWh/total number of customers is 6 million. Electricity flow per capita equals is 0.082kW per capita. This is what represents the electricity flow per person in the Greater Karu Urban Settlement. The total direct energy flow in GKUS comprises of the fuel and electricity primary energy carriers. Reliable electricity supply remains a huge problem, as there is continuous dependence on power supply from the overhead lines from Abuja. There is a significant demand for energy to power domestic, commercial and industrial appliances thereby making it imperative to ensure adequate energy supplies in the Greater Karu Urban Settlement, the energy consumption comprises of the productive use and household sectors.

The structure of the energy consumption for Greater Karu Urban Settlement is similar to the national consumption of the country as a whole. On the national level, the combined electricity production from the hydroelectric power plants which include: Kainji , Shiroro, Jebba dams, and the natural gas plants situated across the country, provide 16% and 83% of the electricity consumed from the national grid. The installed capacity of 12500MW is contributed from hydro-electricity and natural gas. 10,522 MW (83%) fossil fuels and 2,110MW (16%) hydroelectric and 32MW (<1%) is from solar, wind and biomass as at the year 2017 (EIA, 2017). The combined production level stood at 4954 MWh/h at the end of the year 2020, according to the Nigerian bulk electricity trading report (NBET, 2020).

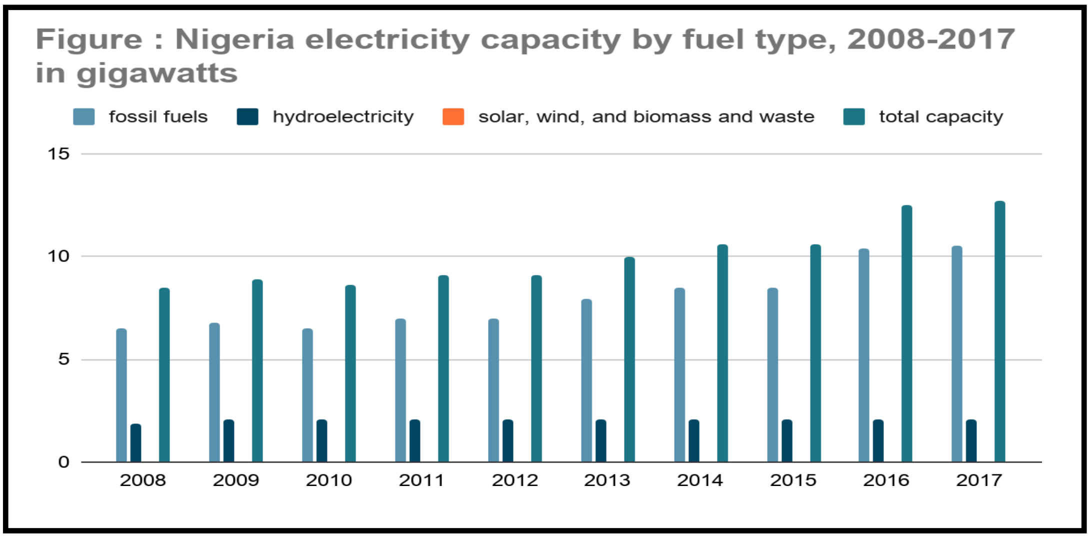

Figure 9. Electricity capacity by fuel type.

Source: Nigerian Bulk electricity trading report (NBET, 2020).

Electricity consumption for the Greater Karu Urban Area is benchmarked against the national consumption level, while the exact figures is being estimated from the projected demand from the productive usage sector which includes: agriculture, manufacturing and construction. This research work combines the projected demand of households and productive activities to reach a conclusion on the overall electricity demand for the informal settlements of GKUA.

On a national level, electricity consumption is still very low in comparison to most developed and developing economies. This is because of the low level of electricity access in rural and urban areas. The electricity access rate of Nigeria remains at 54.4 % at 2017 with a little improvement of 60% in the year 2019. (IRENA, 2017; World Bank, 2019). Electricity access in the country for urban and rural areas topped at 86% and 41.1% respectively (SE4all, 2020).

In the market intelligence report published by the Rural Electrification Authority in 2020. In Nasarawa state about 38%, of the urban population have access to electricity, while 18% of the rural population have access to electricity leaving a deficit in electricity provision of 64% and 82% respectively (REA, 2020). The Greater Karu Urban settlement which is situated in Nasarawa State, consists of hybrid settlements which fall into the category of both rural and urban areas. (Musango et al 2019).

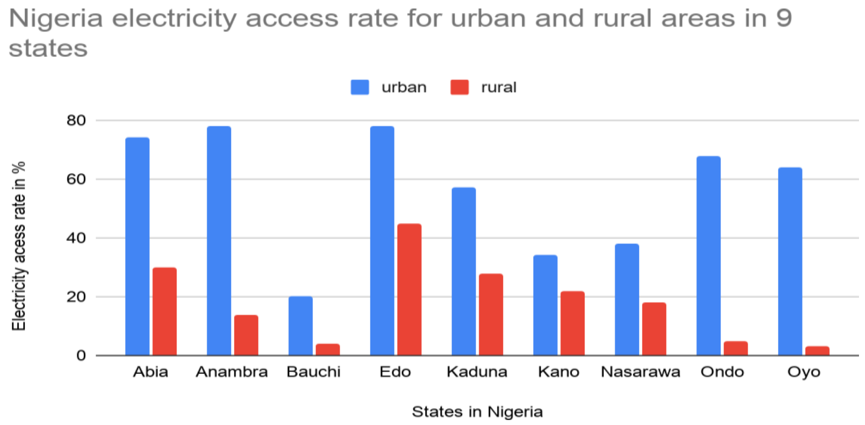

Figure 10. Electricity access rate.

Source: (REA,2020).

The poor access rates across the country signifies a low consumption rate per capita. According to the sustainable for all energy report, the consumption rate per capita is given as 143.7, 135.6 and 153,4 kWh per capita for the years 2010, 2012 and 2014. The population size in these yearsis given as: 159, 168 and 177 million people.

According to the report generated by the international energy agency in the year 2018, Nigeria's electricity consumption is recorded as 30.8TWh and the electricity consumption per capita at 0.2MWh per capita, which is approximately 200KWh per capita (IEA,2021). In developed countries like Spain and the United States of America, electricity consumption in the year 2018 is recorded as 255.6TWh and4,194.4TWh. The huge gap in consumption exists because of the production and manufacturing activities undergone in the United States in comparison to Spain. The gross domestic production in the United States outpaces that in Spain. America has a more robust economy than Spain, which makes it the largest economy in the World. Statistics from the Bureau of Economic Analysis, which is under the auspices of the U.S Department of Commerce, reports that the country experienced an annual growth rate of 4% in the gross domestic product (GDP) in the fourth quarter of 2020, reflecting a slow recovery from the effect of the COVID 19 pandemic streak. The U.S economy also experienced a steep rise of 33.4% growth in GDP in the third quarter of 2020, Spain on the other hand experienced a down growth in GDP of about -12.8% (BEA,2021). The GDP for the U.S in 2020 is $20.93 trillion compared to $1,279,237 million for Spain. However, the electricity consumption per capita in these developed countries is nowhere close to the Nigerian current status.

In 2018, some developing economies like India and some middle eastern countries such as Saudi Arabia and Iran recorded electricity 1.0 MWh, 10.2MWh and 3.3 MWh per capita respectively. In the continent of Africa, countries like South Africa and Egypt recorded 4.0 MWh and 1.6MWh per capita respectively. At 0.2 MWh per capita, Nigeria will need to improve on electricity access toimprove its economy, in comparison with the rest of the world. The records from the year 2018 indicate a low performance. The Greater Karu Urban areas (GKUA) electricity consumption is benchmarked against the national records, from which exact figures are obtained from the activity levels in the productive usage and household sector of the informal economy.

On the national level, in the year 2015, the residential sector accounted for 57.2% of electricity consumption, 26% and 16.5% was allocated to the commercial and industrial sector respectively.

According to the report generated by the international energy agency in the year 2018, the electricity final consumption by sector is given as 1337.0 ktoe,317.0 ktoe and 609.0 ktoe for the residential, industry and the commercial and public services respectively (IEA,2018).

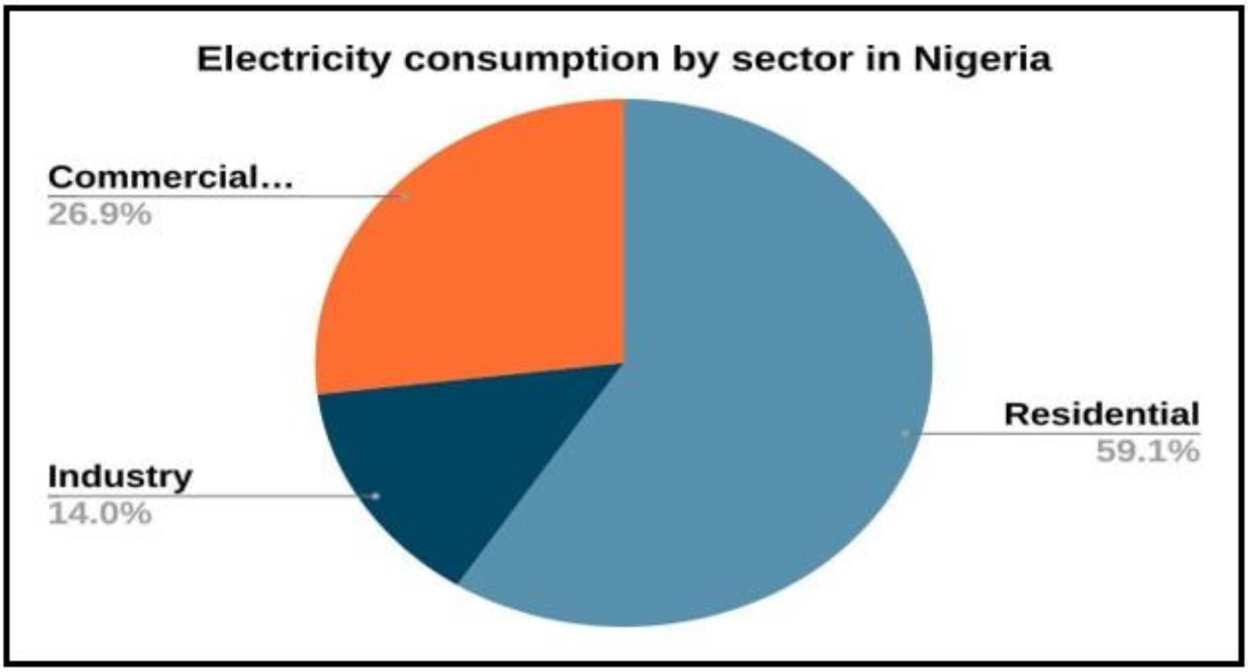

Figure 11. Electricity consumption by sector.

Table 15. Showing the electricity consumption per sector.

Economic sector	Electricity in GWh
Industry	4,057
Transport	Nothing was allocated, the country doesn't have access to electric motors
Residential	14,003
Commercial /public services	6,379
Final electric consumption	24,439
Losses in distribution and transmission	4,895

Source: (IEA, 2018).

5.1.10 Fossil Fuels.

Access to electricity as an energy carrier is very limited in the Greater Karu urban areas, and in this regard the inhabitants' resort to the use of fossil fuels to provide a substitute for their energy needs, Fossil fuel serves as energy carriers, which in most cases provides for the domestic and productive needs of the inhabitants.

The use of kerosene and LPG (Natural gas), is more evident in the cooking sub- section of the household sector of the informal settlements. More so the use of petrol and diesel to fuel backup generators is prevalent in the lightning sub section of the household sector. Diesel and Petrol generators serve the productive usage sector as well, where the fuel sources are used in refrigerating purposes for commercial trading and for the storage of agricultural products. Other fossil fuel sources such as Charcoal, which is derived from coal, is used for cooking amongst residents of these areas. (Gujba et al,2015).

Renewable energy sources such as Biomass is extensively used by homes in cooking, in fact this source of fuel accounts for 85-90% of energy consumption in cooking section of the household sectors in Nigeria (Dioha et al, 2018; Gujba et al,2015). It is the main preference for households in rural/ peri- urban settlements owing to the low cost associated with it in comparison to other sources available.

In this research work, we estimate the energy consumption for the inhabitants of Greater Karu urban area by benchmarking it with the national records.

Table 16. Showing the energy consumption per sector.

Sectors	Crude Oil production	Natural gas production	Biofuels and waste	Electricity	Coal
Transport	22689.0 ktoe			1337.0ktoe	
Industry	445.0 ktoe	116992.0TJ-gross	4153	317.0 ktoe	29.0 ktoe
Residential	642.0 ktoe		95884		
Commercial	1.0 ktoe		2771	609.0 ktoe	
Agriculture			0		
Non-energy use	169.0 ktoe	63 201.0TJ-gross	0		
Non/specified	174.0 ktoe		0		
Final consumption	24,120 ktoe	180193.0TJ-gross	102807	2,263 ktoe	29.0 ktoe

Table 17. Showing the indicators for Nigeria.

Indicator		2009	2010	2011	2012	2013	2014
Electricity production from natural gas sources (% of total)		77.10	75.60	78.24	80.29	81.56	82.41
Electricity production from coal sources (% of total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Access to electricity (% of population)	50.30	51.19	48.00	55.90	54.27	55.60	56.37
Access to electricity, urban (% of urbanpopulation)	84.30	83.39	79.8	87.10	84.13	83.60	84.29
Access to electricity, rural (%of rural population)	31.40	26.90	34.9	35.50	29.61	34.40	31.68
Access to clean fuels and technologies for cooking	1.96	2.19	2.44	2.74	3.09	3.48	3.92

Energy use (kg of oil equivalent per capita)	752.48	721.45	755.99	778.50	798.30	779.85	763.39
Electricity production fromhydroelectric sources (% of total)		22.90	24.40	21.76	19.71	18.44	17.59
Electric power consumption (kWhper capita)	127.18	120.57	136.36	150.13	156.17	142.68	144.48
Fossil fuel energy consumption (% of total)	18.44	15.89	18.03	19.00	18.80	18.63	19.04
GDP per unit ofenergy use	6.26	6.80	6.81	6.76	6.69	7.03	7.43
(Constant 2011 PPP $ per kg of oil equivalent)	6.01	6.58	6.67	6.76	6.81	7.27	7.83
GDP per unit of energy use PPP $per kg of oil equivalent)	86.35	88.83	86.78	86.15	86.45	86.78	87.39
Renewable electricity output (% of total electricity output)	27.10	22.90	24.40	21.76	19.71	18.44	17.59
Electric power consumption (kWhper capita)	127.18	120.57	136.36	150.13	156.17	142.68	144.48
Fossil fuel energy consumption (% of total)	18.44	15.89	18.03	19.00	18.80	18.63	19.04
GDP per unit ofenergy use	6.26	6.80	6.81	6.76	6.69	7.03	7.43
(Constant 2011 PPP $ per kg of oil equivalent)	6.01	6.58	6.67	6.76	6.81	7.27	7.83
GDP per unit of energy use PPP $per	86.35	88.83	86.78	86.15	86.45	86.78	87.39

kg of oil equivalent)							
Renewable electricity output (% of total electricity output)	27.10	22.90	24.40	21.76	19.71	18.44	17.59

Source: (World Bank, 2018).

5.1.11 Energy Balance.

The energy balance for the Greater Karu Urban area includes the imports and exports of the fuel and energy carriers, which represents the energy inflow. The energy out flow consists of the export of energy. Energy cannot be recycled in this regard this research estimates the energy imports that can be obtained from the urban metabolic flow path in the area. The estimates for energy inflows and outflows for the Greater Karu Urban area is benchmarked against the national records for the imports and exports of fuel and electricity energy carriers. On the national level the energy supply and consumption dynamics in Nigeria is largely determined by the electricity constraints, some of the determiners of the consumption dynamics include a reduction in per capita consumption and increase in self-generation. (Dioha et al ,2018; IEA,2014; IEA ,2018; IRENA, 2018). There is an increase in the quantity of crude oil, natural gas and some renewable energy sources like biofuels in the total primary energy supply in Nigeria in 2015 and 2018.In 2015, exports account for 50% of the total primary energy produced.

Table 18. Showing the energy imports and exports.

	Crude oil	Natural gas	Hydro	Biofuels	Electricity
Production	106493	35676	492	111566	0
Imports	0	0	0	0	0
Exports	10622	-20775 TJ- gross	0	0	0
Total primary energy supply	1855	14901	492	0	0

Source: (IEA,2018).

The energy import provided in the primary energy trade of renewable energy sources in the year 2012 and 2017 is 660871 TJ and 979754TJ respectively, while the exports of renewable energy is given as 5270791 TJ and 3776871 TJ consequently. The energy self-sufficiency is given as 189 % and 158% respectively. (IRENA, 2018). The energy self-sufficiency ratio in percentage is determined by the ratio between the national primary energy output which includes: coal, oil, natural gas, renewable energies and the consumption of primary energy in a given year.

Table 19. Showing the supply of renewable energy.

Non-renewable &renewable	2012	2017
Non-Renewable (TJ)	1337808	1652190
Renewable (TJ)	4543348	4920398
Total Primary Energy Supply	5888156	6572588

Source: (IRENA, 2018)

Table 20. Showing the primary energy trade.

	2012	2017
Imports (TJ)	1337808	1652190
Export (TJ)	4543348	4920398
Net trade (TJ)	5888156	6572588
Energy self-sufficiency (%)	189	158

Source (IRENA, 2018).

5.2 Selection of Renewable Energy Sources.

Six renewable energy sources have been identified in the Greater Karu urban area, which can be integrated into the current energy expansion planning on the local and national level subsequently. Currently the Federal government of Nigeria, through the Rural Electrification agency has commenced energy expansion planning to improve on the integration of renewable energy sources into the energy mix.

- The Rural Electrification agency has embarked on several energy expansion programs which include:
- Solar Power Naija.
- Solar Hybrid Mini Grids for Rural Economic Development. Minimum Subsidy Tender for Solar Hybrid Mini Grids.
- Standalone Solar Home Systems for Households and MSMEs. Energizing Education.

Program Phase II.

- Energizing Education Program Phase III.
- Results Based Financing for Productive Appliances & Equipment. COVID-19 Response.
- The third program on the list, which is the minimum subsidy tender (MST) will be implemented in two phases, where the supervising and implementation will be carried out by the Rural Electrification Agency. The agency has prioritized 99sites to be implemented in the first phase. These sites are spread across these states: Oyo, Kwara, Jigawa, Enugu, Delta, Ekiti and Nasarawa.

The Greater Karu Urban Area is located in Nasarawa state, on this basis, this research work will focus on the recent development in the power sector. The six renewable energy sources identified in the Greater Karu Urban Area include:
(R1) Bioethanol (R2) Biomass (R3) Wind Energy(R4) Solar PV Energy(R5) Hydropower
(R6) Solar Thermal Energy.

This research work applies a hybrid selection procedure, which includes the use of PROMETHEE software and Analytical Hierarchy Process (AHP), to select the most preferred renewable energy to be used for meeting the energy demand of the informal settlements located in the Greater Karu Urban Area.
The research study takes a further step to identify how effective the selected renewable energy source can be used.

5.3 Weights used.

The application of the multicriteria method in selecting the preferred renewable energy, involves the weighting of the criteria to determine their level of importance in the selection process.

According to section (4.2.10), out of the different weighting methods identified, we choose the Equal weighting method (EW) and the Analytical Hierarchy Process weighing method. This is carried out in order to compare the outcome of the different processes and rule out any form of inconsistencies and errors in taking these measurements.

5.3.1 Equal weighting method.

To apply the equal weighting method, the decision maker settles for a random score of 0.17 for all the sub criteria to be inputted into the PROMETHEE software, and this is responsiblefor creating the first scenario.

5.3.2 Analytical Hierarchy Process.

From the field of Renewable energy, 100 % of the participants are from Nigeria, where (%) are chosen from government institutions and (%) are chosen from private apply this method, a survey using Microsoft word forms captures the contribution of two groups of criteria weight determiners from expert opinion.

5.4 Community agent participation.

The form will be presented to these two groups to seek a top /bottom and a bottom/top opinion on the weights of the criteria, which will dissect this research work, in order to open it for further discussions that border on energy sustainability issues before coming to a reasonable conclusion.

For the community agent participation, the selection includes inhabitants who have lived with the experience of renewable energy sources as alternatives to fossil fuel usage, either from the exact communities under view or from neighboring areas.

Table 21. Showing the results of the experts.

Knowledge &Experience	High	Medium	Low
(1) Years of experience working in the field of renewable energy	0.8	0.1	0.1
(2) Educational level attained in the field of renewable energy	0.7	0.2	0.1
(3) Their respective knowledge about the selection of renewable energy in peri urban areas.	0.7	0.3	0.1

In this work we use descriptive statistics to determine the mean, median and standard deviation in order to measure the level of competencies of the experts (K):
If the total score falls in the range 0.8 < K< 1.0 the expertise is given a high score. If the total score falls in the range 0.5< K < 0.8 medium the expert is given a medium score.
If the total score of K < 0.5 the expert is given a low score. In this work we apply the average

value that is obtained from taking the average scores for the total number of experts involved in the assessment.

The degree of internal homogeneity is determined from the Cronbach coefficient, which is calculated from the questionnaires attached to the Annex II.

From 0.7 to 1 is an acceptable range to pass the reliability test of the questionnaires, below 0.7 is questionable and we have obtained 0.83.

To obtain reliable estimations of group experts' assessment, selecting the most appropriate method is key (Velychko et al, 2017).

Table 22. Showing the number of community participants.

Results			
Number of participants	High	Medium	Low
Total	50		

Table 23. Showing the equal weights used in the decision-making process.

Criteria	Weights used (Equal weighting method)
C1	0.1
C2	0.1
C3	0.1
C4	0.1
C5	0.1
C6	0.1
C7	0.1
C8	0.1
C9	0.1
C10	0.1
C11	0.1
C12	0.1
C13	0.1
C14	0.1

Table 24. Showing the results of the community agent participation.

Results			
Number of participants	High	Medium	Low
Total	50%		

Table 25. Showing the entropy weights used in the decision-making process.

Criteria	Weights used (Entropy weight)
C1	0.037
C2	0.008
C3	0.008
C4	0.035
C5	0.036
C6	0.069
C7	0.122
C8	0.065
C9	0.070
C10	0.547
C11	0.421
C12	0.159
C13	0.046
C14	0.007

Table 26. Showing the criteria weights obtained by using the AHP method.

Criteria	Weights used from the AHP method
C1	0.0413
C2	0.1601
C3	0.1363
C4	0.0413
C5	0.0584
C6	0.0829
C7	0.0708
C8	0.1143
C9	0.1143
C10	0.0829

C11	0.0413
C12	0.0264
C13	0.0145
C14	0.0145

The results are obtained from the analysis of the expert opinion.

5.4.1 Results of the survey.

Firstly, the level of expertise of the specialists in the field of renewable energy is identified by level of education and degree of experience, once the specialists have been selected, the questionnaire is administered in 3 different rounds of a Delphi format to ensure that the opinions obtained remain consistent.

5.4.2 Qualitative Criteria.

The qualitative criteria are measured with the involvement of expert and community agents. The professionals are obtained from the renewable energy field with level of education and experience as important attributes required for their involvement. The expert and community agents are asked to give opinion on qualitative criteria used to rank the renewable energy sources that can serve as a substitute for electricity supply in Greater Karu Urban Area. For the experts, 50% are drawn from government institutions/universities and 50%from the private sector.

Table 27. Showing the results of the qualitative criteria.

Qualitative criteria	C2	C3	C4	C14
Biomass	3	3	3	3
Biogas	3	3	3	3
Solar PV	5	5	3	3
Wind Energy	3	3	1	5
Hydroelectric	3	3	5	4
Solar Thermal Energy	4	4	2	4
Cronbach alpha	0.83			

5.4.3. Renewable Energy sources for the production of electric power in GKUA.

The electricity access rate in the Greater Karu Urban Area is estimated to be the same as that of Nasarawa state on a regional level. The coverage is about 28% for the rural and 38% for the urban section of the Greater Karu Urban Area, the reason for having these two access rates is as a result of the hybrid type of settlements that have become an integral part of its structurallayout. (REA, 2020).

The electricity consumption per inhabitant is estimated to be the same as that of Nasarawa state, which is further obtained from the average national electricity consumption rate. This methodology of estimating the consumption rate is derived from the average household electricity consumption in Nigeria. It is assumed in this work that every home with access to electricity consists of the same basic appliances i.e., a fridge, television set and energy bulbs for lighting (Dioha, 2018; Dioha et al, 2019; Gujba et al,2015). The rate is given as 0.2MWh/capita % of electricity is consumed in the residential sector, 26.9% in the commercial sector and the remaining 14.1% is consumed in the industrial sector (IEA, 2018).

However, these rates are on the national level, the exact electricity consumption for the Greater Karu Urban Area is derived from the productive usage and household sector. Electricity production to the Greater Karu Urban Area comes from the Abuja Electricity Distribution Company to households and businesses that are included in the customer database, however some of these customers still receive inadequate electricity supply, the hours of electricity supply on an average to homes in Nasarawa state is 6 hours per day. (REA, 2020). Most inhabitants resort to the use of backup diesel and petrol generators when faced with this amount of shortage. On the other hand, there are a number of inhabitants who are not registered customers, in this case they resort to the use of illegal connections to households who have been properly documented, creating huge collection losses for the distribution company. Which deters the distribution company (DISCOS) from making payment commitments to the generating companies (GENCOS) for electric power received.

Table 28. Showing the efficiency of biomass technology.

Steam turbines (Gustavsson,1997)	30%
Combined Cycle heat and power (Gustavsson, 1997)	43%
Co-firing (IRENA,2018)	36-44%
Combined Heat and Power/co-generation (IRENA,2018)	70-90%
Average efficiency	49.5%

Table 29. Showing the efficiency of biogas technology.

Biogas power station (Hakawati et al, 2017).	35%
Combined Cycle Gas Turbine (Hakawati et al, 2017).	58%
Fuel power station (Hakawati et al,2017).	40%
Sabatier + electrolysis (NREL, 2004).	74%
Average efficiency.	51.75%

Table 30. Showing the efficiency of wind technology.

Wind turbines (Pieralli et al, 2015).	30-40%
Wind turbines (IRENA,2016).	40%
Average efficiency.	36%

The scope of study requires the investigation of the average efficiencies of the available renewable energy technologies.

Table 31. Showing the efficiency of Solar PV technology.

Efficiency	
Mono-crystalline PV (IRENA,2019))	17%
Multi-Crystalline PV (IRENA,2019)	18%
Average efficiency	18%

Table 32. Showing the efficiency of hydroelectric power technology.

Efficiency	
Large hydropower plant (IRENA,2019).	90%
Micro and Small Hydro (Nasir,2014).	80-90%
Micro and Small Hydro (Hatata et al,2019; Walczak,2018; Garcia,2018).	60-80%

Table 33. Showing the efficiency of concentrated solar power.

Efficiency	
Concentrated solar-power (IRENA, 2019).	30%
Average Efficiency	30%

Table 34. Showing the overall efficiency of all the renewable energy technologies.

Efficiency	
Biomass (R1)	49.5%
Biogas (R2)	51.75%
Wind (R3)	36%
Solar PV (R4)	17.5%
Hydroelectric (R5)	80%
Solar Thermal (R6)	30%

Availability of source: The results for the weights of these criteria, which are obtained from is the table below.

A lickert scale of 1 to 5 is used to determine the level of compatibility of the renewable energy sources with the Nigerian renewable energy policy.

Where:

I. No availability.
II. Little availability.
III. Medium availability.
IV. Enough availability.
V. Excessive availability.

The results of the interviews are presented below:

Table 35. Showing the results of the interview with criteria C2.

Renewable energy sources	Weights	Sources
Biomass (R1)	3	Interview
Biogas (R2)	3	Interviews
Wind (R3)	3	Interviews
Solar PV(R4)	5	Interviews
Hydroelectric (R5)	3	Interviews
Solar thermal	4	Interviews

Maturity of technology: A Likert scale of 1 to 5 is used to determine the level of maturity of the renewable energysources where the score of 1 is given to the investigation stage and a score of 5 is given to the commercial stage.

- Investigation and development.
- Advanced investigation.
- Pilot Scale.
- Commercial.

Table 36. Showing the results of the interview with criteria C3.

Renewable Energy sources	Investigation and Development	Advanced Investigation	Pilot Scale	Commercial
Biomass			*	3
Biogas			*	3
Wind energy			*	3
Solar PV			*	5
Hydroelectricity			*	3
Solar Thermal			*	4

Urban obstacles: A Likert scale of 1 to 5 is used to determine the obstruction to urban traffic flow of the renewable energysources with the score of 1 given to no obstacle and 5 given to source that creates more than enough obstacle.

Where:

I. No obstacle.
II. Little obstacle.
III. Medium obstacle.
IV. Enough obstacle.
V. More than enough obstacle.

The results of the Interviews are presented below:

Table 37. Showing the results of the interview with criteria C4.

Renewable energy sources	Weights	Sources
Biomass (R1)	3	Interview
Biogas (R2)	3	Interviews
Wind (R3)	3	Interviews
Solar PV(R4)	1	Interviews
Hydroelectric (R5)	5	Interviews
Solar Thermal (R6)	2	Interviews

Table 38. Showing the results of the interview with their capacity factors.

Renewable Energy sources	Capacity factor	Sources
Biomass	64.9%	(EIA,2020)
Biogas	70%	(EIA,2009)
Wind Energy	37.1%	(DUKES,2012)
Solar PV	13-15%	(DUKES,2012)
Hydroelectricity	39.8%	(EIA,2020)
Solar Thermal	37.0%	(EIA,2020)

Table 39. Quantitative results for the LCOE.

Renewable energy sources	USD/kWh	Specific plant cost USD/kW	Load hours	Source
Biomass	0.066	2141-2380		(IRENA,2019) (Kost et al.2018)
Biogas	0.04	2088 -4177	5000- 7000	(Kost et al.2018)
Solar PV	0.045	714-1600		(Kost et al.2018)
Wind	0.053 onshore 0.115 offshore			(IRENA,2018) (Kost et al.2018)
Hydroelectric	0.047	> l100- 7650 large) 1500- 6000 (Run of River1300-8000) 2000-3000 (micro)		(Kost et al,2018;IRENA,2018)
Solar Thermal	0.182			(IRENA,2012)

Table 40. Quantitative results for operational and maintenance cost.

Renewable	USD/kWh/year	Source
Biomass	42.82	(NREL,2020)
Biogas	41.76	(IEA,2018)
Wind	33	(NREL,2020)
Solar PV	18	(NREL,2020)
Hydro	34	(IRENA,2019)
Sular Thermal	110	(IRENA,2018)

Table 41. Quantitative results for CO_2 emissions.

Renewable energy sources	CO_2 geq/ kWh	Average	Source
Biomass	7.2-90		IRENA 2019 Sgarbossa et al,2020
Biogas	80		Sgarbossa et al,2020
Wind	5.0-8.2		Wang &Sun, 2012Silva& Raadal,2017
Solar PV	40		(Reich et al2007; NREL,2020)
Hydroelectric	Run of riverplants - 19.1 Reservoir plants -21.0		Silva &Raadal (2019)
Solar Thermal (R6)	56		Silva & Raadal (2019)

Table 42. Quantitative results for investment cost.

Renewable energy sources	(USD/kW)	Average	Source
Biomass	2141 2400	2270	(IEA,2016) (IRENA.2017)
Biogas	2088		
Wind (onshore)	1600 1500	1550	(IRENA,2019) (IEA,2016)
			(IRENA.2019)
Solar PV	999		
Hydroelectric	1704	1704	(IEA,2016)
Solar Thermal	5774		(IRENA,2018)

Table 43. Quantitative result for land usage.

Renewable energy sources	m^2/MWh	Source
Biomass (R1)	810	Spitsley & Keoleian (2005) Fawcett.M, 2017
Biogas (R2)	237	Spitsley &Keoleian (2005) Fawcett.M, 2017

Wind (R3)	1,3	Spitsley &Keoleian(2005) Fawcett.M, 2017
Solar PV(R4)	15	Spitsley &Keoleian(2005) Fawcett.M, 2017
Hydroelectric (R5)	16.9	Spitsley &Keoleian(2005) Fawcett.M, 2017
Solar Thermal (R6)	19.3	Spitsley & Keoleian(2005) Fawcett.M, 2017

Table 44. Quantitative results for water consumption.

Renewable energy sources	gal/MWh	Average	Source
Biomass	553		(Macknicket al,2011) (Huang FH;2010; DOE/ NAS/NAE/NRC, 2010a)
Biogas	(Biogas dry)-35 dry)- 35 (Biogas pond)-390 (Biogas tower)-235 Tower) -		(Macknick et.al,2011); (Huang FH; 2010; DOE/ NAS/NAE/NRC, 2010a)
Wind	1		(Macknicket et al 2011)
Solar PV	26 33	 29.5	(Macknicketal,2011) (Huang FH, 2010; DOE)
Hydroelectric	4500 4900	4700 0	(Macknicket al,2011)
Solar Thermal	CSP dry trough-78 CSP hybrid Powertower- 170		(Macknick et.al, 2011) (Huang FH; 2010; DOE/ NAS/NAE/NRC, 2010a)

Table 45. Quantitative results for Acidification.

Renewable energy sources	SO_2 (g/KWh)	Average	Source
Biomass	0.18		(Turkoniet al,2013)
			(Nomura et al, 2001)
	0.03-0.94	0.383	(Turkoniet al,2013)
Biogas	0.18		(Nomura.et al, 2001)
	0.02-0.09		(Turkoniet al,2013)
Wind	0.06		(Nomura et al, 2001)
Solar PV	0.12-0.29		(Turkoni et al, 2013)
	0.24- 0.26		(Nomura et al, 2001)
Hydroelectric	0.001-0.03	0.008	(Turkoni et al, 2013)
	0.002		(Nomura et al, 2001)
Solar Thermal	0.12-0.29	0.21	(Turkoni et al, 2013)
	0.24		Nomura et al, 2001)

Table 46. Quantitative results for job creation.

Renewable sources	Manufacturing (Jobs/MW)	Construction Installation (Job/years/MW)	Operation & Maintenance (Jobs/MW)
Biomas(R1) (IRENA, 2003; Lambert, 2012; Tourkolas, 2011)	2.9	14	1.5
Biogas (R2)	5.0	25	6
Wind (R3) – onshore	6.1	2.5	0.2
Offshore(IRENA,2003); (Lambert,2013; Tourkolas,2011)	11	7.1	0.2

Solar PV (R4) (IRENA, 2003)	6.9	11	0.3
Hydroelectric (R5) - large	1.5 -5.5	6	0.3
		15	2.4
Solar Thermal (R6)	4	8.9	0.5

Table 47. Showing employment factors in job/GWh.

Renewable sources	Employment factors (Job-years/GWh)	Average value of employment factor
Biomas (R1) (IRENA, 2003); (Lambert, 2012; Tourkolas, 2011)	0.21 0.80	0.61
Biogas (R2) (Wei et al, 2010)	0.47	0.47
Wind (R3) (IRENA,2003) Lambert,2013; Tourkolas,2011)	0.17	0.4
Solar PV (R4) (IRENA,2003;Wei et al,2010)	1.23;0.87	1.05
Hydroelectric (R5)(Wei et al, 2010; Tourkolas,2011)	0.27; 0.33	0.3
Solar Thermal (R6)Wei et al,2010)	0.23	

Table 48. Qualitative results for compatibility.

Renewable sources	Support	Sources
Biomass		
Biogas		
Wind		
Solar PV		
Hydroelectric		
Solar Thermal		

A Likert scale of 1 to 5 is used to determine the level of support of the renewable energy sources with the Nigerian renewable energy policy.

Where:

1. No support.
2. Little support.

3. Medium support.
4. High support.
5. Very high support.

The results of the Interviews are presented below:

Table 49. Qualitative results from the interview.

Renewable energy sources	Compatibility	Sources
Biomass (R1)	3	Interviews
Biogas (R2)	3	Interviews
Wind (R3)	3	Interviews
Solar PV(R4)	5	Interviews
Hydroelectric (R5)	4	Interviews
Solar Thermal (R6)	4	Interviews

5.4.4. Results from PROMETHEE.

The values of the criteria obtained from section 5.4 is used in the PROMETHEE software application. The multicriteria selection of the best renewable energy source for the informal settlements through the categorization of criteria weight values to include that which is derived from the Equal weight method, AHP weight method and the Entropy weight method. As a result of the difference in their relative functions the ranking of the renewable energy source produces slightly different results as shown in Table 56.

Table 50. Ranking of renewable energy alternatives.

Renewable energy	Ranking		
	Equal Weight Method	Analytical Hierarchical Method	Entropy Method
Solar PV	1	1	1
Wind	2	2	2
Hydroelectric	3	3	6
Biogas	4	5	4
Biomass	5	4	5
Solar thermal	6	6	3

Table 51. Showing the ranking of alternatives using the Equal weight method.

Renewable Energy	Phi	Phi+	Phi-
Solar PV	0.2893	0.4351	0.1458
Wind	0.0926	0.2652	0.1727
Hydroelectric	-0.0195	0.2241	0.2436
Biogas	-0.0924	0.1740	0.2664
Biomass	-0.1133	0.1593	0.2727
Solar thermal	-0.1566	0.1035	0.2622

Table 52. Showing the net outranking flow using Analytic Hierarchy Process method (AHP).

Renewable Energy	Phi	Phi+	Phi-
Solar PV	0.4022	0.5034	0.1012
Wind	0.0696	0.2356	0.1660
Hydroelectric	-0.0312	0.1971	0.2282
Biogas	-0.1214	0.1407	0.2621
Biomass	-0.1470	0.1287	0.2757
Solar thermal	-0.1722	0.0471	0.219

Table 53. Showing the net outranking flow using the Entropy method (ENW).

Renewable Energy	Phi	Phi+	Phi-
Solar PV	0.4635	0.5621	0.0986
Wind	0.2597	0.3842	0.1245
Hydroelectric	-0.0122	0.1909	0.2031
Biogas	-0.00195	0.2439	0.2634
Biomass	-0.01745	0.1694	0.3439
Solar thermal	-0.5170	0.1076	0.6246

5.4.5 Prioritization.

Table 54. Showing the ranking performed by the PROMETHEE methodology.

Ranking	Alternatives	Phi	Phi+	Phi-
1	Solar PV	0.8915	0.9480	0.0565
2	Wind	0.8330	0.8901	0.0570
3	Biogas	0.6944	0.8058	0.1114
4	Hydroelectric	0.3510	0.7934	0,4423
5	Solar Thermal	-1.2436	0.2029	1.4466
6	Biomass	-1.5264	0.1552	1.6817

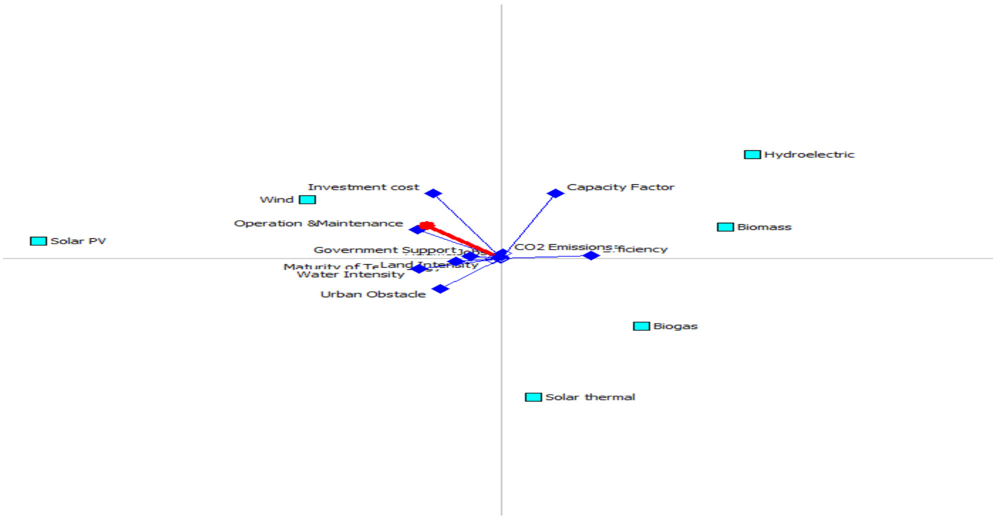

Figure 12. Promethee GAIA plane using the equal weight method (EW).

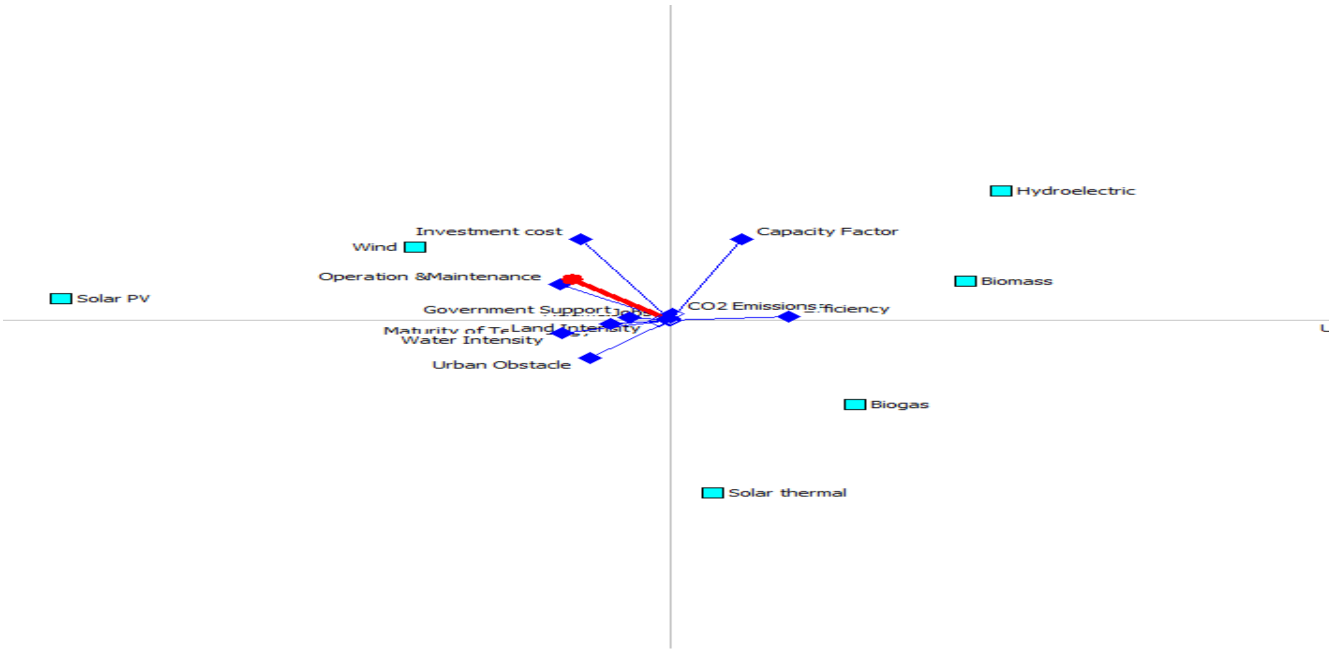

Figure 13. PROMETHEE GAIA plane using the AHP weight method (AHP).

Figure 14. PROMETHEE GAIA plane using the Entropy method (ENW).

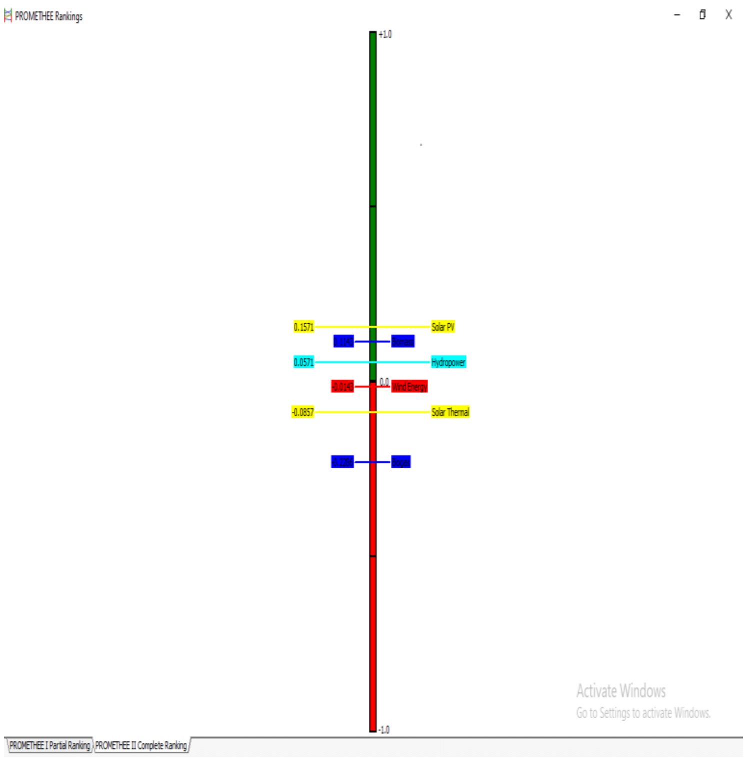

Figure 15. PROMETHEE complete ranking.

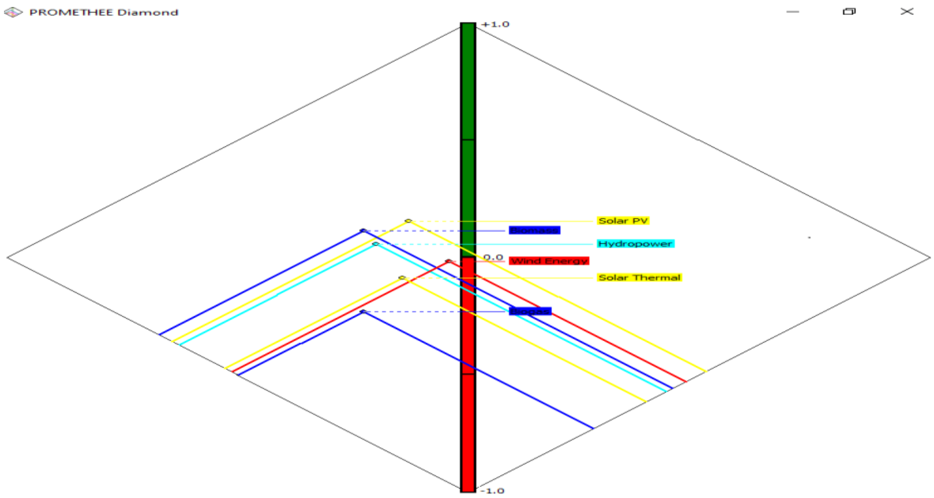

Figure 16. PROMETHEE diamond using the equal weight method.

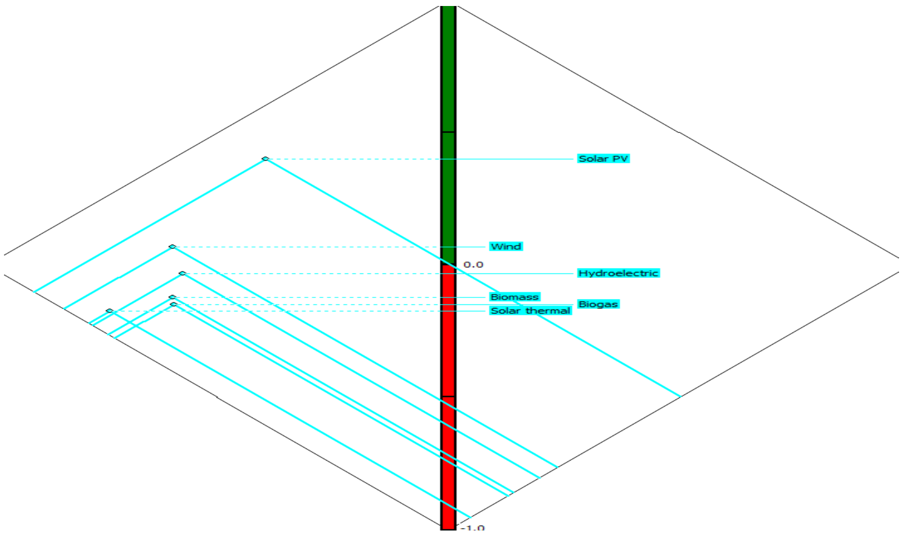

Figure 17. PROMETHEE diamond using the AHP method.

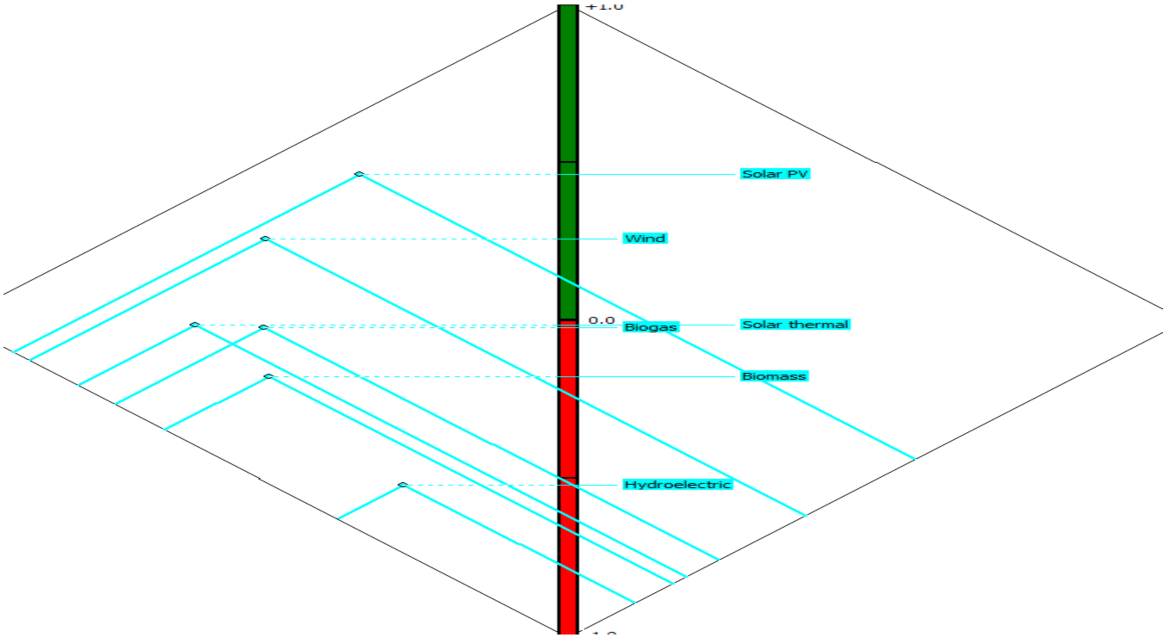

Figure 18. PROMETHEE diamond using the Entropy method.

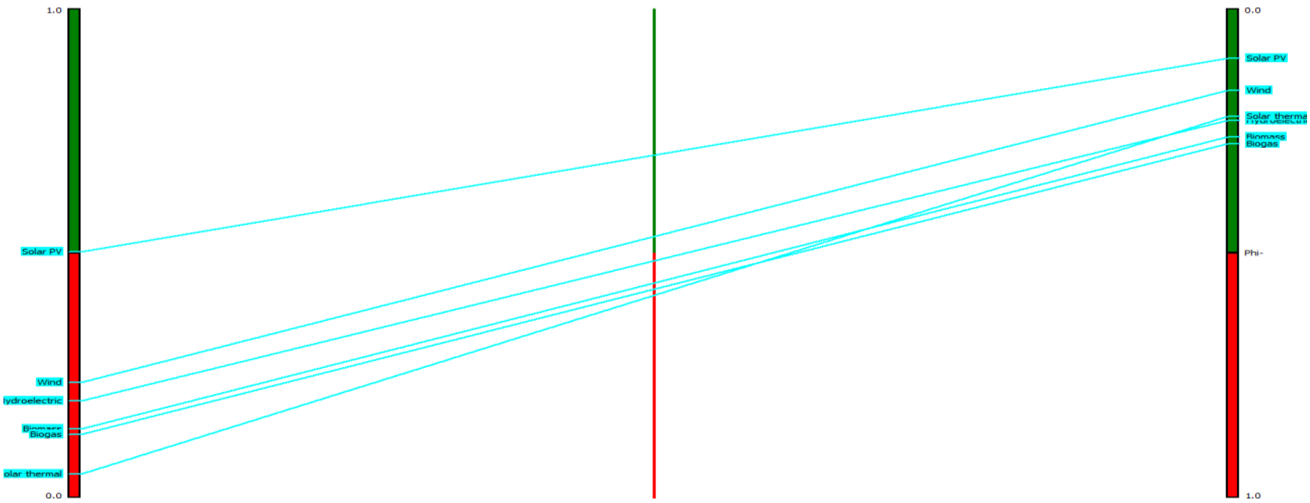

Figure 19. Partial ranking using the AHP method.

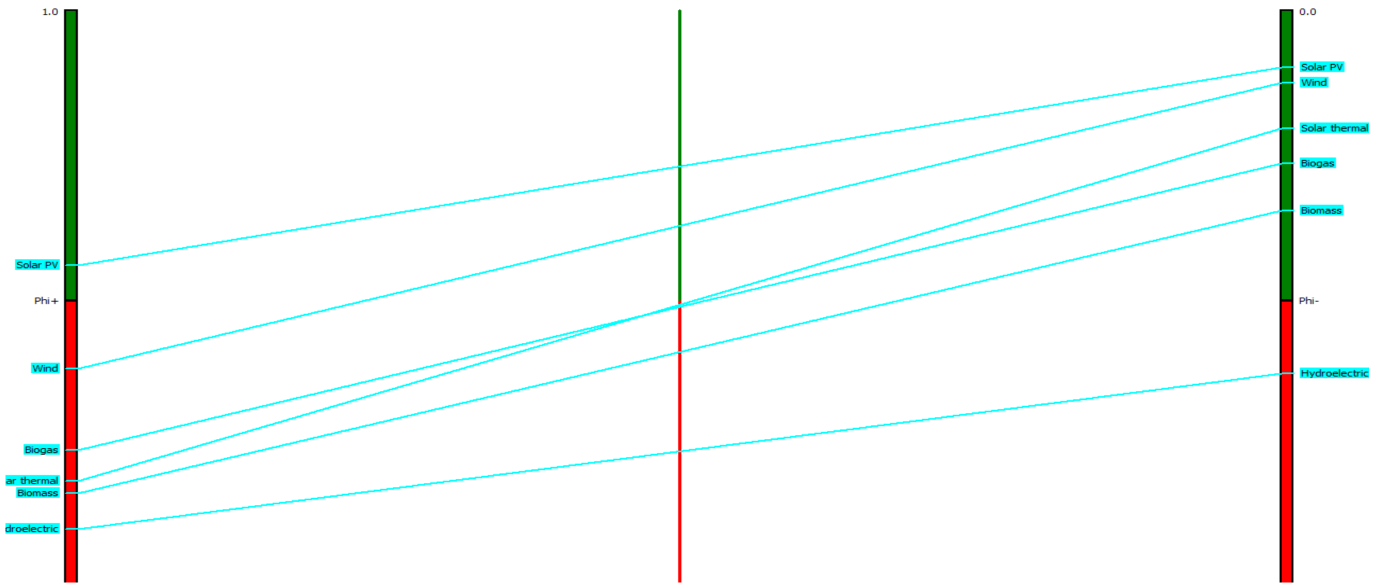

Figure 20. Partial ranking using the Entropy method.

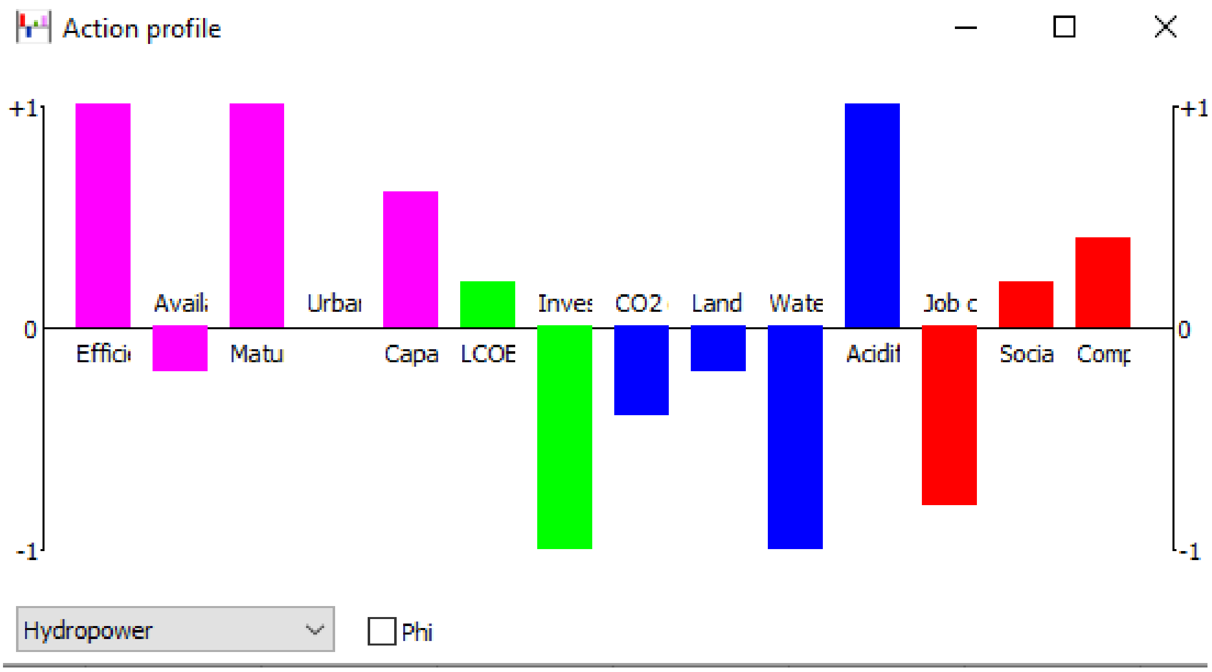

Figure 21. Action profile for Hydropower.

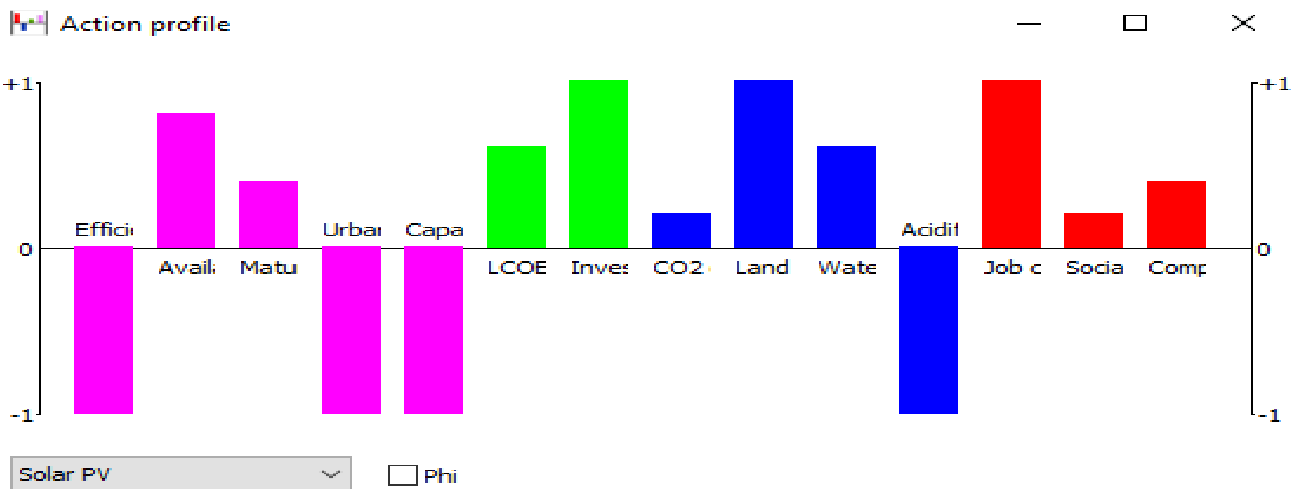

Figure 22. Action profile for Solar PV.

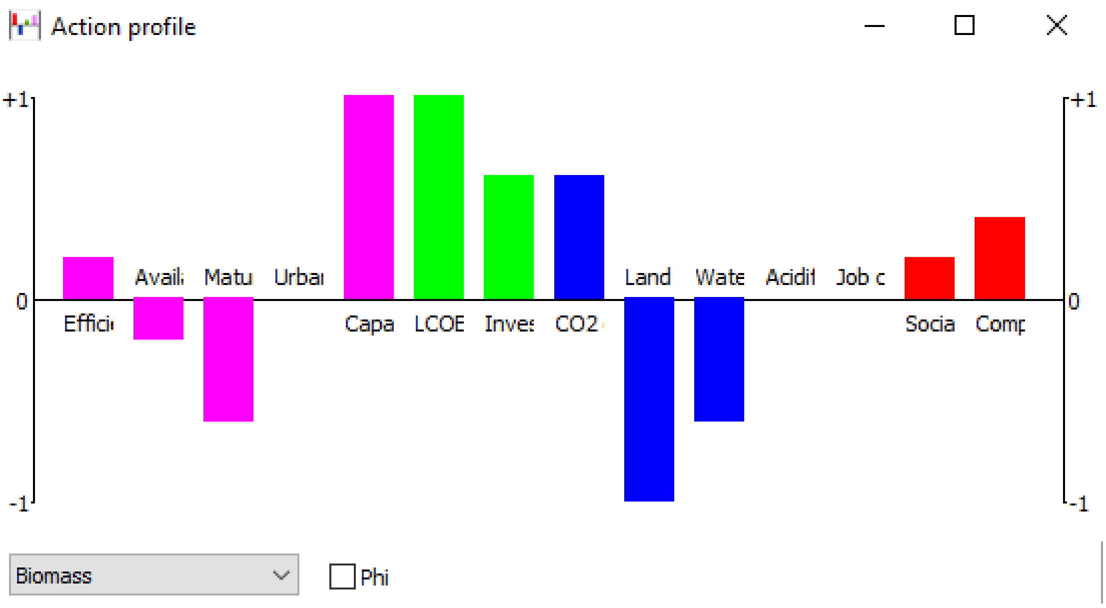

Figure 23. Action profile for Biogas Energy.

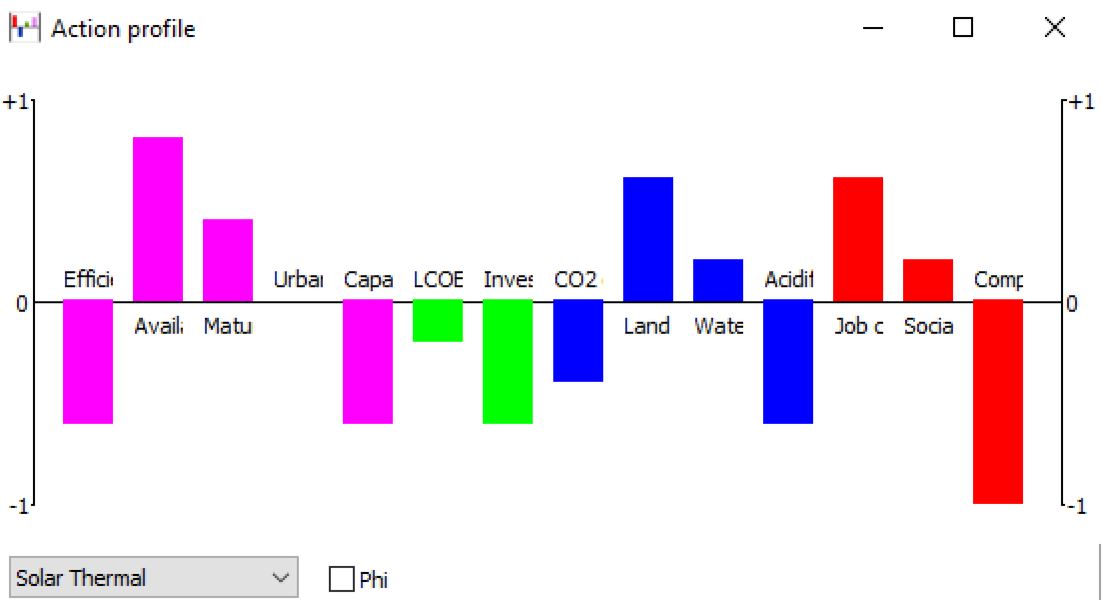

Figure 24. Action profile for Solar Thermal.

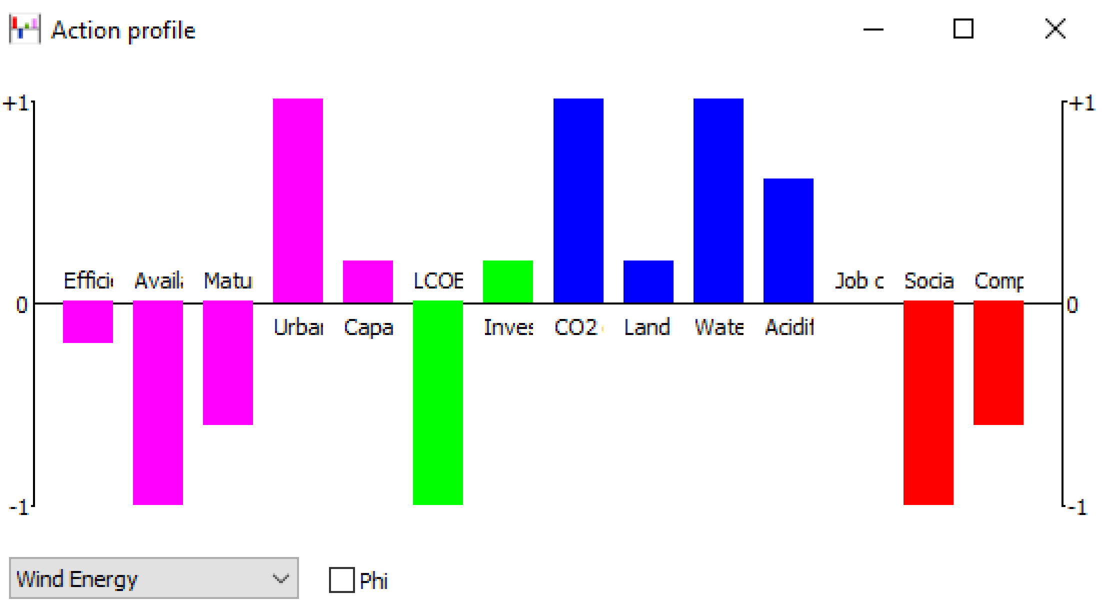

Figure 25. Action profile for Wind Energy.

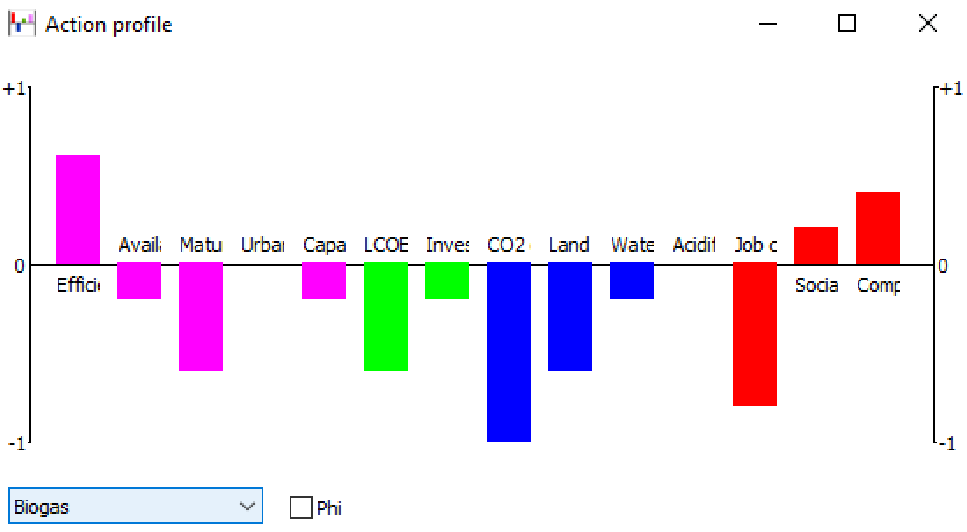

Figure 26. Action profile for Biomass Energy.

5.4.6 Community energy model.

The informal energy planning is facilitated with the use of the community energy model. The energy demand that the Greater Karu Urban area requires is represented in the residential and productive use sector of the local/ economy.

In the analysis of the case study, we identify the direct energy carriers; which includes electricity and fuel and determine how the current energy model can be transformed from a linear to a circular model through the concept of urban metabolism (Zhang et al, 2014).

The community energy model fulfils the research objectives which include: To quantify the energy demand of the informal settlements in view.

To examine the direct energy flows in the informal households and productive activities, to determine how to change the current energy model from linear to circular. To determine the contribution of community agents to urban energy planning through abottom/up-approach.

The energy diagnosis is carried out in the typologies of households and productive use, these typologies are being created to community specification. The four informal communities in view, possess different characteristics that have become determinant of the type of electricity and fuel carriers utilized to provide for their energy needs. (Smit et al,2019). We identify four typologies of informal settlements, and tailor their energy requirements to be community specific, which is a branch off from the general categorization of informal settlements.

5.4.7 Sampling procedures.

In this research work, we carry out samples from the total population of inhabitants in the informal settlements of the Greater Karu Urban Area. These settlements include New Nyanya, Orozo,Ado and Uke. In the Greater Karu urban Area, there are a total of 17 informal settlements present, because of the time required to complete this project, we have decided to carry out this research study by using a sample size of 4 out of a sample frame of 17 informal.

For this research work, we apply the random sampling method to select samples from each cluster of dense areas with the help of google earth and QGIS software. The random sampling enables usto select houses and enterprises which fall into the productive usage of electricity in order to complete this study.

Questionnaires are administered to randomly selected households and productive use enterprises. Out of all the houses on the grid, we collect samples of 265 households and 195 productive enterprises.

Out of the sample size of 265 carried out in the survey, 215 households responded which represents 81.1% of the total households sampled.

The remaining 12% absented. For the productive enterprises, a total of 165 responded, which represents 84.6% of the total sample size of 195 productive enterprises.

Table 55. Showing the results of the sample collected.

Mararaba	882	1	80		83	
Ado	332	80	60	60	45	55
Orozo	627	60	65	45	60	40
New Nyanya	549	80	60	40	50	30
Aso	712					
NewKaru	455					
Tudun wada	247					
Uke	226	70	80	50	60	40
Laifi						
Auta ba	382					

Laifi			
Gurku	465		
Zhewu road	236		
Korodoma	451		
Kuchikau	468	47	
Adon	361		
Kasa			
Kabayi	1020		
Nyanya	450		
Gwandara			
Total	8050	324	307

5.4.8 Findings from sampling.

The implication of this assertion is that in this research work all the houses and settlements identified are compared with this yardstick with regards to energy usage and consumption (Ibitoye, 2013).

In Greater Karu urban sprawl, it has been generally observed that the fuel type for major household present include: Kerosene and LPG as major choices for cooking in the householdsin the planned areas.

The difference in price and availability makes Kerosene a preferred carrier. Charcoal and wood (Biomass) serve as alternatives in the period of inadequacy of supply of kerosene and LPG. The high price of LPG makes it less attractive for rural households. (Ibitoye, 2013).

For lightning purposes Kerosene is also the fuel choice in non-electrified households and in many electrified households (Rikko, 2016)

There is a higher availability of Wood in most rural areas of the southern part of Nigeria and a reduction in amount with continuous approach up North. Notwithstanding, it is still a major source of fuel for cooking notably used by the rural poor in Greater Karu, Wood fuel still poses a great threat to a clean surrounding. WHO (2012) estimates 1.5 million people die every year with the continuous usage of fuel wood.

Other subsectors that represent domestic/household energy consumption are refrigerating, air conditioning and water heating, which are popular amongst the settlements with energy access.

The level of income of each household is a strong determiner of what electricity choices are available for the inhabitants with regards to gaining access to energy. The 1999 and 2006 population census figures published by the National Bureau of Statistics (2009) as the baseline, estimates population of Nigeria in 2005 to be 137 million with 46.72% of households having access to public electricity. Large number of households designated as having access but really do not have electricity for most of the time due to epileptic supply from the National Grid. In Greater Karu area, the income inequality affects the electricity consumption to a large extent going by recent studies (Dong, 2018). The commercial/industrial sector of Greater Karu is characterized with informality, as a result of the non-existence of legislature to govern the activities therein.

The absence of regulation sees the proliferation of energy carriers such as Gasoline, Diesel and LPO which are used to power appliances for agriculture, manufacturing and Domestic/service in the productive use of energy sector. The end users of electricity in the productive use of energy are determined by the level of human activity and the type of electrical appliances used in the different sector.

The World Bank report on productive usage under the ESMAP study (ESMAP.2018), sets the standard for the categorization of the productive use sector into agriculture, manufacturing/construction and the domestic/service. This research categorizes the productive sector present in the Greater Karu from the recommendation of the ESMAP study.
From the sampling conducted we are able to identify typologies of household and productive settlement, through these findings we establish the metabolic flow pattern.

5.4.9 Typology of households.

The typologies of households are derived from the literature review on informal settlements (Rikko et al,2019, Smit et al,2019 and UN, Habitat, 2013). Five categories of informal settlements were identified to include:

Category A: Located in the township.

Category B: Settlements that contain houses that have become slums.

Category C: Settlements that are characterized by the invasion and occupation of land by squatter camps.

Category D: These settlements are used as relocation sites for destitute and displaced persons by the government.

Category E: Hybrid settlements that have emerged over time as a result of middle class and lower- class settlers cohabiting together. (Smit, et al,2019). It is from this classification that this research work derives the categorization of 4 out of the 17informal settlements situated in the Greater Karu Urban Area (GKUA) of Nasarawa State in Nigeria. We select the 4 informal areas particular to this study, and categorize them into the following:

Type M informal settlement; It is characterized by the presence of formal structures or buildings which have a shed or shack attached to it either from the front entrance of the main building or behind it. These shacks are illegal structures constructed on formal buildings by settlers who are unable to afford the rents for shops and living space to fend for their families, so these structures are erected with an informaltype of agreement with the owner of the formal building, wherein such agreement covers a mutually beneficial service arrangement between both parties. It is often depicted as a poor man serving the rich man, and in return the rich man permits the erection of these illegal structures around the periphery of his compound without obtaining planning permission from the government or municipal authority.

The type M informal settlement can often be seen in the township area within the Greater KaruUrban Area, where the majority of the middle-class settlers are situated. The middle class
settlers are able to live above the poverty line of being able to afford more than 2$per day to feed (UN,2020). They contribute a large input to the formal sector of Abuja, the capital of Nigeria, where they offer their services in the Educational, and tourism sectors inAbuja. See the chat of informal settlers.

In return for their services, they are paid above the minimum monthly salary as stipulated by the federal government, which amounts to N30,000 (Naira per month), some of these informal workers that contribute to the formal sector in Abuja, are qualified to take on more skilled jobs in these sectors due to a fraction in possession of higher degrees from the Universities, Polytechnics and Higher institutions of learning. However, their salaries are not adequate to provide them with the means of affording to live in Abuja, so they commute every day from Abuja where they work to the township area of the Greater Karu Urban Area.

Type H informal settlement: These settlements are characterized as hybrid because they are illegal shacks attached to formal municipal flats (M), which have been built for formal sector workers. These settlements are Ilegal and unplanned and do not fit into the building requirements stipulated by the Government..

Type S informal settlement: These settlers are majorly destitute who live in independent communities of their own consisting of both extended and nuclear family members, alongside close friends and relatives. They include clusters of shacks or sheds that are erected on empty lands that have received government approval to build. In this scenario, the owner of the land, is faced with the challenge of funding his building project so leaves the land bare and unfenced, thereby attracting the invasion of the squatter settlers who take advantage of the empty land to set up residential shacks and sheds to cater for the housing challenge of their family and friends. Problems often arise in the form of a land tussle, when there is readiness from the rightful ownerto commence the erection of building structures on his land, after a quit notice has been issued to the illegal settler. The illegal settlers in most cases put up a strong resistance, insisting that they have occupied the land for years and lay claims on ancestral rights to trump over whatever legal rights the original owner obtains from the government Generally the legal precedence follows from these arguments from the local community courts to the state and then on the national level where litigation can linger for so many years, without an end in sight to a possible outcome. This is also due to the weak institutions that are prevalent in the Country, where the enforcement of legal rights and privileges are often met with huge challenges.

Type A settlement: These settlements are characterized on the periphery of the Greater Karu Urban Area, closer to the rural areas & villages. They are extensions of the Greater Karu Urban Area into a large expanse of land that is available for agricultural activities. Unlike the H type settlement which includes skilled informal workers that fit into the formal sector of the economy of Abuja, these settlers are the largest contributors of the agricultural sector, where a huge numberare involved in both subsistence farming to cater for their and internal needs, and commercial farming that serves the larger population of Abuja and the whole country at large. However, they are characterized as informal settlements because they live in mud huts that do not fall under the approval of building structures by the Government both regional and local. Some of the farming lands they cultivate their agricultural produce on, are inheritances from their ancestors.

In some cases, these lands are often government owned and are involved in a land tussle with the locals who claim such rights or privileges that comes with ownership. Additionally, these settlers erect makeshift tents with polythene roofs made from sacks of rice and garri in anywhere they deem it convenient in order to commute to their farms easily on a daily basis.

Type I settlements. These are the informal settlements that have erected proper building structures on illegal land, they are the ones responsible for damaging government laid down pipelines and infrastructures to transport crude oil and gas resources. They constitute a large chunk of illegal electricity theft because they live in close proximity to neighbors who have buildings that have been approved by the government.

They also contribute a large fraction to the productive use sector of the informal economy, where their commercial activities include: Food vending, welding, vulcanizes and ice block merchants. These settlers are the backbone of the financial sector of the informal economy of Greater Karu Urban Area, in some cases, they are able to sell their products/services to the informal and formal workers that occupy the formal sector of the economy of Abuja, which is the Capital City of Nigeria.

5.4.10 Typology of Productive Enterprise.

Findings from the sampling carried out on the informal settlements in the Greater Karu Urban Area, includes the typologies of productive use enterprises, which is also an integral part of the energy diagnosis. We derive these typologies from the global technical assistance partnership that is administered by the World Bank, which includes bilateral official sponsorship from the German International Co/operation (GIZ) under the flagship of the Energy sector management assistance program (ESMAP). The ESMAP focuses on promoting productive use of energy (Gouvello & Durix,2008; Vance et al, 2013). Generally, the productive use sectors are divided into three main sub sectors namely:

- Agriculture.
- Manufacturing.
- Commercial and local industry.

(Peters et al,2013; Gouvello &Durix, 2008, Rikko 2019, Makinde 2018). See Chapter4.

In the Greater Karu Urban Area, we find the following typologies of settlements that characterize the type of productive use of energy, along with the enterprises that are present.

Category A:

Informal settlements are predominantly agriculture based and the productive activities include cash crops, food crops, fishing and livestock farming.

Category M: Informal settlements are characterized by the level of local production of good suchas wood and textile materials.

Category C & I: Informal settlements engage in productive activities that offer services, e.g food vending, metallurgy and blacksmithing.

5.4.11 Results of sampling for New-Nyanya settlement.

New Nyanya settlement shares boundaries with Mararaba, Ado, Masaka, New Karu and Kurunduma.It is in close proximity to the Federal Capital Territory, closing with a distance of about 30 KM (Kilometers) from Abuja, which is the Capital City of Nigeria It is characterized with a population size of about 850,000 (NUDB, 2020).

New Nyanya settlement is very commercial in nature, as majority of inhabitants commute on a daily basis to the Capital City of Abuja to either sell their products manufactured locally or provide skilled services to the formal sector.

The settlement falls under the household typology H, I and M, and the productive enterprise typology C&I, and Category M. From the 50 households and 30 productive enterprises sampled, our findings revealed in the table below that 53 % were male and 47% were females. 15 households fit the description of the Type H informal settlement, 15 of the households fit the description of the Type M settlement and the remaining 20 possess the characteristics of the I type settlement.

Table 56. House data for New Nyanya.

Housing Typology	Number of respondents
Type H (Formal structure with a shack attached to the building).	15
Type I (Illegal structures).	20
Type M (Municipal flats & Federal housing units).	15
Total	50

Table 57. Household composition.

Household Composition	Size	Age	Monthly Income	Composition
Type H (Formal structure with a shack attached to the building).	4 to people	Adult (35- 50)	N 32,000	1 Adult Male, 1 Wife, 2 to 3 Children
Type I (Illegal structures)	4 to people	Adult (45-70)	N 41,000	1 Adult Male, 1 or 2 Wives, 3 to 5 Children
Type M (Municipal flats and federal housing unit).	Not more than 5	Adult (38-60)	N 83,000	

From the 30 productive enterprises sampled ,our findings reveal that 65% aremale run businesses and 35% of the businesses belong to female.

Table 58. Showing data for productive enterprises in New Nyanya.

Enterprise Typology	Size	Respondents
Category (C&I).		20
Category M.		10
Enterprise Composition.		
Category(C&I).	2 to 5	
Category (M).	5 to 10	

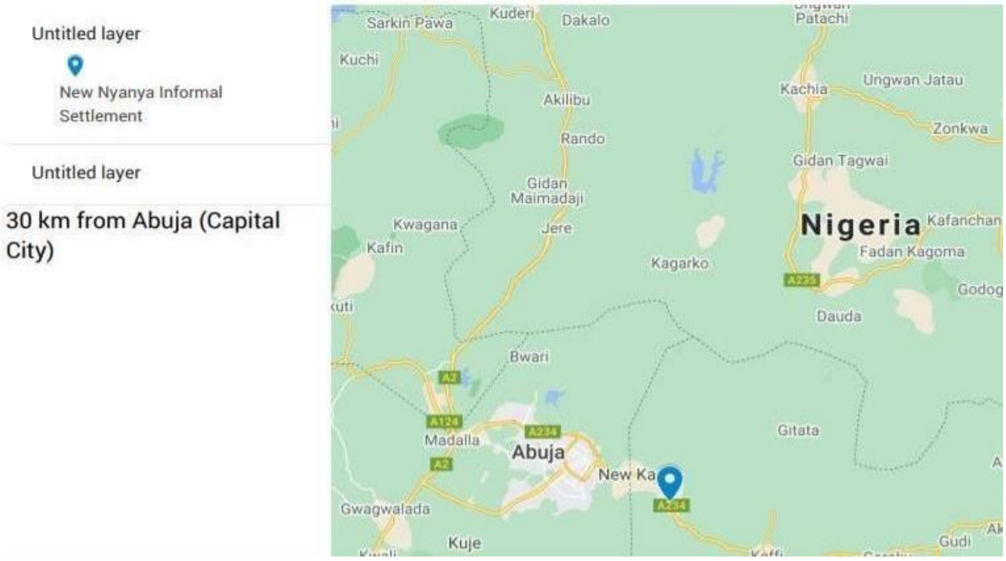

Figure 27. Map of New Nyanya settlement.

5.4.12 Results of sampling for Orozo Informal settlement.

Orozo settlement shares boundaries with Lokogoma, Uke and Nyanya, it is in close proximity to the Federal Capital Territory, closing with a distance of about 26 KM (Kilometers) from Abuja, which is the Capital City of Nigeria. It is characterized with a population size of about 393,000 people in 2019 (NUDB, 2020).

Orozo settlement is very commercial and Agro- based, because of it being situated on the periphery, extending into the new municipality of Keffi Majority of inhabitants commute on a daily basis to the Capital City of Abuja to either sell their products, which are manufactured locally with a large number working as subsistence and commercial farmers.

The settlement falls under the household typology S and I, and the productive enterprise typology AFrom the 60 households and 40 productive enterprises sampled, our findings reveal that out of the 60households, 55 % were male and 45% were females. 30 households fit the description of the Type S informal settlement, 30 of the households fit the description of the Type I settlement.

Table 59. Household data for Orozo settlement.

Housing Typology	Number of respondents
Type I (Illegal structures)	30
Type S (Squatter camps)	30
Total	60

Table 60. Household composition for Orozo settlement.

Household Composition	Size	Age	Monthly Income	
Type I (proper building structures on illegal land).	4 to 5people	Adult (35- 50)	N41000	1 Adult Male, 1 Wife, 2 to3Children
Type S (Squatter camps with cluster of shacks).	4 to 8 people	Adult (45-70)	N24000	1 AdultMale,1 or 2 Wives, 3 to 5 Children

From the 40 productive enterprises sampled our findings reveal that 60% are male run businesses and 40% of the businesses belong to female.

Table 61. Enterprise typology for Orozo settlement.

Enterprise Typology	Respondents
Category (C&I)	20
Category A	20

Table 62. Enterprise composition for Orozo settlement.

Enterprise Composition	Work Size	Monthly Income	Male owned	Female owned
Category (C&I).	2 to 5			
Category A.	5 to 10			

Figure 28. Map of Orozo settlement.

One man village settlement shares boundaries with Mararaba, Ado, Masaka, New Nyanya and Kurunduma. It is in close proximity to the Federal Capital Territory, closing with a distance of about33 KM from Abuja, which is the Capital City of Nigeria. It is characterized with a population size of about 690,000 people (NUDB, 2020).

The settlement falls under the household typology I and S, and the productive enterprise typology C&I, and Category A.

From the 60 households and 40 productive enterprises sampled, our findings revealed in the table below that out of the 60 households that responded to the questionnaires, 53% were male and 47% were females. 30 households fit the description of the Type I informal settlement, 30 of the households fit the description of the Type S settlement.

5.4.13 Results of sampling for Ado informal settlement.

One man village settlement shares boundaries with Mararaba, Ado, Masaka, New Nyanya and Kurunduma. It is in close proximity to the Federal Capital Territory, closing with a distance of about33 KM from Abuja, which is the Capital City of Nigeria. It is characterized with a population size of about 690,000 people (NUDB, 2020).

One man village settlement is very commercial in nature, as majority of inhabitants commute on a daily basis to the Capital City of Abuja to either sell their products manufactured locally or provide skilled services to the formal sector.

The settlement falls under the household typology I, H and M, and the productive enterprise typology C&I, and Category M.

From the 45 households and 55 productive enterprises sampled, our findings revealed in the table below show that out of the 45 households that responded to the questionnaires, 53% weremale and 47% were females. 15 households fit the description of the Type H informal settlement, 15 of the households fit the description of the Type M settlement and the remaining 15 possess the characteristics of the I type settlement.

Table 63 Household typology in Ado.

Housing Typology	Number of respondents
Type H (Formal structure with a shack attached to the building).	15
Type I (Illegal structures).	15
Type M (Municipal flats)	15

Table 64. Household composition in Ado.

Household Composition	Size	Age	Monthly Income	Composition
Type H (Formal structure with a shack attached to the building.	4 to 5 people	Adult (35- 50)	N32,000	1 Adult Male, Wife, to 3 Children.
Type I (Squatter camps with cluster of shacks).	4 to 8 people	Adult (45-70)	N41,000	1 Adult Male, 1 or 2 Wives, 3 to 5 Children.
Type M (Municipal flats)	Not more than 5	Adult (38-60)	N83,000	

Table 65. Showing the typology of enterprise in Ado.

Enterprise Typology	Respondents
Category (C&I)	30
Category M	25

Table 66. Showing the composition of enterprise in Ado.

Enterprise Composition	Work Size	Monthly Income	Male owned	Female owned
Category (C&I)	2 to 5			
Category (M)	5 to 10			

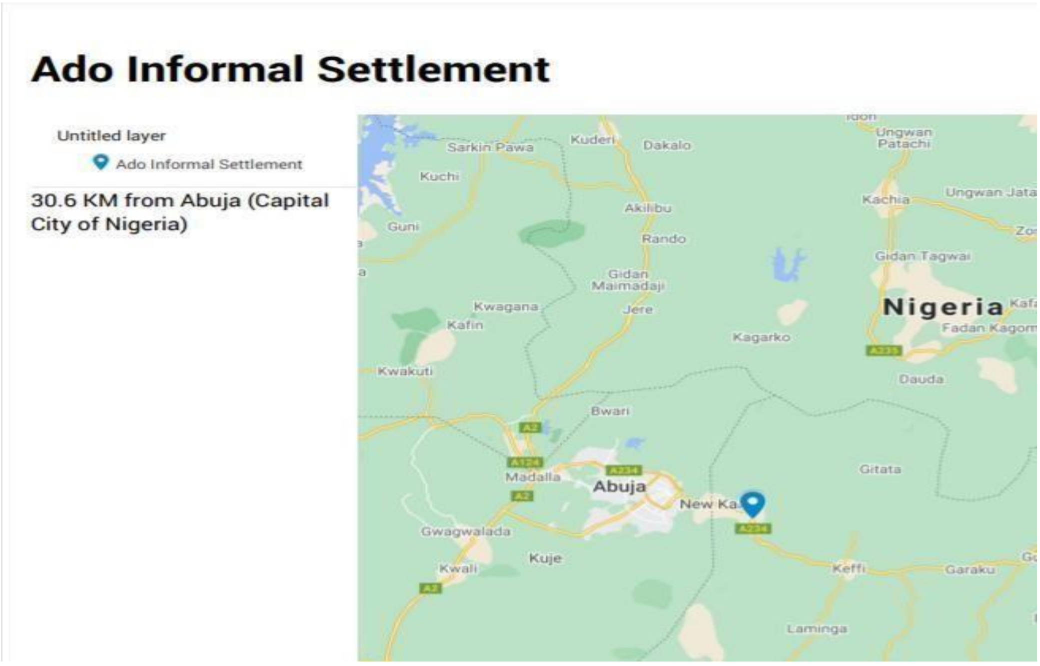

Figure 29. Map of Ado settlement.

5.4.14 Results of sampling for Uke informal settlement.

Uke settlement shares boundaries with the Gora community and it is the capital of Karshii town. It is a bit further than the rest of the informal settlements because it is situated on the periphery like Orozo, but the difference is that Ozoro extends into Abuja, while Uke extends into a smaller municipality of Nasarawa State, creating a significance in the type of households and productive enterprises.

It is about 34km (Kilometres) from Abuja, which is the Capital City of Nigeria. It is characterized with a population size of about 263,000 (NUDB, 2020).

Uke settlement is agriculture based, and it is surrounded by one of the tributaries of the River Niger and Benue, the two most important rivers in Nigeria. River Niger provides 15% of Nigeria's power generation, through the Large Hydropower Plants installed in Shiroro and Kainji Dam of Niger State. The settlement falls under the household typology H and S, and the productive enterprise typology C&I, and Category M.

From the 60 households and 40 productive enterprises sampled, our findings are revealed in the table below that out of the 60 households, 53 % were male and 47% were females. 60 householdsfit the description of the Type A informal settlement.

Table 67. Household typology in Uke settlement.

Housing Typology	Number of respondents
Type A (Shacks built on land inherited from ancestors).	30
	30
Total	60

Table 68. Household composition in Uke settlement.

Household Composition	Size	Age	Monthly Income	Composition
Type A (Shacks built oninherited land).	4 to 10 people	Adult (35- 80)	N5000 -24000 (Naira)	1 Adult Male, Wife, to 3 Children

From the 40 productive enterprises sampled our findings reveal that 65% are male run businesses and 35% of the businesses belong to female.

Table 69. Enterprise data for Uke settlement.

Enterprise Typology	Respondents
Category A	12
	18

Table 70. Enterprise composition for Uke settlement.

Enterprise Composition	Work Size	Monthly Income	Male owned	Female owned
Category (A)	2 to 5			

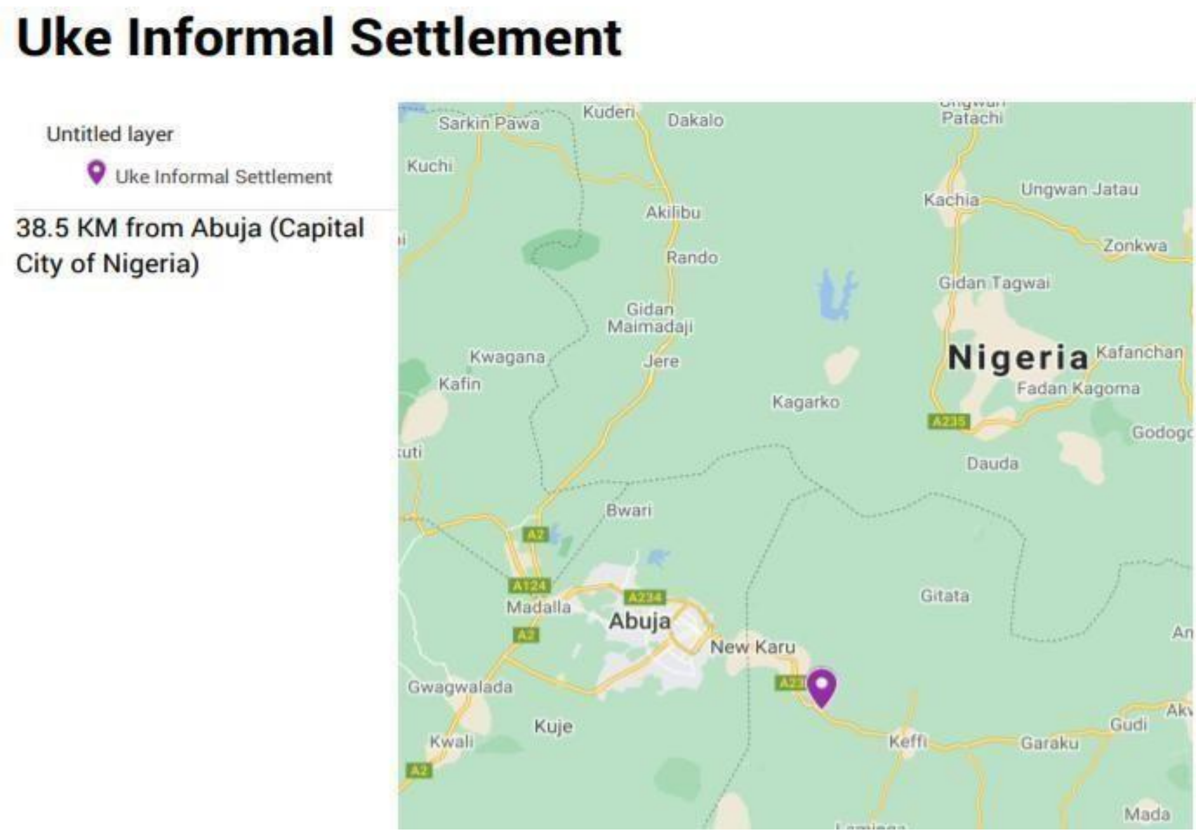

Figure 30. Map of Uke settlement.

5.4.15 Energy Metabolism of the informal settlements.

The energy metabolism of the informal settlements is obtained from the survey carried out through the sampling of the households and the enterprises involved in the productive uses of energy and electricity.

In the work of Kovacic & Giampetro (2016), there are certain factors that impact on energy consumption in informal settlements, which are made manifest through the composition of persons and the behavioral dynamics in household and productive units. The total population of the sampled settlements, include a wide demographic that extends through age and gender. In the Greater Karu Urban Area, there is an uneven distribution of Male and Female gender according to their ages as a result of religious and family political ideologies which remain the pillars of societal norms in these settlements. Different age group compositions determine the pattern of energy flow in some cases. When household composition changes, the energy flow and demand changes in that dimension consequently.

Table 71. Showing the overall sample data for GKUA.

Settlements	Samples of houses collected	Sample of productive enterprises collected	Number of responses for house survey	Number of responses for productive enterprise survey
New Nyanya Settlement	60	40	50	30
Orozo Settlement	65	45	60	40
Ado Settlement	60	60	45	55
Uke settlement	80	50	60	40
Total	265	195	215	165

Table 72. Percentage composition of each household typology.

Person	(%)
I person	1%
2 persons	5%
3 persons	10%
4 persons	24 %
5 persons	30%
6 persons	25 %
7 persons	3%
8 -10 persons	2%

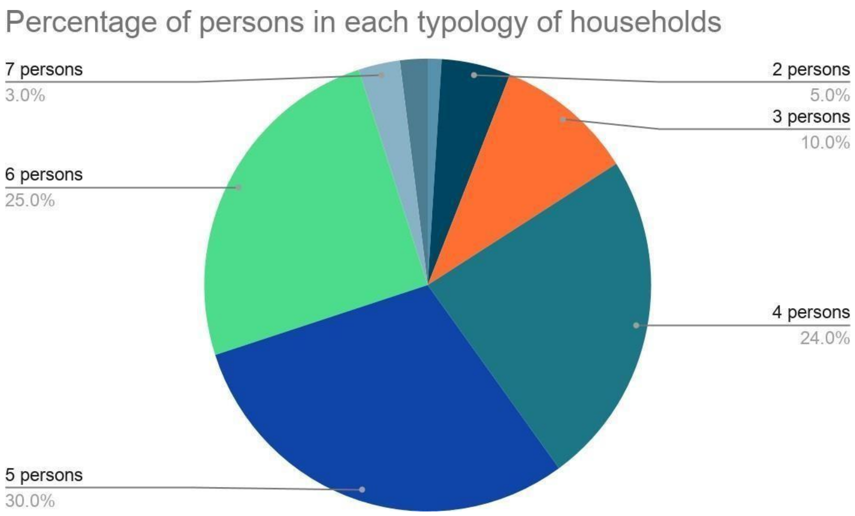

Figure 31. Percentage composition of persons in the household typologies.

The composition of both household and productive enterprises characterizes the societal metabolism of informal settlements. (Smit et al. 2019, Kovic et al,2016, Rikko 2019, Makinde, 2018). The variation in composition reveals the influence of energy drivers that are responsible for determining the energy flow pattern, which is particular to each household and productive enterprise typology. A household composition of 10 persons will reveal a different energy consumption pattern from a household with lesser occupants, more so is the difference in the level of energy affinity for larger enterprises in comparison with smaller ones. The distinction of various energy carriers as preference choices for different households and productive enterprises, is a justification for the amount of income each typology of the settler is willing to spend for a suitable energy provider. In most cases, the income of each household and productive enterprise is a major driver for electricity consumption (Al- Bajjali & Shamayleh, 2018). The survey data from the Greater Karu Urban settlement show how energy demand varies across households and productive enterprises.

The Greater Karu Urban settlement receives electricity from three major sources which are: (i) Abuja Electricity Distribution Company; illegal connections and through some renewable energy sources under the Nigerian electricity support program, which is supervised by the Rural Electrification Agency. (REA).

From the household data 50 % of the household are electrified, 35 % resort to illegal connections and the remainder rely on solar mini grids and solar PV for electricity supply.
In comparison with the national average of 45 % of the population without electricity.

Table 73. Showing illegal connections.

Connections	
Grid Connected	Underserved/ unconnected
58%	42%

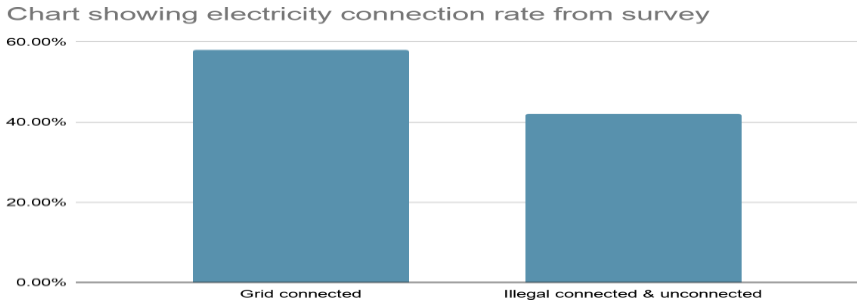

Figure 32. Electricity connection rate.

Holistically, the capacity for energy consumption in the households is generally lower than that in the productive use enterprises, when we include the exosomatic devices, which are the electrical appliances used to bolster production activities.

From our findings, we reveal that the electricity consumption pattern is driven by the following factors, which are: composition ofhousehold and productive use enterprises, income of household and productive enterprises and exosomatic devices used in the different household and enterprises electricity access.

Metabolic patterns are a reflection of the dynamics within the composition of the different typologies of household and productive use enterprises in these settlements, understanding the complexity of the flow analysis, enhances the ability to proffer solutions to the energy supply challenge.

5.5 Energy demand estimate of the informal settlements.

We use the appliance approach method to estimate the electricity consumption foreach typology of household and productive enterprise from the survey that was done, before arriving at an overall estimated electricity consumption for each of the informal settlements. In addition, we estimate the energy demand for fuel carriers with the use of the energy conversion table, in order to get the overall direct energy demand that includes the fuel and electricity carriers. According to Zhang et al (2014), the energy consumption is given as the product of the energy intensity and the Level of Activity which is expressed as the numbers of household usage, the energy intensity is measured in kWh/ household, The efficiency of the appliance is also factored in to give a multiplier effect on the productive capacity of the electrical equipment.

Final Energy Analysis formula is given as:

$$E = \sum Q_i \times L_i \tag{28}$$

Where E = Energy demand = activity level.

Li= energy intensity.

Where u = useful energy intensity and n = efficiency (Dioha,2018). For this research work we apply the formula for the useful energy analysis to determine the consumption resulting from the activity carried out by the electrical appliance present in each typology of household and enterprise of the informal settlements in view.

5.5.1 Sectors of Household and productive usage.

For this research work we disaggregate the informal household sector into energy demand activities namely: cooking, lightning, refrigerating air conditioning and other electrical appliances. The informal demand tree is compared and benchmarked against the energy demandactivities in the Nigeria household sector.

Cooking: The average Nigerian household has a size of 5 and 6 for urban and rural areas respectively. The activity levels of cooking fuels in the year 2010 is given as 51.7% for Kerosene, 2.1% for LPG (cooking gas), 0.9% electricity, 46,0% for firewood. (Dioha,2018, Ibitoye,2013). The energy intensity is given as 0.8 GJ/capita/year, when it is multiplied by 5 persons per household in urban areas and 6 persons per household in rural areas, it results in the value of energy intensity of 0. 44GJ.household/year and 0.48GJ/household/year respectively. Electric stoves have an efficiency of 95%, gas and kerosene stoves have an efficiency of 60% and 55% (Gujba. Et al 2015).

Lightning: There is a distinction in the use of energy sources for lightning purposes for Nigerian households, for households that are electrified which constitutes about 58%

nationally, (IEA,2018), electricity is the main source for lightning purposes, while non electrified households' resort to the use of kerosene in lanterns. Electrified households make use of incandescent bulbs, which accounts for 41% and 58% make use of CFLs and about 1% account for LED bulbs (Dioha,2018; Ibitoye 2013). The energy intensity for kerosene used for lightning purposes is 281kJ/household/ year.

Refrigerating: A fridge has an estimated energy intensity of 402kWh/household/year (Ibitoye,2013).

Air conditioning. The estimated energy intensity for air conditioners is 4600kWh/annum according to the National Bureau of statistics (2005). A different value of energy intensity is derived from the work of Dioha (2018), and it is given as 826 kWh/household /year. The average of these two estimates is 4613kWh/household/year.

Water heating: The power rating of electrical heaters in Nigeria is 2kW are used within the range of 10-30 mins, the energy intensity is estimated as 365kWh/household/year.

Other Electrical appliances. The energy intensity for other appliances like tv, radio and DVD players are estimated as 285-395kWh/annum (Ibitoye, 2013) and 250kWh/household/year. (Dioha, 2018), the average of the energy intensity value is given as 310kWh/household/year. Findings from the sampling carried out on the informal settlements in the Greater Karu UrbanArea, includes the typologies of productive use enterprises, which is also an integral part of the energy diagnosis. We derive these typologies from the global technical assistance partnershipthat is administered by the World Bank, which includes bilateral official sponsorship from the German International Co/operation (GIZ) under the flagship of the Energy sector management assistance program (ESMAP). The ESMAP focuses on promoting productive use of energy (Gouvello & Durix, 2008; Vance et al,2013).

Generally, the productive use sectors is divided into three main sub sectors namely: agriculture, manufacturing, commercial and local industry. (Peters et al, 2013; Gouvello &Durix, 2008,Rikko 2019, Makinde 2018). See Chapter 4.

In the Greater Karu Urban Area, we find the following typologies of settlements that characterize the type of productive use of energy, along with the enterprises that are present.

- **Category A** informal settlements are predominantly agriculture based and the activities include cash crops, food crops, fishing and livestock farming.
- **Category M** informal settlements are characterized by the level of local production of goodssuch as wood and textile materials.
- **Category C & I** informal settlements engage in productive activities that offer services, e.g. food vending, metallurgy and blacksmithing.

5.5.2 Energy intensities for the typology of household and productive use.

For each typology of household and productive enterprise derived from the sampling carried out, we determine their energy intensities by using the appliance approach formula. The energy intensity is the energy consumption by appliance per household per year as denoted below in the equations: Energy consumption of appliance per year = power rating (watts) x hours used per day number of years.

Energy consumption of appliance per household/year = energy consumption per year x number of persons/ household size. The typologies of informal settlements M, H and I, A and S. Where M represent residential areas with the presence of municipal flats, H represent areas where small shacks are attached to formal and planned buildings.

I represent areas with building structures erected on illegal land. These are the electrified typologies of informal settlements. Type H and M get most of their electricity supply from illegal connections, while type are municipal flats under electricity coverage from the national grid.

The typology A and S, which represent Agro based settlements and Squatter camps, are the residential areas without grid electricity and are represented in national data as non-electrified areas.

Typology H

The shacks attached to the front or back of formal buildings have a household composition of 1 Adult male, 1 Adult Female and about 3 children, The shacks cover an average size of 10 to 30m^2.The roofs are made of aluminum sheets to protect the household members from rain and the scorching heat from the sun. Other areas of the country where the informal sector thrives includes the same classification of informal settlement economic sector, in bigger informal areas such as those present in Lagos State, which was the previous capital city of the country, with a population of 14 million (NPC,2020), also have in it informal sectors that can be broadly categorized into the Agriculture/Farming, Commercial and Manufacturing productive enterprises. In the Greater KaruUrban Area, we find the following typologies of settlements that characterize the type ofproductive use of energy, along with the enterprises that are present.

Category A: informal settlements are predominantly agriculture based and the productive activities include cash crops, food crops, fishing and livestock farming.

Category M: informal settlements are characterized by the level of local production of goods such as wood and textile materials.

Category C & I: informal settlements engage in productive activities that offer services, e.g. food vending, metallurgy and blacksmithing.

Table 74. Showing the disaggregated household consumption for typology H

Disaggregated house-hold sector	Basic Appliance used	Household size	Hour usage/day	Power rating & Efficiency	Energy load per household per year
Cooking	Electric stove	5	5hours	2.5kW	4562.5kWh
	Kerosene Stove	5	5 hours(1litre)	Energy conversion rate at 10kWh/litre see conversion table	3,650 kWh
Lightning	Rechargeable Lamps	5	5hours	0.02 to 0.03kW	36.5 kWh
Refrigerating	Not in usage for this typology				
Water heating	Not in usage for This typology				
Air conditioning	Not in usage for this typology				
Other appliances	Radio set Phone charger	55	5hours 5 hours	0.005kW - 0.004kW	9.125 kWh
Total					8258.125kWh

Typology M.

The municipal flats are government approved structures for residential purposes for civil servants. This household lives above the minimum wage. These households constitute the largest number of electrified households from the survey carried out. We assume 5 hours exposure to electricity from the grid from the average number of hours of electricity usage in the whole of Nasarawa State. (REA,2020). However, the with a family size of 10, it is assumed that an additional 3 hours of appliance usage is applicable to this household.

The household comprises 1 Adult male, 1 Adult Female and about 2 children and 5 to 6 extended family members occupying about $50m^2$.

Table 75. Showing the disaggregated household consumption for typology M.

Disaggregated Sector	Basic Appliance used	Household Size	Hour Usage	Power rating	Energy load per household per year
Cooking	Electric stove	10	8 hours	2 to 3kW	7,300kWh 2584kWh @365 litres per
Cooking	LPG stove	10	5 hours(1litre)	Energy conversion factor of	year
	LPG Stove			7.0833kWh per litre.	
	Kerosene	10	5 hours(1litre)	Energy conversion rate at 10kWh/litre see conversion table.	3650 kWh
Lightning	Incandescent	10	8 hours	0.1 kW	292kWh
Refrigerating	Bulbs Fridge	10	8 hours	0.3kW	876kWh
Water heating	Electric kettle	10	8 hours	3kW	8,760kWh
Air conditioning	Air conditioner	10	8 hours	1KW	2,920KWh
Others					
	TV Set	10	8 hours	0.05kW	146 kWh
	DVD set	10	8 hours	0.1 kW	292 kWh
	Gaming	10	8 hours	0.15 kW	292 kWh
Total	Washing machine	10	8 hours	0.5 kW	1460kWh
					28,864kWh

Typology I.

This typology comprises block houses that are erected on gas pipeline network/ infrastructural facilities and illegal lands without the approval from the Government. These households are illegal and constitute the largest portion of households involved in energy theft. flats are government approved structures for residential purposes for civil servants. They are mainly occupied by unemployed youths, apprentices in the informal commercial sector and smaller families who cannot afford to pay for building approvals to purchase lands. We assume 5 hours exposure to electricity from the grid from the average number of hours of electricity usage in the whole of Nasarawa State.(REA, 2020).

The household comprises 1 Adult male, 1 Adult Female and 2 or 3 children occupying about 20 to 40 m^2.

Table 76. Showing the disaggregated household consumption for typology I.

Disaggregated sector	Basic Appliance used	Household size	Hour Usage	Power rating &Efficiency	Load per household per year
Cooking	Electric stove,LPG stove	2 to 5 persons	5 hours	2 to 3kW	4,562kWh
Cooking		2 to 5 persons	5hours (1litre)	Energy conversion factor of 7.0833kWh per litre	
					2585 kWh.
	Kerosene	2 to 5 persons	5hours(1litre)		
				Energy conversion rateat 10kWh/litre see conversion table	3650 kWh
Lightning	Incandescent bulbs	2 to 5 persons	5 hours	0.1kW	182.5kWh
Refrigerating	Fridge	2 to 5 persons	5 hours	0.3kW	547.5kWh
Water heating	Electric kettle	2 to 5 persons	5 hours	3kW	5,475kWh
Air conditioning	Air conditioner	2 to 5 persons	5 hours	2 kW	3,650kWh
Other appliances	TV set	2 to 5 persons	5 hours	0.4 kW	730 kWh
Total					21,382kWh

Typology A.

This typology comprises of makeshift tents with raffles or clothing material for house roofing to protect it from sunlight and heavy rainfall, which are erected on land inherited through their ancestral lineage without seeking government consent. They are located on the periphery of the Greater Karu Urban Area. The houses are very rural in nature and are far away from the electricity grid. They constitute the largest portion of unelectrified households from the survey carried out. They are mainly occupied by farmers and cattle rearers.

The household comprises 1 Adult male, 2 or more Adult Female and 6 -8 children, occupying about 70m^2.

Table 77. Showing the disaggregated house hold consumption for typology A.

Disaggregated house-hold sector	Basic Appliance used	House hold size	Hour Usage	Power rating & Efficiency	Energy intensity per household/per year
Cooking	Firewood	8-10	6 hours(1.84kg)	Using the energy conversion factor of 5.3kW/kg, using the energy conversion factor of 7.345kWh; 8.05 kWh/kg	3559kWh
Cooking	Charcoal	8-10	6 hours (2.5kg)		7,345kWh
Lightning	Candles & Torchlight with batteries	7 hours (7pm - 1am)			
Refrigerating	Not used in this typology				
Water heating	Not used in this typology				
Air conditioning	Not used in this typology				
Other appliances	Not used in this typology				
Total					10,904kWh

Typology S.

This typology comprises makeshift tents with iron or aluminum roofing houses, they form a cluster of settlement camps by intruding into government approved lands. They are mostly occupied by immigrants from other states and unemployed persons. They are in close proximity to the electricity grid, but are without connection. They erect structures on public infrastructures such as gas pipeline network/ infrastructural facilities and illegal lands without the approval from the Government. These households are illegal and constitute the largest portion of households involved in energy theft.

The household comprises 1 Adult male, 2 Adult Female and 4 -6 children occupying about 20 to $80m^2$.

Table 78. Showing the disaggregated household consumption for typology S.

Disaggregate household sector	Appliance used	House hold size	Hour usage	Power rating	Energy Load per household per year
Cooking	Kerosene stove	4 to 8 persons	5 hours (1 litre)	Energy conversion rate at 10kWh/litre see conversion table	3650 kWh
Lightning	Torchlight with batteries		5 hours	0.001kW	1.865kWh
Refrigerating	Not in use in this typology				
Water heating	Not in use in this typology				
Air conditioning	Not in use in this typology				
Other appliances	Radio set				
Total					3,651kWh

Category A informal settlements are predominantly agriculture based and the productive activities include cash crops, food crops, fishing and livestock farming.

Table 79. Showing the appliance load for productive enterprise category A.

Disaggregated productive-sector	Basic Appliance used	Size of productive enterprise	Number of hours used	Power rating &Efficiency	Energy load per enterprise per year
Maize Milling	Maize miller	6 to 8 persons	5hours	18.6 kW for three phase motor	33,945kWh

Rice Milling	Rice Miller	6 to 8 persons	5 hours	11.2 kW	20,440kWh
Sorghum milling	Sorghum miller	6 to 8 persons	5 hours	5.0 kW	9,125kWh
Cowpea milling	Cowpea Miller	6 to 8 persons	5 hours	5.2 kW	9,490kWh
Soy bean milling	Soy bean Miller	6 to 8 persons	5 hours	5.2 kW	9,490kWh
Cassava Grating	Grating machine	6 to 8 persons	5 hours	5kW to 7.5kW	11,406kWh
Maize threshing	Maize thresher	6 to 8 persons	5 hours	14 kW for three phases motor	25,550kWh
Rice threshing	Rice thresher	6 to 8 persons	5 hours	1.03kW	1,879.75kWh
Sorghum threshing	Sorghum	6 to 8 persons	5 hours	1kW	1,825kWh
Cassava Grating	Grating machine	6 to 8 persons	5 hours	5kW to 7.5kW	11,406kWh
Maize threshing	Maize thresher	6 to 8 persons	5 hours	14 kW for three phasemotor	25,550kWh
Rice threshing	Rice thresher	6 to 8 persons	5 hours	1.03kW	1,879.75kWh
Sorghum threshing	Sorghum	6 to 8 persons	5 hours	1kW	1,825kWh
Rice Parboiling	parboiler	6 to 8 persons	5 hours	0.3 to 0.9kW	1,095kWh
Cashew processing	Kernel				
Shea Butter Processing					
Aquaculture	Electric water pump	6 to 8 persons	5 hours	3.7 to 22.4 kW	23,816kWh

Milk cold storage	Freezer	6 to 8 persons	5 hours	0.2 to 365kWh	365kWh
Cocoa Drying	Mechanical dryer	6 to 8 persons	5 hours	0.3kW	547.5kWh
Milk sterilizer	Sterilizer	6 to 8 persons	5 hours	4.5kW	8,2122kWh
Incubating eggs	Incubator	6 to 8 persons	5 hours	0.08 to 0.16 kW	219kWh
Total					161,969kWh

Source: Nigerian Power sector program 2020, USAID.

Table 80. Showing the appliance load for productive enterprise category M.

Disaggregated Productive use sector	Basic Appliance used	Enterprise size	Hour Usage	Power rating & Efficiency	Energy load per enterprise per year
Manufacturing		6 to 8 persons	5 hours		
Textile & clothes	Sewing machine	6 to 8 persons	5 hours	0.2 kW	365kWh
Welding	Electric welding machine	6 to 8 persons	5 hours	3 to 7.5 kW	9,581.25 kWh
Blacksmith	Induction	6 to 8 persons	5 hours	15 kW	27,375kWh
drilling	Electric drilling machine	6 to 8 persons	5hours	0.4kW	720 kWh
Popcorn maker	Pop corn maker	6 to 8 persons	5 hours	1.5 to 2.1 kW	3,285 kWh
Bakery	Bakery oven	6 to 8 persons	5 hours	5kW	9,125 kWh
Wood manufacturing	Sawmill	6 to 8 persons	5 hours	1kW	1825 kWh
Soap manufacturing	Soap cutting machine	6 to 8persons	5 hours	0.4 kW	720 kWh
Jam production	Electric Jam producer	6 to 8 persons	5 hours	1kW	1,825kWh
Packaging	packager	6 to 8 persons	5 hours	0.25 -3kW	5,931kWh

Table 81. Showing the appliance load in productive enterprise category C.

Disaggregated productive use sector	Basic Appliance used	Enterprise size	Hour Usage	Power rating & Efficiency	Energy load per enterprise per year
Food vending	Electric stove	3 to 5 persons	5 hours	2kW	3,650kWh
Ice block vending	Fridge	3 to 5 persons	5 hours	0.4 kW	730 kWh
Cyber cafe	computer	3 to 5 persons	5 hours	0.015-0.1kW	104kWh
Hairdresser salon	Clippers and hairdryers	3 to 5 persons	5 hours	0.05 kW	91.25kWh
Video games centre	Game consoles	3 to 5 persons	5 hours	0.16kW	292kWh
Print shop	printer/scanner	3 to 5 persons	5 hours	0.5- 2kW	2,281kWh
Sports viewingcentre	television	3 to 5 persons	5 hours	0.05-0.2 kW	228.125 kWh
Total					7,376kWh

5.5.3 Activity levels by energy type.

The percentage composition of New Nyanya settlement relative to the total energy consumption for the 4 informal settlement is given below.

In the sample collected New Nyanya settlement consists of 50 households and 30productive enterprises which represent a total activity level of 80. This represents 21.05 % of the total activity level of the four settlements sampled. Therefore, the Total energy consumption for New Nyanya settlement using equation.

Where I is the energy intensity and Q is the Energy Demand

Total energy consumption E (New- Nyanya) = 21.05. % of 1040MWh per year. We obtain an estimate of 218 MWh per year.

In terms of energy flow into the Greater Karu urban settlement, there are several energy sources which are used in the household and for productive usage. We derive our estimation for energy demand by inputting the energy intensity obtained from the data obtained.

Out of the 215 households that responded to the survey questionnaire in the four informal settlements, the following is a breakdown of household activity levels by energy source type.

Table 82. Household activity level by energy source.

Fuel	Cooking	Lightning	Water heating	Air conditioner	Refrigerating
Kerosene	40%	30%	30%		
Wood	14%				
LPG	17%		22%		
Candles		30%			
Charcoal	14%				
Batteries					
Diesel	1%			5%	16.5%
Petrol generator	1%			5%	14.18%
Grid electricity	13%	25%	20%	63%	43%

Out of the 165 productive enterprises that responded to the survey questionnaire in the four informal settlements, the following is a breakdown of productive activity level by energy source type.

Table 83. Showing the breakdown of the productive activity levels.

Fuel	Agriculture	Manufacturing	Commercial &local industry
Energy Fuel Type			
Diesel	21%	33%	30%
Petrol	4 %	20%	22%
Grid electricity		7%	15%

Total energy consumption for 215 households and 165 productive enterprises from the sampling is given as a cumulative sum:

$$TE = (Useful\ energy\ from\ 215\ households + 165\ productive\ enterprises) \tag{29}$$

Total Energy (TE) =

Z$\{Useful\ energy\ from\ 215\ \mathrm{h}ouse\mathrm{h}olds + 165\ productive\ enterprises\ \}.$

Useful energy from 215 households is given as the summation of the energy consumption from the typologies of settlements in the four informal areas sampled, where (h) represents households

$$Useful\ energy\ (h) = \sum Energy\ consumption\ for\ typologies\ (\mathrm{H}+M+ + I + A+\mathrm{S}) \tag{30}$$

Where H,M,I,A and S represent the typologies of households in the GKUA.Useful energy from 165 productive enterprises is given as the summation of the energy consumption from the typologies of enterprises in the four informal areas sampled, where (p) represents productive enterprises.

$$Useful\ energy\ (p) = \sum Energy\ consumption\ for\ productive\ enterprise\ typologies\ (Category\ A + Category\ M + Category\ C) \quad (31)$$

Table 84. Showing the energy consumption for household typology and productive categories.

Typologies	
Household Type H	8,258kWh/household per year.
Household Type M	28,864 kWh/ household per year.
Household Type I	21,382 kWh/ household per year
Household Type A	10,904 kWh/ household per year.
Household Type S	3651kWh/ household per year.
Productive Category A	161,969 kWh/enterprise per year.
Productive Category M	62,212kWh/enterprise per year.
Productive Category C&I	7,376kWh/enterprise per year.32530kWh.
Other appliances	2929kWh.
Total energy load	340,075kWh per year.

5.5.4 Overall Energy demand for New-Nyanya settlement.

Table 85. Showing the summary of energy consumption in the informal settlements.

Household Typology	Productive Enterprise	Number of sampled houses	Number of sampled enterprises
15 H	20 C	50	30
15 M	10 M		
20 I			

Using equations (30) and (31) E(Household) = ∑ (Energy load H typology) * 15 + (Energy load M typology) *15 +(Energy load I typology *20).

E(Enterprise) = $\sum\{(\ Energy\ load\ C\ typology\ ) * 20 + (Energy\ load\ M\ typology) * 10)\}$.

Overall energy for New-Nyanya= $\sum[E(Household)_{New\ Nyanya} + E\ (Enterprise_{New\ Nyanya})]$.

Overall energy demand for New-Nyanya = 984,470kWh +769,640 kWh = 1754110kWh.

Table 86. Showing the energy consumption by fuel type.

Sector	Total energy per sector	Kerosene	Fuel Wood	LPG	Charcoal	Electricity Grid	Diesel	Petrol
Cooking	542,130kWh	60%		20%		10%	5%	5%
Lightning	8,577.5kWh	25%		10%		35%	15%	15%
Water heating	240,900kWh	35%		35%		30%		
Air-conditioning	116,800kWh					90%	5%	5%
Refrigerating	24,140kWh							
						60%	25%	15%
Agriculture								
Local Commerce & Industry	147,520kWh					10%	55%	35%
Local Manufacturing	622,120kWh					10%	70%	20%
Others	51,293kWh							
Total	1,754,110kWh							

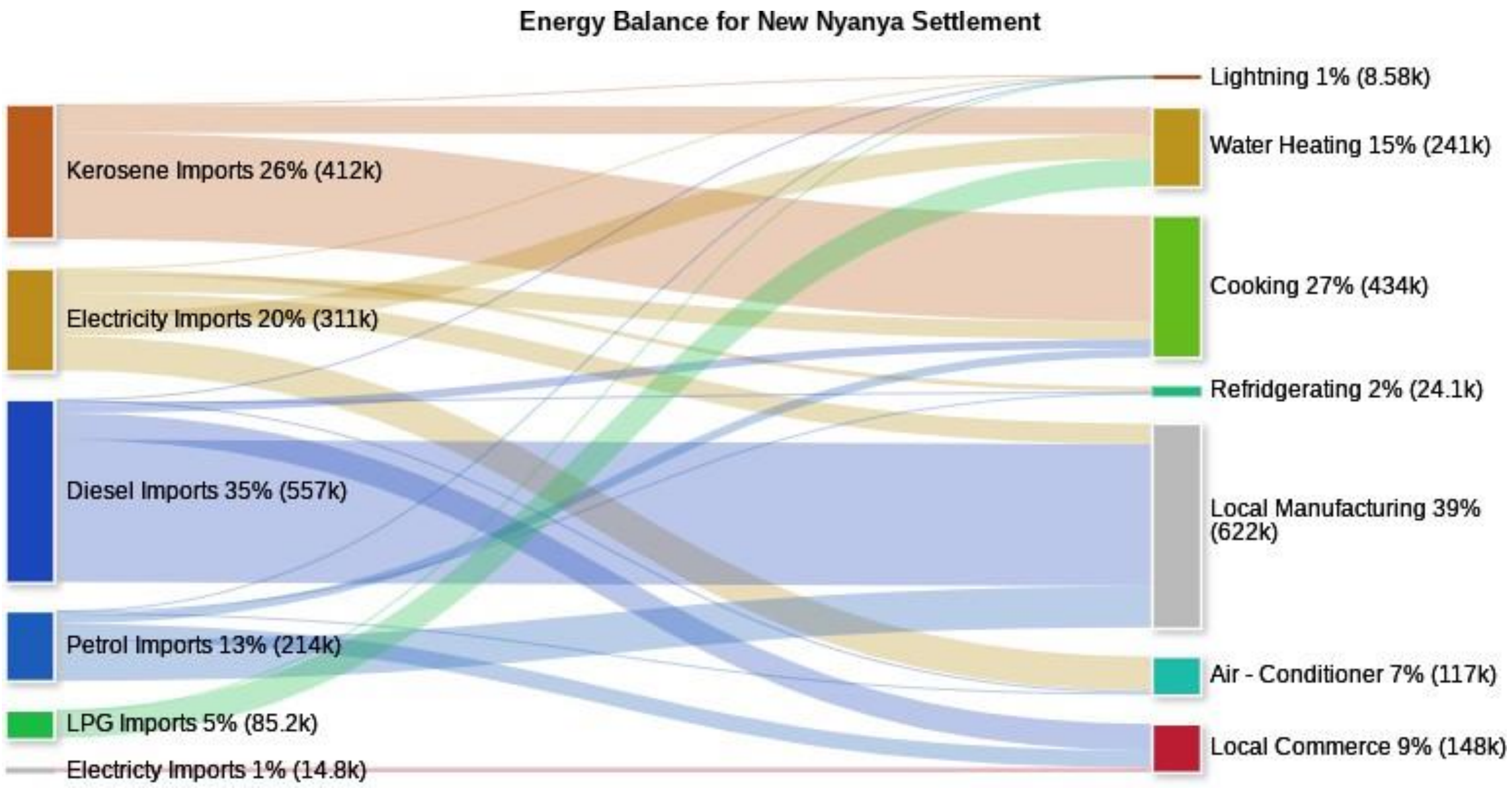

Figure 33. Energy balance for New Nyanya.

5.5.5 Overall energy demand for Orozo settlement.

Table 87. Showing the energy demand for Orozo settlement.

Household Typology	Productive Enterprise	Number of sampled houses	Number of sampled enterprises
30 I	20 C	60	40
30 S	20 A		

Using (30) and (31) .From Table 91 the total energy demand is given as:

E (Household) = $\sum\{(\ Energy\ load\ I\ typology\ ) * 30 + (Energy\ load\ S\ typology) * 30\}.$

E (Enterprise) = $\sum\{(\ Energy\ load\ C\ category\ ) * 20 + (Energy\ load\ A\ category) * 20)\}.$

Overall energy for Orozo = $\sum[E(Household)_{Orozo} \quad + \ E\ (Enterprise)]$

Overall Energy for Orozo settlement = 750,990kWh + 3,386,870kWh.

Overall Energy demand= 4,137,860kWh.

Table 88. Showing the energy consumption by fuel type in Orozo settlement.

Sector	Total energy per sector	Kerosene	LPG	Electricity Grid	Diesel	Petrol
Cooking	433,410kWh	50%	30%	20%		
Lightning	5475kWh	35%	25%	30%	5%	5%
Water heating	164250kWh	50%	20%	20%	5%	5%
Air- conditioning	109,500kWh			80%	10%	10%
Refrigerating	16,425kWh			60%	20%	20%
Agriculture	3,239,350kWh			10%	70%	20%
Local Commerce	147,520kWh			35%	35%	30%
Local manufacturing						
Others	21,751kWh					
Total	4,137,860kWh					

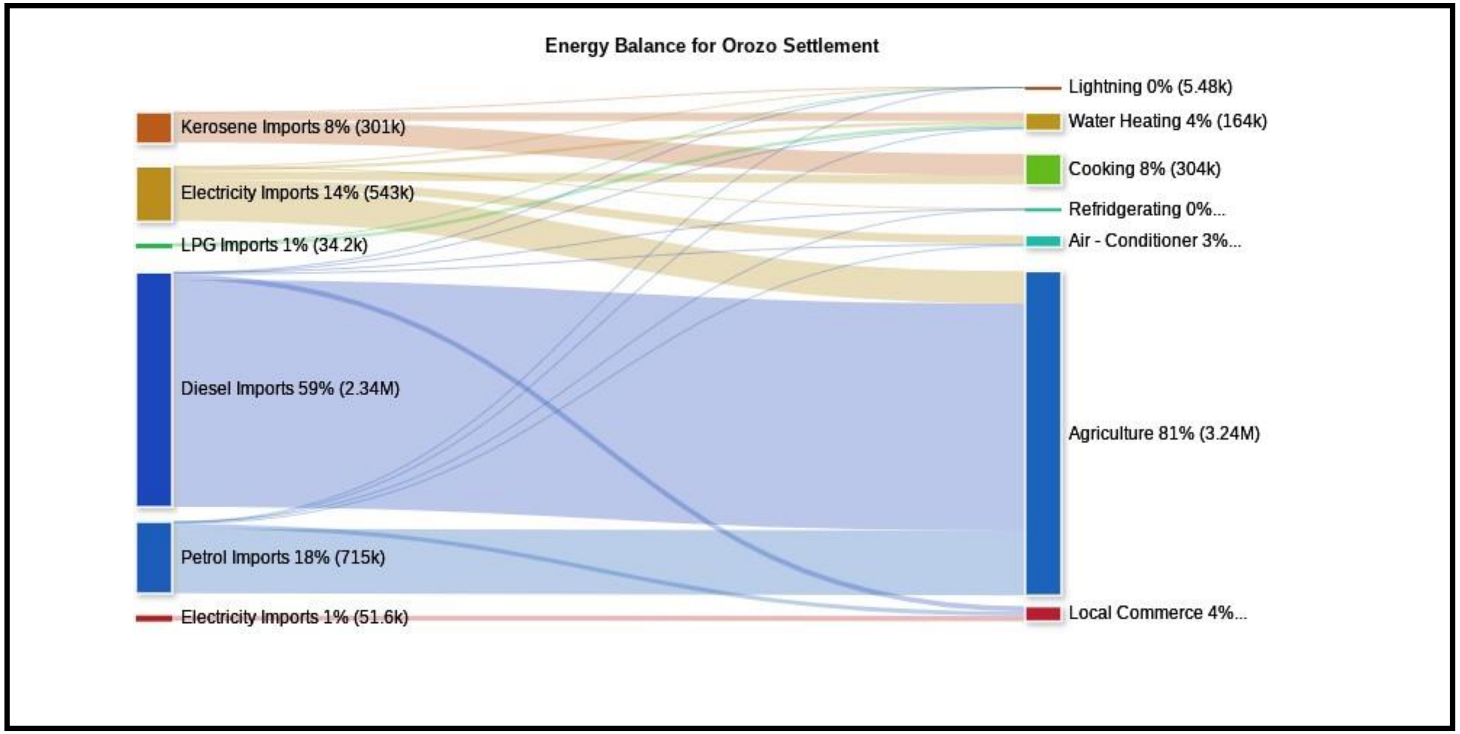

Figure 34. Energy balance for Orozo.

5.5.6 Overall energy demand for Ado settlement.

Table 89. Overall energy demand for Ado settlement.

Household Typology	Productive Enterprise	Number of sampled houses	Number of sampled enterprises
15 I	30 C	45	55
15 H	25 M		
15 M			

From Table 84 using (30) and (31)

E(Household) = ∑ (Energy load H typology) * 15 + (Energy load M typology) *15 + (Energy load I typology *15).

E(Enterprise) = ∑ (Energy load C category) * 30 + (Energy load M typology) *25.

Overall Energy for Ado settlement = 877,560 + 1,776,580 Overall Energy Demand = 2,654,140kWh.

Table 90. Showing the energy demand for Ado settlement.

Sector	Total energy per sector	Kerosene	LPG	Charcoal	Electricity Grid	Diesel	Petrol
Cooking	488,152kWh	60%	20%		10%	5%	5%
Lightning	7665kWh	30%	10%		25%	15%	15%
Water heating	213,525kWh	35%	35%		30%		
Air- conditioning	98,550kWh				90%	5%	5%
Refrigerating	21,352.5kWh				60%	25%	15%
Agriculture							
Local Commerce & Industry	221,280kWh				15%	60%	25%
Local Manufacturing Others	1,555,300kWh				15%	60%	25%
Others	48.699kWh						
Total	2,654,140kWh						

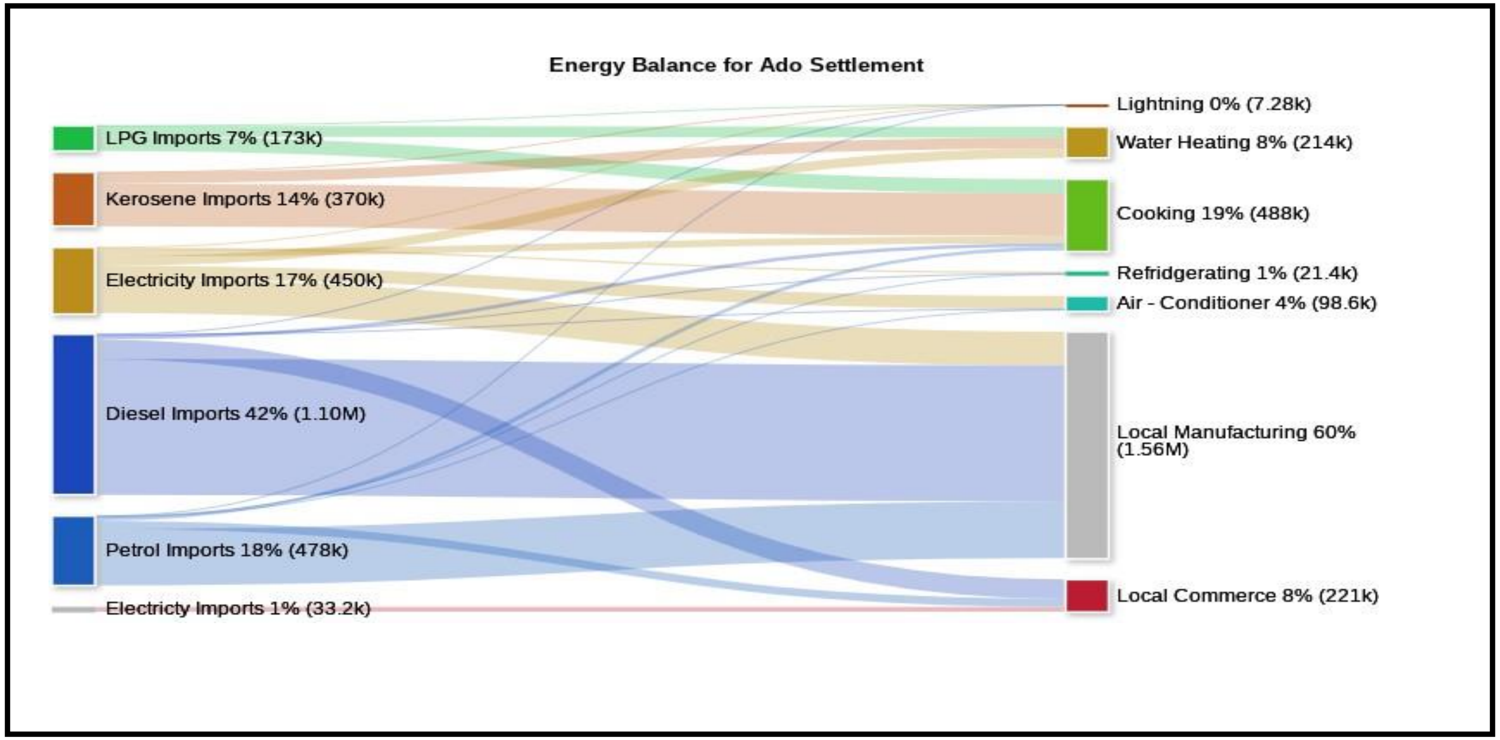

Figure 35. Energy balance for Ado settlement.

5.5.7 Overall energy demand for Uke settlement.

Table 91. Overall energy demand for Uke settlement.

Household Typology	Productive Enterprise	Number of sampled houses	Number of sampled enterprises
60 A	40 A	60	40

E (Household) = $\sum\{(\,Energy\ load\ A\ typology\,) * 60\}.$

E (Enterprise) = $\sum\{(\,Energy\ load\ A\ Category\,) * 40\}.$

Overall energy for Uke = $\sum\{E(Household)\ +\ E\ (Enterprise)\}.$

Overall energy requirement for Uke settlement = 7,133,000kWh.

Table 92. Showing the energy consumption from the fuel type from Uke settlement.

Sector	Total energy per sector	Fuel wood	LPG	Charcoal	Diesel	Petrol
Cooking	654,240kWh	50%		50%		
Lightning						
Water heating						
Air-conditioning						
Refrigerating						
					85%	15%
Agriculture	6,478,760kWh					
Local Commerce & Industry						
Local Manufacturing						
Total						
	7,133,000kWh					

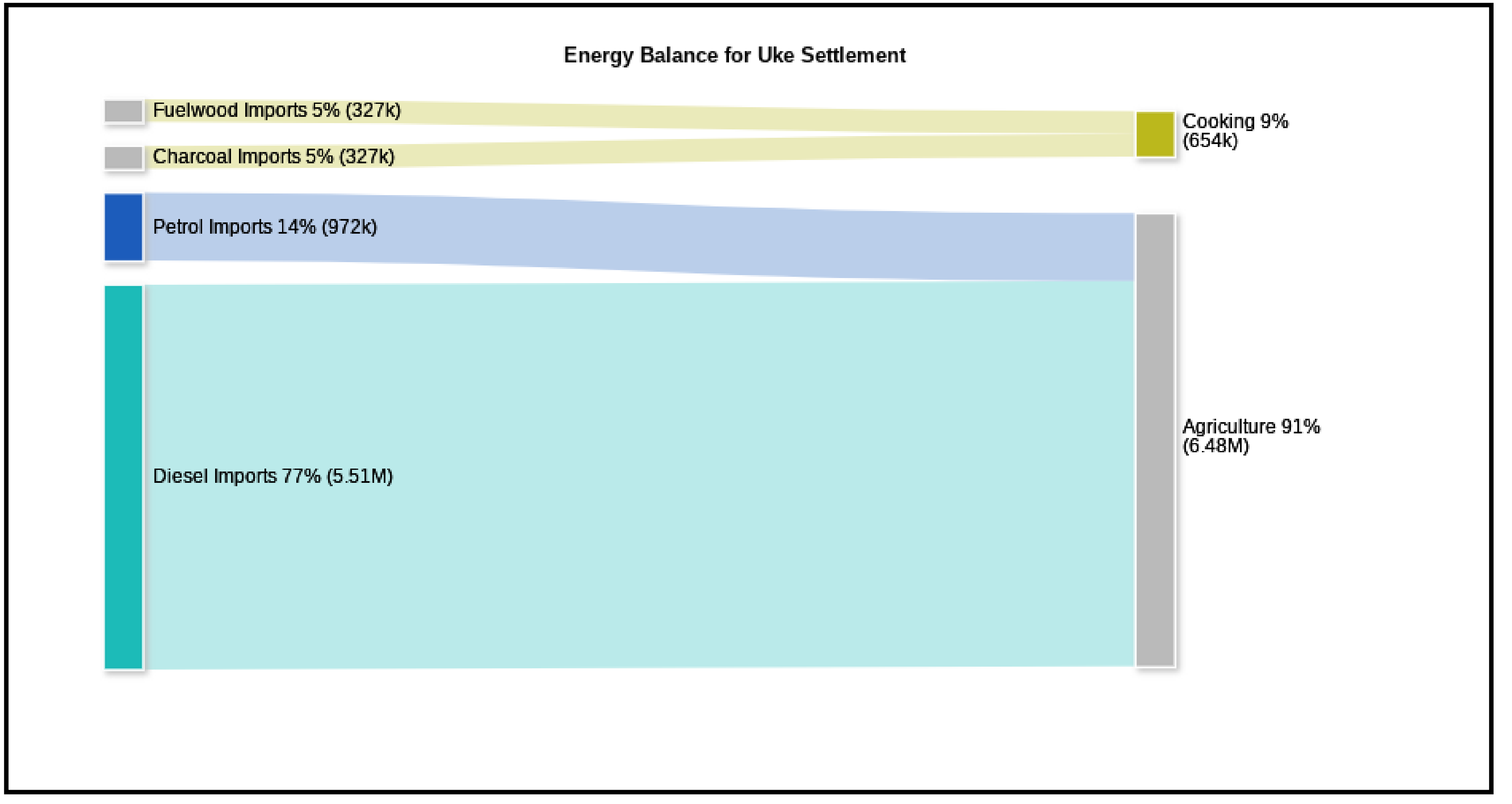

Figure 36. Energy balance for Uke settlement.

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5.5.8 Potential for Biomass.

In Nigeria the production of methane is done from crops and animal waste. The potential for Biomass from animal and crop waste is estimated to be 83 million tonnes per year and 83 million tonnes per year respectively (Akuru et al ,2017; Akuru & Ogbonnaya 2014; Adewale & Godson 2015; Ozoegwu et al 2017; Jekayinfa, 2020).

The Biomass resources identified within the country include forest residues, agricultural residues, human and energy crops. Agricultural residues include cassava, maize, sorghum, millet, rice where cassava and maize crops are the largest contributors. Agricultural residues have an energy potential of 1.08E +18 joule (1.08 Exa- joule). Animal waste have a potential of 0.65 E + 18 joule, municipal waste 0.11E +18 joule and 0.05 E + 18 joules respectively. While Fire wood and charcoal are 0.38 E + 18 joules and 0.05 E +18 joules respectively (Jekayinfa, 2020 & Akuru 2017).

Table 93. Biomass potential in Nigeria.

Technical Potential (J)	Biomass Source
0.38 E +18J	Fire wood
0.05 E +18 J	Charcoal
0.65 E + 18J	Animal waste
0.11 E + 18J	Solid waste
1.09 E + 18J	Agricultural residues
0.05 E + 18 J	Forest residues

The energy crops and agricultural residues which account for 1.57 E +18J (summation of agricultural and forest residues, fire woods and charcoal) account for 83 million tons per year. Energy crops such as Cassava and Maize account for 28.2 million hectares of arable land. Fire wood and charcoal residues account for 11 million hectares of forest land. The animal waste consists of 211 million assorted animals which include Cows, Goats, Sheep and Chicken. The production potential ranges from61 million – 211 million tons/yr. (Ozoegwu etal ,2017; Aliyu et al 2015).

The Greater Karu Urban Area consists of arable land for the cultivation of agricultural residues, and forest residues. It also includes the presence of animal waste from cows, sheep and goats, which come from livestock farming. In the informal areas of Orozo, New Nyanya and Ado settlement, quite a number of poultry farming activity that can be identified.

Uke settlement is very agriculture based, so there is a large presence of Cattle rearing and livestock farming in larger quantities in comparison to New Nyanya, Orozo and Ado settlement. Furthermore, in Uke settlement there is more land mass for Deforestation activitiesthat produce fuel wood and to facilitate arable farming of energy crops like Cassava. The available land mass is considerably larger in comparison to what is identified in Orozo, New Nyanya and Ado settlements.

Amongst the four informal settlements, cassava is the most abundant energy crop and we estimate the bio energy potential for the provision of electricity within these settlements. In thisresearch work estimating the potential from livestock farming and animal waste is beyond the scope.

We estimate how much energy can be provided for the use of biogas and biofuel from the use of cassava. Furthermore, we determine the quantity that can be produced and used to replace the fossil fuel sources in the household and productive sectors of the informal settlements.

Cassava is popular for its food value growth and industrial value amounting to 8 billion US dollars in global trade in the year 2010. It is grown between latitudes 30N and 30S, which is within the geographical location of the Greater Karu Urban Area. (Ozoegwu et al, 2017). Cassava is primarily grown to provide food for domestic consumption, it can be processed into food items which include garri (a staple West African food), and fufu (fermented paste and flour). Fufu is produced by soaking Cassava in water for 4-6 days, to allow it get soft and ferment.
The consumption is equivalent to 238 kcal per capita. The Cassava starch waste when pre-treated can provide bio energy.

The production of methane from the anaerobic digestion of cassava by microbes is calculated following the methodology recommended by the Intergovernmental panel on Climate Change (IPCC). Anaerobic digestion is a microbial process of decomposition of organic materials without the use of oxygen to produce methane gas (CH_4). The process of anaerobic digestion occurs four phases:
Hydrolysis, acidogenesis, acetogenesis and methanogenesis.
The methane gas obtained from the process of anaerobic digestion is what is responsible for providing the energy value. 1000 litres of methane gas provide a calorific value of 7000 kcal of

energy, which is equivalent to 8.6kWh (Ozoegwu et al, 2017 & Akuru et al 2014). The IPCC recommends two equations given below:

$$CH_4 = P_T \times MSW \times DOC_I \times DOC_f \times F_c \times F_{CH4} \times C_{pm} \times (1 - OX) \quad (32)$$

$$Electricity_w = CH_4 \times W_I \times W_{frac} \times LHV_{Methane} \quad (33)$$

Where:

CH4, annual amount of methane from urban solid waste, in kg CH4/year POB, population MSW, per capita amount of waste in kg/inhabitant, DOC_f fraction of degradable organic carbondissimilated.

F_C, correction factor of CH4 for aerobic decomposition during the year of deposition, FCH_4, fraction of CH4 in the landfill gas generated.

Cpm, quotient of molecular weights CH4/C.

DOC $_I$, degradable organic carbon fraction in type I waste OX oxidative factor. Wi, fraction of waste type I by waste category.

Table 94. Parameters used in determining the Biomass potential.

Parameter	Values	Sources
Population	2,000,000	(UN,Habitat, 2012).
MSW (kg/hab/year)	200	(Ukpanyang .,et al 2022).
DOCf	0.77	(IPCC, 2006a).
Fc	1	(IPCC, 2006a).
FCH4	0.5	(IPCC, 2006a).
Cpm	16/12	(IPCC, 2006a).
OX	0	(IPCC, 2006a).

	Paper 4%	(Anyanwau & Adefila, 2014).
	Nylon 7%	(Anyanwau & Adefila, 2014).
Wi	Plastic 1%	(Anyanwau & Adefila,2014).
	Bottle/glass 7%	(Anyanwau & Adefila, 2014).
	Other waste	
	Metals/Cans 6%	(Anyanwau &Adefila,2014).
	Ashes 11%	(Anyanwau &Adefila,2014).
	Wood 7%	(Anyanwau & Adefila, 2014).
	Food waste 33%	(Anyanwau & Adefila, 2014).
	Food 15%	
	Wood 43%	
DOCi	Hygienic waste 24%	(IPCC, 2006b)
	Paper 40%	
	Textiles 24%	
Emissions of CH4	30,723 T CH4/year	33,865 tons/year
Density	0.656kg/m3	

Emissions of CH_4 is 33,865 tons /year. The lower heating value of methane is 37.20 MJ/ton. Applying the equation 33, the value of 307,637 MJ of electricity is obtained from methane produced per year. The value of Wfrac (waste collection efficiency) is 74 % for Nigeria (Ukpanyang et al,2022).

Using the energy conversion table below (see table 95):
we obtain 85,454 kWh of electricity production annually, which can be used as a replacement for the fossil fuel in the informal settlements of Greater Karu Urban Area.

Table 95. Showing the table for energy conversion.

Types of Fuel	Energy Content in MJ	Energy Content in kWh	Energy Content in Kcal
Petrol	32 (MJ/Litre)	8.88 (kWh/litre)	
Kerosene	36 (MJ/Litre)	10 (kWh/litre)	
Diesel	38 (MJ/Litre)	10.55 (kWh/litre)	
Ethanol	23 (MJ/Litre)	6.388(kWh/litre)	

Wood fuel	19 (MJ/kg)	5.3 (kWh/kg)	
Methane	50-55 (MJ/Kg)	13.8 (kWh/kg)	
Natural Gas (CNG)	44.4 (MJ/Kg)	12.33 (kWh/Kg)	
Biogas	44.(MJ/Kg)	12.22 (kWh/Kg)	
Biodiesel	33 (MJ/Kg)	9.166 (kWh/Kg)	
Electricity	3.6 (MJ/kWh)	1	
Calorific content		1	860 Kcal/kWh
LPG	25.5 MJ/Litre	7.0833 (kWh/litre)	

Source: The Engineering tool box (2022).

5.5.9 Potential for Solar.

Nigeria has abundance of solar energy potential with fairly distributed solar radiation and an average duration of sunshine of about 5 to 6 hours. The Greater Karu Urban Area is situated in the Northern part of the country, which receives more sunshine than the other regions of the country. The duration of sunshine in the Northern region is above 6 hours. The average solar radiation of the country is 3.5-7.0 kW/m2 /day. (Bamisile et al,2017; Petinrin,2014).

The general output of a solar PV cell is between 250 watts and 400 watts of power. The formula for calculating the solar panel output is given by Output power = number of hours of sunlight in a day × power rating.

The technical potential of solar technology is determined with the formula below:

$$P = A_{\mathrm{H}} \times I \times F_{\mathrm{REDF}} \times \eta_r \tag{34}$$

Where:

P, technical potential in kWh/year.

A $_{FV}$ is the area available for the placement of ceilings in m^2.I is average global irradiationin kWh/m2.

Fr reduction factors due to architectural availability Ŋ r solar potential reduction factor

I, which represents the solar irradiation for GKUA and is given as 6.0kW/m^2/day. (Petinrin, 2014).

The area available for the placement of ceilings is gotten from the average size in meters of households in the Greater Karu Urban Area. The average size of house- holds obtained is 60 m^2. Therefore, the value for $\mathbf{A_H}$ is given as $60m^2$. This estimation is in agreement with the methodology proposed by (IEA, 2002).

The value for the reduction factor $\mathbf{F_{REDF}}$ for the Greater Karu Urban Area is derived from the methodology proposes by Wiginton and colleagues (2010) where four factors that affect the functionality of roofs were given as; Shadow, which is caused by the presence of other buildings; elements such as TV antennas and satellite dishes, which occupy the space of the roofing area and the orientation of roofs; which depends on the roof type. Majority of the roofs in the building structures of the Greater Karu Urban Area have sloped roofs.

Romero et al (2017) establish the equation of Fr for sloped roofs as 0.9, and for flat roofs and other ceilings, the values were given as 0.8 and 0.85.

$$F_{\mathrm{REDF}} = C_{\mathrm{res1}} \times C_{\mathrm{res2}} \times C_{\mathrm{res3}} \times C_{\mathrm{res4}} \times C_{\mathrm{res5}} \times (C_{GCR} - C_{as}) \times C_{FV} \times C_{ST} \tag{35}$$

Where:

C_{res1}, construction restrictions.

C_{res2} is the restrictions because of historic buildings and C_{res3} the restrictions due to the effect of the shadowsC_{res4} restrictions is due to the orientation of the surface, $Cres_5$ restrictions is due to the inclination of thesurface, C_{GCR} restrictions is due to separation of panel.

C_{as} represents the restrictions due to the area for maintenance required and C_{FV} is the availability for the placement of photovoltaic cell. C_{ST} represents the availability for the placement of thermal solar panels.

Table 96. Showing the parameters to obtain the solar potential.

Reduction Factor	Value	Source
Cres1	0.85 for all roofs 0.8 for plane roofs0,9for sloped roofs	(Romero et al,2017).
Cres2	(1-2,)	(IRENA,2018).

Cres3	0.75 for all roofs 0.8 for inclined roofs 0.7 plane roofs	(Romero et al,2017).
Cres4	0.96	(Barraghan 2018).
Cres5	0.90	(Barraghan,2018).
CGCR / Cas	0.81 for all roofs 1 for inclined roof 0.62 for plane roofs	(Barraghan,2018).
CFV	1	
CST	0.98	(Barraghan,2018).
Fr	0.437	

By applying equation (34) and the reduction factor Fr obtained from equation (35) and 80% efficiency rate, the value P is given as:

$P = A_H .I. F_{REDF}. Ŋ r$

P= 125 kWh per day, which translates to 45,937 kWh/year approximately 46MW per year. This can be used as a fossil fuel substitute in the informal settlements of Greater Karu Urban Area.

5.5.10 Potential for Wind.

The wind energy potential in Nigeria varies across regions, with the Northern part of the country having record wind speeds that average within 4.0m/s to 6.0m/s, which is slightly higher than what is obtained in the southern part. In the south, wind speed ranges between 2.0m/s to 4.0 m/s. The highest wind speeds can be expected in states like Sokoto, Jos and Kano (Agbetuyi etal, 2012; Ajayi 2010). According to the Nigerian meteorological department report NIMET (2010), wind speed values for Nasarawa state falls within the range of 4.80m/s to 5.80m/s. The Greater Karu Urban Area is within Nasarawa state so the estimated value for the wind speed corresponds to what is obtained for Nasarawa state as a whole. The turbine efficiency is 40%.

The specific power available in a cross-sectional area (A) perpendicular to the direction of the wind speed is given as:

$$P_{wind} = {}^{1}/_{2} \times A \times v^{3} \times \rho \tag{36}$$

Where ρ is the standard air density (1.225kg/m3).V^3 is the mean wind speed (m/s),with an average wind speed of 5.0 m/s and turbine diameter of 10m, the Area (A) is obtained as 78.55m^2 and the technical potential is estimated as 21,072 kWh in a year.

5.5.11 Potential of Hydropower.

The main River in the Greater Karu Urban Area is the River Uke, which is situated in the Uke region. The Uke River is a tributary of the River Niger which is the largest River in West Africa.

The River Uke is often called Dogon Ruwa by the indigenes of that reside in the Uke informal settlement (Alamba et al 2016). It runs through the center of the Uke town and itis an important source of water resources for domestic and agricultural activities. The River Uke has the abundance of different species of fishes, which serves the purpose of providing protein to the inhabitants, and a means of income for the individuals involved in fish farming.
It is located between latitude 8^0 53' N and $8^0$56' N and longitude $7^0$39'E to 7^o 46’ E.

Among the objectives set out to determine the hydro potential for River Uke include the general formula which is given as:

$$P_0 = g \times H \times Q \times \eta \times \rho \tag{37}$$

.

Where: P_0 is the Potential Output Power in W and ŋ is the overall efficiency of the hydropower scheme. H is the available head in meters.
Q is the design discharge rate in m^3/s

ρ is the density of water, which is 1000$kg/m^{3.}$
g is the acceleration due to gravity given as 9.81 $m/s^{2.}$

With reference to the energy potential estimate for a small hydroelectric plant, the efficiency of the turbine and the generator is 0.9 and 0.95 (Barraghan,2018).

For the categorization of hydro- electric plants in general, the values of flow rates (Q) determine if the plant is a large > 30 MW or a small plant 1-20 MW. (Zarma,2006). Rivers with flows below 10m^3/s fall under the category of small, while large plants fall between flow rates of 10 m^3/s to 100m^3/s.

In order to estimate the potential for River Uke, we integrate the data for the River Niger from previous studies carried out.

The average discharge for River Uke is estimated as 8 m^3/s which is in the same category of other tributaries of the River Niger i.e Kurra I, Kurra II,Richa I and Richa II.

The River Niger on its own has an average discharge rate of 6335 m3/s (Zarma,2006).The value of H from estimates is given as 240 meters, we compare this value with that of River Kurra I II and Richa I and II which have head measurements of 290, 430, 480and 400 meters respectively.

The installed capacity of River Kurra I II and River Richa I, II are given as 25, 15, 36 and 25 MW respectively (Zarma,2006; Odje et al,2018).

Using Equation 37, we derive the technical potential of River Uke:

$P_0 = g.H.Q.ŋ. \rho$

$= 9.8 \times 240 \times 8 \times 1000 \times 0.9$

= 148GWh in a year with 8760 plant operating hours annually.

A total of 148.34 GWh of renewable energy potential is obtained from the GKUA annually.

6 Community participation in energy usage.

The second objective of this research work is to determine the contribution of a bottom-up approach to realizing the self-sufficiency energy agenda in the informal settlements under investigation. A first step to this approach is to include the results of the survey carried out in section 5. for household and productive enterprise. Where the findings reveal the energy metabolism of both electricity and fossil fuel carriers.

The analysis includes the participation of community agents in the overall decision making with regards to the actualization of self-sufficiency in these informal settlements. We find that in order for the sustainable agenda to be achieved, there are community energy indicators that need to be considered in the planning process.

In this analysis, we carry out a semi/ structured interview that follows from the survey of household and productive enterprises result obtained in section 5.3, which illustrates a bottom –up approach to the planning process.

The semi structured interviews are carried out on the basis of the gender framework and how the respective roles of each gender group in the household and productive enterprises involvedin the sampling affects the transition of the current energy model.

The tables consist of six community energy indicators that have been selected to measure the level of participation of gender groups on the local level. The level of participation will enable this research work to open up the discussion on gender participation in the community level and how it affects the transition of a linear to a circular model, in order to justify the results of this research work.

The community energy indicators are:

i. Level of participation in household activities.
ii. Level of participation in the productive sector.
iii. Level of participation in entrepreneurship.
iv. Level of participation in land ownership.
v. Level of participation in ownership of productive appliances.
vi. Level of participation in access to capital.

6.1 New Nyanya settlement.

Table 97. Showing the level of household activities in New Nyanya.

Participation of men (%)	Participation of women
Household Activity30%	70%

Table 98. Showing the level of participation in productive activities in New Nyanya.

Productive Activities	Job/Work Participation of men (%)	Job/Work participation of Women (%)
Agricultural		
Commercial &Industry	65%	45%
Local Manufacturing	85%	15%

Table 99. Showing the level of participation in business ownership in New Nyanya.

Ownership of productive enterprise	Ownership of enterprise by men (%)	Ownership of enterprise by women (%)
Agricultural		
Commercial &Industry	70%	30%
Local Manufacturing	90%	10%

Table 100.Showing the level of participation in land ownership in New Nyanya.

Ownership of land for productive uses	Ownership of land by men (%)	Ownership of land by women (%)
Agricultural		
Commercial &Industry	70%	30%
Local Manufacturing	70%	30%

Table 101. Showing the level of participation in ownership of appliances in New Nyanya.

Ownership of productive appliances	Ownership of appliance by Men(%)	Ownership of appliance by Women(%)
Agricultural		
Commercial &Industry	60%	40%
Local Manufacturing	60%	40%

Table 102. Showing the level of participation in capital funding in New Nyanya.

Access to funding	Access to funding by men (%)	Access to funding for women (%)
Agricultural		
Commercial &Industry	55%	45%
Local Manufacturing	65%	35%

6.2 Orozo Settlement.

Table 103. Showing the level of participation in household activities in Orozo.

Participation of men (%)		Participation of women (%)
Household Activity	30%	70%

Table 104.Showing the level of participation in productive activities in Orozo

Productive Activities	Job/Work Participation of men (%)	Job/Work participation of women (%)
Agricultural	50%	50%
Commercial &Industry		
Local Manufacturing	70%	30%

Table 105.Showing the level of participation in business ownership in Orozo.

Ownership of productive enterprise	Ownership of enterprise by men(%)	Ownership of enterprise by women (%)
Agricultural	55%	45%
Commercial &Industry		
Local Manufacturing	30%	70%

Table 106.Showing the level of participation in land ownership in Orozo.

Ownership of land for productive uses	Ownership of land by men(%)	Ownership of land by women (%)
Agricultural	55%	45%
Commercial &Industry		
Local Manufacturing	60%	40%

Table 107.Showing the level of participation in ownership of appliances in Orozo.

Ownership of productive appliances	Ownership of appliance by men (%)	Ownership of appliance by women (%)
Agricultural	45%	55%
Commercial &Industry		
Local Manufacturing	70%	30%

Table 108.Showing the level of participation in capital funding in Orozo

Access to funding	Access to funding by men (%)	Ownership of appliance by women (%)
Agricultural	60%	40%
Commercial &Industry		
Local Manufacturing	70%	30%

6.3 Ado Settlement.

Table 109.Showing the level of participation in household activities in Ado

Participation of men (%)		Participation of women (%)
Household Activity	30%	70%

Table 110. Showing the level of participation in productive activities in Ado

Productive Activities	Job/Work participation of men (%)	Job/Work participation women (%)
Agricultural		
Commercial &Industry	60%	40%
Local Manufacturing	70%	30%

Table 111.Showing the level of participation in business ownership in Ado.

Ownership of productive enterprise	Ownership of enterprise by men(%)	Ownership of enterprise by women (%)
Agricultural		
Commercial &Industry	65%	35%
Local Manufacturing	60%	40%

Table 112.Showing the level of participation in ownership of land in Ado.

Ownership of land for productive uses	Ownership of land by men (%)	Ownership of land by women (%)
Agricultural		
Commercial &Industry	65%	35%
Local Manufacturing	75%	25%

Table 113. Showing the level of participation in ownership of appliances in Ado.

Ownership of productive appliances	Ownership of appliance by Men (%)	Ownership of appliance by Women (%)
Agricultural		
Commercial &Industry	60%	40%
Local Manufacturing	60%	40%

Table 114.Showing the level of participation in access to funding in Ado.

Access to funding	Access to funding by men (%)	Access to funding by women (%)
Agricultural		
Commercial &Industry	55%	45%
Local Manufacturing	60%	40%

6.4 Uke Settlement.

Table 115.Showing the level of participation in household activities in Uke.

Participation of men (%)	Participation of women (%)
50%	50%

Table 116.Showing the level of participation in productive activities in Uke.

Productive Activities	Job/Work Participation of men (%)	Job/ Work Participation of women (%)
Agricultural	50%	50%
Commercial &Industry		
Local Manufacturing	65%	35%

Table 117.Showing the level of participation in business ownership in Uke.

Ownership of productive enterprise	Ownership of enterprise by men (%)	Ownership of enterprise by women (%)
Agricultural	50%	50%
Commercial &Industry		
Local Manufacturing	75%	25%

Table 118.Showing the level of participation in land ownership in Uke

Ownership of land for productive uses	Ownership of land by men (%)	Ownership of land by women (%)
Agricultural	60%	40%
Commercial &Industry		
Local Manufacturing	60%	40%

Table 119.Showing the level of participation in ownership of appliances in Uke.

Ownership of productive appliances	Ownership of appliance by men (%)	Ownership of appliance by women (%)
Agricultural	55%	45%
Commercial &Industry		
Local Manufacturing	60%	40%

Table 120. Showing the level of participation in capital funding in Uke.

Access to funding	Access to funding by men (%)	Ownership of appliance by women(%)
Agricultural	60%	40%
Commercial &Industry		
Local Manufacturing	65%	35%

7 POLICY CASE SCENARIO.

Three scenarios are identified to analyze the inclusion of renewable energy in the informal settlements of Greater Karu Urban Area of Nasarawa State. The reference case scenario which represents the current energy model, the Policy Scenario I and Policy Scenario II, which are scenarios that include the Nigerian Renewable Energy strategic plan on a medium- and long-term basis.

In the three scenarios, the Nigerian population growth rate of 3.47% is applied in order to project the energy demand from the base year in 2010 until 2050, which is the final year of the projection estimate. The potential of the renewable energy sources obtained in Chapter 5 are summarized as follow: Biomass with a potential of 85.4MWh per year (see 5.5.8), Solar with a potential of 46MWh per year (see 5.5.9), Hydro-electricity energy with a potential of 148 GWh per year (see 5.5.11) and Wind energy with a potential of 21 MWh per year (see 5.5.10). The total sum equals = 148.34 GWh per year.

The total energy demand for the Greater Karu Urban Area is obtained from the summation of the individual energy consumption of New-Nyanya, Orozo, Ado and Uke settlement. The total energy demand is **15679110kWh per year**, see Tables 85,87,89 and 91.

The Reference Case scenario assumes that, there will be zero net contribution of these renewable energy potential to the energy balance of the four informal settlements, because the reference case scenario assumes that the total energy supply to the informal settlements is derived from fossil fuels.

The Policy case scenario (RESI), applies the technical potential of Solar PV, which is 46 MWh to the energy balance of the four informal settlements.

What is observed in the Sankey Diagrams of the settlements is a reduction in the importation of the fossil fuel sources used in the disaggregated components of the household and productive sector from the percentage differences. Policy Case Scenario (RESII), applies the technical potential of all the renewable energy sources which is 148.34GWh per year, see Figure 39, which represents the energy balance with the use of the Sankey diagram. It is observed that there is a lower percentage of fossil fuel importation in comparison to the energy balance for the Policy Case Scenario 1 (RESI), see Figure 38.

7.1 Reference Case scenario.

This scenario (RES0) establishes the base case, where the informal settlements are characterized with the use of the current energy model, which includes the fossil fuel, Electricity from the Grid and the illegal electricity theft as the direct energy source. For this research work we assume that the base case scenario commences in the year 2010. We identify urbanization as the energy driver for consumption in the household and productive sectors of the informal settlements. By applying the estimate for the growth rate of the population of Nigeria we are able to project the energy demand from the year 2020 till 2060.

In this scenario, we measure the overall energy balance for the four informal settlements in the disaggregated house hold and productive use sectors. With the analysis carried out in section 5, which includes the sampling of data and the typologies of the house hold and productive uses sectors, the overall energy balance for the Greater Karu Urban Area without the inclusion of any renewable energy technology is depicted below in the Sankey Diagram.

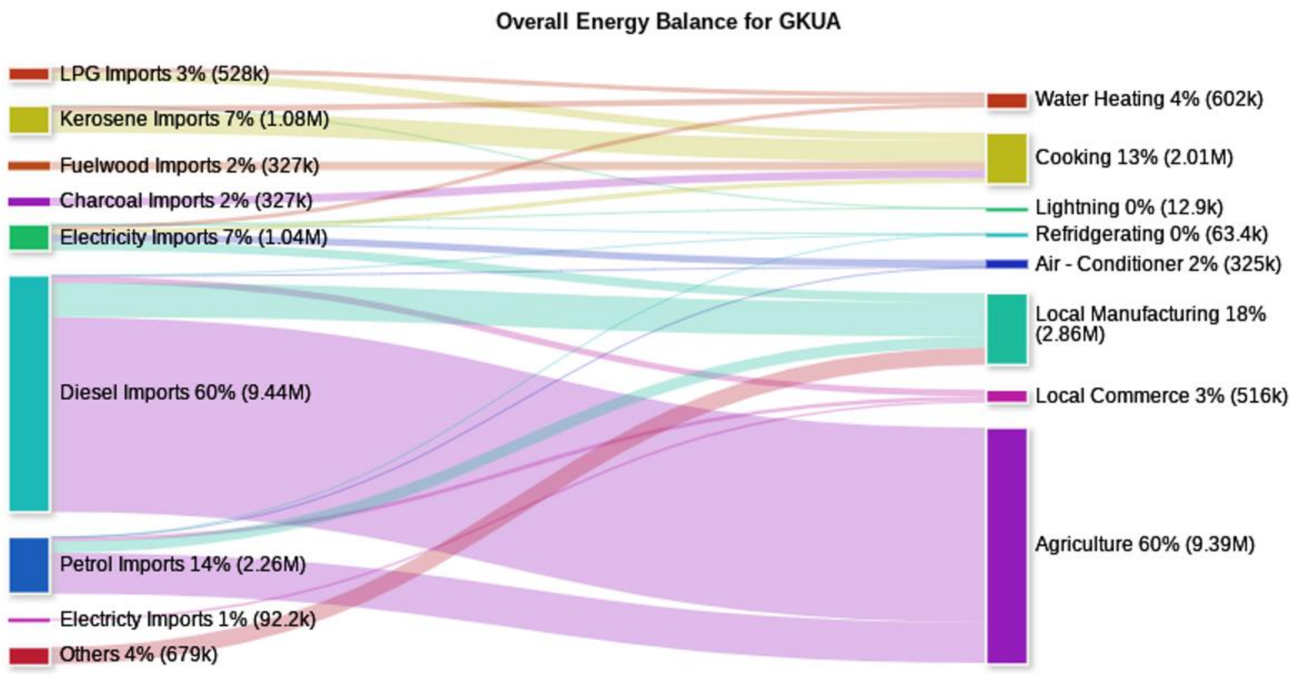

Figure 37. Overall energy balance for GKUA.

7.2 Policy Case Scenario.

This scenario is further divided into Policy Case Scenario I and Policy Case scenario II.
In the policy scenario, we apply the provisions of the Nigerian Renewable Energy and Energy Efficiency objectives, which are summarized below:

With regards to the household sector, the policy makes provision for the use of renewable energy technologies and energy efficient appliances for cooking, heating, air -conditioning, lightning and productive appliances. The strategy implementation involves the inclusion of the National Renewable Energy Action Plan (NREAP) and the National Renewable Energy Efficiency Action Plan (NEEAP). Both Action plans are to be implemented under a short-, medium- and long-term schedule.

The National Renewable Energy Efficiency Plan (NEEAP) is simplified as thus.

The short-term strategy (2015) includes:

- The deployment of the use of energy efficient stoves and renewable energy technologies by 2015.
- Promoting the use of LED bulbs for lighting activities in the household sector and eradicating the use of incandescent bulbs.

The middle term strategy (2020).

- Enactment of all relevant legislation required for policy implementation by 2020.
- Energy efficiency improvement at 2.5% per year.
- 40% reduction of energy intensities by 2030.

The long-term strategy (2030).

- Replacement of all old energy appliances beyond 2030.
- 100% access to clean energy and use of LPG for cooking.
- Enactment of all relevant legislation required for policy implementation by 2030.

The National Renewable Energy Action Plan (NREAP) is simplified as thus:

- Renewable energy target growth rate of 7% of Hydro Power, Wind, Biomass, Solar PV & Thermal.
- Additional Wind capacity of 55 MW.
- Additional Solar PV capacity of 117MW.
- Additional Biomass Capacity of 5.0MW.
- Additional Large Hydro Power of 2121MW.
- Additional Small Hydro Power of 4549MW.

The middle term strategy (2020).

- Enactment of all relevant legislation required for policy implementation by 2020.
- Additional Wind Capacity of 621 MW.
- Additional Solar PV Capacity of 1343 MW.
- Additional Biomass Capacity of 5.7 MW.
- Additional Large Hydro Power of 4549 MW.
- Additional Small Hydro Power of 1607 MW The long. term strategy (2030).
- Replacement of all old energy appliances beyond 2030.
- Enactment of all relevant legislation required for policy implementation by 2030.
- Additional Wind Capacity of 321MW.
- Additional Solar PV Capacity of 6831 MW.
- Additional Biomass Capacity of 292MW.
- Additional Large Hydro Power of 4627MW.
- Additional Small Hydro Power of 8174 MW.

Under the Nigerian Renewable Energy Master Plan (2013). The target is to increase the supply of renewable electricity from 13% of total electricity generation in 2015 to 23% in 2025 and 36% by 2030.

However, this research work we utilize the medium- and long-term implementation schedules from the National Renewable Energy Plan to analyze the scenarios.

We identify our Policy Case Scenario 1 to reflect the medium-term goals of the Nigerian

Renewable Energy and Energy Efficiency Policy and the National Renewable Energy Master Plan. The scenarios are summarized below:

7.3 Policy Case Scenario I: 2010 to 2020 (short term strategy).

0% reduction in energy consumption of fossil fuel.

Policy Scenario I: 2020 to 2030 (medium term strategy). Achievement of 40% reduction in energy consumption of fossil fuel.Replacement of old energy appliances**.**

The energy balance for the four informal settlements in the Greater Karu Urban Area applying policy case scenario (I) is shown below:

In this scenario, we estimate that in-order to achieve 40% reduction in energy consumption of fossil fuel sources, there is an increase in renewable energy supply in the final electricity generated, we assume that the current trend in the deployment of Solar PV and mini grids by the Rural Electrification Agency represents this stage, see Section 3.

We apply the 40% reduction in the energy consumption of fossil fuel sources in the energy balance model of the Greater Karu Urban Area to see the possibility of substituting with a renewable energy source. Solar energy is selected as the only renewable energy source **(**RES 1**)** to provide the substitute for fossil fuel consumption in the household and productive sectorsof the informal settlements. We estimate that there is an increase from 0 % in the reference scenario to 36% of solar renewable energy resources as predicted in the National Renewable Energy Masterplan in the medium-term target plan that runs up till the year 2030.

With regards to the replacement of appliances we use the medium-term efficiency target of 2,5% in the action plans of the (NEEAP), and we assume that all the in efficient bulbs have been replaced by LED bulbs. At this percentage rate we also assume that 40% of LPG stoves will replace all the inefficient paraffin and fuel woodstoves available for cooking.

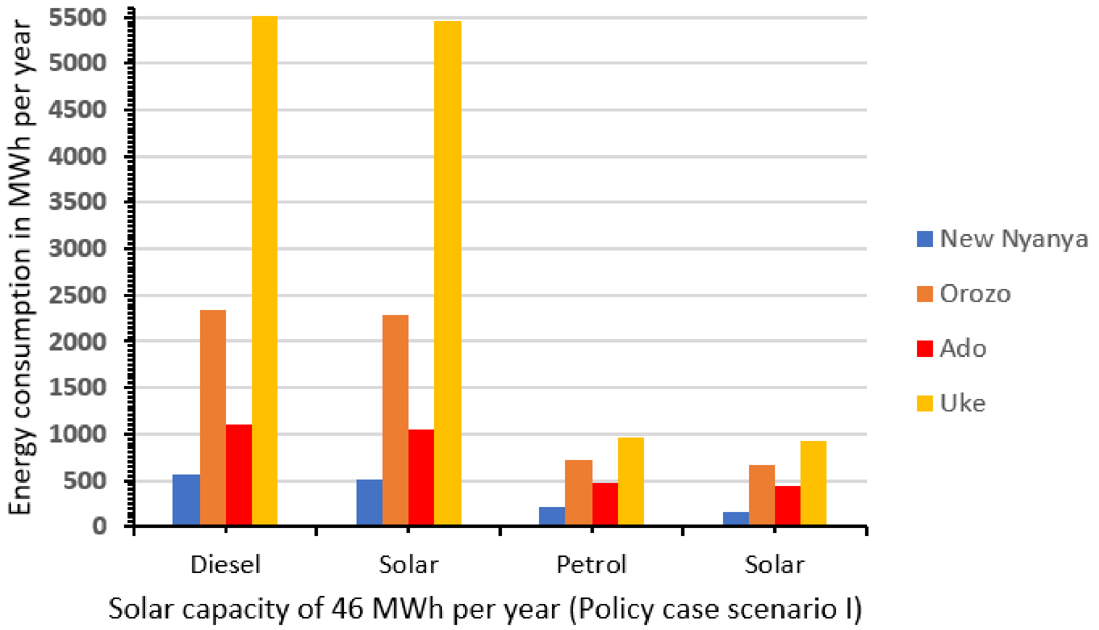

Figure 38. Overall energy balance using Policy case scenario I.

7.4 Policy Case Scenario II: 2030 to 2050 (long term strategy).

100% access to clean energy:

- Total Replacement of Kerosene and Fuelwood stoves by efficient LPG for cooking
- Total Replacement of incandescent bulbs with LED and CFL bulbs for lightning
- Solar Deployment (100%), Hydro-Power Deployment (100%), Biomass Energy Deployment (100%) of the total electricity generation implemented and supervised under the Rural Electrification Energy Agency Electrification Program and in the country's electricity generation mix.

On the basis of these conditions, we apply a 100% reduction in the energy consumption of fossil fuels in the energy balance model of the Greater Karu Urban Area. We deploy all the renewable energy sources selected for the informal settlements in view (RES 2). The combined energy potential of Biomass, Hydropower and Solar renewable energy sources are selected, toprovide the substitute for the consumption of fossil fuel sources in the household and productive sectors of the informal settlements. The application of a 100 % reduction in the energy consumption of fossil fuel implies that the total energy demand for the household and productive sectors will be met by the combined potential of the three renewable energy sources (RES2), which are selected based on the ranking conducted earlier, see Figure 39.

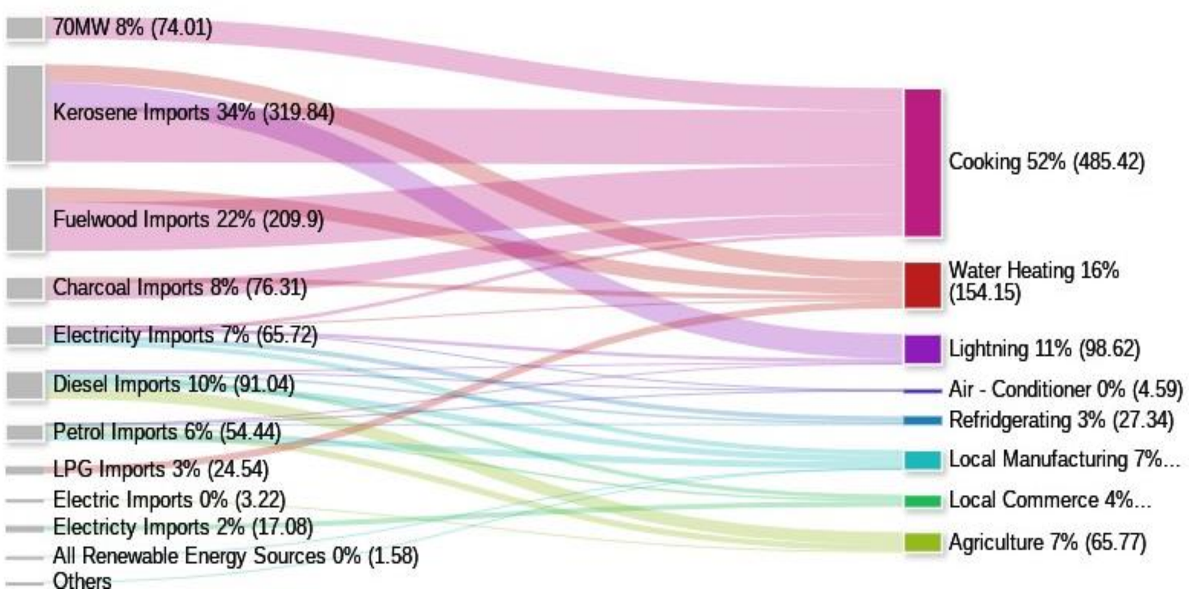

Figure 39. Overall energy balance using policy case scenario II.

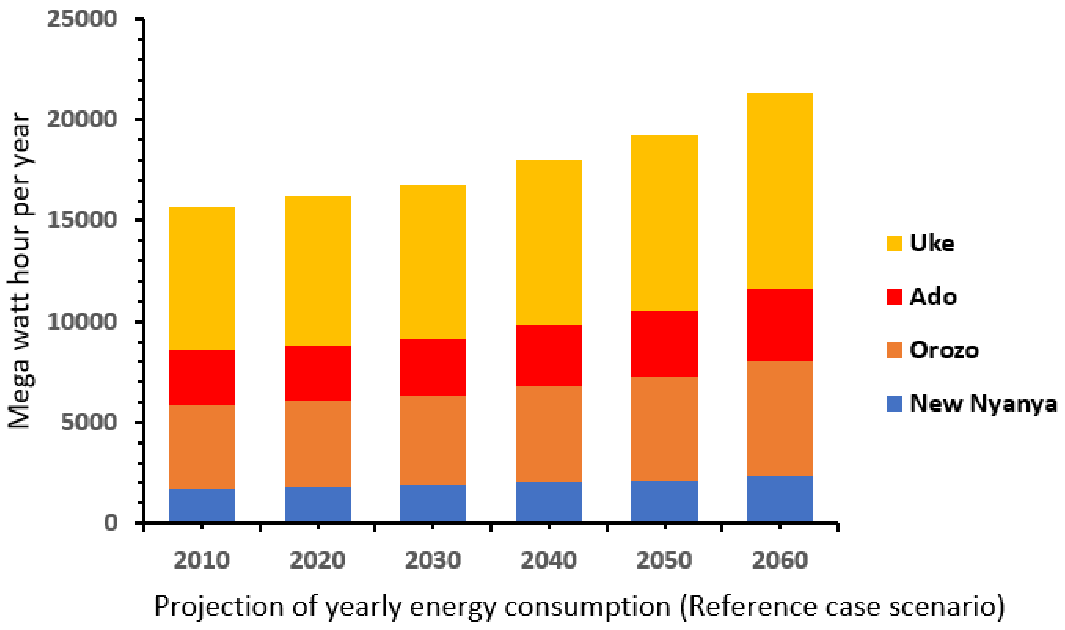

Figure 40. Reference case scenario.

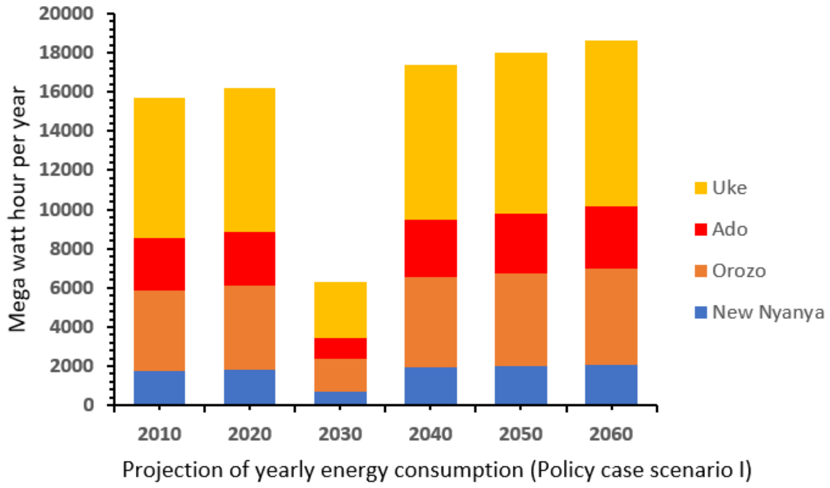

Figure 41. Policy case scenario I.

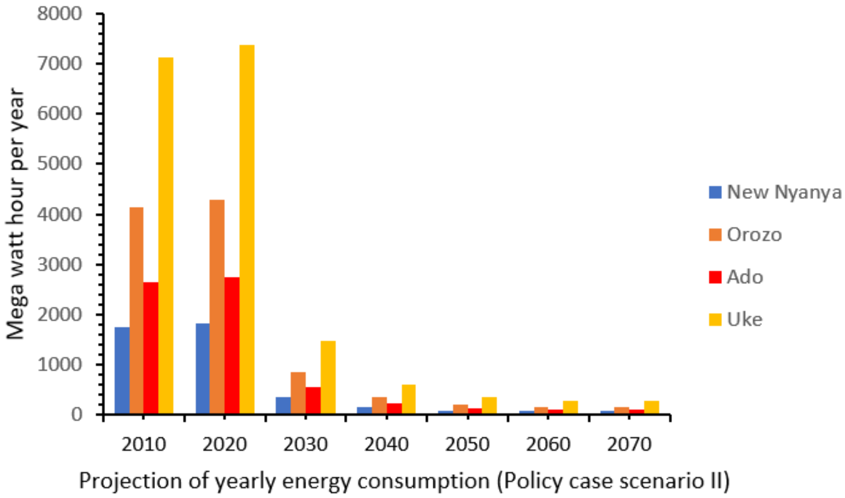

Figure 42. Policy case scenario II.

From the three charts obtained, it is observed that the energy demand rate is projected to be on the rise as the population growth increases at 3.4%, from the year 2010 to 2050, with an average increase in energy demand of about 48% every year, however the case is different in Policy Case Scenario 1 and II.

In Policy Case Scenario I, the energy demand increases from 2010 to 2030, and then begins to experience a steep fall. The steep fall is very much expected as a result of the implementation of the renewable energy policies by the Federal Government.

It is expected that Beyond the year 2030, there will be a drastic reduction in energy intensities in the household sector where firewood and charcoal will be replaced with renewable and energy efficient cooking stoves. In addition, in the lighting sector, incandescent bulbs will be replaced with LED bulbs. Subsequently, it is expected that the demand rate will rise again, due to the increase in population size in these informal settlements, and a slower implementation time to enable the full integration of renewable energy, regionally and nationally. The last chart that represents Policy Case Scenario II, it is expected that after the first fall in the energy demand in 2030, the fall will extend into 2050 and beyond, as it is expected that renewable energy sources will be fully integrated into the energy mix both locally and nationally, thereby forcing the reduction in the importation and subsequent consumption of fossil fuel sources. This is in accordance with the long- term energy plan, which is provided inthe renewable energy policy.

7.5 Energy Indicators.

The energy indicators selected are applied to the three scenarios which are, the reference scenario, the policy case I scenario and policy case II scenario. The indicators are chosen because of their ability to measure the level of sustainability that is attained when there is an inclusion of renewable energy through a 40% reduction in the consumption of fossil fuel (Policy case I), and 100% (Policy case II) respectively. At a 100 % reduction level, there is a zero importation of fossil fuel sources into the Greater Karu Urban Area, which constitutes a significant change in the current energy model. which constitutes a 0% reduction in the importation. The indicators chosenserve the function of yardsticks for measuring the level of self-sufficiency from the ongoing fossil fuel replacement in the scenarios.

Several indicators are available in literature to determine the level of self -sufficiency, in this thesis, we apply the use of three energy sustainable indicator, which is deemed suitable for thetype of analysis that is carried out and the nature of the case study. The indicators are:

7.5.1 Price of Energy (PES).

The equation that denotes the price of energy is gives as:$PE = LCOE \times (1 + Ut) \times (1 + T)$

Where:

LCOE is the levelized cost of energy.

Ut is the energy utility component, which is given as 15%.

T is the tax applicable to each source, where the upstream production tax in Nigeria is 65% in the first five years and 85% after five years under the Petroleum Profit Tax regime.

The values for the LCOE are obtained from Table 39.
Table 121.Showing the price of energy.

Scenarios	PE (USD/kWh)	IVA (%)	Utility (%)	LCOE (USD/kWh)
RES0	0.1138	0.65	0.15	0.06
RESI	0.0517	0	0.15	0.045
RESII	0.08	0	0.15	0.072

7.5.2 Avoided CO_2 emissions indicator.

The determination of this indicator is derived from the standardized measurement from combining the methodology from IRENA (2016).

IRENA applies the CO_2 avoided emissions calculator to determine the amount of CO_2 released in different scenarios as presented below for Nigeria as a whole. This methodology is applied to this research work, as a result of inadequate data due to the informal nature of this study in measuring the CO_2 emissions indicator.

Table 122. Showing the scenarios with CO_2 emissions.

Scenarios	Avoided Emissions
RES0	0 tonnes/CO_2 e
RES I	0.1090 million tonnes/CO_2 e
RES II	2.673 million tonnes /CO_2 e

By applying the IRENA avoided emissions calculator, it determines that when only Solar Energy issued as a substitute for fossil fuel under the Nigeria country energy outlook, 0.109 million tonnes/CO_2 emissions is avoided.

The other scenario created by IRENA, is when Wind, Solar and Hydroelectricity are used as a replacement for Natural Gas, Oil and Coal, which gives 2.673 million tonnes/CO_2 emissions avoided.

The energy scenario adopted by IRENA, 2016 is similar to the scenarios in this research work, the reason why it is applied in this case as an indicator.

7.5.3 Creation of employment.

The equation for this indicator is given as:

$$E_m = \sum_{i}^{m} D_i * LE_i$$

Where Em is the number of jobs.

Iei is the employment factor Di is the total energy demand for the four informal settlements obtained from Table 85,87,89 and 91.

The value for Di is obtained as 15,679 MWh per year for the four informal settlements in the Greater Karu Urban Area.

The value for the employment factor in the three scenarios RES0, RESI and RES II are derived from the combination of the Tables 46 and 47 under the analysis of the provision of jobs sub criteria. Which have been previously derived from Equation 27 in section 4 of this research work. The values are summarized in the table below:

Table 123.Showing the parameters for job creation in the three scenarios.

Scenarios	Em	Di (GW/year)	Iei (Job-year/GWh)
RES 0	1	15.679	0.07 (fossil fuel)
RES I	16.46	15.679	1.05 (Only Solar)
RES II	47.977	15.679	3.06 (Biomass, Biogas,Wind &Hydro-electric)

8 DISCUSSION AND CONCLUSIONS.

The basis of the discussion for this thesis is premised on the analysis that is carried in a sequential order from section 1 to section 7. The argument centered on whether renewable energy sources are capable of changing the metabolic structure of energy consumption from a linear to a circular model, seeing that energy, which is a metabolic input cannot be recycled in comparison with other substrates such as food and waste, materials, which underline the principle of urban metabolism. Renewable energy inclusion in the energy matrix in a hybrid multi structural settlement is examined to determine the possibility of replacing the fuel and energy carriers currently in use.

8.1 Discussion.

It was estimated that the number of people living in informal settlements rose to about 1 billion, in 2018, with expectations for further exponential growth in the future. This represents 13% of the world's population. The implication of this is that urban planning must be resilient to withstand the pressure emerging from the trend of rapid urbanization across the globe. In other to find solution to this problem, it is necessary to understand the relationship that exist between cities and its inhabitants through the concept of urban metabolism.

The urban metabolism concept is used as a tool to examine the characteristics of a city and determine the directions of all the processes within and outside the city's boundaries. This research work, reveals that the energy model is linear, because energy cannot be recycled in comparison with other substrates within the city's boundaries however, energy is optimized alongside other substrates if the source from which it is derived from is sustainable. This research proposes a circular model for energy pathway that ensures its efficient usage and subsequent replenishment is obtained from clean and reliable sources of energy. The research work takes a crucial step, by investigating the energy metabolism in informal hybrid settlements, in order to influence policy decisions that aim at improving energy access in underserved and unservedcommunities.

The research analyzed six renewable energy technologies in four hybrid multi-structural settlements, which represent the co-existence of formal and informal settlements within the boundaries of the study area.

The urban metabolism methodology is applied to the Greater Karu Urban Settlement, which is a conurbation of informal settlements and housing, surrounded with formal settlements. The methodology examines the energy metabolic process, and reveals the requirements of household and productive use of electricity. The methodology proposed, determines the means to achieve self-sufficiency through the careful consideration of energy information on a community level and in the absence of any formal or legal basis. From the community, there are factors that strengthen the argument in support of the sufficiency of renewable energy potential in the Greater Karu Urban Area and how they determine the push towards self-sufficiency.

The selection of the renewable energy technologies in these areas are undergone according to the dimensions of multi criteria decision making, where technical, environmental, social and economic factors are put into consideration with a view to obtain the most preferred renewable technology. Six renewable energy sources were identified to be present in the Greater Karu Urban Area, which include Solar PV, Hydroelectricity, Wind Energy, Solar thermal,Biomass and Biogas. Fourteen criteria were examined through literature review and general survey conducted with the use of experts with experience in the field of renewable energy.

The experts were drawn from public and private institutions, with more participants from the government institutions and the federal universities of science, while the rest were entrepreneurs and business owners. The fourteen criteria displayed unique characteristics, after the questionnaires were administered in different rounds. The random index obtained from Saaty(1980), see Table 8, is used as a prerequisite to determine the consistency level in the responses from the exercise conducted for experts, which is carried out with the principles thatunderline the Analytical Hierarchy Ranking process (AHP). The random index value for a 14by 14 matrix is obtained as 1.58 in this thesis.

Using the AHP method for evaluating consistency in the expert opinion, it is a requirement that the consistency ratio must be less than 0.1. In our research we determine the consistency ratio as the one between the consistency index and the random index, which follows the principle laid down in the work of Saaty (1980). The consistency index obtained from the expert opinion is 0.002274 The reliability of the expert evaluation was strengthened with a highvalue of the Cronbach alpha number. In this work, itis obtained as 0.83.

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The AHP methodology provides the details of the relationship within criteria, the intercriteria links are used to establish the outperformance of one criterion over the other from the amount of weight apportioned to each of them.

The advantage of the AHP methodology is that it allows the ranking of criteria based on their level of importance, through a pair wise comparison. The AHP scale which measures thelevel of importance by using the range of figures 1 to 9, signifies that the most important criteriais given a score of 9 and the least important criteria is given a score of 1.

The results obtained from the AHP process involving the renewable energy experts, see Table 26, reveals that the most important criteria is the availability of source (C2) with a weight of 0.16. The next important is the criteria (C3), with a weight of 0.136. The third and fourth mostimportant criteria are (C8) and (C9) which are the investment cost and CO2 emissions with both weights of 0.114. Other criteria such as the levelized cost of energy (C6), land use intensity(C10), operation and maintenance cost (C7), capacity factor (C5), urban obstacle (C4), water use intensity (C11), efficiency (C1), and acidification (C12), are ranked, 5^{th}, 6^{th}, 7^{th}, 8^{th}, 9,10^{th},11^{th} 12th with weights of 0.0829,0.070,0.058,0.0413,0.0413,0.0413, and 0.0264.

The social criteria which are listed as job opportunity and gov support are the least important with weights of 0.01450 obtained respectively. The most important criteria, availability of source (C2) and maturity of technology (C3), are two technical criteria, out of a total of four. The other technical criteria; capacity factor (C5) and urban obstacle (C4) are less influential than (C2) and (C3), nevertheless still remain a determining factor in the selection of the renewable energy sources within the informal settlements. Criteria (C2) and (C3) measure the ability for the renewable energy sources to be readily available and adequate for the onward delivery to the end-users. The importance of a criterion relative to another cannot be overemphasized because the outcome of the decision making depends on their weight attributes. Therefore, the decision-making process eliminates bias in pronouncing any judgement with regards to preference and choices, from the accurate determination of criteria weights.

The importance of the influence of a criterion is observed with the land use intensity criteria (C6). The four informal settlements are of varying sizes in m^2 which implies that some communities are easily overwhelmed with the presence of a renewable energy source in comparison to others. The typologies I, M and S hybrid informal settlements are most likely to feel the effect of renewable energy sources that impede the flow of goods, people and materials. This is as a result of the dense structures, which are in close proximity to each other, which characterize these settlements. On the other hand, the hybrid informal settlement A and S are characterized with the possession of large expanse of land, where the urban obstacle sub-criteria (C4) and land use intensity (C10) are of little or no importance. The criterion (C1), which represents the efficiency of the generating sets, is given the lowest weight score amongst the technical criteria. The result of the expert opinion indicates that the technical criteria on an average are the most important, however the importance of the economic criteria is highly significant. The investment cost (C8), the LCOE (C6) and the operations and maintenance cost (C7), determine the amount of money that is required throughout the life cycle of a renewable energy source. Therefore, how that money is recovered from the end users is an important factor in the selection process. The renewable energy tariffs charged to customers, need to be cost reflective to ensure that every penny of investmentis levelized across the electricity value chain. The generator, transmission and the distribution sectors of the electricity supply chain needs to be fully funded, to support the existence of the renewable technology. The operation and maintenance cost is given the lowestlevel of importance amongst the three economic sub criteria, while the investment cost (C8) and levelized cost of energy (C6) are adjudged the best.

This can be attributed to the fact that the operation and maintenance cost are a percentage of the investment cost. In essence, the values of the fixed and variable operational cost are already accounted for in the capital cost of installation, making it less likely to be an important determining factor in comparison with the capital cost of which it is attached to since it is a dependent cost.

In addition, another reason that can be attributed to the lower importance given to the criterion for operation & maintenance cost, is the fact that some renewable energy technologies do not require as much maintenance in comparison to the other.

The environmental sub-criterion (C9), which represents CO_2 emissions is ranked 4th. The importance of this criterion in informal settlements is very significant in all the typologies presented in this research work. The rising prevalence of building-related illness (BRI) and sick building syndrome (SBS), in informal households in Nigeria, pose a general health concern. The symptoms include; headache, nausea, running nose and skin dermatitis, which are linked to the poor quality of air resulting from the release of carbon monoxide from fossil fuel generator fumes and CO_2 emissions. This has come to symbolize the importance of this criterion in informal settlements (Ekhaese & Omohinmin, 2014). The environmental sub-criterion for land use intensity (C7) and water use intensity (C11) are important in determining the selection of renewable energy sources on the basis of the amount of water and land that is available in the different typologies of informal settlements. For example, the typology A and S settlements can accommodate higher water intensity in comparison to typology H, I and M, so it is expected that the renewable energy sources that utilize a lower volume of water in producing electricity is preferentially selected. Typology A and S settlements are situated closer to the boundaries of GKUA, and closer to streams and rivers which possess the potential for small hydroelectric plants. This is evident in the Uke settlement. However, the reason the criteria (C7) and (C11) are not as important as the criterion (C9), is because of the varying requirements of each typology of settlement, therefore some settlements find land and water use intensity a necessity than others.On the other hand, CO_2 emissions reduction is a necessity for all the informal settlements. The social criteria; employment opportunities (C13) and government support (C14) are given the lowest cores for level of importance. This can be attributed to perception of the experts that even though renewable energy sources can bring infrastructural development to an informal settlement, there is a low chance of providing enough jobs for the populace. Seeing that a lot of funding will be required to train and sensitize the informal settlers on the operational use of the renewable energy technology. This is a responsibility the government might decide to put aside for other capital expenses in the federal budget. In addition, the level of trust between the government and the citizens is perceived to be low, judging from precedent.

Cronbach’s alpha coefficient of 0.83 is obtained from the rounds of questionnaire administered to the experts, out of the fourteen sub criteria, four sub criteria are classified as qualitative and the rest as quantitative. The qualitative sub criteria are (C2), (C3), (C4) and (C14) and they are subjected to a scale of 1 to 5 in order to determine their respective weights. The value of 0.014 was obtained for the consistency ratio. Seeing that the measure of internal consistency should be less than 0.1, the results of the expert opinion are good.

The results from the expert survey establishes the intercriteria relationship through a pair wise comparison conducted by the Analytical Hierarchy Process. The AHP allows us to subject the criteria to the opinion of experts, who determine their level of importance amongst each other on a Likert scale of 1 to 9. However, in order to eliminate the bias that is associated with the weight determination of criteria from this method, we employ another approach by using the entropy method and the equal weight method in order to create a comparative analysis.

The comparative analysis is carried out using three scenarios which include the entropy weight method (ETM), the AHP method and the equal weight method (EW). The equal weight and AHP method represent the objective methods of weight determination, while the entropy method represents the subjective method of criteria weight determination. The three scenarios are inputted into the PROMETHEE- GAIA, and the representation is depicted in Figure 12, 13 and 14.

In the equal weight scenario, all criteria are assigned a weight of 0.1. The GAIA chart shows that the CO_2 emissions (C9) and Efficiency (C1) are closely related to each other but a distance apart from the capacity factor (C5). The investment cost (C8) and the cost of operation and maintenance (C7), are closely related and lie on the same plane, with criteria for land intensity (C10), water intensity (C11) and acidification (C12), see Figure 12. In the second scenario

which represents the AHP method, Capacity factor (C5) is further apartfrom criteria (C9) and (C1), the CO_2 emissions and Efficiency criteria respectively. There is also an observable difference in the distance between the investment cost and the cost of operation and maintenance, water intensity, land intensity and acidification (C7), (C10), (C11) and (C12) respectively. Even though they lie on the same plane, the distance apart is a lot more in comparison with that in scenario 1. In addition to the observed difference, the capacity factor and the efficiency lie on different planes in comparison to the first scenario, see Figure 13. In the third scenario which represents the application of the entropy method, the capacity factor (C5), efficiency (C1) and the CO_2 emissions criteria (C9), all lie on the same plane with very close proximities to each other in comparison to the first and second scenario. While the Investment cost (C8) and maintenance cost (C7) are close to each other but further apart from the gov support (C14) and acidification (C12) criteria. In addition, the water intensity (C11) and urban obstacle (C4) criteria moved from being close to the operation and maintenance cost, gov support, and land intensity criteriato occupy a position directly opposite to the capacity factor, CO_2 emissions and efficiency in the GAIA plane.

The observed difference in the positions of the criteria in the entropy method in comparison to the equal weight and AHP method is a result of the varying weights of the criteria when carried out subjectively and objectively. For the criteria (C5), (C1) and (C9), have entropy weights of 0.036,0.037 and 0.070 respectively which differ from the AHP weights of 0.05, 0.04 and 0.11. This shows that the entropy weights have lower values than the AHP weights, hence a closerrelation is seen within the criteria in the scenario 3 in comparison with scenario 1 and 2. In the first scenario, the three criteria (C5), (C1) and (C9) are each assigned a value of 0.1. The following conclusion applies to the criteria (C8), (C7), (C14), (C12), (C11) and (C4). Their entropy weights are obtained as 0, 06, 0.122, 0.007, 0.159, 0.421 and 0.035, while their AHP weights are given as 0.11, 0.07, 0.03, 0.08 and 0.04. The difference in the position of the investment cost (C8) with the rest of the criteria is evident in the higher weight assigned to it in the AHP scenario with a value of 0.11, in comparison to a lower value of 0.06 and 0.1 which are obtained fromthe entropy and equal weight method respectively.

On the selection of the best renewable energy technology, the three scenarios are in agreement that Solar PV is the most preferred. This is evident in the value of the net outranking flow in the three scenarios, see Table 51, 52,53 and 54. Solar PV has the highest value for the net out-ranking flow of 0, 2893, 0, 4022 and 0, 4635 for scenarios 1, 2 and 3 respectively. This is also consistent for wind energy which occupies the second position with net outranking flow values of 0.0926, 0.0696 and 0.2597 for scenarios 1,2 and 3 respectively. However, there are observable differences in the ranking for Biomass, Biogas, Hydroelectricity and Solar thermal energy sources. In the first scenario, Hydroelectricity is ranked 3rd, followed by Biogas, Biomass and Solar thermal in the order of ranking. While in scenario 2, the Hydroelectric maintains the third position as well, but Biomass and Biogas replace each other in the 4th and 5th positions. In scenario 3, the hydroelectric source is ranked the 4th, while solar thermal is consistent in the last position with all the scenarios.

The reason for this difference is because of the consideration of degree of diversification factor which is applied in the entropy weighing method in scenario 3. The degree of diversification (d_J)eliminates the bias that is associated with the equal weight and AHP weight method.

The potential of the renewable energy technologies is established after the selection and subsequent ranking carried out by the PROMETHEE software. The analysis of the potential of the selected renewable energy technology is done with the consideration of community energy participation, which to a large extent serve as the basis to enact policies that facilitate renewable energy expansion at the local level. The objective of this study is to determine whether renewable energy sources is adequate in spearheading the transition of the current energy model from a linear to a circular, seeing that unlike other urban substrates such as nutrients, waste andeffluents, energy cannot be recycled.

Therefore, there is a need to determine on one hand if the potential of the renewable energy technology is sufficient to replace the direct energy attributed from the use of fossil fuels, and onthe other hand the additional determining factors when community energy participation is included.

In order to establish these options, the diagnosis of the energy metabolic pathway of five typologies of informal housing and 3 categories of productive usage of electricity, which are present in four hybrid multi-structured settlements is carried out.
The informal settlements coexist in the presence of formal settlements in a hybrid multi-structure layout.

The four hybrid multi-structured settlements under investigation are New Nyanya, Ado, Orozo andUke. These settlements are conurbation of small towns located in the Greater Karu Urban Area of Nasarawa State in Nigeria. The Greater Karu Urban Area is a border town which is in close proximity to Abuja City, which is the capital of Nigeria. The settlements in the GKUA area firstemerged from the initiatives of the Federal Government of Nigeria, to accommodate workers inthe civil service, but have metamorphosed into a hybrid multi-structure that presently include the proliferation of informal settlements that are in co- existence with formal settlements under different typologies.

The typologies of informal housing are characterized based on the distance in proximity to the capital city of Abuja. This has come to symbolize, the different electricity expansion

Strategies that need to be undergone in order to create full access to clean and sustainable energy. The understanding goes beyond seeking opportunity cost solutions of extending the national grid in comparison with the deployment of captive electricity through the use of off grid solutions, to the appreciation of the different community energy requirements.

Estimating the energy requirement of the informal settlements involves taking a random sample of households and productive enterprises with a survey questionnaire see Annex II. The sample size was estimated using the Cochran's formular, see Equation (24). At a 95 % confidence interval, 5% margin of error, and the degree of variability (p) with a value of 0.5, we are able to draw up a total sample size of 380. In New Nyanya, Orozo, Ado and Uke informal settlements 82% is obtained as the average response rates for the four informal settlements, with 79% for New Nyanya, 90.15% for Orozo, and 83.3% and 77.5% for Ado and Uke respectively. The typologies of households and productive enterprise are responsible for the distinctive attributes that characterize each informal settlement.

The survey questionnaire sought to find the distribution of the sample statistics along the lines of demography with a clear distinction of age, gender, electricity consumption and social classification. See Annex II.

In New Nyanya hybrid settlement there exist the housing typologies H, M and I and productive enterprise categories C and M. This is similar to the Ado settlement which consists of housing typologies H, M and I. In addition, the Ado hybrid settlement consists of the categories C and M productive enterprise.

Orozo settlement consists of the housing typologies I and S, with the productive enterprise categories C and M, while Uke settlement comprises of only housing typologies A and productive enterprise A in its composition. The difference in the typologies and categories of housing and productive enterprises respectively, is as a result of their relative distance in km to the Capital City of Abuja. New Nyanya and Ado hybrid informal settlements, are 30km and 30.6 km from Abuja respectively, in comparison to Orozo and Uke settlements which are 25.8km and 38.5km respectively.

The significance of their various distance measurements, define the type of economic activity and energy consumption pattern consequently. New Nyanya and Ado Hybrid settlements are right in the center of the GKUA are see Figure 27,28,29 and 30. These settlements record the highest population of the informal settlers who throng in to conduct trade and commercial activities. In essence settlements closer to the center of GKUA are characterized by a high level of congestion, with little availability of space to accommodate squatter settlers in clusters or agriculture and farm related businesses. The difference remains evident in Orozo and Uke hybrid settlements where Orozo is a lot closer to Abuja, but further away from the center of GKUA. In addition, Uke with a distance of 38.5 km is the farthest from the center of GKUA and closer to the border of another state called Benue in the direction east of Abuja. The Uke hybrid settlement is identified predominantly as an Agriculture based settlement even though it consists of illegal informal occupants co-existing with formal and legal land owners.

The income and family sizes also varies across these settlements as seen in tables 57,60,64 and 68. The household in Uke hybrid settlement consists of a family size of 4 to 10 people with an average income of \$60 in a month, which is below the United Nations threshold for poverty which is set at \$2 per person for a day. This family occupy a larger square size of 70 to 80m^2. It typically includes a polygamous family of a man, who heads the home, 2 to 3 wives and about 10 children. The children serve as the major labor source in the farmlands, where agriculture and farming is done on a subsistence level with. The monthly income continues to improve when the involvement in mechanized agriculture progresses. In the household typology A the major fossil fuel energy usage is in cooking, where charcoal and kerosene are used as sources. The salaries are not commensurate with the household typologies H, M and I which are found in center of GKUA, where the settlements of New Nyanya and Ado are situated.

The average income wage for informal households in New Nyanya and Ado hybrid settlements, is \$127 USD per month. This is broken down to include \$80 USD for household typology H, \$100 for household typology I and \$200 for household typology M. The average incomes to the households are higher in New Nyanya and Ado settlements because the majority of the informal settlers are either educated persons who commute to Abuja for formal work in the education and tourism sector or in the informal commercial and manufacturing industry. The presence of the categories of productive enterprises C and M, indicates a better cash flow for the families, where they are able to provide domestic services such as food vending and cleaning, or in the manufacturing of cheaper products that is beneficial to the formal sector of Abuja and to larger extent the surrounding informal communities of GKUA. However, this does not meet the poverty threshold speculated by the United Nations on the global poverty index, because of the large family sizes in existence in these typologies of households. The household typology H consists of a family size of 5, while the household typology M consists of the largest family size of more than10 persons where municipal flats that was once allocated for civil servants working for the government turn into congested flats as a result of the inhabitation of extended family members. see Table 57 and 64.

The household typology S is the most prevalent in Orozo settlement with a small proportion of typology I. The closeness to the borders of Abuja means that the settlers are squatters who have been displaced from the center of GKUA, and Abuja so they exist in clusters through the invasion of land not allocated to them. These household type rely on manufacturing and the provision of informal services to the formal sector of Abuja and the other GKUA settlements, hence the ability to raise an average monthly income of 80$, which is broken down to include: 60$ for household typology S and $100 for household typology I.

The difference in the household typologies and productive enterprises in terms of average income and family size defines the pattern of energy consumption. The appliance approach method is used to determine the energy demand of the four hybrid informal settlements through the summation of the load profile of the household typologies and the categories of productive enterprise.

The total load requirement of the GKUA provides the impetus in determining the potential of the renewable energy that is required. The total load requirement of the four informal settlements of the GKUA is obtained as 15,679,110kWh, and this is broken down to obtain 1,754,110, 4,137,860, 2,654,140 and 7,133,000 kWh for New Nyanya, Orozo, Ado and Uke settlements. The total load requirement for the typologies of households and the productive enterprises is obtained as 340,750kWh see Table.84 The breakdown according to typologies is obtained as; 8,258, 28,864, 21,382, 10,904, and 3,651kWh for H, M, I, A, S. The breakdown of the load requirement for the categories of productive enterprise is obtained as; 161,969, 62,212, and 7,376 kWh respectively.

The energy balance measured the imports of fossil fuel into the GKUA hybrid multi- structural settlements and determined the percentage consumption in the disaggregated household and productive sectors. The disaggregation of the household sector include; cooking, lightning, refrigerating, air-conditioning and water heating. While the productive sector is disaggregated to include the local commerce, local manufacturing and agricultural sub sectors. The overall energy balance for the GKUA show that fossil fuel carriers contribute a total of 15,679,110kWh, from the current energy model. In the informal settlements there are economic activities which make use of equipment with high consumption capacities for manufacturing local goods to be sold to the formal sector. Examples of local manufacturing activities is observed in Ado, and New Nyanya settlement, while agriculture-based activities is the most common in Uke settlement. There is a large presence of welding, blacksmith, soap and local wine and ice block manufacturing in Ado, New Nyanya. In addition, the local commerce industry is also vibrant in Ado and New Nyanya settlements, because they are situated at the center of GKUA.

There is a large presence of barber shops, food vendors, video gaming and business center in the Ado and New Nyanya and Orozo settlements. Local commerce accounts for 3.5% of the total energy consumption in Orozo, 8.4% and 8.3% in New Nyanya and Ado settlements respectively. The total energy consumption in Orozo settlement is 4,137,860kWh per year in comparison to Ado and New Nyanya settlements with annual energy requirements of 2,654,140kWh and 1,754,110kWh respectively. The difference in the energy gap of Orozo in comparison to Ado and New Nyanya settlement is due to the presence of a thriving agricultural sector which contributes about 3,289,350kWh per year to the energy requirement. This agriculture sub sector is absent in Ado and New Nyanya settlement, a critical way to examine this difference involves taking into consideration their relative size and distance to the capital city of Abuja. Orozo is much closer to the boundaries of Abuja, while New Nyanya and Ado settlements are situated in the center of GKUA.

Uke is situated on the other boundary between GKUA and another state of Nigeria called Benue. It is predominantly agriculture based so it contributes the largest energy requirement in the GKUA, with an annual consumption of 7,137,000kWh. The unique character of this settlement is that it is unelectrified, and most of its energy imports are derived from diesel tankers arriving from the oil depots and terminals from the western and southern part of the country. The industry largely operates diesel machines to power rice millers, cassava graters, cashew processors, cowpea threshers and sorghum millers. This equipment are heavy duties with power ratings that range between 8-20 kW, so require a considerable amount of energy to operate them. This is in sharp comparison to the household equipment which range between 0.5 to 5kW.

In the household sector, fossil fuel sources such as kerosene and LPG, are very popular in Orozo, Ado and New Nyanya settlements. Kerosene is the most commonly used fossil fuel source with 60% contribution to the cooking sub sector in New Nyanya and Ado settlements. In Orozo settlement it is also contributes 50% of energy imports for cooking, which represents the largest share of energy sources. This is followed by LPG and electricity at 30%and 20% respectively. There is a minimum contribution of diesel and petrol to the cooking subsector in Ado and New Nyanya settlements at 5% respectively. Even though it is a small contribution of fossil fuel usage in the cooking subsector, it reveals the socio -economic divide between the four informal settlements. Diesel and petrol usage is only affordable to the upper-class informal settlers who can afford to switch over when a black out or power outage is experienced. The informal settlers in Ado and New Nyanya are identified as the working class and enterprise owners, so their income levels are a bit higher than informal settlers in Uke or the squatter settlers in Orozo, The price of diesel and petrol in Nigeria is about 224.8 and 170 naira per litre, which is equivalent to 0.56 and 0.4 USD per litre, which is lower than the worlds average prices at 1.06 and 1.19 USD per litre. However, the informal settlers are low-income earners with salaries that range from (100-250) USD per month.

From the energy balance the estimate of the total energy required from renewable energy to replace the fossil fuels is obtained. In order to determine the potential of the available renewable energy sources involves the use of mathematical expressions see Equations 32,33,34,35,36 and 37.

The second part of the result analysis is carried out on the community level in Chapter 6. The objective is to determine the level of participation of men and women in renewable energy expansion and to strengthen the argument on whether self-sufficiency from renewable energy can solelydetermine the transition from a linear to a circular energy model.

The findings from the community participation reveal six indicators, which are level of participation in household activities, productive activities, capital funding, land ownership, ownership of productive enterprise and ownership of productive appliances. Orozo settlement records the lowest disparity in gender equality in the measurement of the level of participation with the six indicators, with a value of 8.18%. On the other hand, New Nyanya settlement records the highest level of disparity in gender equality, with a value of 30%.

It can be suggested that there is a need to improve on the closure of the disparity in gender equality through the initiation of measures adjudged from the six indicators.

The government should look into improving on gender equality by:

- Increasing capital funding for women and men.
- Subsidizing productive appliances for women.
- Creating access for women to own lands.
- Creating more training programs for women to participate in renewable energy.

8.2 Conclusions.

The importance of renewable energy in informal settlements cannot be overemphasized, in as much as fossil fuels remain a dominant source of energy, it is without doubt that in order to strengthen the level of resilience of a city and its informal settlements, the use of renewable energy is vital for such purpose. The use of renewable energy in informal settlements has created a shift in the outlook of these settlements. In the past, informal settlers were observed as a nuisance to the society at large, seeing that their economic activities were not easily traceable, so it was difficult to determine their level of contribution to societal growth. However, the introduction of renewable energy has opened up those grey areas of untraceable economic activities through the use of the urban metabolism tool. In addition, the landscape of urban planning for cities is being influenced by the presence of informal settlement requirements.

The energy requirements of the informal settlements and slum areas are a pre requisite to the overall planning outcome of a city, and this is driven by the presence of renewable energy technologies available within its boundaries and inner sections. Consequently, the urban metabolism tool has been able to diagnose the energy metabolism pathway of informal settlements thereby providing the necessary information that is required to formalize and integrate informal settlements into the formal city plan therefore changing the structure of urban planning in general.

The individual contributions of this study to promoting the concept of urban metabolism is summarized in the order with which the thesis is conducted.

From the first chapter, this thesis identifies and introduces the problem associated with energy access to informal settlements, of which a provision has already been made in the United Nations sustainable development goal, which is to make cities and human settlements very resilient to adverse changes in energy supply (UN,2019). Making cities resilient is to reduce the import of fossil fuels and the resultant replacement with renewable energy technologies that can be derived from within the boundaries of the city and its informal settlements. The contribution of this study to solving the problem of access to clean energy was to examine the energy requirements for informal settlers with the hope of determining the factors that need to be considered prior to achieving successful implementation of clean energy access and expansion strategy.

Section 1 further identifies the unique feature of informal settlements which makes it difficult for energy accessibility to the central electricity grid amongst several other challenges. This thesis identifies the lack of data and accountability of the energy consumption of informal settlements as a general problem associated with informal electricity planning, and contributes to solving the problem of energy audit through the use of the urban metabolism tool carried out by using random samples of informal settlements in the Greater Karu Urban Area of NasarawaState.

Once the samples are obtained, as a representation of the whole population, a rough estimate of the energy requirement of the informal area can be ascertained. Consequently, this serves as the basis to obtain data for households and bsiness enterprises present in these areas thereby providing the basis for the formalization of informal settlements to the formal sector.

The objective of thesis was to assess the renewable energy sources within the boundaries of the informal settlement to replace the dependence of fossil fuel. This thesis is able to contribute to exploring the availability of renewable energy technologies in the Greater Karu Urban Area of Nasarawa, thereby helping to add to the knowledge of renewable energy sources in Nasarawa State and Nigeria as a whole. The conclusion from this explorative search for renewable energy sources available for replacement, is that these clean energy sources are available but fossil fuel still remains a dominant energy source and can be hybridized with renewable energy sources in order to provide solutions to the problem of intermittency.

The other objective was to determine if the current energy model can be transformed from a linear to a circular type, and this study considered community participation as a pre requisite to obtaining a full transformation. The work was able to contribute to the work on gender equality by observing the level of participation of gender in the household, ownership of productive enterprise, job participation in the productive sector, land ownership, ownership of productive appliances and capital funding. The descriptive statistics in four informal settlements are obtained as a means to justify gender equality as a pre requisite to achieving the full transition from a linear to a circular energy model from the context of sustainability.

Section 2, conducts a literature review on the principle of urban metabolism and a total of 30 studies were reviewed, starting with the different methods of urban metabolism, which we are able to classify as system dynamic analysis, formalization strategy, material flow analysis, and input-output analysis. Few studies such as (Kovacic et al., 2016; Smit et al., 2018; Makinde, 2018) apply the work of urban metabolism to informal settlements. Makinde (2018) applies a multi scale integrated analysis of social and ecosystem metabolism (MUSIASEM)to Enikanni informal settlements, and Smit et al (2018) took a further step to create typologies of informal settlements.

This research work contributes to the body of knowledge of the urban metabolism practice in informal settlements by considering the contribution of productive enterprises to the overall energy requirement. This thesis also contributes by creating different typologies of productive use enterprises and house hold.

Section 2 also reviews literature with regards to the top and bottom planning approach for renewable energy expansion strategies. The top and bottom approaches were compared for preferences. This thesis contributes to the strategic planning approach of electricity expansion by applying a hybridized top and bottom methodology to informal settlements. This thesis applies this hybrid methodology through the use of the opinion of experts in the field of renewable energy, which represents a top planning approach, and the use of community energy participants, which represent a bottom planning approach.

Section 3, highlights the problem of the electricity industry in Nigeria which are identified as low access rates, low direct foreign investments and a huge gender equality gap. This study provides solutions to these problems from the use of the urban metabolism. The thesis considersthese three problems and integrates them into a planning model that can be applied in several informal settlements across the country. It further contributes to improving the energy access rates from the exploration and inclusion of renewable energy technologies into the energy mix of informal settlements.

Section 4, introduces the multicriteria decision-making method used in selecting the best renewable energy source that meets the energy requirements of the informal settlements when subjected to social, technical, environmental and economic criteria. The PROMETHEE method is applied to select Solar PV as the best technology for the informal settlements in the Greater Karu Urban Area in Nigeria. PROMETHEE uses the help of the analytical hierarchy process (AHP) and the entropy method to determine the weights of the criteria used in the selection process. The AHP is used to determine the subjective weights by soliciting the help of experts in the field of renewable energy to assign scores to reflect the importance of the criteriaon the basis of their respective weight sizes The entropy method was used to determine the objective weights of the criteria used in the selection process through the use of some mathematical equations. The contribution of this thesis to the use of multi-criteria decision-making methods, is through the application of a combined weight method of weight determination in order to improve the accuracy of the outcome of the entire decision-making process. Perusing through literature we it was discovered that no study has been conducted by using a combined weight method in the selection of renewable energy sources in informal settlements. Barraghan, (2018) applies a combined weight method with PROMETHEE/GAIA software from the inclusion of direct rating, and equal weight method to select renewable energy sources for an intermediate city of Cuenca in Ecuador.

This study applied a hybrid PROMETHEE/AHP method and the inclusion of equal and entropy weighting methods thereby integrating three weighting methods for the selection of renewable energy sources with the aid ofPROMETHEE/GAIA software, hence contributing to the gap in literature.

In the selection of renewable energy sources from previous studies, sub-criteria such as water use intensity and land use intensity have not been used. So, this workcontributes two economic sub criteria for the selection of renewable energy resources for informal settlements. Most studies on urban metabolism, informality and renewable energy selection refer to land usage in the context of ownership that is required for the formalization ofinformal settlements to formal settlements in the wake of tussle for land ownership. No study has used it as a sub criterion, in renewable energy selection, where it serves the purpose of identifying how much land is required for the life cycle e of a renewable energy technology.

From the analysis carried out on the 14 sub criteria, it identified, that the most important criteria from the expert opinion conducted through the AHP weighing method, was the sub criteria; availability of source (C2), with a value of 0.1601.

Section 5, from the sampling of the informal settlements carried out it was determined that the total energy demand for the Greater Karu Urban Area is given as 15679110kWh, which equates to 1.56 MWh. The highest energy consumption is recorded in the household typology M and productive enterprise Category M as 28,864 kWh and 62,212kWh respectively.

The total potential of renewable energy sources amounts to 148.34GWh, which include Solar energy; 46MWh, Wind energy, 21MWh, Hydroelectric energy, 148GWh; Biomass; 85MWh. The renewable energy sources are sufficient to create a transition from a linear to a circular energy model on the basis of availability. The cooking sector records the highest percentage of activity level in the household and the manufacturing sector records the highest percentage of activity level in productive usage. It is concluded that Solar PV is the best renewable energy source for household purpose, but its intermittency reduces the energy that is required to power machines with larger capacities in the manufacturing industry.

It is of importance to note that a hybrid renewable energy source can be used to improve the substitution process. What this means is that the success of a transition from a linear to a circular model cannot be a 100 percent achieved on renewable energy sources availability, which supports the argument that an inclusion of a hybrid methodology is necessary.

In section 6, six indicators were used to determine the level of participation of male and female community members in renewable energy. The objective was to determine if there is an equal participation of men and women from the results of the descriptive statistics. The disparity between men and women in the level of participation in renewable energy signifies a huge gap in gender equality. The average participation of men in all the six indicators used for the measurement was obtained from the semi structured interview. The highest value of differential in gender equality is obtained from New Nyanya settlement with a differential value of 30% in the level of participation of men and women using the community level indicators. The lowest differential value in the level of participation is obtained from Orozo settlement, with a value of 8.18%, thereby suggesting that it is the most gender equality compliant informal settlement. It can categorically be stated hereon that the transition from a linear model to a circular model cannot be achieved without the inclusion of gender equality even when the renewable energy sources is in abundance. If the agenda is sustainability and the intention is to create a sustainable model of energy supply and consumption then gender mainstreaming is vital to achieving this objective regardless of the amount of available renewable energy for substituting fossil fuel carriers.

Section 7, analyzed the renewable energy expansion plan from a policy perspective. The total energy demand obtained as 1,567,9110kWh per year. The energy demand is projected for the Greater Karu Urban Area is projected from the year 2010 till the year 2050, which is in accordance to the energy policy plans of the country Nigeria as a whole. It can be concluded that as the energy demand increases at the population rate of 3.47%, the renewable energy resources are available to meet this demand, on the condition that the renewable energy policy plans are fully implemented. On the basis of the indicators of price PE, CO_2 emissions and Creation of Jobs (E_m), it is conclusive to say that the inclusion of all the renewable energy sources, i.e Wind, Solar, Hydroelectricity and Biomass creates more savings in energy prices, CO_2 emissions and the creation of more jobs to benefit the community members.

8.3 Future proposal

The objective of this study was to determine the energy and fuel carriers in the Greater Karu Informal Hybrid settlement, the work was able to focus on the productive and household sector of the informal areas, however the transport sector was not taking into consideration as a result of the limitation of data. It is on this premise that future studies should be carried out with regards to the inclusion of this sector of the informal economy in the study of urban metabolism.

The selection and prioritization of the renewable energy sources was carried out with the use of the PROMETHHE Gaia software, other software packages can be employed for the selection process of renewable energy, there are other outranking methods available for this purpose such as; TOPSIS, ELECTREE, VIKOR etc., which can be explored in the selection of renewable energy sources for developmental and energy expansion studies.

With regards to the criteria weighting methods employed in this study, which were the Equal, AHP and Entropy weight method, there are other criteria weighting methods such as the IDOCRIW, KEMIRA, WAPSAS and CRITIC, that can be applied to future studies on renewable energy expansion and development.

DISCUSIÓN Y CONCLUSIÓN.

La base de la discusión de esta tesis se basa en el análisis que se presenta de manera secuencial desde la sección 1 a la 7. Dicha discusión se centra en determinar si las fuentes de energía renovables son capaces de cambiar la estructura metabólica del consumo de energía desde un modelo lineal a uno circular ya que la energía no se puede reciclar en comparación con otros sustratos como la comida, materiales o los desperdicios que constituyen el principio del metabolismo urbano. Del mismo modo, se examina la inclusión de energías renovables en la matriz energética en un asentamiento híbrido multi-estructural para determinar la posibilidad de sustitución de los vectores energéticos y combustibles actualmente en uso.

Discusión.

Se estimó que en el 2018 el número de personas viviendo en asentamientos marginales se elevó por encima del billón de personas y cuenta con unas expectativas muy alta de un crecimiento exponencial. Esto representa a el 13% de la población mundial. Además, implica que el desarrollo urbanístico debe de tener la resistencia necesaria para soportar la presión que surge de este desarrollo que crece tan rápido y se da en todo el mundo. Con el fin de poder encontrar una solución a este problema es necesario comprender la relación que existe entre las ciudades y sus habitantes mediante el concepto de urbanismo metabólico.

El concepto de urbanismo metabólico se usa como herramienta para examinar las características de una ciudad y determinar las direcciones de todos los procesos dentro y fuera de los límites de la ciudad. Este trabajo de investigación revela que el modelo de energía es linear porque la energía no se puede reciclar en comparación con otros sustratos de la ciudad. Sin embargo, la energía se optimiza junto con otros sustratos si la fuente de la que se deriva es sostenible. Este estudio propone un modelo circular para el metabolismo energético, un camino que asegura su eficiencia de uso y la reposición posterior que se obtiene mediante fuentes de energía limpias y confiables. Este estudio supone un avance crucial al investigar el metabolismo energético en asentamientos marginales híbridos y para poder influenciar en las decisiones políticas con el fin de mejorar el acceso a la energía en comunidades deprimidas.

Este estudio analiza la tecnología de seis fuentes de energía renovable en cuatro asentamientos híbridos y multi-estructurales que representa la coexistencia de asentamientos marginales con zonas urbanas dentro de los límites de esta área de estudio.

La metodología del urbanismo metabólico se aplica al asentamiento urbano de Greater Karu que es un conjunto de asentamientos y viviendas marginales rodeadas de núcleos urbanos. Dicha metodología examina el proceso metabólico de energía y determina las necesidades domésticas y el uso productivo de la electricidad. La metodología propuesta determina la manera de alcanzar la autosuficiencia mediante un estudio exhaustivo de los datos energéticos de una comunidad ante la ausencia de cualquier tipo de base legal. Dicha metodología muestra múltiples factores que se posicionan a favor de la suficiencia energética renovable en el área de Greater Karu.

La selección de renovables en estas áreas se lleva a cabo de acuerdo con la toma de decisiones multicriterio en la que se tienen en cuenta los factores técnicos, ambientales, sociales y económicos con el fin de obtener la energía renovable más adecuada. Se identificaron seis fuentes de renovables en el área urbana de Greater Karu que incluyen la solar, hidroeléctrica, eólica, solar térmica, biomasa y biogás. Del mismo modo, se examinaron catorce criterios mediante una revisión de la literatura y una encuesta general realizada por expertos en energías renovables. Los expertos procedían de instituciones públicas y privadas junto con representantes de instituciones gubernamentales y de universidades federales de ciencias, y el resto de expertos eran empresarios o dueños de negocios. Los catorce criterios mostraron características únicas al ser administrados en diferentes rondas. El índice aleatorio obtenido de Saaty (1980), ver tabla 8, se utiliza como requisito previo con el fin de determinar el nivel de consistencia en las respuestas del ejercicio realizado por expertos, el cual se realiza con los principios que sustentan el proceso analítico de ranking jerárquico (AHP). El valor del índice aleatorio para una matriz de 14 por 14 es de 1.58 en esta tesis. Es requisito que el índice de consistencia sea menor de 0.1 utilizando el método AHP para la evaluación de la consistencia en opinión de los expertos. En nuestra investigación determinamos la razón de consistencia como aquella entre el índice de consistencia y el índice aleatorio, lo cual sigue el principio establecido en el trabajo de Saaty (1980). El índice de consistencia obtenido a partir de la opinión de expertos es de 0,002274. La fiabilidad de la evaluación de expertos se fortaleció con un alto valor del número alfa de Cronbach. En este trabajo se obtiene un valor de 0.83. Se les pidió a los expertos que clasificaran los pesos de cada uno de los criterios utilizados en la selección de las alternativas de energía renovable.

La metodología AHP proporciona los detalles de la relación dentro de los criterios: Los enlaces entre criterios se utilizan para establecer el rendimiento superior de un criterio sobre el otro a partir de la cantidad de peso asignado a cada uno de ellos.

La ventaja de la metodología AHP es que permite clasificar los criterios en función de su nivel de importancia, a través de una comparación por pares. La escala AHP mide el nivel de importancia utilizando un rango de cifras que van del 1 al 9, lo que significa que el criterio más importante recibe una puntuación de 9 y el menos importante de 1.

Los resultados obtenidos por los expertos en renovables mediante el proceso AHP revelan que el criterio más importante es la disponibilidad de la fuente (C2) con un peso de 0.16, ver tabla 26. El siguiente criterio en importancia es el criterio (C3) con un peso de 0.136. Los criterios que le siguen en importancia en la posición tercera y cuarta son el (C8) y (C9) que son el costo de inversión y las emisiones de CO_2 ambos con un valor de 0.114. Otros criterios como el coste nivelado de energía (C6), intensidad del uso del suelo (C7), el factor de capacidad (C5), los obstáculos urbanísticos (C4), la intensidad del uso de agua (C11), la eficiencia (C1) y la acidificación (C12) se encuentran en las posiciones número 5, 6,7,8,9,10,11 y 12 con valores de 0.0829,0.070,0.058,0.0413,0.0413,0.0413 y 0.0264.

Los criterios sociales que se enumeran como son la oportunidad laboral y el apoyo del gobierno son menos importantes con valores obtenidos de 0.01450 en ambos casos. Los criterios que resultan más importantes son la disponibilidad de la fuente (C2) y el grado de madurez tecnológico (C3) que son dos criterios técnicos de un total de cuatro. Los demás criterios técnicos tales como el factor de capacidad (C5) y los obstáculos urbanos (C4) son menos influyentes que (C2) y (C3). Sin embargo, siguen siendo factores determinantes en la selección de las fuentes de energía renovables en asentamientos marginales. Los criterios (C2) y (C3) miden la disponibilidad de fuentes de energías renovables, así como su adecuación a los usuarios finales en una escala comercia. No es conveniente exagerar la importancia de estos criterios frente a otros ya que el resultado de la toma de decisiones depende de la ponderación de todos los valores. Por lo tanto, para que la toma de decisiones se elimina la parcialidad con respecto a las preferencias por un valor concreto. El criterio (C5) que es el factor de capacidad resulta crucial para determinar el nivel de producción de electricidad que se puede logar a partir de la capacidad total del grupo electrógeno. Sin embargo, los expertos han considerado que es menos prioritario que los criterios (C2) y (C3) porque la disponibilidad de fuentes de energía renovables supera con creces cualquier importancia que se lede al tamaño de los grupos electrógenos. Esta narrativa es consistente con el criterio de intensidad del uso de la tierra (C6). Los cuatro asentamientos marginales considerados en este estudio poseen diferentes tamaños en lo que se refiere a metros cuadrados lo que implica que algunas comunidades presenten dificultades con la presencia de una fuente de energía renovable frente a otras. La diferencia en tamaño se observa en la tipología de los asentamientos considerados en este estudio. Los asentamientos marginales híbridos de las tipologías I y M tienen más posibilidad de sentir el efecto de las renovables que obstaculizan el flujo de bienes, personas y materiales. Esto puede distorsionar el ecosistema como resultado de la densidad de las estructuras que se encuentran próximas entre sí. Por otro lado, las tipologías de asentamientos híbridos del tipo A y S se caracterizan por tener una gran extensión de tierra en las que los obstáculos urbanísticos (C4) y la intensidad del uso de la tierra (C10) son de muy poca o ninguna importancia. El criterio de eficiencia de los grupos electrógenos (C1) recibe las puntuaciones más bajas por parte de los expertos que indican que los criterios técnicos de media son más importantes. A pesar de ello, la importancia de los criterios económicos es muy significativos. El coste de inversión (C8), el LCOE (C6) y los costes de operaciones y mantenimiento (C7) determinan la cantidad de dinero que se necesita a lo largo del ciclo de vida de una fuente de energía renovable. Por lo tanto, determinar la manera en la que el usuario final recupera ese dinero es un factor importante en el proceso de selección. Las tarifas de energías renovables que pagan los usuarios incluyen los costos necesarios para garantizar la inversión que se realiza para garantizar la cadena de valor de la electricidad. Los sectores de generación, transmisión y distribución de la cadena de suministro de electricidad deben de estar completamente financiados para respaldar la existencia de la tecnología renovable. El costo de operación y mantenimiento recibe el nivel de importancia más bajo entre los tres criterios económicos, mientras que el costo de inversión (C8) y el costo de nivelación energética (C6) son los más relevantes.

Todo esto se puede atribuir al hecho de que el costo de operación y mantenimiento son un porcentaje del coste de inversión. En esencia, los valores del costo operativo tanto fijo como variable ya están contabilizados en el costo de capital de instalación. De hecho, es menos probable que sea un factor determinante e importante en comparación con el costo de capital al que está vinculado ya que es un factor dependiente.

Además, otra razón que puede atribuirse a una menor importancia que se le otorga al criterio de costo de operación y mantenimiento es el hecho de que algunas tecnologías de renovables no requieren de tanto mantenimiento. Esto implica que el costo de mantenimiento varía según el tamaño de la planta y de los requisitos específicos de los diversos componentes.

El criterio de carácter medioambiental (C9) el cual representa las emisiones de CO_2 se sitúa en el puesto número 4 de la comparación realizada. La importancia de este criterio en asentamientos marginales es muy significativa en todas las tipologías presentes en este estudio. La creciente prevalencia de enfermedades relacionada con la construcción (BRI) y el síndrome del edificio enfermo (SBS) en infraviviendas en Nigeria plantea un problema de salud pública. Los síntomas incluyen dolores de cabeza, náuseas, congestión nasal y problemas de dermatitis que se asocian a la pobre calidad del aire. Esta mala calidad del aire se atribuye las emisiones de monóxido de carbono del humo de generadores de combustibles fósiles y a las emisiones de CO_2. Todos estos problemas de salud han llevado a subrayar la importancia de este criterio en asentamientos marginales (Ekhaese & Omohinmin, 2014). El criterio de la intensidad de uso de la tierra (C7) y el uso intensivo del agua (C11) son esenciales a la hora de determinar las fuentes de energía renovables en base a las reservas de agua disponibles en las diferentes tipologías de asentamientos marginales. Los asentamientos de tipología A y S pueden acomodar una mayor intensidad de agua en comparación a los de tipología H,I y M. Es por ello que se espera que se seleccionen preferentemente las fuentes de energía renovable que utilizan un gran volumen de agua para producir electricidad. Los asentamientos de las tipologías A y S se encuentran centra de los límites de GKUA y más cerca de arroyos y ríos lo que conlleva un mayor potencial para pequeñas plantas hidroeléctricas. Esto se hace evidente en el asentamiento de Uke. Sin embargo, las razones para el criterio (C7) y (C11) no san tan importantes con las del criterio (C9). Esto se debe a la variación de requisitos que presenta cada tipología de asentamientos y que por lo tanto hace que algunos asentamientos encuentren el uso intensivo de agua más necesario que otros. Por otra parte, la reducción de emisiones de CO_2 es una necesidad en todos los tipos de asentamientos. Los criterios sociales que incluyen las oportunidades de empleo (C13) y el apoyo gubernamental (C14) son los que menos se valoran en importancia. Esto se puede atribuir a la percepción que tienen los expertos sobre el tema. Aunque las energías renovables pueden llevar a un desarrollo de la infraestructura en los asentamientos, hay pocas posibilidades de que conlleve oportunidades laborales a la población. Esto supondría destinar una gran cantidad de fondos económicos para entrenar y sensibilizar a la población local sobre el uso operativo de la tecnología de las energías renovables. El gobierno debe decidir si deja esta responsabilidad a un lado en favor de otros gastos del presupuesto gubernamental. Además, el nivel de confianza de los ciudadanos hacia el gobierno se percibe como muy bajo basándose en datos previos.

El coeficiente alfa de Cronbach es de 0.83 y se ha obtenido de los cuestionarios administrados a los expertos a partir de catorce subcriterios de los cuales cuatro son cualitativos y el resto son cuantitativos. Los cualitativos son los subcriterios (C2), (C3), (C4) y (C14) sujetos a la escala de Likert del 1 a un 5 para determinar el peso de cada uno. El valor de 0.83 del coeficiente alfa de Cronbach representa un buen resultado obtenido ya que este valor debe estar entre 0.7 y 1. Los valores entre 0.1 y 0.7 son cuestionables e inaceptables.

Los resultados de la encuesta a expertos establecen la relación entre criterios a través de una comparación por pares realizada por el proceso de jerarquía analítica. El AHP nos permite someter los criterios a la opinión de los expertos que son los que determinan su nivel de importancia entre ellos en una escala de Likert del 1 al 9. Sin embargo, para poder eliminar la parcialidad que se asocia a la determinación de criterios de este método, se emplea el método de entropía y el método de la determinación de peso con el fin de crear un análisis comparativo.

El análisis comparativo se lleva a cabo en tres escenarios que incluye los métodos de entropía, el de determinación de pesos (ETM), el método AHP y el de la igualdad de pesos. El de la igualdad de pesos y el AHP representan métodos objetivos para determinar el peso mientras que el método de entropía es subjetivo.

Los tres escenarios se integran en el software PROMETHEE GAIA y la representación de cada escenario se muestra en los gráficos GAIA en las Figuras 12, 13 y 14.

En el escenario de igual ponderación a todos los criterios se le asigna el valor de 0.1. El gráfico de GAIA muestra que las emisiones de CO_2 (C9) y eficiencia (C1) están estrechamente relacionadas entre sí pero manteniendo una distancia del factor de capacidad (C5). El coste de inversión (C8) y el coste de operación y mantenimiento (C7) están estrechamente ligados en el mismo plano junto con la intensidad de la tierra (C10), intensidad del agua (C11) y la acidificación (C12), ver la Figura 12.

En el segundo escenario que representa el método AHP, el facto de capacidad (C5) está distanciado de los criterios (C9) y (C1), así como de las emisiones de CO_2 y el criterio de eficiencia respectivamente. También se observa una diferencia en la distancia entre el costo de inversión y el costo de operación y mantenimiento, intensidad hídrica, intensidad de suelo y acidificación (C7), (C10), (C11) y (C12) respectivamente. Incluso si se encuentran en el mismo plano la distancia es mayor que la se observa en el escenario 1. Además de la diferencia observada, el factor de capacidad y la eficiencia recaen en planos diferentes en comparación con el escenario 1, ver la Figura 13.

En el tercer escenario que representa la aplicación del método de entropía, el factor capacitador (C5), la eficiencia (C1) y el criterio de emisiones de CO_2 (C9) se encuentran en el mismo plano con mucha proximidad en comparación con el primer y el segundo escenario. Mientras tanto el coste de inversión (C8) y el coste de mantenimiento (C7) se mantienen juntos pero separados del apoyo gubernamental (C14) y el criterio de acidificación (C12). Además, los criterios de intensidad hídrica (C11) y el obstáculo urbanístico (C4) pasaron de estar cerca de los criterios de costo de operación y mantenimiento, apoyo gubernamental e intensidad del suelo a ocupar una posición directamente opuesta al factor de capacidad, las emisiones de CO_2 y la eficiencia en el plano GAIA.

La diferencia que se observa en las posiciones de los criterios en el método de entropía en comparación con el método de peso igual y AHP es el resultado de las variaciones de criterios cuando se lleva a cabo de manera subjetiva u objetiva. Para los criterios (C5), (C1) y (C9) tiene pesos de entropía de 0.036,0.037 y 0.070 respectivamente lo que difiere de los pesos AHP de 0.05,0.04 y 0.11. Esto evidencia que los pesos de entropía tienen valores más bajas que los pesos de AHP y por lo tanto una relación más estrecha dentro de los criterios en el escenario 3 en comparación con los escenarios 1 y 2. En el primer escenario, los criterios (C5), (C1) y (C9) se les asigna un valor de 0.1. La siguiente conclusión se aplica a los criterios (C8), (C7), (C14), (C12), (C11) y (C4). Los pesos de entropía que se obtienen son de 0.06,0.122,0.007,0.159,0.421 y 0.035 mientras que los pesos del método AHP son de 0.11,0.07,0.03,0.08 y 0.04. La diferencia en la posición del coste de inversión (C8) respecto al resto de criterios se evidencia en el mayor peso que se le da en AHP con un valor de 0.11, frente a un valor inferior de 0.06 y 0.01 que se obtiene del método de entropía y del peso de equivalencia respectivamente.

A la hora de elegir la mejor tecnología de renovables hay un consenso por parte de los tres escenarios al elegir la energía solar fotovoltaica como la preferida, ver las Tablas,51,52,53 y 54. La energía solar fotovoltaica tiene el valor más alto para el flujo de rango superior neto de 0,2893, 0,4022 y 0,4635 para los escenarios 1,2 y 3 respectivamente. Esto también es aplicable a la energía eólica que ocupa la segunda posición con valores de 0.0926, 0.0696 y 0.2597 para los escenarios 1, 2 y 3 respectivamente. Sin embargo, se observan diferencias en el ranking para la biomasa, el biogas, la energía hidroeléctrica y la solar termal. En el primer escenario, la energía hidroeléctrica se posiciona en el tercer lugar seguida del biogas, la biomasa y la solar termal. Mientras en el escenario 2 la hidroeléctrica se mantiene en la tercera posición también, pero la biomasa y el biogas se reemplazan la una a la otra en la cuarta y quinta posición. En el escenario 3, la energía hidroeléctrica es la última de la clasificación mientras que la solar termal que ocupaba la última posición en los escenarios.

La razón de esta diferencia se debe a la consideración del grado de diversificación que se aplica en el método de ponderación de entropía en el escenario 3. El grado de diversificación (d_J) elimina el sesgo asociado con los métodos de pes igual y peso AHP que se utilizan en los escenarios 1 y 2. Hay una segunda posición en la clasificación para el viento en los tres escenarios.

El potencial de cada una de las renovables se establece tras una selección y posterior jerarquización llevada a cabo por el software PROMETHEE. El análisis potencial de cada una de las renovables se lleva a cabo teniendo en cuenta la participación energética de la comunidad, que en gran medida sirve de base para promulgar políticas que faciliten la expansión de energía renovable a nivel local. El objetivo de este estudio es determinar si las fuentes de energía renovables son adecuadas para encabezar una transición del modelo lineal que es actual a uno circular ya que la energía a diferencia de otros sustratos no se puede reciclar. Por lo tanto, hay que determinar si el potencial de la energía renovable es suficiente para reemplazar el uso de combustibles fósiles y los factores adicionales cuando se incluye la participación de la comunidad.

Para establecer estas opciones, se realiza el diagnóstico de la ruta metabólica de cinco tipologías de viviendas chabolistas y tres categorías de uso productivo de la electricidad presentes en cuatro asentamientos híbridos multiestrucuturados.

Los asentamientos marginales coexisten junto con centros urbanos en un esquema multiestructural hibrido.

Los cuatro asentamientos de esta investigación son New Nyanya, Ado, Orozo y Uke. Estos asentamientos son un conjunto de pequeñas ciudades situadas en el área urbana de Greater Karu del estado de Nasarawa en Nigeria. El área urbana de Greater Karu es una ciudad limítrofe a las proximidades de la ciudad de Abuja, la capital de Nigeria. Los asentamientos en el área de GKUA surgieron de las iniciativas del gobierno de Nigeria para acomodar funcionarios, pero se han transformado en una multiestructura hibrida en la que coexiste asentamientos marginales con centros urbanos regulados.

Las tipologías de viviendas marginales chabolistas se clasifican en función a la proximidad a la capital, Abuja. Esta ha llevado a diferentes estrategias de expansión de la electricidad que deben llevarse a cabo para crear un acceso completo a la energía limpia y sostenible. La importancia de los requerimientos energéticos de la comunidad es más importante que buscar soluciones de costo para extender la red nacional eléctrica.

El poder estimar los requerimientos energéticos de hogares chabolistas implicó tomar muestras aleatorias de hogares y empresas como se puede ver en el cuestionario ver Annexo II-. El tamaño de la muestra fue estimado usando la ecuación de Cochran´s formulario see Equation (24).

La fiabilidad es del 95% con un margen de error del 5% y el grado de variabilidad (p) con un valor de 0.5 se han analizado 380 muestras.New Nyanya, Orozo, Ado y Uke. Se obtuvo una respuesta del 82% de los encuestados en los cuatro asentamientos, con un 79% en New Nyanya, 90.15% en for Orozo, 83.3 % para Ado y 77.5% para Uke.

Las tipologías de hogares y empresas son responsables de los distintos atributos que caracterizan cada asentamiento.

La finalidad del cuestionario es encontrar la distribución de las estadísticas de la muestra con una clara distinción de edad, género, consumo de electricidad y clasificación social ver Annexo II.

En el asentamiento hibrido de New Nyanya existen las tipologías de vivienda H, M y I en la categoría empresarial la C y la M. Estas características son similares a las del asentamiento de Ado con tipologías de vivienda H, M y I respectivamente. Además, el asentamiento de Ado cuenta con las categorías C y M para la categoría empresarial. El asentamiento de Orozo consisten en tipologías de vivienda I y S con categorías A y M para las empresas. En el caso de Uke, solo aparece la categoría A tanto para viviendas y empresas.
La diferencia en tipologías y categorías es el resultado de la distancia en kilómetros de la capital del país, Abuja. Los asentamientos de New Nyanya y Ado están a 30 y 30.6 kilómetros de la capital en comparación con los de Orozo y Uke que están a 25.8 y 38.5 kilómetros de la misma. La distancia define el tipo de actividad económica y por lo tanto los patrones de consumo energético. Los asentamientos de New Nyanya y Ado están en el centro de GKUA como se ve en las Figuras 27, 28, 29 y 30. Estos asentamientos cuenta con la mayor concentración de población de los asentamientos con una actividad basada principalmente en el comercio. Estos asentamientos

localizados en el centro de GKUA se caracterizan por un alto nivel de hacinamiento, con poca disponibilidad de espacio para acomodar negocios relacionados con la agricultura o la ganadería. Esta diferencia se hace patente en los asentamientos de Orozo y Uke ya que Orozo está mucho más cerca de Abuja y lejos del centro de GKUA. Uke con una distancia de 38.5 km de distancia es el asentamiento más lejano del centro de GKUA y más cercano al estado de Benue al este de la capital. Este último asentamiento está basado predominantemente en la agricultura en la que conviven plantaciones legales e ilegales.

Los ingresos y el tamaño de las familias varia de un asentamiento a otro como se puede ver en las tablas 57,60,64 y 68. Las viviendas en Uke suelen alojar de media de 4 a 10 personas con una media de ingresos de 60$ por mes. Estos ingresos son más bajos que el umbras de la pobre de 2 dólares americanos por día y por persona que describe la ONU. Cada familia suele vivir en una choza de unos 70-80 metros cuadrados hechas de bambú. Normalmente este tipo de viviendas corresponden a familia polígamas de un hombre con 2 o 3 mujeres y con una media de 10 niños. Los niños sirven como mano de obra en las granjas en las que se desarrolla una actividad de subsistencia Los ingresos mejoran en los casos en lo que se cuenta con una mecanización del proceso de agricultura. En la tipología de vivienda del tipo A, el carbón y el keroseno son las mayores fuentes de energía a la hora de cocinar. Sin embargo, los salarios no se corresponden con las tipologías de hogares H, M y I situadas en el centro de GKUA donde los asentamientos de New Nyanya y Ado son los más cercanos en proximidad.

La media de ingresos de estas viviendas en asentamientos de New Nyanya y Ado es de 226 dólares americanos por mes. 60 dólares para la tipología H, 100 dólares para la tipología I y 200 dólares para la tipología M. La media de ingresos es más alta en los hogares de New Nyanya y Ado porque la mayoría de la población tiene un nivel cultural y de educación más alto. Estas personas combinan empleos en Abuja en sectores como el de la educación o el turismo con actividades sin regular en el campo comercial o de manufacturación. La presencia de las categorías de empresas productivas de las categorías C y M indica un mejor flujo de caja para las familias que subsisten con venta de comida callejera, limpieza o elaboración de productos hechos a mano. Sin embargo, no se llega al umbral mínimo de pobreza que marca la ONU y el índice de pobreza mundial debido al tamaño de las familias de este tipo de viviendas. La tipología H de vivienda consisten en una familia de 5 miembros mientras que en la tipología M engloba familias de más de 10 personas. En esta tipología las viviendas son aquellas viviendas de protección oficial pertenecieron a funcionarios del gobierno y han resultado en viviendas abarrotadas por familias numerosas. Aun así, la media de ingresos de este tipo de hogares es de 200 dólares americanos por mes ver Tablas 57 y 64.

La tipología de hogar S es la que prevalece en el asentamiento de Orozo con una pequeña proporción de tipología I. En este contexto se produce un desplazamiento de personas sin hogar o bajos ingresos a las proximidades de la frontera de GKUA con Abuja. En esta tipología de hogares las personas dependen de manufacturación ilegal y sector servicios proporcionados a las ciudades mencionadas previamente. Esto les proporciona una media de ingresos de 80 dólares americanos mensuales, frente a los 60 de la tipología S y a los 100 de la tipología I.

Las diferencias en la tipología de hogares, tamaños familiares y diferencias de empresas productivas definen el patrón de consumo energético. La aplicación de este método se usa para determinar la demanda de energía en estos cuatro asentamientos marginales de carácter híbrido mediante la suma de las diferentes tipologías de hogares y las categorías de producción empresarial.

El requisito de carga total de GKUA proporciona el ímpetu necesario para determinar el potencial de la energía renovable que se requiere. La suma total obtenidad de estos cuatro asentamientos de GKUA es de 15,679,110 kWh que se dividen en 1,754,110, 4,137,860, 2,654,140 y 7,133,000 kWh para New Nyanya, Orozo, Ado y Uke respectivamente. La carga total que se requiere para las diferentes tipologías de hogares y empresas productivas es de 340,750kWh ver Tabla 84. De manera que se distribuyen 8,258, 28,864, 21,382, 10,904, y 3,651kWh para las categorias H, M, I, A, S.El balance energético midió las importaciones de combustible fósil en los asentamientos híbridos multiestructurales de GKUA y determinó el porcentaje de consumo en los hogares sectores productivos.

El sector de la vivienda se divide en cocina, alumbrado, refrigeración, aire acondicionado y agua caliente. Mientras tanto el sector productivo se divide en comercio local, manufacturación local y sector de la agricultura. El balance energético total de GKUA muestra que los distribuidores de combustible fósil contribuyen con un total de 15,679,110kWh al modelo actual de energía. El sector de la manufacturación local contribuye a la mayor porción de consumo de energía con 18.3 MW por año, seguido de la agricultura ya la cocina con un 30% y 7% respectivamente del balance total. Esto indica que en los asentamientos marginales hay actividades económicas con equipamientos que hacen un gran consumo energético para manufacturar productos locales que posteriormente se venden en el comercio regulado. Se observan ejemplos de actividades de este tipo en los asentamientos de Ado, New Nyanya y Orozo mientras que las actividades relacionadas con la agricultura se dan más en el asentamiento de Uke. Hay una gran presencia de la industria siderúrgica, herrería, producción de vino y jabón local y bloques de hielo en los asentamientos de Ado, New Nyanya y Orozo. Además, la industria del comercio loca se hace visible en los asentamientos de Ado y New Nyanya ya que se sitúan en el centro de GKUA.

Hay una gran presencia de barberos, vendedores de comida, vendedores de videojuegos y negocios en el centro de Ado y en los asentamiendoes de New Nyanya y Orozo. El comercio local supone un 3.5% del consumo energético total de Orozo, un 8.4% de New Nyanya y un 8.3% de Ado respectivamente. El consumo total del asentamiento de Orozo es de 4,137,860kWh al año en comparación a los 2,654,140kWh de Ado y a los 1,754,110kWh de New Nyanya. La diferencia energética entre Orozo frente a Ado y a New Nyanya se debe a la agricultural que contribuye con un requerimiento energético anual de 3,289,350kWh.
Este sector de la agricultura está ausente en los asentamientos de Ado y New Nyanya.

En el asentamiento de Uke donde predomina la agricultura hay un consumo anual de 7,137,000kWh. Este asentamiento no cuenta con red eléctrica y la mayoría de la energía proviene de tanques de diesel que provienen del oeste y el sur del país. La mayoría de la industria operan con maquinaria diésel como el caso de las segadoras o los molinos. Se trata de equipamientos pesados con un gasto de unos 8-20 kW. Por lo tanto, requieren de un gran consumo energético para operar en comparación con el consumo de hogares que se sitúan en un 0.5-5kW.

En el sector de la vivienda, las fuentes de energía fósil como el keroseno y el LPG son muy populares en los asentamientos de Orozo, Ado y New Nyanya. Keroseno es el más usado con un 60% de su uso para cocinar en New Nyanya y Ado. En el caso de Orozo es del 50%. Esta fuente de energía va seguida por el LPG y la electricidad con un 30% y un 20% de consumo respectivamente. La contribución del diesel o la gasolina a la hora de cocinar es mínima en los asentamientos de Ado o New Nyanya con un 5%. A pesar de ser un porcentaje mínimo se aprecian diferencias de uso en los cuatro asentamientos. Solo las clases medias y altas pueden permitirse el uso. En los asentamientos de Ado y New Nyanya se concentran las clases obreras y los propietarios de negocios con un nivel de ingresos ligeramente superior al de Uke y Orozo que se encuentran en las tipologías A y S en las fronteras de GKUA. El precio del diésel o la gasolina en Nigeria es de un promedio de 165 nairas por litro lo que equivale a 0.4-0.5 dólares americanos por litro lo que está por debajo de la media mundial que se encuentra entre 1.06-1.19 dólares americanos por litro. Sin embargo, estamos hablando de asentamientos marginales con salarios muy bajos que se sitúan entre los 100-250 dólares americanos mensuales.

Del estudio de energías se puede determinar que el total de energía requerido para pasar de las fuentes de energía fósiles a las renovables requiere el de ecuaciones matemáticas que determines estimaciones aproximadas de las cantidades.

La metodología de PROMETHEE selecciona la energía solar como la prefería tras el acuerdo de métodos subjetivos y objetivos de pesos aplicados. El potencial de la energía solar se ha determinado mediante fórmulas matemáticas. También se determina el potencial de la energía eólica, hidráulica y de biomasa para crear escenarios de inclusión de energías renovables con las pautas propuestas por las directivas de política de energía renovable y eficiencia energética de Nigeria.

La segunda parte de los resultados del estudio se lleva a cabo en el apartado 6. El objetivo es el de determinar el nivel de participación de hombres y mujeres en la expansión de las renovables y comprobar si las renovables son capaces de transformar un modelo de linear a circular.

Los resultados de la participación de la comunidad revelan seis indicadores que indican el nivel de participación en activades del hogar, actividades productivas, inversión de capital, propiedad de tierras, de empresas y aparatos productivos. El asentamiento de Orozo muestra la menor disparidad entre géneros en el nivel de participación de los seis indicadores con un valor de 8.18%. Por otro lado, el asentamiento de New Nyanya muestra el mayor nivel de disparidad entre géneros con un valor de 30%.

Se sugiere que hay una necesidad de mejorar en la disparidad de igualdad de género tomando medidas de reajuste de los seis indicadores.

El gobierno debería mejorar en la igualdad de género de la siguiente manera:

- Aumento de la financiación de capital tanto para hombres como para mujeres.
- Financiación de aparatos productivos para mujeres.
- Acceso de las mujeres a sus propias tierras.
- Creación de programas de aprendizaje relacionados con las energías renovables para

mujeres.

Conclusión

que los combustibles fósiles siguen siendo una fuente predominante de energía. Sin embargo, el uso de energías renovables resulta indispensable para fortalecer el nivel de resiliencia de una ciudad y dichos asentamientos El uso de la energía renovable en estas áreas deprimidas económicamente ha creado un cambio de perspectiva en dichos asentamientos. En el pasado, estas zonas se percibían como una molestia para la sociedad en general ya que sus actividades económicas no eran fáciles de rastrear. Por este motivo era difícil determinar el nivel de contribución al crecimiento social. Sin embargo, la introducción de la energía renovable ha hecho posible que esas áreas grises de actividades económicas difíciles de rastrear salgan a la luz gracias al metabolismo urbano. Además, la planificación urbanística de ciudades con un paisaje cambiante se ha visto influenciada por las necesidades de los asentamientos marginales. Los requisitos energéticos de dichos asentamientos y barrios marginales son un requisito previo a la hora de elaborar la planificación urbanística de una ciudad. Esto se debe a la presencia de las diferentes tecnologías de energía renovable disponibles dentro de sus límites y secciones internas. Por consiguiente, la herramienta del metabolismo energético ha sido capaz de diagnosticar el camino a seguir en estos asentamientos, al proporcionar la información necesaria para integrar estas áreas en los planes de actuación urbanística de las ciudades, cambiando la estructura general de dichos planes.

Las contribuciones a título individual de este estudio, con el fin de promover el concepto de metabolismo urbano, se resumen en el orden en el que se desarrolla la tesis doctoral.

Desde el primer capítulo, esta tesis identifica y plantea el problema del acceso a la energía en asentamientos marginales de la cual las Naciones Unidas ya había hecho una provisión con el objetivo de un desarrollo sostenible. Dicho objetivo es crear ciudades y asentamientos muy resistentes a cambios adversos en el suministro de energía (UN, 2019). El poder crear ciudades resistentes contribuye a la reducción de la importancia de los combustibles fósiles y resulta en una sustitución en favor de la energía renovable tanto en las ciudades como en sus zonas marginales. La mayor contribución de este estudio, ante la problemática de acceder a las energías limpias, es el de determinar los requisitos energéticos de estas zonas deprimidas económicamente con la esperanza de definir los factores que se deben tener en cuenta a la hora de implementar energías limpias y estrategias para su expansión y desarrollo.

La primera sección de esta tesis se centra en identificar las razones que dificultan el acceso a la energía de la red eléctrica central en estos asentamientos deprimidos económicamente. Este trabajo de investigación pone de manifiesto la falta de datos referentes al consumo energético de estas áreas como consecuencia de la falta de seriedad en el desarrollo de un plan eléctrico. Del mismo modo, contribuye a solucionar dicha problemática mediante el uso de la herramienta del metabolismo urbano al proporcionar ejemplos del estado de Nasarawa como ejemplo que representa a la población general. En consecuencia, este estudio sirve como base para obtener datos sobre los hogares y los negocios de esta área, así como proporcionar las bases para organizar los asentamientos adecuadamente.

El objetivo de esta tesis es el de buscar fuentes de energía renovable dentro de las limitaciones que plantean estos asentamientos para poder reemplazar la dependencia actual de combustibles fósiles. Este trabajo es capaz de contribuir en el desarrollo de las zonas urbanas de Nasarawa y en la totalidad de Nigeria proporcionando información pertinente sobre fuentes de energía renovable. La conclusión es que existen fuentes de energías renovables disponibles pero los combustibles fósiles siguen siendo la fuente de energía predominante que puede combinarse con las renovables con el fin de proporcionar soluciones a los cortes de suministro. Otro objetivo es determinar si el modelo energético actual se puede transformar de lineal a circular. Para lograr tal fin, este estudio considera que la participación de la comunidad es un requisito primordial para obtener una transformación total. Además, este trabajo contribuye a la igualdad de género al observar los niveles de participación de hombres y mujeres en los hogares, así como su nivel de implicación en empresas del sector productivo, la propiedad de tierras y de capital. Las estadísticas descriptivas en cuatro asentamientos marginales se obtienen con el fin de justificar la igualdad de género como un requisito previo a la hora de lograr la transición completa de un modelo lineal a circular en un contexto sostenible.

La segunda sección lleva a una revisión de la literatura sobre los principios del metabolismo urbano. Se han revisado un total de 30 estudios comenzando con los diferentes métodos de metabolismo urbano que podemos clasificar como análisis dinámico de sistemas, estrategia de formalización, análisis de flujo de materiales y análisis de entrada y salida. Pocos estudios (Kovacic et al., 2016; Smit et al., 2018; Makinde, 2018) ponen en práctica el uso del metabolismo urbano en asentamientos marginales. Makinde (2018) aplica un análisis integrado de escala múltiple de metabolismo social y ecosistémico (MUSIASEM) en los barrios marginales de Enikanni. Smith et al (2018) fue un paso más allá al crear una tipología de estos asentamientos.

Esta investigación tiene el objetivo de contribuir al conocimiento existente que hay sobre la puesta en práctica del metabolismo urbano en zonas deprimidas económicamente. Esta tesis al mismo tiempo contribuye mediante la creación de categorías de empresas productivas presentes en estas zonas marginales.

Además, la sección 2 también revisa la literatura con respecto a la planificación superior e inferior, junto con los enfoques para las estrategias de expansión de las energías renovables. Los enfoques superior e inferior se compararon para las preferencias. Esta tesis contribuye al enfoque de planificación estratégica de la expansión de la electricidad mediante la aplicación de una metodología híbrida de arriba y abajo en los asentamientos marginales. Esta tesis aplica esta metodología híbrida mediante el uso de la opinión de expertos en el campo de las energías renovables, que representa un enfoque de planificación superior, y el uso de participantes comunitarios de energía, que representan un enfoque de planificación inferior.

La sección número 3 pone de manifiesto los problemas de la industria eléctrica en Nigeria, así como la poca accesibilidad, la falta de capital extranjero y una enorme brecha en la igualdad de género. Este estudio proporciona soluciones a dichos problemas mediante el uso del modelo de metabolismo urbanístico en asentamientos marginales. La tesis considera tres problemas y los integra en un plan de actuación que puede ser puesto en práctica en múltiples asentamientos marginales por todo el país siguiendo el mismo patrón. Del mismo modo, contribuye a mejorar las ratios de accesibilidad a la energía a partir de la implementación de las tecnologías que ofrecen las energías renovables.

También se evalúa el problema de la financiación mediante la selección de los proyectos de energía adecuados. El elevado coste de la electricidad, los costes de producción y mantenimiento, y el costo de instalación de estas tecnologías proporcionan los datos necesarios para llevar a cabo inversiones adecuadas mediante proyectos de desarrollo.

La tesis identifica la mejora en el trabajo del gobierno federal de Nigeria con la expansión de la energía solar en comunidades poco desarrolladas. Esto contribuye al trabajo realizado en el país junto con los avances en otras renovables como la energía eólica o hidroeléctrica. También se exploran las disposiciones para la consideración de otras fuentes alternativas de energía renovable en el marco de la política de energía renovable y eficiencia energética de Nigeria mediante la creación de planes de actuación basados en predicciones de demanda energética para dichas energías renovables.

El apartado 4 realiza una introducción al método de multicriterio de la toma de decisiones para seleccionar la mejor fuente de renovables para asentamientos marginales considerando parámetros sociales, técnicos, medioambientales y económicos. El método PROMETHEE se ha usado para determinar la energía solar fotovoltaica como la mejor opción en los suburbios del área urbana de Nasarawa en Nigeria. PROMETHEE utiliza la ayuda del proceso analítico jerárquico (AHP) y el método de entropía para determinar los pesos de los criterios utilizados en el proceso de selección. El método de entropía fue usado con el fin de determinar criterios de peso mediante ecuaciones matemáticas. La contribución de este trabajo al método criterio de toma de decisiones es la aplicación del método de peso para mejorar la precisión de los resultados del proceso de toma de decisiones. Al examinar la literatura, encontramos que no se ha realizado ningún estudio utilizando un método de peso combinado en la selección de fuentes de energía renovable en asentamientos marginales. Barraghan, (2018) aplica un método de peso combinado con el software PROMETHEE/GAIA a partir de la inclusión de calificación directa y método de igual peso para seleccionar fuentes de energía renovable para la ciudad intermedia de Cuenca en Ecuador. Este estudio aplica un método híbrido PROMETHEE/AHP y la inclusión de métodos de ponderación iguales y de entropía, integrando así tres métodos de ponderación para la selección de fuentes de energía renovable con la ayuda del software PROMETHEE/GAIA, contribuyendo así a abrir un nuevo camino en la literatura científica sobre la materia.

En la selección de fuentes de energía renovable de estudios previos, los criterios como la intensidad del uso del agua y la intensidad del uso del suelo no se han considerado en ningún estudio para la selección de energía renovable en asentamientos marginales a partir de estudios anteriores en el mismo campo, por lo que este trabajo aporta dos subcriterios económicos para la selección de recursos energéticos renovables para dicho contexto. La mayoría de los estudios sobre el metabolismo urbano, y la selección de energías renovables se refieren al uso de la tierra en el contexto de la propiedad que se requiere para la formalización de suburbios a asentamientos formales a raíz de la lucha por la propiedad de la tierra. Ningún estudio lo ha utilizado como un subcriterio, en la selección de energía renovable, donde sirve para identificar cuánto terreno se requiere para el ciclo de vida y de una tecnología de energía renovable.

De este análisis se extraen 14 sub criterios que nos permiten concluir que el más importante desde el punto de vista de los expertos se ha extraído mediante el método de peso AHP. Este es el subcriterio técnico denominado como disponibilidad de la fuente (C2) con un valor de 0.1601.

En el apartado 5, la recopilación de datos realizada en diferentes asentamientos determinó que la demanda total de energía para el Gran Área Urbana de Karu se da como 15679110kWh, lo que equivale a 1,56 MWh. El mayor consumo de energía se registra en la tipología de hogar M y la categoría de empresa productiva M con 28.864 kWh y 62.212kWh respectivamente.

El potencial total de fuentes de energías renovables asciende a 43.576MW, que incluyen la energía Solar; 17MW, energía eólica, 0,76MW, energía hidroeléctrica, 8,5MW; biomasa; 18MW.

Las fuentes de energía renovable son suficientes para crear una transición de un modelo de energía lineal a uno circular en función de la disponibilidad. Se determina que, del balance energético de los cuatro asentamientos, hay 37MW disponibles de fuentes renovables de energía. tras la sustitución de combustibles fósiles en los hogares y empresas productivas. El sector de la cocina registra el mayor porcentaje de nivel de actividad en el hogar y el sector de manufacturación registra el mayor porcentaje de actividad en el uso productivo. Se concluye que la energía solar fotovoltaica es la mejor fuente de energía renovable para uso doméstico, pero debido a su intermitencia que reduce la energía que se requiere para alimentar máquinas con mayores capacidades en la industria manufacturera, se recomienda que se pueda utilizar una fuente de energía renovable híbrida. Lo que esto significa es que el éxito de una transición de un modelo lineal a uno circular no puede lograrse al 100 por ciento en la disponibilidad de fuentes de energía renovable, lo que respalda el argumento de que es necesaria la inclusión de una metodología híbrida.

En la sección 6, se utilizaron seis indicadores para determinar el nivel de participación de los miembros masculinos y femeninos de la comunidad en el uso de energía renovable. El objetivo fue determinar si existe una participación igualitaria de hombres y mujeres a partir de los resultados de la estadística descriptiva. La disparidad entre hombres y mujeres en el nivel de participación en energías renovables significa una enorme brecha en la igualdad de género. La participación promedio de los hombres en cada uno de los seis indicadores utilizados para la medición se obtuvo de la entrevista semiestructurada. El mayor valor de diferencial en igualdad de género se obtiene del asentamiento New Nyanya con un valor diferencial de 30% en el nivel de participación de hombres y mujeres utilizando los indicadores a nivel comunitario. El valor diferencial más bajo en el nivel de participación se obtiene del asentamiento de Orozo, con un valor de 8.18%, lo que sugiere que es el asentamiento que más cumple con la igualdad de género. Se puede afirmar categóricamente aquí que la transición de un modelo lineal a un modelo circular no se puede lograr sin la inclusión de la igualdad de género, incluso cuando las fuentes de energía renovables son abundantes. Si la agenda es la sostenibilidad y la intención es crear un modelo sostenible de suministro y consumo de energía, entonces la incorporación de la perspectiva de género es vital para lograr este objetivo, independientemente de la cantidad de energía renovable disponible para sustituir a los combustibles fósiles.

La sección 7 analizó el plan de expansión de las energías renovables desde una perspectiva política. La demanda total de energía obtenida fue de 1.567.9110kWh por año. La demanda de energía proyectada para el área urbana de Greater Karu se proyecta desde el año 2010 hasta el año 2050, lo cual está de acuerdo con los planes de política energética de Nigeria en su conjunto. Se puede concluir que a medida que la demanda de energía aumenta a la tasa de población del 3,47%, los recursos de energía renovable están disponibles para satisfacer esta demanda, a condición de que los planes de política de energía renovable se implementen en su totalidad. Sobre la base de los indicadores de precio, emisiones de CO_2 y Creación de Empleo (Em), es concluyente decir que la inclusión de todas las fuentes de energía renovables, es decir, eólica, solar, hidroeléctrica y biomasa genera más ahorros en los precios de la energía.

Propuesta futura.

El objetivo de este estudio ha sido determinar el tipo de energía y proveedores de combustible en el asentamiento marginal hibrido de Greater Karu. El trabajo ha sido capaz de focalizarse en el sector productivo y doméstico de asentamientos marginales, aunque no se ha tenido en cuenta el sector del transporte por la falta de datos al respecto. Bajo esta premisa se deben realizar futuros estudios que incluya este sector en el estudio del metabolismo urbano.

La selección y priorización de las fuentes de energía renovables se realizó mediante el software PROMETHHE GAIA aunque se pueden emplear otros paquetes de software para el proceso de selección de energías renovables. Existen otros métodos disponibles tales como TOPSIS, ELECTREE, VIKOR etc. que se pueden utilizarse en la elección de renovables para estudios de desarrollo y expansión energética.

En referencia a los métodos de ponderación y criterios empleados en este estudio, fueron seleccionados Equal. AHP y Entropy aunque existen otros tales como IDOCRIW, KEMIRA, WAPSAS y CRITIC que se pueden emplear en futuros estudios de expansión y desarrollo de fuentes de energía renovables.

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10 Annex I

Application of the Analytical hierarchy weighing scale for selecting criteria (Expert Determination). This section allows the determination of criteria weights by requesting the opinion of experts in apportioning weights to the quantitative criteria that cannot be measured usingbibliographical sources. The questionnaires consist of two sections.

The first section involves the use of a Likert scale of 1 to 5, to determine the weights of the qualitative criteria with the use of expert opinion in the three rounds conducted in a Delphi Study. The second section involves the use of a AHP nominal scale of 1 to 9, to determine the intra-criteria importance, which involves expert opinion, that is conducted in three rounds in a Delphi study.

The following criteria are subjected to the expert opinion through a Delphi study, which is conducted in three rounds of questioning.

The criteria are listed below:
(C2) Availability of source
(C3) Maturity of technology
(C4) Urban obstacles
(C14) Governemnt support & Compatibility with public policies.

(C2) Availability of sources:

This criterion is used to determine if the renewable energy technology is available to be used in the informal settlements. It is required to analyze the level of availability of the renewable energy technology on a rating scale. On a scale of 1 to 5, give your opinion on the level of availability as presented in the table below:

No Availability	Little Availability	Medium Availability	Enough Availability	Excess Availability
1	2	3	4	5
No Availability	Little Availability	Medium Availability	Enough Availability	Excess Availability
1	2	3	4	5

(C3) Maturity of technology:

This sub criteria indicates how the renewable energy technology is distributed at local, regional and international levels. It indicates different levels of advancement in renewable energy technology. Level (C) denoting the commercial viability of the technology, which reflects its readiness for consumption on a commercial scale. Give your opinion on the level of maturity of the renewable energy technologies.

Investigate	Investigate & Develop	Advanced Investigation	Pilot	Commercial
1	2	3	4	5

(C4) Urban obstacle:

This criterion is used to determine if the renewable energy technology will impede the energy metabolic flow by occupying available space, which could otherwise be used to erect something else in the informal settlements. It is required to analyze the level of obstruction that the renewable energy contributes. On a scale of 1 to 5, give your opinion on the level of availability as presented in the table below:

No obstacle	Little obstacle	Moderate obstacle	Enough obstacle	More than enough obstacle
1	2	3	4	5

(C14) Government support & Compatibility with public policies:

This sub criteria determines if the renewable energy technology is socially accepted by the public and in accordance with the government policies in place. Give your opinion on the level of acceptance and compatibility of the renewable energy technologies using the rating scale provided in the table below:

No support	Little support	Medium support	Enough support	More than enough support
1	2	3	4	5

Sample Survey Questionnaires.

Section 1: Criteria weight selection (Expert determination).

A. The following criteria have been included in the selection of renewable energy technologies in informal settlements. Please rank the criteria listed below according to their level of importance on a scale of 1 to 9.

B. Scoring Scale:

1 = Equal Importance
2 = Equal to Moderate Importance.
3 = Moderate Importance.
4 = Moderate to strongly important
5 = Strong Importance.
6 = Strongly to very strong importance
7 = Very strong Importance.
8 = Very strong to extremely important
9 = Extreme Importance.

The sub criteria are listed below:

☐Efficiency ____________
☐Availability of source ____________
☐Maturity of technology ____________
☐Urban obstacles ____________

☐ Capacity factor ____________

☐ Levelized cost of electricity ____________

☐ Operation and Maintenance cost ____________

☐ Investment cost ____________

☐ CO_2 emissions ____________

☐ Land usage ____________

☐ Water consumption ____________

☐ Acidification ____________

☐ Job opportunities ____________

☐ Government support ____________

Section 2: Qualitative Criteria.

In this section, there are four qualitative criteria used in the selection of the most appropriate renewable energy technology. The qualitative weight of the criteria is determined with the use of the Likert scale, where numbers 1 and 5 indicate the lowest and highest weight values respectively.

Sub criterion T2 measures the availability of the renewable energy source.
Sub criterion T3 measures the level of maturity of renewable energy technology.
Sub criterion T4 measures the obstruction to urban traffic with the construction and development of renewable energy technology.
Sub criterion S2 measures the level of government support for renewable energy technology.

C. The six renewable energy technologies are listed below:

☐ Biomass
☐ Biogas
☐ Solar PV
☐ Wind Energy
☐ Hydroelectricity
☐ Solar thermal

D. On a scale of 1 to 5 assign the weight attributed to each renewable energy technology with respect to the sub-criterion (T2).

☐ No availability.
☐ Little availability.
☐ Medium availability.
☐ Enough availability.
☐ Excess availability.

E. On a scale of 1 to 5 assign the weight attributed to each renewable energy technology with respect to the sub-criterion (T3).

☐ Investigation.
☐ Investigation and Development.
☐ Advanced investigation.
☐ Pilot.
☐ Commercial.

F. On a scale of 1 to 5 assign the weight attributed to each renewable energy technology with respect to the sub-criterion (T4).

☐ No obstacle.

☐ Little obstacle.

☐ Medium obstacle.

☐ Enough obstacles.

☐ More than enough obstacles.

G. On a scale of 1 to 5 assign the weight attributed to each renewable energy technology with respect to the sub-criterion (S2).

☐ No government support.

☐ Little government support.

☐ Moderate government support.

☐ Enough government support.

☐ More than enough government support.

Section 3: Expert Eligibility

A. What is your knowledge level about the use of renewable energy sources for slum settlements?

☐ (1) Analysis of fewer than 10 pieces of specialized literature on renewable energy use in slum settlements.

☐ (2) Analysis of about 10 specialized literature on renewable energy use in slum settlements.

☐ (3) Analysis of more than 10 specialized literature on renewable energy use in slum settlements.

☐ (4) Analysis of 30 pieces of specialized literature on renewable energy use in slum settlements.

☐ (5) Analysis of more than 30 pieces of specialized literature on renewable energy use in slum settlements

B. What is your level of education in the field of renewable energy?

☐ (1) PhD

☐ (2) Msc

☐ (3) Bsc

☐ (4) Others

C. What is your level of work experience in the field of renewable energy?

☐ (1) 0-5 years

☐ (2) 10 years

☐ (3) 20 years

☐ (4) Other

Annex II. Survey Questionnaires.

Annex II

Sample Survey Questionnaires

Section 1: Socio-economic characteristics of Household

A. What is your gender ☐(1) Female or ☐ (2) Male?

B. What is your age group?.

☐ (1) 16-25 years
☐ (2) 25-40 years
☐ (3) 40-60 years
☐ (4) 60- 80 years
☐ (5) Others

C. What is your occupation?.

☐ (1) Technician
☐ (2) Owner of agriculture based productive enterprise
☐ (3) Owner of commercial based productive enterprise
☐ (4) Apprentice
☐ (5) Others

D. What is your income wage?.

☐(1) below 30,000 Naira
☐ (2) 30,000
☐ (3) 50,000 Naira
☐ (4) Above 50,000 Naira
☐ (5) Unemployed

E. What is your monthly energy bill.

☐(1) below 1000 Naira
☐ (2) 1000-4000 Naira
☐ (3) 4000 Naira
☐ (4) Above 5000 Naira
☐ (5) Do not pay for electricity

F. What energy source do you use the most for domestic activities?.

☐ (1) LPG
☐ (2) Electricity
☐ (3) Kerosene
☐ (4) Fuelwood
☐ (5) Others

G. What energy source do you use in your productive enterprise?

☐ (1) Kerosene
☐ (2) Electricity

☐ (3) Gasoline
☐ (4) Diesel
☐ (5) Others

H. How much are you willing to pay for an alternative energy source?
☐ (1) Not interested in paying for energy
☐ (2) Less than my current bill
☐ (3) The same with my current bill
☐ (4) More than my energy bill

I. Which of the building type below best describes your dwelling/building?
☐ (1) Congested municipal flat
☐ (2) Duplex/Bungalow with shed at gatehouse.
☐ (3) Clustered sheds with aluminum roof
☐ (4) Traditional huts
☐ (5) Face-me-i-face-you'

J. What type of material is used in constructing your building?
☐ (1) Bamboo
☐ (2) Aluminum
☐ (3) Concrete
☐ (4) Others

K. What is your education level?
☐ (1) Primary level
☐ (2) Secondary level
☐ (3) Tertiary level
☐ (4) Others

L. What is your knowledge level about the use of renewable energy?
☐ (1) No knowledge
☐ (2) Little knowledge
☐ (3) Moderate knowledge
☐ (4) High level of knowledge
☐ (5) More than high level of knowledge

Section 2: Household energy consumption devices.

Please provide information about the household usage of the appliances using the table below.

Appliance	Tick if used	Quantity (Number)	Power rating (W)	Model (if power rating is unavailable)	
Freezer	☐				
Fridge or fridge/freezer	☐				
Pressing iron	☐				
DVD (CD+video player)	☐				
Incandescent lamp	☐				
Fluorescent tube	☐				
Compact fluorescent lamp (CFL)	☐				
Light emitting diode (LED)	☐				
Television	☐				
Complete radio (simple radio+DVD)	☐				
Stereo speaker	☐				
Laptop	☐				
Electrical water coil	☐				
Computer	☐				
Fan	☐				
Vacuum cleaner	☐				
Air conditioner	☐				
Heater (for space heating)	☐				
Micro wave	☐				
Gas and electric oven	☐				
Food blender/mixer	☐				
Coffee maker	☐				
Washing machine	☐				
Shaving machine	☐				
Voltage regulator	☐				

Section 3: Productive energy consumption devices

Please provide information about the appliances for productive usage in the table below.

Appliance	**Tick if used**	**Quantity (Number)**	**Power rating (W)**	**Model (if power rating is unavailable)**	
Maize milller	☐				
Rice miller	☐				
Sorghum miller	☐				
Cowpea miller	☐				
Soybean miller	☐				
Cassava miller	☐				
Maize thresher	☐				
Rice thresher	☐				
Sorghum thresher	☐				
Cowpea thresher	☐				
Sorghum thresher	☐				
Rice Parboiler	☐				
Cashew processor	☐				
Shea butter processor	☐				
Aquaculture	☐				
Cold milk storage	☐				
Cocoa dryer	☐				
Milk sterilizer	☐				
Egg incubator	☐				

Section 4: Household energy consumption pattern

For each of the appliance used in your household and for the day please provide information on the duration of hours used and the period of the day during which it is used. Please see the example below

Example: Last week Friday, Chuks turned on his (TV) from 3 pm to 8 pm and he turned on his electric stove from 5 pm to 8pm.

Appliance	Duration of use (hours)	Time of the day																							
		6am	7	8	9	10	11	12	1pm	2	3	4	5	6	7	8	9	10	11	00	1am	2	3	4	5
TV	5																								
Electric stove	**3**																								

Appliance	Duration of use (hours)	Time of the day																							
		6am	7	8	9	10	11	12	1pm	2	3	4	5	6	7	8	9	10	11	00	1am	2	3	4	5

Section 5: Productive energy consumption pattern

For each of the appliance used in enterprises and for the day please provide information on the duration of hours used and the period of the day during which it is used. Please see the example below

Example: Last week Friday, Chuks (Rice miller) was on from 1pm to 2pm in the day and his Rice thresher was on from 7 pm to 9 pm.

Appliance	Duration of use (hours)	Time of the day																							
		6am	**7**	**8**	**9**	**10**	**11**	**12**	**1pm**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**00**	**1am**	**2**	**3**	**4**	**5**
Rice Miller	2																								
Rice Thresher	**2**																								

Appliance	Duration of use (hours)	Time of the day																							
		6am	**7**	**8**	**9**	**10**	**11**	**12**	**1pm**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**00**	**1am**	**2**	**3**	**4**	**5**

Community energy indicators	Man (%)	Woman (%)
Participation in household activities		
Participation in productive usage		
Ownership of productive enterprise		
Ownership of land for productive usage		
Ownership of productive appliances		
Access to Capital		
Participation in training and vocational skills		