Olayungbo *et al. Sustainable Energy Research* (2024) 11:11
https://doi.org/10.1186/s40807-024-00105-3

Sustainable Energy Research

RESEARCH

Open Access

# Investigating the role of subsistence renewables in alleviating power poverty within Nigeria's energy-mix strategy

David Oluseun Olayungbo[1], Ayodele Adekunle Faiyetole[2,3*] and Adenike Anike Olayungbo[4]

**Abstract**

Nigeria, a country rich in renewable sources still heavily relies on nonrenewable energy, of which the government's on-grid supply remains inadequate, and generally of poor services. This study, therefore, investigated subsistence renewables by citizens able to contribute to the country's energy-mix plan and help ameliorate power poverty challenges. Qualitative primary data were sourced using the Delphi experts' method from energy experts and practitioners possessing relevant knowledge bases regarding the energy-mix strategy with an understanding of the power poverty scenarios. The findings show that the effect size in the very high-level option for solar potentials was relatively more than wind and bio sources. The study reveals that citizens could mostly afford low-capacity solar installations, with considerable interest in the energy-mix strategy. Medium-capacity solar was found to be quite unaffordable, leading to a perceptually very low potential for solar. A showstopper in incorporating solar effectively into Nigeria's energy-mix scenario was the citizens' non-affordability of accessing high-capacity systems. It is, however, deduced that affordability and recognition of values are congruous. Conclusively, the experts are optimistic regarding subsistence renewables potentials in the energy-mix strategy. Solar is, however, considered the most crucial, surpassing wind and bio sources. The study suggests that the government could incentivize renewable energy systems, particularly solar, to promote subsistence solutions through affordability by citizens, adoption, and sustainability within the energy-mix strategy. It is further recommended that citizens' income levels should be raised to favor the affordability of off-grid renewable energy systems.

**Keywords** The energy-mix strategy, Nonrenewable energy, Renewable energy production and utilization, Solar energy, Wind energy, Bio energy sources, Sustainability

## Introduction

Almost as everywhere else in the world, renewable energy sources have gained prominence in Nigeria and are expected to increase more rapidly. If combined with existing nonrenewable sources, it could lead to a more cleanly sustainable energy-mix, reduce greenhouse gas emissions, and lower oil/gas energy dependency. In pursuit of the Kyoto Protocol and the revised Lisbon strategy, Nigeria committed itself to derive 12% of its total energy consumption from renewable energy sources by 2020 (Nigerian Electricity Supply Industry: NESI, 2017). The Federal Executive Council in Nigeria approved the National Renewable Energy and Energy Efficiency Policy

---

*Correspondence:
Ayodele Adekunle Faiyetole
aafaiyetole@futa.edu.ng
[1] Department of Economics, Obafemi Awolowo University, Ile-Ife, Nigeria
[2] Sustainable Transportation Labs, Department of Logistics and Transport Technology, Federal University of Technology Akure, Akure, Nigeria
[3] EarthSpace, Lagos, Nigeria
[4] AG Leventis Museum of Natural History, Obafemi Awolowo University, Ile-Ife, Nigeria

(NREEEP), developed in line with the objectives of the National Energy Policy, Rural Electrification Strategy and Plan, Millennium Development Goals, and the National Economic and Development Strategy (Imo et al., 2020; NREEEP, 2015).

Currently, there are two significant types of power plants operating in Nigeria. They are hydroelectric, a renewable source, and thermal or fossil fuel, nonrenewable, power plants. The combined energy source has been 85% gas-fired and 15% hydro-powered (Okoye & Adejumobi, 2021). The major drawback with the gas-fired source is that the electricity supply is often reduced whenever there is a gas shortage or total stoppage through gas pipeline vandalism by militants in the oil-producing area of the Niger Delta. The thermal or gas-fired energy source has a profligate effect on carbon emission (Aslan et al., 2024), hence the climate, informing a concerted effort to mitigating its use and change to or increase the renewable energy stock in a mixed scenario. These efforts include the UNFCCC's (2021) nationally determined contributions (NDC) targets for carbon neutral energy (Faiyetole & Ihemeje, 2022; Olayungbo et al., 2022).

The Council for Renewable Energy of Nigeria (2007) estimates that power outages, energy poverty, bring about a loss of 126 billion Naira (US$984.38 million) annually (Okoye & Adejumobi, 2021), this represents a colossal income loss. According to the Petroleum Product Pricing Regulatory Agency (PPPRA, 2021), the annual consumption of petrol was 14.8 billion barrels (33.9 billion liters), with daily consumption of 93 million liters. Also, the Department for Petroleum Resources (DPR, 2021) reported an amount of petroleum of more than 78% of the total energy consumption in Nigeria. Yet, the oil refineries in the country are not operational, but dilapidated and redundant. It has led the country, the largest oil producer in Africa, to rely on the importation of refined products at international prices at an added cost. At the global level, European countries' demand for gas flared from oil has shifted away from Russia, due to gas supply stoppage there with the ongoing Ukraine–Russian war, to the other oil-producing countries including Nigeria (African News, 2022). Just like Nigeria, with abundance of natural energy, vulnerable households in Russia, an energy-rich country, equally experience energy poverty amid plenty (Yoon, 2024), like many other countries, developing and developed alike, which implies that energy poverty is a global phenomenon.

Harnessing Nigeria's energy resources and charting a new energy future align with NREEEP (2015). Renewable energy technologies are scalable (Mutezo & Mulopo, 2021) and applicable off-grid, such as solar systems, wind systems, biogas digesters, biogas gasifiers, micro-hydropower plants, among others, for homes, offices, industries, villages, and other settlements. Before the privatization of the energy sector, the bulk power stock was gas-fired and hydroelectric power, with the near-total neglect of other viable sources, especially non-hydro-renewable sources. There are many reasons why the government's investments in energy utilities are skewed against renewable energy sources. Few among them are cost per megawatts, mature technology, lack of awareness of accruable benefits, and energy efficiency issues. "The solar energy capture of today's most efficient photovoltaic cell is about 40%, a recent, not yet commercialized development representing an increase of over 15% compared with a commercially available panel" (Green et al., 2015; Faiyetole & Ihemeje, 2022; Faiyetole, 2018, p. 29). These reasons, among others, inform public investment interests and private considerations, thus, the tendency for existing and prospective power investors to invest is disproportionately less in renewable energy in Nigeria.

Electricity per capita (148 KWh) is abysmally poor compared to nations of similar GDP per capita, territorial sizes or populations, such as Pakistan. Pakistan produces three times more power for its people than Nigeria (World Development Indicator, 2020). The power-population index or energy per capita is an indicator of the socio-economic well-being of people in society (Mirza & Szirmai, 2010), which in emission parlance is referred to as carbon intensity of human well-being (Faiyetole, 2019; Jorgenson, 2014). By harnessing all the renewable energy potentials in Nigeria, both via governmental interventions and at subsistence, privately distributed off-grid approaches, could yield more robust energy-mix profile, boost stability and security in power production and supply.

From the foregoing, it is apparent that energy poverty is a problem bedeviling the country's power landscape, which could be addressed with substantial citizens' participation in subsistence production and utilization of renewable energy, especially solar, off-grid, that could complement the national grid power and the mix strategy. Thus, Nigeria must mix its nonrenewable oil and gas power sources with cleaner and sustainable renewable energy in an appreciable extent. Critical is making policies that could increase the private citizens' affordability index, to increase the critical mass of citizens able to afford and deploy renewable energy systems for their households' needs. Thereby, ameliorating energy poverty, with the effect of the inefficiencies of government to increase the total on-grid energy stock in the country. Renewable energy sources must be significantly expanded beyond its 15% composition of the current energy-mix to meet the expanding needs, and to foster energy security and sustainability because the nonrenewable energy sources already widely produced and utilized are grossly inadequate and of grim health and environmental consequences.

The citizens who are unreached with on-grid electricity, inadequate supply, and generally poor services, are forced to ingeniously meet their energy demands, often via self-help. In fact, Hirschmann (2024) advocated a collective self-consumption of renewable energy in the Mediterranean region, which evolved from a decentralized energy production by citizens to cover their energy demand either through smaller installations owned by individuals or wind parks, solar fields, owned by a group of people, like the Refuse-Derived Fuel (RDF) built by University of Nigeria, Nsukka. Thus, the alternative energy supply could include wind, solar, bio energy sources, which is here investigated to determine evidence-based empirics for subsistence renewable energy production and utilization (REPU) towards ameliorating power poverty and climate change issues while fostering the enabling environment for energy-mix strategy.

Subsequently, the following three questions were pertinent: 1. What is the REPU potential in Nigeria? 2. To what extent is renewable focused energy-mix strategy able to solve power poverty challenges? 3. What is citizens' affordability level for solar power solutions uptake considering their monthly earnings and expenditures? (Solar energy is singled out in this affordability objective because it is the most widely deployed at subsistence level of the three REPU in Nigeria). Consequently, this study focused on subsistence, citizens' off-grid renewable energy efforts in a selected energy-mix informed communities as study area. It, therefore, 1. assessed the renewables production and utilization potentials in the energy-mix strategy in Nigeria; 2. examined the extent to which renewable focused energy-mix strategy would solve households' power poverty challenges; 3. evaluated the citizens' subsistence solar energy solutions uptake affordability extent considering their monthly earnings and expenditures.

This paper, therefore, provides insight into the potential of adopting an energy-mix strategy with increased renewable energy via off-grid subsistence approach for solving power poverty challenge, using the industrialized complexes of Lokoja and its suburbs in Kogi state, and a university and solar kiosks in Akure in Ondo State, Nigeria, as a study area. The paper is organized as follows. The relevant extant literature review is presented in Sect. "Literature review", which documents reviews on energy poverty, energy-mix and subsistence renewables. Sect. "Methodology, data collection and analytical methods" provides information on the methodology, data collection and analytical method, with the workflow diagram, while Sect. "Results and discussion" presents the results and discussion of the findings, with summary of the evidence. Conclusions and policy recommendations follow suit.

## Literature review

Energy poverty is consequent upon nations' insufficient supply of grid power systems to a teeming population, which according to Jiang et al. (2024), makes it difficult for households to fulfill their energy needs, while Djeunankan et al. (2024) opined that energy poverty impedes industrialization. It portends serious negative effect on sustainable development in both the developing and developed countries alike, but of grimmer consequences in the developing countries (Kettani & Sanin, 2024). Studies both old and contemporary have explored varying approaches to ameliorating energy poverty. Li et al. (2024) rather found that pension coverage substantially increased modern or clean energy consumption in rural China. Dada et al. (2024) proxied access to electricity and clean energy using financial development as a moderating role for energy poverty and sustainable environment and found that energy poverty increases environmental degradation while access to clean energy and electricity positively impact the environment in 24 African countries. This is consistent with Shen et al. (2024), who found that inclusive finance has a certain capacity to mitigate $CO_2$ emissions by addressing energy poverty in China (Ren et al., 2024). Regarding energy infrastructure and energy expenditure in China, Xiao et al. (2024) found that they play critical role between low-carbon city pilot policy and energy poverty. Yan et al. (2024) investigated the effects of information technology construction on alleviating households' energy poverty in China with the findings that raising residents' income and enhancing their environmental awareness go a long way. Ren et al. (2024) unsurprisingly showed that urban–rural income gap and rural energy poverty were positively correlated.

Solar plants have been deployed to meet the energy needs of energy impoverished communities and to achieve the set climate goals in the agrarian Upper West in Ghana, without which had impacted diversification of their agrarian livelihoods and the adaptation to climate extremes with a gender connotation (Stock et al., 2023). Supporting Kettani and Sanin (2024) who inferred on the competitiveness of solar energy systems in filling the energy poverty gap in Morocco and concluded that affordability is a major drawback to accessibility. Although affordability is a major concern, its economic and environmental advantages make solar option a viable one in most rural low-income areas (Chanchangi et al., 2023). Particularly, subsistence solar renewable energy has been found to improve the living standards and livelihoods of dwellers in economic- and geographically challenged communities by introducing income generating activities, boosting social security, women empowerment and responding to natural disasters (Hossain et al., 2023). Masuku (2024) who assessed the indigent energy policies in Alexandria township in Johannesburg, South Africa, elucidated on the support given by government to low-income households for off-grid energy access. Substantially, solar energy deployment off-grid in low-income regions has been a viable model for subsistence purposes fitting their income level while providing improved livelihood by its ability to mitigate or eradicate energy poverty (Montoya-Duque et al., 2022). It is of essence that the different government agencies saddled with energy, environment and economic (EEE) regulatory policies could formulate and coordinate policies that could potentially ameliorate energy poverty in low-income households. This supports Hosan et al. (2024) and Masuku (2024) that posited that well planned energy policies could mitigate or perhaps eradicate energy poverty.

A significant percentage of empirical works on renewable energy is available for developed and developing countries, such as Adams et al. (2018) for 30 sub-Saharan African countries, Bhattacharya (2003) for Asian countries, Chien and Hu (2007, 2008) and Chang et al. (2009) for the Organisation for Economic Cooperation and Development (OECD) and non-OECD countries, Irfan et al. (2020) for Pakistan, and Akram et al. (2021) for the BRICS (Brazil, Russia, India, China, and South Africa). Zvinavashe et al. (2011) explored the potential benefits of processing and utilizing cassava flour into biofuel for bioenergy generation at the farmstead and the rural community area of Mozambique. In Southern Thailand, Duerrast (2020) examined and found the potential of geothermal resources as part of the country's energy-mix strategy. Usmani et al. (2021) investigated the energy-mix policy in Pakistan, an oil-importing country, during the energy crisis. Renewable energy sources such as wind, solar, and biomass are found in Pakistan as the alternatives able to generate additional 11,000 MW to the supply. Due to global oil and gas fluctuations, Othmane and Antar (2020) explored energy-mix adoption in Algeria. The study documents the availability of 5 kWh per 1 square meter of sunshine, 10 m/s of wind speed, and 286 MW of hydropower generation. The study found renewable energy potential and recommended increasing renewable energy deployment.

Abila (2012) documented biofuel development and its adoption in Nigeria and identified the key drivers, agents, enablers, incentives, and objectives driving biofuel development. It showed an increasing entry of private and public investors into the sector. For example, most of the available conversion technologies and equipment are locally fabricated. The University of Nigeria, Nsukka, has taken a bold step by building an RDF gasification plant that uses organic waste to generate 100 KVA electricity (Nwachukwu, 2019), demonstrating the viability of bio energy for subsistence renewable solutions. Some of the drivers of the biofuel markets are dependence on biomass fuel, poverty level, unemployment, and the current low level of access to improved energy sources. While Towoju (2022) explored the potential of generating biofuel production given the abundance of agricultural residues available such as mango seeds, African star apple seeds, orange peel, and African peers. The study projected that Nigeria's 3% contribution of biofuel renewables can increase to 47%.

The wind power was assumed to have the potential to generate between 4.51 and 21.19 watts per square meter blade area. Energy Commission of Nigeria (2015) reports that wind is strong in the hilly regions of the North, while the Middle Belt and northern fringes demonstrated high potential for excellent wind energy harvest. Wind speeds range from 1.4 to 3.0 m/s in the southern regions and from 4.0 to 5.12 m/s in the extreme North at 10 m height (Ajayi, 2009). The northern part of Nigeria is, therefore, a strategic location to start to harness wind energy in Nigeria. Peak wind speed was shown to generally occur between April and August for most sites.

Okoye and Adejumobi (2021) studied the increasing energy-mix in Nigeria, including renewable energy. The study found that 13,014.40 MW installed capacity of thermal and hydropower, out of which 4,860.87 MW representing 37.35%, was utilized. The study's findings showed that 85% of nonrenewable energy sources and 15% of renewable energy make up the current mix ratio, despite Nigeria's abundance of renewable energy such as sunshine, wind and bio sources. The only source of renewables is hydropower, with a 1,798 MW installed capacity.

From the foregoing, the usable, efficient, and especially cleanly modern energy landscape in Nigeria is worrisome despite the country's huge potential in both the nonrenewable and renewable energy sources, implying energy poverty scenarios across its length and breadth. While energy poverty is a global phenomenon (Bednar & Reames, 2020; Certoma et al., 2023; Dong et al., 2022; Gonzalez-Eguino, 2015; Igawa & Managi, 2022; Nguyen & Nasir, 2021; Nussbaumer et al., 2011; Sher et al., 2014), it hits hard on the African continent more (Nussbaumer et al., 2012), especially in Nigeria (Nussbaumer et al., 2011), partly from its population size, government inefficiencies, and corruption debacles (Agba, 2011). Nussbaumer et al., (2011, 2012) in an Oxford Poverty & Human Development Initiative (OPHI) study, which considered energy deprivation in determining the multidimensional energy poverty index (MEPI) show that Nigeria's MEPI (0.61) and its intensity of energy poverty (0.75), among the worst MEPI ratings in the world. While Ogwumike and Ozughalu (2015) revealed that the determinants of energy poverty in Nigeria, among others, include households' size, members' income, age of household heads, general poverty, and region of residence, while advocated for access to modern energy sources.

It is safe to say that energy poverty is impacted by countries' political economies (Sovacool, 2012) and income level of their citizens. Nguyen and Nasir (2021) found that an increase in income inequality causes higher energy poverty. Igawa and Managi (2022), who considered three indicators of accessibility, reliability, and affordability, in investigating the nexus between energy poverty and income inequality for 37 countries found that affordability is the worst in countries with a middle level of economic development, which are more relevant factors than climate conditions, and recommended a customized criteria for vulnerable households. Guruswamy (2011) specifically recognized the place of appropriate sustainable energy technologies, such as renewable, as beneficial in ameliorating the plights of the energy poor. Following the above reviews of extant literature, it leaves a gap in investigating Nigerian citizens' energy-mix study, in the context of energy poverty, with a focus on subsistence renewable, considering its affordability by households.

## Methodology, data collection and analytical methods

This section documents the methodology, data collection and analytical techniques applied for this study.

### Methodology

The Delphi experts' method was utilized, following Faiyetole and Adesina (2017), and Faiyetole (2019) approach, which involved gathering qualitative primary data from energy experts and practitioners, including engineering academicians, possessing relevant knowledge regarding power poverty, the energy-mix strategy, and renewable energy from various industrial complexes and a university of technology. Consequently, respondents were drawn from Obajana Cement Factory, Itakpe National Iron Ore Mining Company, Ajaokuta Iron and Steel Mill to Geregu Thermal Station, in Kogi State. Further, questionnaires were administered to participants within the engineering faculty of the Federal University of Technology, Akure, as well as at solar energy kiosks situated in the Akure metropolis within Ondo State. Just as energy experts drawn from various industrial complexes, engineering faculty and solar solutions retailers in solar kiosks are expectedly energy-mix strategy informed and served as diverse source but complementary data. The identification of energy experts was facilitated through references and by engaging with officials from the energy and engineering departments within each respective organization. Thus, the administration of the questionnaires was physically done. The Delphi experts' method entails a two-level survey, where the group's statistical representation of the questionnaire was anonymously fed back to the respondents, with a goal to reduce the range of responses and arrive at result closer to experts' consensus (Faiyetole, 2019; RAND, 2013).

### Data collection

The demographic characteristics of these experts are shown in Table 1, from a sample size of 120. Literature shows no consensus on the number of experts needed for a Delphi experts' study, however, Akins et al. (2005) used a panel of 23 experts for a Delphi study, while Faiyetole (2018) used 50. The questionnaire utilized in this study consisted of Likert-type questions that were deemed analytically suitable for application in Ordinal Logistics Regression (OLR), following the procedures outlined for SPSS (Statistical Package for the Social Sciences) by Laerd (2018) and used by Faiyetole (2022a, 2022b) and Faiyetole and Sivowaku (2021). The use of questionnaire as the primary research tool is justified by its ability to elicit information on standardized responses. Such questionnaires are commonly employed in explanatory research, enabling the identification and description of variations in diverse phenomena (Saunders et al., 2009). The following Likert-type questions were asked to elicit information on the objectives. For objective 1, a 5-scale measured, from very low, low, high, very high, to excellent, which is to assess the REPU potentials in the energy-mix strategy, the participants answered questions captured as: A. what is the potential level of renewable energy (solar) in Nigeria? B. what is the potential level of renewable energy (wind) in Nigeria? C. what is the potential level of renewable energy (biofuel/biomass/biogas) in Nigeria. Objective 2, to examine the extent to which renewable focused energy-mix adoption strategy would solve my households' power poverty challenges, with a 5-scale measured Likert, from no extent, little extent, some extent, large extent, to absolute extent. While Objective 3, which is to evaluate the citizens' subsistence solar energy solutions uptake affordability extent, the question read "affordability levels for solar power considering your monthly earnings and expenditures" for A. low-capacity solar solution (1.5KVA) at ~ N300k, B. medium-capacity solar solution (5KVA) at ~ N900K, C. high-capacity solar solution (10KVA) at ~ N1.5 M, all on a 3-scale measured Likert-type options, from cannot afford, can afford, to can very much afford. The variables corresponding to each

**Table 1** Descriptive statistics of the respondents

| Characteristics | Frequency | Percentage | Std. dev |
|---|---|---|---|
| *Present job cadre* | 2.41/4 | 100 | 1.081 |
| Junior staff | 31 | 25.8 | |
| Middle management | 27 | 22.5 | |
| Senior management | 40 | 33.3 | |
| Academics | 21 | 17.5 | |
| No response | 1 | 0.8 | |
| *Job position* | 2.89/6 | 100 | 1.837 |
| Technologist | 22 | 18.3 | |
| Engineer | 34 | 28.3 | |
| Manager | 19 | 15.8 | |
| General manager | 8 | 6.7 | |
| Executive director | 12 | 10 | |
| Academics | 18 | 15 | |
| No response | 7 | 5.8 | |
| *Business unit* | 2.49/5 | 100 | 0.926 |
| Marketing | 13 | 10.8 | |
| Operations | 39 | 32.5 | |
| Production/engineering | 54 | 45 | |
| Others | 11 | 9.2 | |
| No response | 3 | 2.5 | |
| *Professional years of experience* | 2.46/5 | 100 | 1.092 |
| < 5 years | 21 | 17.5 | |
| 6–10 years | 42 | 35 | |
| 11–15 years | 34 | 28.3 | |
| 16–20 years | 17 | 14.2 | |
| 21 > years | 4 | 3.3 | |
| No response | 2 | 1.7 | |
| *Highest educational qualification* | 2.81/5 | 100 | 1.279 |
| OND | 24 | 24.2 | |
| HND | 29 | 19.2 | |
| BSc | 23 | 28.3 | |
| MSc | 34 | 8.3 | |
| PhD | 10 | 20 | |
| *Professional membership* | 2.05/6 | 100 | 1.371 |
| NIM | 33 | 27.5 | |
| NSE | 32 | 26.7 | |
| COREN | 22 | 18.3 | |
| Others | 14 | 11.7 | |
| NIM + COREN | 3 | 2.5 | |
| NSE + COREN | 2 | 1.7 | |
| No response | 14 | 11.7 | |
| *Capacity development gathering in the past 2 years* | 3.22/7 | 100 | 2.166 |
| Workshop | 21 | 17.5 | |
| Conferences | 10 | 8.3 | |
| Seminars | 23 | 19.2 | |
| Training | 28 | 23.3 | |
| Workshop + seminar | 12 | 10 | |
| Workshop + conference + seminar + training | 12 | 10 | |
| Workshop + training | 1 | 0.8 | |

**Table 1** (continued)

| Characteristics | Frequency | Percentage | Std. dev |
|---|---|---|---|
| No response | 13 | 10.8 | |
| *Energy training in the past 2 years* | 2.15/6 | 100 | 1.846 |
| Technical | 46 | 38.3 | |
| Policy | 5 | 4.2 | |
| Management | 28 | 23.3 | |
| Policy + technical | 16 | 13.3 | |
| Technical + management | 4 | 3.3 | |
| Technical + policy + management | 2 | 1.7 | |
| No response | 19 | 15.8 | |

context were subjected to Variance Inflation Factor (VIF) tests, yielding reported results with values not exceeding 2.627, indicating the absence of inflationary effects. Consequently, multicollinearity does not pose a concern (ARA, 2018; O'brien, 2007), confirming the suitability of the variables as predictors within the study models. The total questionnaires (120) administered were retrieved.

### Analytical method: the ordinal logistics regression model

The OLR model was found appropriate for this study as it is commonly used for predicting outcomes, where the dependent variable has ordered categories or levels. Agresti (2010) presented extensions of logistic regressions for ordinal response variables and describes ways of forming logits for ordinal scale. The model estimates the relationship between the independent variables and cumulative probabilities of each category. Assuming we have $n$ observations and $k$ ordered categories ($k>2$). The dependent variable, $Y$, represents the category of each observation, ranging from 1 to $k$, while the independent variables are denoted by $X_1, X_2, ...., X_P$.

The cumulative probabilities of each category are denoted by $P(Y \leq j)$, where $j$ ranges from 1 to $k-1$. The model assumes that the cumulative log-odds follow a linear relationship with the independent variables:

$$\text{Logit}(P(Y \leq j|X)) = \alpha_j - \beta_1 * X_1 - \beta_2 * X_2 - ... - \beta_p * X_p, \quad (1)$$

where $\alpha\_j$ represents the intercept specific to the $j$th cumulative category, and $\beta_1, \beta_2, ..., \beta_p$ are the coefficients associated with each independent variable $X_1, X_2, ...X_p$.

Applying Eq. 1 to both the objectives, with the results presented in Tables 4 and 7, the following equations are informed:

$$\text{Logit}(P(\text{REPU}_{\text{EMS}} \leq 4|X)) = \alpha_j - S * \beta_1 - W * \beta_2 * -B * \beta_3, \quad (2)$$

where REPU_EMS represents the dependent variable in Table 4, which is the Renewable Energy Production and Utilization, REPU, potentials in the Energy Mix Strategy, EMS, in Nigeria, while S, W and B, respectively, represent solar, wind and biomass energy, as the independent variables. Considering that $j$ ranges from 1 to $k-1$, for these Likert questions, $k=5$, and implies $j$ ranges from 1 to 4:

$$\begin{aligned}&\text{Logit}(P(\text{SEAE}_{\text{MEE}} \leq 2|X)) \\ &= \alpha_j - LC * \beta_1 - MC * \beta_2 - HC * \beta_3,\end{aligned} \quad (3)$$

where SEAE_MEE represents the dependent variable in Table 7, which is the citizens' subsistence Solar Energy solutions uptake Affordability Extent, SEAE, as a function of participants Monthly Earnings and Expenditures, MEE, while LC, MC, and HC, respectively, represent low-capacity, medium-capacity, and high-capacity solar energy systems installation, as the independent variables. For these Likert questions, $k=3$, and it implies $j$ ranges from 1 to 2. The OLR acronym for the third objective which measures the extent to which Energy-mix Strategy would solve households Power Poverty challenges is ESPP.

To obtain the probabilities of each category, it is expressed in terms of the cumulative probabilities (Agresti, 2010):

$$P(Y = j|X) = P(Y = j|X) - P(Y = j - 1|X). \quad (4)$$

The intercepts $\alpha_j$ and coefficients $\beta_1$, $\beta_2$, and $\beta_3$ are approximated using various estimation techniques including the maximum likelihood estimation. The model predicts the category for new observations by calculating the cumulative probabilities using the estimated coefficients and intercepts. The OLR assumes the proportional odds assumption, which implies that the effect of the independent variables on the cumulative odds is constant across different categories. Figure 1 shows the workflow diagram of the methodology.

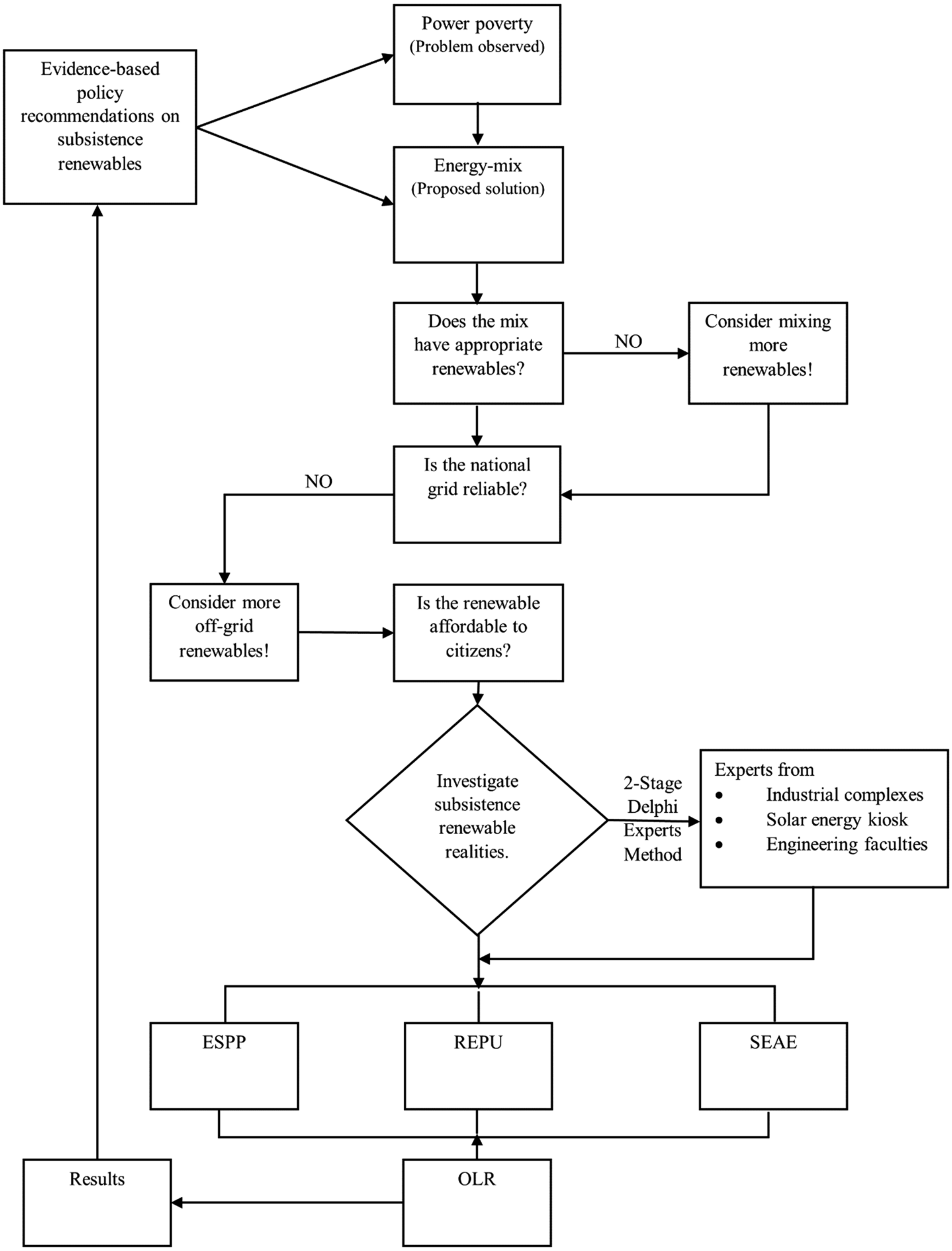

**Fig. 1** Workflow diagram of the methodology

### Validity and reliability of instruments

Validity refers to the extent to which a questionnaire effectively measures the objectives it aimed to accomplish (Saunders et al., 2009). Conversely, reliability pertains to the consistency of producing consistent outcomes when measuring the same constructs. In essence, reliability implies that significant findings should not be mere isolated occurrences but rather demonstrate repeatability. To ensure the clarity and validity of the survey instrument, a pilot test was conducted and utilized as the first stage of the Delphi experts' approach. Based on the results of the pilot test, certain questions were revised to enhance lucidity. Control checks were implemented by phrasing the same question in different ways, thereby increasing the validity of self-report claims, given that a self-administered questionnaire was employed in this study. To strengthen the analysis and enhance the reliability of the results, multiple statistical techniques were employed. In addition to the application of the OLR model, descriptive statistics, including ordinal-to-ordinal cross-tabulation with Kendall's *tau-b*, were utilized in the examination of the data, thereby bolstering the robustness of the analysis, with significant repeatability of results across the different analytical methods used.

### Descriptive statistics of the respondents

The descriptive statistics of the data are presented in Table 1.

From Table 1, with a weighted mean of 2.41, the respondents were mainly in the middle management cadre, while (55.8%) of the respondents were in middle management and above, about eighteen per cent (17.5%) were in the academia. At least (46.6%) have technical skills, either as technologists or engineers, whereas (32.5%) function as managers and executives in their respective organizations, with (15%) as academics. With a weighted average of 2.89, more respondents hold managerial positions. According to Litvaj et al. (2022), a growing sustainability context in businesses has made decisive decision-making imperative for managers, like the technical personnel, who are becoming more acquainted with their business line. A sizable number of the respondents work in operations and productions/engineering, i.e., 2.49 weighted mean and (77.5%), with (80.8%) and (2.46/5), who have at least six years of professional work experience in the energy sector and academia. About seventy-six percent (75.8%) or (2.81/5) of the respondents hold a degree, while (20%) are doctorate holders.

To further ascertain the respondents' understanding of energy-mix contemporary technical, management, and policy contexts, information on their professional association membership, attendance of any local or international energy capacity development gatherings in the past two years, and their attendance of energy-related training in the past two years were sought. About twenty-seven (26.7%) were members of the Nigerian Society of Engineers (NSE). Most of the respondents (2.05/6) were engineers. And (18.3%) were registered members of the Council for the Regulation of Engineering in Nigeria (COREN), while (1.7%) were indicated to be members of both professional associations. About twenty-eight (27.5%) of the respondents were members of the Nigerian Institute of Management (NIM), while (2.5%) indicated being a member of the NIM and COREN. Substantially, about ninety percent (89.2%) have attended different workshops, conferences, seminars, and training capacity development gatherings in the energy sector in the past two years. With a weighted mean of 3.22, the respondents have mostly attended energy seminars. Remarkably, about forty percent (38.3%) have had technical training in the past two years. Approximately eighty five percent (84.2%) have had different technical, management, policy, and regulatory training combinations in the past two years. Specifically, with a 2.15 weighted mean, the respondents have had training in policy and technical frames of the energy training spectra. The upskilling training embarked on by the energy experts in technical and policy frames is in line with what is expected in developing holistic contexts and understanding the technical dynamics of the new policies and is consistent with (Jaiswal et al., 2021; Pavlova, 2019).

Thus, the demographics of the respondents give a solid basis to believe their expert opinion because they have the requisite knowledge and exposure to make an informed conclusion.

## Results and discussion

The findings obtained from these analyses are presented in the tables below and herewith discussed.

### Estimating the effects of the experts' demographics on the potential of subsistence REPU in the energy-mix strategy to solve power poverty

The extent to which subsistence REPU in the energy-mix strategy in Nigeria could potentially ameliorate households' power poverty challenges was analyzed using the experts' demographical variables. The goodness-of-fit for the model implies Pearson's $\text{Chi}^2$ (521.075) with 405 degrees of freedom at a $p$-value (0.000). The lowest and repeated combined categories of options were referenced out, to give way for opinions from the higher and singular options demographics. The results are shown in Table 2. The effect size (ES) on the extent to which the energy-mix adoption strategy could solve power challenges in Nigeria are statistically significant for the middle and senior management cadre, respectively, at ($\alpha = 0.05$) and ($\alpha = 0.01$). The senior management thus has a better overview of the paradigm. Expectedly, the engineers, and managers and executive directors have the highest ES, respectively, (1.719), and (1.803) and (7.803). Experts with the highest professional years of experience significantly at ($\alpha = 0.01$), i.e., ($p = 0.008$) contribute to the model, and implies that the longer professionals' years of experience, the more their opinions count. Professionals with a master's level of education working in the field have ES (1.052).

The respondents who have participated in energy-mix seminars and a combination of energy capacity development gatherings have a higher effect size

**Table 2** The extent to which REPU in the energy-mix strategy would solve households power poverty challenges, ESPP, based on demographic variables

| Covariates | VIF | Level | Effect size (ES) | Wald (*p*-value) |
|---|---|---|---|---|
| Present job cadre | 2.508 | Junior staff (ref.) | – | – |
| | | Middle management | 4.370 (1.144–16.691) | 4.653 (0.031)* |
| | | Senior management | 6.998 (1.774–27.602) | 7.722 (0.005)** |
| | | Academics | 1.302 (0.016–105.074) | 0.014 (0.906) |
| Job position | 2.627 | Technologist (ref.) | – | – |
| | | engineer | 1.719 (0.399–7.407) | 0.528 (0.468) |
| | | Manager | 1.803 (0.398–8.178) | 0.584 (0.445) |
| | | General manager | 0.855 (0.097–7.534) | 0.020 (0.888) |
| | | Executive director | 7.803 (0.686–88.726) | 2.743 (0.098) |
| Years of experience | 1.350 | < 5 years (ref.) | – | – |
| | | 6–10 years | 1.037 (0.314–3.425) | 0.004 (0.953) |
| | | 11–15 years | 1.076 (0.273–4.245) | 0.011(0.917) |
| | | 16–20 years | 0.468 (0.055–3.944) | 0.488 (0.485) |
| | | > 20 years | 0.029 (0.002–0.403) | 6.936 (0.008)** |
| Highest educational qualification | 1.884 | OND (ref.) | – | – |
| | | HND | 0.782 (0.235–2.603) | 0.161 (0.688) |
| | | B.Sc | 0.376 (0.087–1.625) | 1.715 (0.190) |
| | | M.Sc | 1.052 (0.195–5.682) | 0.003 (0.953) |
| | | Ph.D | 0.100 (0.008–1.269) | 3.153 (0.076) |
| Capacity development gathering in the past 2 years | 1.507 | Workshop | 2.005 (0.019 -211.378) | 0.086 (0.770) |
| | | Conferences | 2.245 (0.018–278.738) | 0.108 (0.742) |
| | | Seminars | 7.891 (0.074–846.393) | 0.750 (0.386) |
| | | Workshop + seminar | 5.068 (0.036–715.399) | 0.413 (0.520) |
| | | Workshop + conferences + seminars + training | 6.795 (0.049–934.159) | 0.582 (0.446) |
| | | Workshop + training (ref.) | – | – |
| Energy training in the past 2 years | 1.818 | Technical | 0.022 (0.001–0.966) | 3.912 (0.048)* |
| | | Policy | 0.012 (0.000–0.795) | 4.269 (0.039)* |
| | | Management | 0.023 (0.001–0.984) | 3.875 (0.049)* |
| | | Policy + technical | 0.065 (0.002–2.791) | 2.027 (0.155) |
| | | Technical + management | 0.392 (0.007–21.600) | 0.210 (0.647) |
| | | Technical + policy + management (ref.) | – | – |

Effect sizes of energy experts' opinions; ref. denotes reference category; *p*-values for the ES that are statistically significant are denoted with asterisks (< 0.05 *; < 0.01 **; < 0.001 ***; 0.0001 = ****)

contributions to the model. The ES of the respondents with a combination of technical and management training is the highest (0.392). However, energy experts who had technical, policy/regulatory, and management training in the past two years have statistically significant contributions to the model, respectively, at ($p = 0.048$), ($p = 0.039$), and ($p = 0.049$). This is consistent with Jaiswal et al. (2021), who found that upskilling employees on new technology, such as artificial intelligence, and regarding this study, energy, will improve their relevance and contextual understanding of the emerging field.

### Subsistence renewable energy production and utilization potentials within the energy-mix strategy

Regarding the hypothesis of the potential of renewable energy production and utilization impacts on energy-mix strategy in Nigeria. As shown in Table 3, three-quarters of the experts consider, to no extent, as low regarding solar energy deployment. About two-fifths (37.5%) indicated very low for wind, while approximately three-fifths (62.5%) considered it very low with biogas/biofuel/biomass deployment. Kendall's *tau-b* correlation coefficient is positively significant for this option for solar REPU at (*tau-b* = 0.300, $p = 0.000$). According to the respondents, the options of little extent and some extent for solar REPU remain low potential for the energy-mix strategy.

**Table 3** The relationship between REPU potentials with the ESPP

| **The renewable energy production and utilization potentials** | **Solar (%)** | | | | | | | **Wind (%)** | | | | | | | **Bio (%)** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **The extent of energy-mix adoption** | **Very low** | **Low** | **High** | **Very high** | **Excellent** | **K *tau-b*** | ***p*-value** | **Very low** | **Low** | **High** | **Very high** | **Excellent** | **K *tau-b*** | ***p*-value** | **Very low** | **Low** | **High** | **Very high** | **Excellent** | **K *tau-b*** | ***p*-value** |
| To no extent | 0.0 | 75.0 | 25.0 | 0.0 | 0.0 | 0.300 | 0.000 | 37.5 | 37.5 | 12.5 | 12.5 | 0.0 | 0.124 | 0.125 | 62.5 | 25 | 0.0 | 12.5 | 0.0 | 0.179 | 0.016 |
| Little extent | 25.0 | 50.0 | 17.7 | 0.0 | 8.3 | | | 41.7 | 16.7 | 16.7 | 0.0 | 0.0 | | | 33.3 | 50.0 | 8.3 | 8.3 | 0.0 | | |
| Some extent | 25.0 | 39.0 | 10.7 | 7.1 | 17.9 | | | 42.9 | 46.4 | 7.1 | 3.6 | 0.0 | | | 28.6 | 21.4 | 35.7 | 3.6 | 10.7 | | |
| Large extent | 12.5 | 22.9 | 31.3 | 22.9 | 10.4 | | | 31.3 | 33.3 | 22.9 | 10.4 | 2.1 | | | 35.4 | 14.6 | 27.1 | 14.6 | 8.3 | | |
| Absolute extent | 0.0 | 20.8 | 20.8 | 41.7 | 16.7 | | | 41.7 | 16.7 | 20.8 | 16.7 | 4.2 | | | 29.2 | 0.0 | 41.7 | 16.7 | 12.5 | | |

**Table 4** The REPU potentials in Nigeria

| Covariates | VIF | Level | Effect size | Wald ($p$-value) |
|---|---|---|---|---|
| Potential renewable energy (solar) PU | 1.864 | Very low | 0.390 (0.056–2.724) | 0.902 (0.342) |
| | | Low | 0.209 (0.037–1.189) | 3.114 (0.078) |
| | | High | 0.533 (0.087–3.254) | 0.465 (0.495) |
| | | Very high | 1.669 (0.348–7.998) | 0.411 (0.521) |
| | | Excellent (ref.) | – | – |
| Potential renewable energy (wind) PU | 1.146 | Very low | 0.025 (0.001–0.528) | 5.619 (0.018)* |
| | | Low | 0.015 (0.001–0.337) | 7.010 (0.008)** |
| | | High | 0.019 (0.001–0.453) | 5.996 (0.014)* |
| | | Very high | 0.029 (0.001–0.772) | 4.469 (0.035)* |
| | | Excellent (ref.) | – | – |
| Potential renewable energy (biofuel) PU | 1.829 | Very low | 2.297 (0.329–16.030) | 0.704 (0.401) |
| | | Low | 1.592 (0.210–12.069) | 0.202 (0.653) |
| | | High | 4.030 (0.695–23.354) | 2.417 (0.120) |
| | | Very high | 2.053 (0.334–12.606) | 0.603 (0.437) |
| | | Excellent (ref.) | – | – |

Effect sizes of energy experts' opinions; ref. denotes reference category; $p$-values for the ES that are statistically significant are denoted with asterisks (< 0.05 *; < 0.01 **; < 0.001 ***; 0.0001 = ****)

The respondents thus consider solar REPU in the energy-mix strategy to be high in the large extent option and very high at (41.7%) in the absolute extent for the energy-mix strategy in Nigeria. It generally indicates that solar energy uptake in the energy-mix is beneficial socio-economically, and consistent with Kata et al. (2021), Kumar (2020), and IRENA and CEM (2014). Rio and Burguillo (2009) had shown the impact of solar energy deployment on local sustainability.

On the other hand, the wind REPU had the lowest consideration as a potential energy-mix strategy. While biofuel's options with ($tau\text{-}b = 0.179$, $p = 0.016$) are reasonably lower than solar REPU. These findings imply that the respondents see more significant potential in solar REPU than biogas/biomass/biofuel than wind in the energy-mix strategy in the Nigerian economy. It is consistent with IRENA and CEM (2014), which had shown that jobs per newly installed MW in the OECD, the USA, and South Africa, for onshore wind and solar photovoltaic, were, respectively, 8.6 and 17.9; 12.1 and 20; and 27 and 69.1. Solar energy indeed will have more socio-economic benefits than wind in the energy-mix strategy in Nigeria.

The REPU potentials, as shown in Table 4, where the highest option, excellent, was referenced out, considering it had the lowest frequencies of choices among all the options that include very low, low, high, and very high, is found to be sufficient. It reveals that for wind REPU, the ES shows significant $p$-values for all the options from very low to very high. The respondents thus imply very highly (0.029) with ($p = 0.035$) regarding the potential of wind REPU in Nigeria, but lowly with the strongest significance value (0.008) at $\alpha = 1\%$ being of potential REPU. Although the ordinal logistic regression results for solar and bio sources is statistically found not significant, as shown in Table 4; a situation that may have arisen from the categorical referencing of excellent (with lowest frequency option), the correlation results in Table 3 have, however, shown significant $p$-values for both the solar (0.000) and bio energy sources ($p = 0.016$), which the study relied on to proceed with the interpretation of the odds ratio (effect size) in the OLR results for both of solar and bio energy. The other compelling reason for proceeding with the interpretation of bio and solar potential is hinged on the super abundance of the two sources in Nigeria (e.g., Giwa et al., 2017). Consequently, the ES for biofuel/biogas/biomass within the high option is the largest (4.030), which shows that the respondents consider that the odds of the potential of biofuel/biogas/biomass is much higher than the other ordered options for biofuel/biogas/biomass, particularly about twice as high than the very high option in being a good candidate for REPU. A similar behavior is experienced for the solar REPU here.

## Solar energy solutions affordability extent towards solving power poverty

The non-significance of $p$-value for solar REPU potential and bio energy source regression results shown in Table 4 notwithstanding, the study proceeded to investigate solar energy solutions affordability extent towards solving energy poverty issues in Nigeria for several reasons that include its abundance and availability, which is ubiquitous (Alanne & Cao, 2019). For example, 17,459 billion MJ of solar energy is incident on the country's total surface area per day (Giwa et al., 2017), including exposure of an average of 6 h of sunshine per day that reaches 8 h in the northern part (Charles, 2014; Okoye & Adejumobi, 2021). Solar technology has witnessed the most unprecedented technological advancements of all energy sources since the 50 s (Breyer et al., 2021; Green et al., 2015) that include advances in scalability and modularity of its different modules, from rooftop, wall, window, foldable, to solar plant, which makes it an energy source of choice (Hernandez et al., 2019). On environmental impact, solar plant has been found to be competitive with wind energy plant delivering net green energy after accounting for inputs and ecosystem maintenance energy (Daaboul et al., 2023). Solar energy is resilient and reliable and seen as the energy of the future. Importantly, for social and economic benefits, regarding affordability, the price of solar photovoltaic energy has declined by 88 per cent, from ($0.417) 2010 to ($0.048)/kw-hour in 2021, while wind energy recorded 68 per cent decline in price and only 14 per cent for biomass (Osman et al., 2022).

Thus, like the wind REPU, the ES of the very high choice for solar is the largest, which implies that the respondents are very highly optimistic about the potential of solar as a good candidate for REPU in Nigeria, which is also consistent with the results in Table 3, i.e., 41.7% very high potential for REPU and at an absolute extent energy-mix strategy, and IRENA and CEM (2014). The effect of the affordability of renewable energy production and utilization of solar systems on the extent of the energy-mix strategy is equally captured, and results shown in Table 7. The highest option, can very much afford, was referenced out, considering that there are two other options of cannot afford and can afford, found to be sufficient based on affordability issues in considering it's a developing country focused study. The low-capacity solar installation is considered in the range of 1KVA output capacity and at (N550,000.00) price at the time of gathering research data, which was approximately US $960.00 at a prevailing exchange rate of $1 = N570 (the exchange range has become unstable and currently fluctuates at about N1,250 to a $1). The medium capacity is considered 2.5KKVA at (N1,900,000.00), approximately US $3300.00, while the high-capacity output is considered 5KVA at (N2,300,000.00), which is about US $4,000.00. The respondents who can afford low-capacity solar systems have the largest ES (0.574), implying the odds of can afford is higher than cannot afford. However, the odds of cannot afford even the low solar capacity is statistically significant at $\alpha = 1\%$. This current pattern repeats itself with medium and high-capacity solar affordability respondents. It implies that participants earnings and expenditures are not with a good purchasing power able to allow the respondents, who though know the value of solar REPU in the energy-mix strategy, could not afford the solar solution for their households. But the respondents who can afford solar solutions consider the viability of the energy-mix strategy. Thus, it can be deduced that affordability and recognition of values are correlated and congruous with the Penchansky and Thomas' (1981) health policy and health services concept of access, with dimensions that include affordability, accessibility, availability, adequacy, acceptability, implementation, and evaluation (Saurman, 2016).

In Table 5, Kendall's *tau-b* correlation coefficient result is positive and significant for a low-capacity solar solution at ($tau\text{-}b = 0.337$, $p = 0.000$). Three-quarters (75%) of the respondents who cannot afford low-capacity solar energy solutions and affordability thought its effect on the energy-mix strategy would be to no extent. The number is about three-fifths (62.5%) for medium affordability solar installations and approximately four-fifths (87.5%) for high solar energy solutions affordability. About three-fifths (58.3%) of the respondents who cannot afford low-capacity solar energy solutions thought its extent in the energy-mix strategy would be little. Essentially, the same little extent option regarding solar energy affordability and the extent of energy-mix strategy, but with a progressively higher percentage of pessimism, as medium affordability turns out (75%) and while high is (87.5%). The respondents who can afford low-capacity solar installations considered its relevance in the energy-mix strategy in Nigeria (53.6%), (68.8%), and (75%), respectively, to some extent, large and absolute options.

The more respondents can afford to install solar solutions, the likelihood they believe in its viability as an energy-mix strategy and in agreement with Table 4 (Penchansky & Thomas, 1981; Saurman, 2016), where a link is deduced with accessibility, affordability, and recognizing value. It can be deduced that the energy-mix is a function of the affordability of the options.

As renewable energy, particularly solar energy, is a significant solution in Nigeria's energy-mix strategy, further analyses were made about its production and utilization potentiality and affordability. The results are shown in Table 6. With a ($tau\text{-}b = 0.265$, $p = 0.001$) in the low solar installation affordability option, the result has semblance with the result for solar affordability with the energy-mix strategy, implying that the respondents who can afford low solar capacity installations see potentiality in solar systems in Nigeria. See Tables 4 and 5 and Saurman (2016); Penchansky and Thomas (1981). Unlike the

**Table 5** Relationship between SEAE (affordability) and ESPP

| **Solar energy affordability** | **Low (%)** | | | | | **Medium (%)** | | | | | **High (%)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **The extent of energy-mix adoption** | **Cannot afford** | **Can afford** | **Can very much afford** | **K *tau-b*** | ***p*-value** | **Cannot afford** | **Can afford** | **Can very much afford** | **K *tau-b*** | ***p*-value** | **Cannot afford** | **Can afford** | **Can very much afford** | **K *tau-b*** | ***p*-value** |
| To no extent | 75.0 | 25.0 | 0.0 | 0.337 | 0.000 | 62.5 | 37.5 | 0.0 | 0.129 | 0.110 | 87.5 | 12.5 | 0.0 | 0.042 | 0.625 |
| Little extent | 58.3 | 33.3 | 8.3 | | | 75.0 | 8.3 | 16.7 | | | 83.8 | 8.3 | 8.3 | | |
| Some extent | 37.7 | 53.6 | 10.7 | | | 60.7 | 32.1 | 7.1 | | | 75.0 | 21.4 | 3.6 | | |
| Large extent | 12.5 | 68.8 | 18.8 | | | 60.4 | 35.4 | 4.2 | | | 85.4 | 14.6 | 0.0 | | |
| Absolute extent | 8.3 | 75.0 | 16.7 | | | 37.5 | 62.5 | 0.0 | | | 70.8 | 29.2 | 0.0 | | |

**Table 6** Relationship between solar REPU potentials and SEAE in Nigeria

| **Solar energy affordability** | **Low (%)** | | | | | **Medium (%)** | | | | | **High (%)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Potential of solar REPU in Nigeria** | **Cannot afford** | **Can afford** | **Can very much afford** | **K *tau-b*** | ***p*-value** | **Cannot afford** | **Can afford** | **Can very much afford** | **K *tau-b*** | ***p*-value** | **Cannot afford** | **Can afford** | **Can very much afford** | **K *tau-b*** | ***p*-value** |
| Very low | 56.3 | 37.5 | 6.3 | 0.265 | 0.001 | 87.5 | 6.3 | 6.3 | 0.126 | 0.126 | 81.3 | 18.8 | 0.0 | 0.210 | 0.019 |
| Low | 30.8 | 59.0 | 10.3 | | | 51.3 | 43.6 | 5.1 | | | 92.3 | 7.7 | 0.0 | | |
| High | 18.5 | 70.4 | 11.1 | | | 55.6 | 44.4 | 0.0 | | | 81.5 | 18.5 | 0.0 | | |
| Very high | 8.7 | 69.6 | 21.7 | | | 56.5 | 39.1 | 4.3 | | | 69.6 | 30.4 | 0.0 | | |
| Excellent | 20 | 53.3 | 26.3 | | | 46.7 | 40.0 | 13.3 | | | 60.0 | 26.7 | 13.3 | | |

**Table 7** Effect of SEAE on solving power poverty challenges in Nigeria

| Covariates | VIF | Level | Effect size | Wald (*p*-value) |
|---|---|---|---|---|
| Low-Capacity Solar Affordability (1KVA) @N550K | 1.318 | Cannot afford | 0.170 (0.047–0.610) | 7.389 (0.007)** |
| | | Can afford | 0.574 (0.197–1.672) | 1.035 (0.309) |
| | | Can very much afford (ref.) | – | – |
| Medium-Capacity Solar Affordability (2.5KVA) @N1,900 K | 1.678 | Cannot afford | 8.577 (1.022–71.956) | 3.922 (0.048)* |
| | | Can afford | 7.202 (0.949–54.666) | 3.645 (0.056) |
| | | Can very much afford (ref.) | – | – |
| High-Capacity Solar Affordability (5KVA) @N2300 K | 1.373 | Cannot afford | 0.000 (0.000–0.000) | 1943.134 (0.000)**** |
| | | Can afford | 0.000 (0.000–0.000) | – |
| | | Can very much afford (ref.) | – | – |

Effect sizes of energy experts' opinions; ref. denotes reference category; *p*-values for the ES that are statistically significant are denoted with asterisks (< 0.05 *; < 0.01 **; < 0.001 ***; 0.0001 = ****)

insignificant *tau-b* result of the solar affordability with the energy-mix strategy in the high solar capacity affordability range, the solar potentiality shows a significant *tau-b* at ($p = 0.019$) despite showing consistency with the 'cannot afford' options.

Comparing Tables 6 and 7 shows consistent results, indicating that respondents who can afford low solar capacity installations perceive the potential of solar systems in Nigeria. For the medium-capacity output of solar REPU, Table 7 shows that the respondents generally cannot afford the present cost of such a system at 8.577 ES, significant $p$-value (0.048), which also corroborates the medium-level result in Table 6. At a highly significant value ($p = 0.000$), the low affordability of accessing high-capacity solar system installations is a significant determinant showstopper in Nigeria's solar energy production and utilization challenge. Largely, the agreements found with the different methods and approaches support the reliability of the research instruments, including the consistency in the results, from the descriptive, Kendall's tau-b correlations to the OLR models utilized. Concerning REPU and particularly solar REPU, the findings reveal that when you can afford it, your recognition of its values is better appreciated.

## Summary of the evidence

The extent to which the energy-mix adoption strategy can alleviate power poverty is statistically significant for middle and senior management expertise-cadre, while the latter demonstrates a more comprehensive understanding, in the same manner as the engineers, managers and executives. Extensive professional experience, master's level of education, participation in energy-mix seminars, training, and capacity development events, such as technical, policy or regulatory and management, statistically enhance the models. It resonates with Jaiswal et al. (2021), suggesting that upskilling employees in emerging fields like energy-mix enhances their contextual understanding and relevance. Most experts surveyed in the study consider solar energy deployment to be of high potential for Nigeria's energy-mix strategy and especially at subsistence level, which is consistent with Rio and Burguillo (2009). Solar energy uptake is seen as beneficial socio-economically and is supported by previous research findings (IRENA & CEM, 2014; Kata et al., 2021; Kumar, 2020). While the potential of bio sources for renewable energy production and utilization in Nigeria is seen as reasonably lower than solar REPU but higher than wind energy. Energy experts consider bio sources to have significant potential, particularly within the high option. Thus, the study indicates a favorable view towards integrating solar energy into Nigeria's energy-mix, with less enthusiasm for wind energy but significant potential seen in biofuel/biogas/biomass. Although the respondents show optimism about solar energy potential as a good candidate for REPU in Nigeria, affordability was considered a showstopper to its widespread adoption. It implies that at the off-grid, subsistence (households) level to solving energy poverty in line with Rio and Burguillo (2009) and energy-mix diversification to substantial renewables, affordability is a significant factor influencing the extent of solar energy inclusion in the energy-mix strategy by the citizens. The study shows that the extent of affordability beclouds perceptions of solar REPU viability in the energy-mix, such that those who can afford solar solutions are more likely to believe in its potential as part of the energy-mix, which maintains Penchansky and Thomas (1981) and Saurman (2016) notions on affordability and accessibility. The results of the various analysis applied consistently show that affordability influences the recognition of solar energy's value in Nigeria's energy-mix. Informing that affordability and accessibility play crucial roles in determining the feasibility of renewable energy solutions. The study further shows that affordability is a significant challenge, particularly with high-capacity solar installations, positing barrier to wider adoption and utilization especially at subsistence level.

## Conclusions

The analysis underscores the importance of demographic factors and professional development in shaping perspectives on addressing power poverty challenges through subsistence REPU in Nigeria's energy-mix strategy. The study suggests that solar energy deployment may offer more socio-economic benefits and sustainability implications compared to wind and bio sources in the energy-mix strategy, indicating a favorable view towards integrating solar energy into Nigeria's energy-mix, with less enthusiasm for wind but significant potential seen in biofuel/biogas/biomass. The study found a link between affordability and recognition of values in REPU regarding its potential, especially in the energy-mix strategies and alleviation of citizens' power poverty issues. It highlights the importance of affordability in determining the feasibility and acceptance of solar REPU as a substantial part of Nigeria's energy-mix strategy, emphasizing the need for policies and initiatives to address affordability issues to promote wider adoption of REPU especially as off-grid, subsistence solutions, among the citizens. Adopting energy-mix strategies has been found to have a high potential for improving power supply, access, and security. The consistency in results across different methodologies supports the reliability of the research findings, enhancing confidence in the conclusions drawn. It is recommended to intensify efforts in diversification of the country's energy stock by government incentivization of renewable energy access, particularly, solar. Further, the different EEE regulatory policy agencies could be saddled with the formulation and coordination of policies that support households and could potentially ameliorate energy poverty in low-income households, including raising income levels.

### Abbreviations

| | |
|---|---|
| COREN | Council for the Registration of Engineering in Nigeria |
| DPR | Department of Petroleum Resources |
| ES | Effect size |
| NESI | Nigerian Electricity Supply Industry |
| NIM | Nigerian Institute of Management |
| NIPP | National Integrated Power Project |
| NREEEP | National Renewable Energy and Energy Efficiency Policy |
| NSE | Nigerian Society of Engineers |
| OECD | Organisation for Economic Cooperation and Development |
| OLR | Ordinal Logistics Regression |
| PPPRA | Petroleum Products Pricing Regulatory Agency |
| RDF | Refuse-derived fuel |
| REPU | Renewable Energy Production and Utilization |

### Acknowledgements

The authors wish to extend their sincere gratitude to the reviewers for their invaluable feedback and insightful evaluation, which significantly enriched the article.

### Author contributions

D.O.O. and A.A.F. designed the research and wrote the manuscript including the data analysis and discussion. A.A.O. administered the questionnaire and helped with data coding.

### Funding

The authors declare that they received no funding for the research.

### Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

### Competing interests

The authors declare that they have no competing interests.

Received: 9 December 2023 Accepted: 12 March 2024

### References

Abila, N. (2012). Biofuel development and adoption in Nigeria: Synthesis of drivers, incentives and enablers. *Energy Policy, 43*, 387–395. https://doi.org/10.1016/j.enpol.2012.01.019

Adams, S., Klobodu, E. K. M., & Apio, A. (2018). Renewable and nonrenewable energy, regime type, and economic growth. *Renewable Energy, 125*, 755–767. https://doi.org/10.1016/j.renene.2018.02.135

African News. (2022). Europe turns to Nigeria to fill the gap in gas supply. https://www.africanews.com/2022/04/12/europe-turns-to-nigeria-to-fill-the-gap-in-gas-supply//. Accessed 14 April 2022.

Agba, M. S. (2011). Energy poverty and the leadership question in Nigeria: An overview and implication for the future. *Journal of Public Administration and Policy Research, 3*(2), 48–51.

Agresti, A. (2010). *Analysis of ordinal categorical data* (2nd ed.). New Jersey: Wiley.

Ajayi, O. O. (2009). Assessment of utilization of wind energy resources in Nigeria. *Energy Policy, 37*, 750–753. https://doi.org/10.1016/j.enpol.2008.10.020

Akins, R. B., Tolson, H., & Cole, B. R. (2005). Stability of response characteristics of a Delphi panel: application of bootstrap data expansion. *BMC Medical Rsearch Methodology*. https://doi.org/10.1186/1471-2288-5-37

Akram, R., Chen, F., Khalid, F., Huang, G., & Irfan, M. (2021). Heterogeneous effects of energy efficiency and renewable energy on economic growth of BRICS countries: a fixed effect panel quantile regression analysis. *Energy, 215*(Part B), 119019.

Alanne, K., & Cao, S. (2019). An overview of the concept and technology of ubiquitous energy. *Applied Energy, 238*, 284–302. https://doi.org/10.1016/j.apenergy.2019.01.100

ARA. (2018). Applied regression analysis. Lesson 10.7—Detecting multi-collinearity using variance inflation factors. Accessed on 2 Nov 2021 from PSU.edu at https://online.stat.psu.edu/stat462/node/180/

Aslan, A., Ilhan, O., Usama, A.-M., Savranlar, B., Polat, M. A., Metawa, N., & Raboshuk, A. (2024). Effect of economic policy uncertainty on CO2 with the discrimination of renewable and non renewable energy consumption. *Energy*. https://doi.org/10.1016/j.energy.2024.130382

Bednar, D. J., & Reames, T. G. (2020). Recognition of and response to energy poverty in the United States. *Nature Energy, 5*, 432–439. https://doi.org/10.1038/s41560-020-0582-0

Bhattacharya, S. C., Abdul-Salam, P., Pham, H. L., & Ravindranath, N. H. (2003). Sustainable biomass production for energy in selected Asian counties.

*Biomass and Bioenergy, 25*, 471–482. https://doi.org/10.1016/S0961-9534(03)00085-0

Breyer, C., Bogdanov, D., Khalili, S., & Keiner, D. (2021). Solar photovoltaics in 100% renewable energy systems. Encyclopedia of Sustainability Science and Technology (Living Reference Work Entry), 1–30. https://doi.org/10.1007/978-1-4939-2493-6_1071-1.

Certoma, C., Corsini, F., Di Giacomo, M., & Guerrazzi, M. (2023). Beyond income and inequality: The role of socio-political factors for alleviating energy poverty in Europe. *Social Indicators Research, 169*, 167–208.

Chanchangi, Y. N., Adu, F., Ghosh, A., Sundaram, S., & MalLick, T. K. (2023). Nigeria's energy review: Focusing on solar energy potential and penetration. *Environment, Development and Sustainability, 25*, 5755–5796. https://doi.org/10.1007/s10668-022-02308-4

Chang, T. H., Huang, C. M., & Lee, M. C. (2009). Threshold effect of the economic growth rate on the renewable energy development from a change in energy price: Evidence from OECD countries. *Energy Policy, 37*, 5796–5802. https://doi.org/10.1016/j.enpol.2009.08.049

Charles, A. (2014). How is 100 percent renewable energy possible for Nigeria? Global Energy Network Institute (GENI). http://geni.org/globalenergy/research/renewable-energy-potential-of-nigeria/100-percent-renewable-energy-Nigeria.pdf.

Chien, T., & Hu, J.-L. (2007). Renewable energy and macroeconomic efficiency OECD and non-OECD economies. *Energy Policy, 35*, 3606–3615. https://doi.org/10.1016/j.enpol.2006.12.033

Chien, T., & Hu, J.-L. (2008). Renewable energy: An efficient mechanism to improve GDP. *Energy Policy, 36*, 3045–3052. https://doi.org/10.1016/j.enpol.2008.04.012

Daaboul, J., Moriarty, P., & Honnery, D. (2023). Net green energy potential of solar photovoltaic and wind energy generation systems. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2023.137806

Dada, J. T., Ajide, F. M., & Al-Faryan, M. A. S. (2024). The moderating role of financial development in energy poverty–sustainable environment linkages: Evidence from Africa. *Management of Environmental Quality*. https://doi.org/10.1108/MEQ-08-2023-0268

Djeunankan, R., Tadadjeu, S., & Kamguia, B. (2024). Linking energy poverty and industrialization: Empirical evidence from African countries. *Energy*. https://doi.org/10.1016/j.energy.2024.130374

Dong, K., Dou, Y., & Jiang, Q. (2022). Income inequality, energy poverty, and energy efficiency: Who cause who and how? *Technological Forecasting and Social Change, 179*, 121622. https://doi.org/10.1016/j.techfore.2022.121622

DPR. (2021). Department of Petroleum Resources. Victoria Island, Lagos State, Nigeria.

Duerrast, H. (2020). Geothermal resources in southern Thailand-part of a renewable energy mix. *International Conference on Sustainable Energy and Green Technology*. https://doi.org/10.1088/1755-1315/463/1/012146

Energy Commission of Nigeria. 2015. Plot 701C, Central Business District, Abuja, Nigeria, www.energy.gov.ng. Accessed Nov 2019.

Faiyetole, A. A. (2018). Potentialities of space-based systems for monitoring climate policies and mitigation of climate process drivers. *Astropolitics: the International Journal of Space Politics and Policy, 16*, 28–48. https://doi.org/10.1080/14777622.2018.1436329

Faiyetole, A. A. (2019). Outside-in perspectives on the socio-econo-technological effects of climate change in Africa. *International Sociology, 34*(6), 762–785. https://doi.org/10.1177/0268580919867837

Faiyetole, A. A. (2022a). Impact of Covid-19 on willingness to share trips. *Transportation Research Interdisciplinary Perspectives, 13*, 1–11. https://doi.org/10.1016/j.trip.2022.100544

Faiyetole, A. A. (2022b). COVID-19 stimulated travel behavior policy framework with evidence from travel change in southwestern Nigeria. *Transactions on Transportation Sciences, 3*, 1–13. https://doi.org/10.5507/tots.2022.018

Faiyetole, A. A., & Adesina, F. A. (2017). Regional response to climate-change and management: An analysis of Africa's capacity. *International Journal of Climate-Change Strategies and Management, 9*(6), 730–748. https://doi.org/10.1108/IJCCSM-02-2017-0033

Faiyetole, A. A., & Ihemeje, G. C. (2022). Climate governance and justice: Power pull and unequal exchanges with peripheral Africa. In R. Sooryamoorthy & N. E. Khalema (Eds.), *The Oxford handbook of the sociology of Africa*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780197608494.013.36

Faiyetole, A. A., & Sivowaku, J. T. (2021). The effects of aircraft noise on psychosocial health. *Journal of Transport and Health, 22*, 1–19. https://doi.org/10.1016/j.jth.2021.101230

Giwa, A., Alabi, A., Yusuf, A., & Olukan, T. (2017). A comprehensive review on biomass and solar energy for sustainable energy generation in Nigeria. *Renewable and Sustainable Energy Reviews, 69*, 620–641. https://doi.org/10.1016/j.rser.2016.11.160

Gonzalez-Eguino, M. (2015). Energy poverty: An overview. *Renewable and Sustainable Energy Reviews, 47*, 377–385.

Green, M. A., Keevers, M. J., Thomas, I., Lasich, J. B., Emery, K., & King, R. R. (2015). 40% efficient sunlight to electricity conversion. *Progress in Photovoltaics, 23*, 685–691. https://doi.org/10.1002/pip.2612

Guruswamy, L. (2011). Energy poverty. *Annual Review of Environment and Resources, 36*, 139–161. https://doi.org/10.1146/annurev-environ-040610-090118

Hernandez, R. R., Armstrong, A., Burney, J., Ryan, G., Moore-O'Leary, K., Diedhiou, I., Grodsky, S. M., Saul-Gershenz, L., Davis, R., Macknick, J., Mulvaney, D., Heath, G. A., Easter, S. B., Hoffacker, M. K., Allen, M. F., & Kammen, D. M. (2019). Techno–ecological synergies of solar energy for global sustainability. *Nature Sustainability, 2*, 560–568. https://doi.org/10.1038/s41893-019-0309-z

Hirschmann, S. (2024). The role of citizens in producing and consuming their own renewable energy. IEMed, European Institute of the Mediterranean. Accessed on 12 January 2024 from https://www.iemed.org/publication/the-role-of-citizens-in-producing-and-consuming-their-own-renewable-energy/

Hosan, S., Sen, K. K., Rahman, M. M., Karmaker, S. C., Chapman, A. J., & Saha, B. B. (2024). Mitigating energy poverty: A panel analysis of energy policy interventions in emerging economies of the asia-pacific region. *Energy*. https://doi.org/10.1016/j.energy.2024.130367

Hossain, M. L., Shapna, K. J., & Li, J. (2023). Solar energy brightens lives and strengthens the resilience of geographically challenged communities in Bangladesh. *Energy for Sustainable Development, 74*, 79–90.

Igawa, M., & Managi, S. (2022). Energy poverty and income inequality: An economic analysis of 37 countries. *Applied Energy*. https://doi.org/10.1016/j.apenergy.2021.118076

Imo, E. E., Olayanju, A., Ibikunle, F. A., & Dahunsi, S. O. (2020). Impact of small hydropower developments on rural transformation in Nigeria. *IOP Conference Series Earth and Environmental Science*. https://doi.org/10.1088/1755-1315/445/1/012023

IRENA and CEM. (2014). "The socio-economic benefits of large-scale solar and wind." An econValue report. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2014/Socioeconomic_benefits_solar_wind.pdf

Irfan, M., Zhao, Z., Panjwani, M. K., Mangi, F. H., Li, H., Jan, A., Ahmad, M., & Rehman, A. (2020). Assessing the energy dynamics of Pakistan: Prospects of biomass energy. *Energy Reports, 6*, 80–90. https://doi.org/10.1016/j.egyr.2019.11.161

Jaiswal, A., Arun, C. J., & Varma, A. (2021). Rebooting employees: Upskilling for artificial intelligence in multinational corporations. *The International Journal of Human Resource Management, 33*(6), 1179–1208. https://doi.org/10.1080/09585192.2021.1891114

Jiang, L., Shi, X., Feng, T., & Yan, M. (2024). Age-driven energy poverty in urban household: Evidence from Guangzhou in China. *Energy for Sustainable Development*. https://doi.org/10.1016/j.esd.2023.101369

Jorgenson, A. K. (2014). Economic development and carbon intensity of human wellbeing. *Nature Climate Change, 4*, 186–189. https://doi.org/10.1038/nclimate2110

Kata, R., Cyran, K., Dybka, S., Lechwar, M., & Pitera, R. (2021). Economic and social aspects of using energy from PV and solar installations in farmers' households in the Podkarpackie Region. *Energies, 14*, 3158. https://doi.org/10.3390/en14113158

Kettani, M., & Sanin, M. E. (2024). Energy consumption and energy poverty in Morocco. *Energy Policy*. https://doi.org/10.1016/j.enpol.2023.113948

Kumar, M. (2020). Social, economic, and environmental impacts of renewable energy resources. In K. E. Okedu, A. Tahour, & A. G. Aissaou (Eds.), *Wind solar hybrid renewable energy system*. IntechOpen. https://doi.org/10.5772/intechopen.89494

Laerd Statistics. (2018). Ordinal logistics regression using SPSS statistics. Statistical Tutorials and Software Guides. https://statistics.laerd.com. Accessed 27 Apr 2020.

Li, J., Gao, J., & Liu, H. (2024). Reducing energy poverty by nearly universal pension coverage of rural China. *World Development*. https://doi.org/10.1016/j.worlddev.2023.106524

Litvaj, I., Ponisciakova, O., Stancekova, D., Svobodova, J., & Mrazik, J. (2022). Decision-making procedures and their relation to knowledge management and quality management. *Sustainability, 14*(1), 572. https://doi.org/10.3390/su14010572

Masuku, B. (2024). Rethinking South Africa's household energy poverty through the lens of off-grid energy transition. *Development Southern Africa*. https://doi.org/10.1080/0376835X.2023.2300411

Mirza, B., & Szirmai, A. (2010). Towards a new measurement of energy poverty: A cross-community analysis of rural Pakistan. United Nations University–Maastricht Economic and Social Research and Training Centre on Innovation and Technology Working Paper Series 024.

Montoya-Duque, L., Arango-Aramburo, S., & Arias-Gaviria, J. (2022). Simulating the effect of the Pay-as-you-go scheme for solar energy diffusion in Colombian off-grid regions. *Energy*. https://doi.org/10.1016/j.energy.2022.123197

Mutezo, G., & Mulopo, J. (2021). A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. *Renewable and Sustainable Energy Reviews, 137*, 110609. https://doi.org/10.1016/j.rser.2020.110609

NESI. (2017). Nigerian Electricity Supply Industry Statistics. http://nesistats.org. Accessed January 2019.

Nguyen, C. P., & Nasir, M. A. (2021). An inquiry into the nexus between energy poverty and income inequality in the light of global evidence. *Energy Economics, 99*, 105289.

NREEEP. (2015). National Renewable Energy and Energy Efficiency Policy. Approved by the Federal Executive Council for the electricity sector; Federal Ministry of Power, Federal Republic of Nigeria.

Nussbaumer, P., Bazilian, M., & Modi, V. (2012). Measuring energy poverty: Focusing on what matters. *Renewable and Sustainable Energy Reviews, 16*(1), 231–243. https://doi.org/10.1016/j.rser.2011.07.150

Nussbaumer, P., Bazilian, M., Modi, V., & Yumkella, K.K. (2011). Measuring energy poverty: focusing on what matters. OPHI WORKING PAPER NO. 42. https://www.ophi.org.uk/wp-content/uploads/OPHI_WP_42_Measuring_Energy_Poverty1.pdf

Nwachukwu, J. O. (2019). UNN sets records, generates electricity from organic waste. https://dailypost.ng/2019/03/19/unn-sets-record-generates-electricity-organic-waste/, Accessed from Daily Post June 2023.

Ogwumike, F. O., & Ozughalu, U. M. (2015). Analysis of energy poverty and its implications for sustainable development in Nigeria. *Environment and Development Economics, 21*(3), 273–290. https://doi.org/10.1017/S1355770X15000236

Okoye, C. U, & Adejumo, I.A. (2021). "Increasing energy mix in Nigeria's electric grid through renewable energy development." *IRE Journals* 5(5). ISSN: 2456-8880.

Olayungbo, D. O., Faiyetole, A. A., & Olayungbo, A. A. (2022). Economic growth, energy consumption, and carbon emissions: The case of Nigeria. In A. Rafay (Ed.), *Handbook of research on energy and environmental finance 4.0* (pp. 259–276). IGI-Global. https://doi.org/10.4018/978-1-7998-8210-7.ch010

Osman, A. I., Chen, L., Yang, M., Msigwa, G., Farghali, M., Fawzy, S., Rooney, D. W., & Yap, P.-S. (2022). Cost, environmental impact, and resilience of renewable energy under a changing climate: A review. *Environmental Chemistry Letetrs, 21*, 741–764. https://doi.org/10.1007/s10311-022-01532-8

Othmane, T. O., & Antar, H. (2020). Algeria's future energy mix: The challenges to transit to renewable energy. *Economic and Management Research Journal, 14*(3), 125–142.

Pavlova, M. (2019). Emerging environmental industries: Impact on required skills and TVET systems. *International Journal of Training Research, 17*(1), 144–158. https://doi.org/10.1080/14480220.2019.1639276

Penchansky, R. D. B. A., & Thomas, J. W. (1981). The concept of access: Definition and relationship to consumer satisfaction. *Medical Care, 19*(2), 127–140. https://doi.org/10.1097/00005650-198102000-00001

PPPRA. (2021). Petroleum Product Pricing Regulatory Agency. Federal Capital Territory, Abuja Nigeria.

Ren, Y.-S., Kuang, S., & Klein, T. (2024). Does the urban–rural income gap matter for rural energy poverty? *Energy Policy*. https://doi.org/10.1016/j.enpol.2023.113977

RioBurguillo, P. M. (2009). An empirical analysis of impact of renewable energy deployment on local sustainability. *Renewable and Sustainable Energy Reviews, 13*(6–7), 1314–1324. https://doi.org/10.1016/j.rser.2008.08.001

Robert, M. (2007). A caution regarding rules of thumb for variance inflation factors. *Quality and Quantity, 4*, 673–690. https://doi.org/10.1007/s11135-006-9018-6

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research methods for business students* (5th ed.). Pearson Education Limited.

Saurman, E. (2016). Improving access: modifying Penchansky and Thomas's Theory of Access. *Journal of Health Services Research and Policy, 21*(1), 36–39. https://doi.org/10.1177/1355819615600

Shen, Q., Wu, R., Pan, Y., & Feng, Y. (2024). Explaining and modeling the impacts of inclusive finance on $CO_2$ emissions in China integrated the intermediary role of energy poverty. *Humanities and Social Sciences Communications, 11*, 82. https://doi.org/10.1057/s41599-023-02595-w

Sher, F., Abbas, A., & Awan, R. U. (2014). An investigation of multidimensional energy poverty in Pakistan: A province level analysis. *International Journal of Energy Economics and Policy, 4*(1), 65–75.

Sovacool, B. K. (2012). The political economy of energy poverty: A review of key challenges. *Energy for Sustainable Development, 16*(3), 272–282.

Stock, R., Nyantakyi-Fripong, H., Antwi-Agyei, P., & Yeleliere, E. (2023). Volta photovoltaics: Ruptures in resource access as gendered injustices for solar energy in Ghana. *Energy Research and Social Science*. https://doi.org/10.1016/j.erss.2023.103222

Towoju, O. A. (2022). Residues to energy: A study on improving the renewable energy mix in Nigeria. *Journal of Energy Research and Reviews, 10*(1), 47–56. https://doi.org/10.9734/jenrr/2022/v10i130248

UNFCCC. (2021). NDC Registry (Interim). https://www4.unfccc.int/sites/NDCStaging/pages/Party.aspx?party=NGA

Usmani, R. A., Asim, M., & Manzoor, S. (2021). Renewable energy and energy crises in Pakistan. *Psychology and Education, 58*(2), 8714–8727.

World Development Indicator. (2020). The World Bank 1818 H Street N.W. Washington, D.C. 2020 20433. USA.

Xiao, Y., Feng, Z., Li, X., & Wang, S. (2024). Low-carbon transition and energy poverty: Quasi-natural experiment evidence from China's low-carbon city pilot policy. *Humanities and Social Sciences Communications, 11*, 84. https://doi.org/10.1057/s41599-023-02573-2

Yan, H., Yi, X., Jiang, J., & Bai, C. (2024). Can information technology construction alleviate household energy poverty? Empirical evidence from the "broadband China" Pilot Policy. *Energy Policy*. https://doi.org/10.1016/j.enpol.2023.113966

Yoon, Y. (2024). Poverty in the midst of plenty: Identifying energy poverty, hardship and vulnerable households in Russia. *Energy Research and Social Science*. https://doi.org/10.1016/j.erss.2023.103362

Zvinavashe, E., Elbersen, H. W., Slingerland, M., Kolijn, S., & Sanders, J. P. (2011). Cassava for food and energy: Exploring potential benefits of processing of cassava into cassava flour and bioenergy at farmstead and community levels in rural Mozambique. *Biofuel, Bioproduct & Biorefining, 5*(2), 151–164. https://doi.org/10.1002/bbb.272

## Publisher's Note