Carbon Neutrality

ORIGINAL ARTICLE

Open Access

Understanding Nigeria's transition pathway to carbon neutrality using the Multilevel Perspective

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Abstract

Nigeria, at the 2021 Conference of Parties (COP26) meeting in Glasgow announced a commitment to transitioning her carbon economy to reach net-zero by 2060. One year after, the country's drive for carbon neutrality is shrouded with uncertainties despite numerous policies targeted at it. This study employed the Multilevel Perspective (MLP) and PESTLE (Political, Economic, Social, Technological, Legal, Environmental) analytical framework to assess the politics of low-carbon transition in Nigeria. We used a triangulation of literature review, document analysis, and survey to build the theoretical, historical, and empirical bases for the enquiry. The findings show that the current low-carbon transition process is characterised by few potential drivers and many barriers with critical uncertainty effects. The key drivers are: Nigeria's potentials for carbon sink/nature-based solutions; vast renewable energy resources; strong niche market demand; and huge opportunities for employment in the renewable energy sector. The major barriers are: poor management of the energy regime; weak infrastructural base; dependence on global climate fund; fossil fuel-based economy; cost of renewable energy options; and impacts of climate change, among others. The barriers with critical impacts outweigh the potential drivers at the ratio of 4:1 thereby playing greater role in characterizing Nigeria's transition pathway as the 'reconfiguration transition pathway' within the 'emergent transformation context.' Therefore, unless the identified regime barriers are eliminated, the current transition pathway may not deliver the low-carbon targets. Considering the huge mitigation potentials of Nigeria's vast forests and natural ecosystem for carbon sink, the study recommends investment in nature-based solutions in synergy with energy system management as the most convenient and cost-effective pathway to attaining carbon neutrality by 2060.

Keywords Carbon neutrality, Energy transition, Multilevel perspective, Renewable energy

1 Introduction

The 2015 Paris Agreement marked a major milestone in the global promotion of transition to a low-carbon economy. Parties to the Paris agreement are anticipated to fast-track transition from unsustainable energy regimes to a net-zero carbon emission status by mid-century [1]. As a signatory to the Paris agreement, Nigeria acknowledges that transition to carbon neutrality is fundamental to achieving sustainable economic growth [2]. The Nigerian president at the COP26 meeting in Glasgow announced Nigeria's commitment to transitioning its carbon economy to reach net-zero by 2060. In doing so, the President also highlighted some difficulties which lie on the county's carbon transition pathway to include among others, the need for greater international finance and technical partnership, and Nigeria's reliance on fossil fuel (especially gas) to drive the energy sector of the economy [3]. In view of the current socio-economic

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trajectory and the worsening energy crisis in the country, some scholars have described Nigeria's net-zero carbon transition declaration as too ambitious [3–5]. Others have expressed concerns that the climate goals are not properly aligned with the political and economic realities in Nigeria and may have a huge implementation gap in the years to come [6]. There is therefore the need to further interrogate Nigeria's transitional pathways to carbon neutrality to gain better understanding to the proximate factors that may mediate the transition trajectory.

Nigeria has demonstrated significant commitment to the global efforts at tackling climate change. Following the ratification of the Paris agreement in March 2017, Nigeria submitted in 2021 its final updated Nationally Determined Contribution (NDC) by which she pledged an unconditional 20% emission reduction below business-as-usual by 2030, and a 47% emission reduction conditional upon international financial support, technology transfer and capacity building [7]. In addition, Nigeria has approved the National Climate Change Policy (NCCP) 2021-2030 and signed the Nigeria Climate Change Act 2021. Despite these achievements, numerous challenges in the energy sector seem to undermine the drive for carbon neutrality by 2060 [5]. Contrary to the expectations of the National Energy Masterplan 2014, worsening energy poverty has forced a reversal in the transition path to clean and efficient energy system in the past 6 years [8]. Presently, more Nigerians are on the descending course of the energy ladder – shifting from gas to kerosene, and from kerosene to biomass. The increasing rate of unemployment, poverty, and rising debt profile due to the COVID-19 induced recession in Nigeria are visible challenges to Nigeria's attainment of her NDC goals and low-carbon transition [5, 6]. Achieving carbon neutrality by 2060 will entail progressively phasing out and profoundly modifying Nigeria's carbon-intensive economy. This is intensely challenging and requires extensive research to inform effective visioning for a seamless transition. Dearth of accurate and timely information is the bane of Nigeria's transition to a carbon-neutral future [5].

Nigeria's low-carbon transition process is currently shrouded with uncertainties despite numerous policy documents targeted at it [6, 9]. Nigeria stands at a vulnerable position in a world which targets the total elimination of fossil fuel my mid-century. The country's major trade partners like United States, China, Japan, and the European Union have all committed to carbon neutrality by 2050, while some of them have already set targets to phase out vehicles that run on oil by 2030. The risk for future global oil markets upon which Nigeria's economy is heavily depended is averred and not theoretical. The Nigerian government understands also, that not responding to the global pressure on low-carbon transition will compromise its ambition to economic prosperity, hence the recent policy measures targeted at achieving a carbon-neutral future [2]. But global trends also suggest that pursuing ambitious goals for carbon neutrality without an all-inclusive growth in the renewable energy alternatives will further skew the energy outlook with devastating impacts on the local economy [8, 10]. Many developing countries (Nigeria inclusive) may have been 'boxed to a corner' to hastily commit to net-zero carbon transition without first unbundling their peculiar socio-technical regime complexities, as to guarantee an all-inclusive transition [11]. Low-carbon transition strategies in most developing countries are top-down driven, without sufficient consideration of the poorer society [9, 12]. This study employed the Multilevel Perspective (MLP analytical framework to advance a politically nuanced analysis of transition to carbon neutrality. The overarching questions posed by the study are: 1 what dynamics within the Nigeria socio-technical regime define her low-carbon transition pathway? 2 What are the barriers to attainment of carbon neutrality by 2060? The study also addresses the question as to what carbon neutrality means to an ordinary citizen,and how that may impact the success or otherwise of the transition process. The study aims at defining a more sustainable low-carbon transition pathway for Nigeria and the developing countries of the world in general.

2 Methodology

2.1 Analytical framework

This section explains the theories and concepts adopted by the study as framework for analysis which include: the Multilevel Perspective (MLP) and the PESTLE (Political, Economic, Social, Technological, Legal and Environmental) factor analysis.

2.1.1 The Multilevel Perspective

The Multilevel Perspective is a middle-range analytical framework that explains how change happens and what constitutes the critical factors of a transition [13, 14]. The framework is called multilevel because it conceptualises the processes of sociotechnical transition at three levels namely: the sociotechnical niche,the regime; and the landscape [15]. The 'sociotechnical niche' is the micro-level platform where radical innovations or technological inventions are generated [16]. Niches provide protective spaces for path-breaking discoveries and radical alternatives which supply the structural backbone for transition [17]. The 'regime' occupies the meso-level and is composed of primary actors in transition such as: institutions, government agencies, techniques, legislations, regulations, standards, practices, and networks based on norms and rules [13]. At the macro-level is the 'landscape' comprising of factors like environmental changes (e.g., climate change or natural disaster), demographic changes, global macro-economic trends (e.g., fluctuation in oil price), political changes, etc. [17]. The MLP conceptualises transitions as long-term structural changes encompassing the initiation of disruptive pressures by landscape factors (such as global warming) which exerts tension on the existing institutional regime (e.g., government policies, industrial systems, and available technologies) thereby necessitating a drive for and adoption of niche innovations [12, 13]. The political arena is the actual area of transitions contestation which shapes societal responses to transitions. This position is true of transition dynamics in Nigeria and other developing nations in general [18].

Despite its usefulness as a framework for sustainability transitions analysis, the MLP has been criticised for not having in-depth consideration of politics and power in the transition process, and the existing regimes as actors able to drive change [19, 20]. In addition, the MLP has been criticised for favouring a bottom-up view of transition as deriving from the niche towards the regime, exclusive of the possibility of a transformative change that could emanate from within the regime itself [21]. Recognising these limitations, we deepened understanding of the MLP framework with theories of transition pathway and contexts (see Appendix 1); and combined the MLP with PESTLE analysis – another analytical technique that filled its perceived gaps.

2.1.2 PESTLE analysis

PESTLE (Political, Economic, Social, Technological, Legal, and Environmental) analysis is a framework frequently applied to evaluate and monitor the macro-environmental factors which have potentials to impact organisations or their policies and strategies [22]. The main thrust of PESTLE analysis is to carry out a detailed examination of the future as it pertains to a policy or action and take proactive measures to define a sustainable pathway to success [23]. PESTLE analysis has profound relevance in sustainability transition studies as seen in the works of Kordana and Slys [24], and Zahari and Romli [25].

PESTEL analysis comprises of six macro-environmental factors as follows. The 'Political' factors are regime issues like regulations, deregulations, tax policies, incentives, environmental or material standards, consumer protection, import–export restrictions, government stability, and bureaucracy which may influence a certain policy [22]. The 'Economic' factors are macro-economic determinants such as interest rates, funding sources, foreign exchange rates, and inflation rates which impact performance and directly affect policies with long-term implications [26]. The 'Social' factors examine the people and communities, and consider issues such as cultural trends, demographics, indigenous people's perceptions, social awareness etc. The 'Technological' factors refer to niche innovations like automations, technological transfer, research and development which may transform or replace existing technologies for industrial or societal operations. The 'Legal' factors include jurisdictional laws that affect the society and industries, which may include factory rules, consumer laws and safety standards. The 'Environmental' factors are landscape issues of global concern such as climate change, natural disaster, and sustainable settlement issues [22, 26].

2.2 The study area

This study adopted the case study approach, with Nigeria as the case site. Nigeria with a population of over 200 million, being the largest economy in Africa and the largest emitter of GHG in the continent [7], has a leading role to play in the achievement of the goals of the Paris climate agreement in this region. Nigeria's concern with climate change is complicated by the fact that her economy is dependent on fossil fuel while her internal energy consumption is highly dependent on the importation of refined petroleum products [2]. This makes it difficult for the country to decouple emissions from economic growth trajectory. With the recent price fluctuation in global oil market due to the Russia-Ukraine war and other factors driving the global energy demand, the Nigerian economy has become vulnerable to external macroeconomic conditions. Nigeria's national GHG net emissions based on the year 2015 data stands at 712,638 Gg CO_2-eq all derived from the agriculture, forestry, and other land uses (AFOLU); energy, industrial processes, and product use (IPPU); and waste [27]. The leading sector is AFOLU with 476,949 Gg CO_2-eq (66.9%) of total emissions. The energy sector ranked second with 28.2%, while waste (3.0%) and IPPU (1.9%) ranked third and fourth respectively [27]. Concerning the direct GHGs, CO_2 dominates with 82.3% of the emissions, followed by CH_4 (12.4%) and N_2O (5.3%). Nigerian government has embraced actions for GHG mitigation necessary to contribute to the goal of maintaining the global temperature to below 1.5 °C by 2030. To this end, and in keeping with the country's NDC, Nigeria has identified some pathways to reducing GHG emissions including investment in renewable energy, and reduction of direct emissions from the energy sector, AFOLU, and oil and gas sector [2]. The country boasts of high renewable energy potentials especially from solar, hydro, biomass, and wind energy. She is estimated to have solar energy of about 27 times her total fossil fuel resources, and more than 115,000 times the current total generated electricity capacity [7].

2.3 Methodological approach

The study employed a triangulation of data collection methods to build the historical, theoretical, and empirical bases for the analysis of transition pathway in Nigeria. We engaged in extensive literature review to understand the transition theories relevant to the Nigeria's context and to develop the analytical framework for the study. We carried out document analysis of government policy papers relating to climate change and energy transition some of which include: the National Climate Change Policy (NCCP) 2021 – 2030; the 2050 long-term low-emissions development strategy for Nigeria; the Nigeria's updated NDC – 2021; the Nigerian Climate Change Act (NCCA) 2021; the Nigeria National Adaptation Plan (NAP) framework 2020; and the National Renewable Energy and Energy Efficiency Policy (NREEEP) 2015. Through the document analysis the study identified key low-carbon transition strategies and targets and subsisting policy debates; examined both socio-technical and regime level responses; and compared the interim outcomes of these transition policies with our theoretical expectations. The document analysis was conducted using the Multilevel Perspective (MLP). Using this framework, the study classified the low-carbon transition drivers and barriers as factors being propelled by three interrelated forces: the landscape, the regime, and niche innovations. Thereafter, the study aggregated the potential drivers and barriers, and mapped their co-evolutional interaction. The outcome of this analysis was then used to compile a structured questionnaire for the empirical phase of the study.

The survey aspect of the study involved collection of empirical data through structured questionnaire, and expert elicitation. An expert elicitation is a research survey method by which the established views of experts in each field and over a particular subject matter are obtained [28, 29]. It involves obtaining quantitative assessments of indeterminate variables, or qualitative understanding pertinent to a given scientific issue [30]. Expert elicitation has been used in numerous studies on energy transition, climate change and policy [24, 28, 30, 31]. Shostak et al. [32] derived a statistical formula by which the minimum number of experts necessary to participate in a survey may be determined based on the assumption that the necessary number of experts ($N_{experts}$) is defined by an error rate (ε) as expressed in Eq. (1). Assuming an error rate of 5%, we applied this statistical model to arrive at 33 experts who took part in the study. Detailed information concerning the selected experts is contained in Table 4 in Appendix 2.

$$N_{experts} = 0.5(3/\varepsilon + 5) \quad (1)$$

The study combined two different Expert Elicitation methods: in-person interview and self-administered web-based survey. We utilized the opportunity of the stakeholders' policy review conference and workshops organized by the Department of Climate Change, Federal Ministry of Environment Abuja, Nigeria in September, and November 2022 to select the experts. The selected experts were trained on the theoretical background of the study to understand the meaning of the different socio-technical levels of the MLP framework (regime, niche, and landscape), and how it applies to low-carbon transition. Following that, a semi-structured interview was conducted which required the experts to identify and list among others:

a. The potential drivers of low-carbon transition which are associated with the regime, niche, and landscape levels, respectively.
b. The barriers to low-carbon transition which are associated with the regime, niche, and landscape levels, respectively.
c. Existing policies for low-carbon transition in Nigeria and discussion on the state of their implementation.
d. To make a comparison of the energy transition process in Nigeria with other countries in the region.

Based on the interviews, we refined the potential drivers and barriers to carbon neutrality and reviewed other variables of energy transition identified through the MLP analysis. A structured questionnaire was designed which contained exhaustive lists of existing policies, potential drivers, and barriers to low-carbon transition with their corresponding assessment protocols based on probability trend and uncertainty. The self-administered web-based survey was based on the structured questionnaire. The Expert Elicitation survey was conducted following a seven-step procedure (see Appendix 3).

The results of the surveys were then fed into the PESTLE framework in other to operationalize the MLP and ascertain the relative strength of the potential drivers and barriers of the low-carbon transition process. After that, we used the results of the PESTLE analysis to construct an Impact/Uncertainty Grid (IUG) to ascertain the combined effects of the interactions between the potential drivers and barriers, and to build scenarios that best describe the transition pathway on-going in Nigeria. The IUG is a two-dimensional matrix by which potential impacts of elements are plotted against their uncertainties to determine the factors that constitute predetermined trends and critical uncertainties in other to form scenarios [33]. Ideally the result is a graphical pattern, showing relevant factors spread over the entire range of the axes. The IUG clusters the relevant factors into secondary elements, predetermined trends, and critical uncertainties. Secondary elements exert low impacts and low/moderately high uncertainties and are therefore mostly ignored in building scenarios [33]. Critical uncertainties have a high impact and are therefore the most crucial factors as well as the most difficult to manage. The Impact/Uncertainty Grid was done by plotting the Expert Elicitation (EE) scores of the potential drivers against barriers of the same score. The potential drivers which had no corresponding barriers (and vice-versa) were independently plotted in the matrix (Fig. 3). The green vertical and the red horizontal grids which divided the matrix into 4 quadrants represent the global (overall mean for the EE scores of the potential drivers and barriers, respectively. The 1st and 2nd quadrants represent the secondary elements; the 3rd quadrant represents the predetermined trends, while the 4th quadrant represents the critical uncertainties. The final task of the IUG was to identify meta-categories by looking for commonalities among the critical elements. We grouped the elements in the trends and the critical uncertainty regions into meta-categories to form scenarios based on the transition pathway/context they represent.

3 Results and discussion

3.1 MLP analysis of the drivers and barriers to carbon neutrality in Nigeria

Using the MLP, the study identified the potential drivers and barriers to carbon neutrality based on three analytical levels: the regime, niche, and landscape (Table 1). The results are presented along the three analytical levels in the following sections.

3.1.1 The potential drivers and barriers at the regime level

i. Renewable energy resources (RD1). Nigeria is rich in renewable energy resources in the areas of solar energy, hydropower, biomass-to-energy, wind energy, and biofuel. The Nigerian Concentrated Solar Power (CSP) potentials is valued at 36,683 MW; Photovoltaic (PV) solar power (492,471 MW); hydropower (12,220 MW); small hydro (735 MW); wind energy (36,683 MW); and biomass (7,291 MW) [18]. This is massive and can deliver enough energy to cater for the entire West African region if exploited sustainably. The Nigeria updated NDC plans to generate 30% of on-grid and 13 GW of off-grid electricity from RE, while phasing out diesel and gasoline power generators by 2030 [6]. Studies elsewhere have also identified RE resources as primary drivers of low-carbon transition [10, 34].
ii. Efficiency in energy use (RD2). Pursuing energy efficiency through improvement in the energy system – generation, transmission, and distribution, including better marketing options is Nigeria's key priority in the energy sector. Nigeria's NDC energy sectorial plan shows that improving on the present state of energy efficiency in all sectors of the economy to 2.5% per year, could result in a 40% reduc-

Table 1 Potential drivers and barriers to carbon neutrality in Nigeria

Sociotechnical Level	Potential drivers	Barriers
Regime level	RD1- Renewable energy resources RD2 – Efficiency in energy use RD3 – Compliance with UNFCCC requirements	RB1- Poor governance support RB2- Weak policy implementation RB3- Strategic interest RB4- Poor articulation of Landscape pressure RB5- Dependence on external funding RB6- Extreme Poverty RB7- Volatile international oil prices RB8- Policy inconsistence RB9- Energy poverty RB10- Energy Subsidies RB11- Data transparency RB12- Biomass economy RB13- Management of the energy system
Niche Level	ND1- Strong niche market demand ND2- Existence of RE centres ND3- Employment opportunities RE tech ND4- Potentials for Carbon sink/ NBS	NB1 – Expensive/complex RE technologies NB2- Weak infrastructural base NB3-Technology transfer/capacity building NB4- Gas flaring
Landscape Level	LD1- Global Climate Fund	LB1- Climate Change Impact LB2- Population growth LB3- Carbon tax LB4- Weak climate governance LB5- Global disinvestment in fossil fuel

tion in total energy consumption by 2030 measured in terms of energy intensities, hence contributing to significant reduction in GHG emission [7]. The drive for energy efficiency in Nigeria is presently hinged on energy cost management. To maximize the potentials of these factors, there is the need to adopt more energy efficient technologies as well as energy efficient housing designs and neighbourhood architecture [10].

iii. Compliance with the UNFCCC requirements (RD3). The UNFCCC requirements – ratification of the Paris agreement, submission of the NDC, preparation and submission of long-term low emission plan, and the passage of national climate change law have all been complied with by Nigeria. This puts the country in an advantageous position to negotiate for climate assistance at the international arena [2]. But timely implementation of these instruments is a big challenge for the nation [6]. While agreeing with this view, Amo-Aidoo et al. [35] noted that current global climate change mitigation programs in Ghana and most other countries that are party to the UNFCCC have not been able to meet the Paris agreement's targets.

Some barriers have been identified with the regime level of carbon neutrality in Nigeria and they are as follows:

i. Poor governance support (RB1). The private sector has been identified as main drivers of energy transition [36]. In Nigeria, there is poor governmental support to the private sector for carbon neutrality [6]. There are no incentives in place to drive green investment, and this makes it unattractive to private investors. In line with this thought, Ahmed [37] observed that the success of any pathway towards achieving global climate targets will not depend solely on global geopolitics, but rather effective governance support within national development priorities, and directed to broader private sector and community participation.
ii. Weak policy implementation (RB2). Governments in this region create good policies but are most times deficient in their implementation [6, 38]. Nigeria's low-carbon policies are yet to be mainstreamed into the national budgeting system making their implementation unsustainable [6, 39]. Most other African countries grabble with weak climate policy implementation due to lack of political will, corruption, and funding inadequacies [5, 40].
iii. Strategic interest (RB3). Gas has been identified as the transition fuel in Nigeria [41]. The strategic interest of Nigeria is the continuous investment in fossil fuel exploration to drive development in other energy sectors, and this contradicts the nation's policies on carbon neutrality [6]. The national energy master plan 2014 and the Nigeria Petroleum Industry Act (PIA) 2021 make provisions for massive investment in new petroleum and gas explorations [41]. There is the need to harmonise the nation's strategic interest on energy transition with global climate change initiatives.
iv. Poor articulation of landscape pressure (RB4). Nigeria appears not to have properly articulated the balance between the country's developmental needs to meet rapid population growth and the need to reduce unemployment and poverty with her drive for carbon neutrality [11]. The effects of other landscape pressures like fluctuating global oil prices, international conflicts like the Russia – Ukraine war, global pandemic, etc. are not always properly forecasted and mainstreamed into national policies and plans. Landscape pressures must be properly articulated in strategic planning to achieve the SDGs. Some of the Landscape pressures are disruptive in nature and have the capacity to destabilize regime efforts at both national and global scale.
v. Dependence on external funding (RB5). The Nigeria energy transition plan is estimated to cost USD1.9 trillion to achieve carbon neutrality by 2060. Greater part of this fund is expected to come from global climate funds which have proved unreliable over the years [42]. As different nations work to meet their mitigation and adaptation goals, the Climate Technology Centre and Network (CTCN) was set up by the UNFCCC as a key institution to help nations achieve their commitments under the Paris agreement [43]. The CTCN has already received 160 requests for financial and technical assistance from countries including Nigeria. The US and a group of other countries announced a pledge of USD23 million in November 2021 to support the CTCN initiative to deliver tailored technical assistance to developing countries [43]. The developed nations have yet to fulfil their pledges to the CTCN, as well as their obligations to the international climate fund, and this is adversely affecting climate mitigation and adaptation programs in developing countries, Nigeria inclusive.
vi. Extreme poverty (RB6). Nigeria's year 2022 budget was implemented under a 37% deficit, which was

funded through domestic and foreign loans, pushing the debt profile higher, up to N45 trillion by the end of 2022. The country lacks the financial capacity to implement her amended NDC pledges which is estimated to cost USD117 billion by 2030 [44]. Poverty is very endemic in Nigeria with 133.1 million Nigerians declared poor in 2022 [42], and more than 40% of the population living below the poverty line [45]. The SDG 7 speaks to universal access to affordable and reliable energy. Within the context of current RE costs, over 50% of Nigerians cannot afford RE solutions. Ali et al. [46] also identified poverty as a major barrier to green economy implementation and consequent low-carbon transition in Ghana. Poverty is both a cause and effect of climate change [5]. The poor are often forced to engage in unsustainable exploitation of natural resources (like illegal felling of trees for charcoal production) when their livelihoods come under intense pressure.

vii. Volatile international oil market (RB7). Fluctuation in oil price at the global stage increases investment risks in the energy sector and creates instability and unpredictability [47]. Nigeria's economy is highly dependent on oil exploration. Though oil exports account for only 13% of the GDP, it also accounts for 95% of foreign exchange earnings, and generates over 80% of the national income [12]. Nigeria experienced deep economic recession in 2016 with the GDP declining by -2.2% because of sharp drop in global oil prices [48]. Zhao et al. [10] also observed high dependence on fossil fuel as a major barrier to China's drive for carbon neutrality by 2060.

viii. Policy inconsistence (RB8). Favourable policy instruments drive energy transition [36]. Policy inconsistence has been observed in the energy transition sector in Nigeria, arising from conflicts in different instruments such as the Nigeria climate change Act 2021 and the petroleum industry Act 2021, and the national energy master plan as against Nigeria's finale NDC. Currently, Nigeria does not generate much electricity from coal but the recent energy policy has included coal as target energy source, with plans to revitalize the coal mines [49]. There are also lots of contradictions between the final NDC claims and the 2022 and 2023 Appropriation Acts, as there appears not to be clear plans and reasonable financial allocation for RE developments in the Appropriation Acts.

ix. Energy poverty (RB9). Nigeria has vast energy resources with oil reserves of about 35 billion barrels, gas reserve of 5.8 trillion M^3, and 21 million Tonnes of bituminous coal reserves, including anthracite [2]. The country also has about 13,000 MW power generations installed capacity, but only delivers an actual capacity of less than 5,000 MW due to poor maintenance of generation and transmission infrastructure, and pipeline vandalism resulting to unsteady gas supply and poor power distribution regime among other factors [18]. Despite the enormous energy endowments of the country, access to efficient energy is abysmal. The energy supply per capita is 35GJ, and that is less than 30% of global average [50]. Less than 20% of homes connected to the national grid enjoy up to 12 h daily electricity supply [12]. This has given rise to high dependence on off-grid petrol and diesel-powered generators for most power needs [51]. Bridging the energy gap in Nigeria can hardly be conceived without fossil fuels which are cheaper alternatives as at present time compared to renewable energy.

x. Energy subsidies (RB10). The current energy regime in Nigeria is highly dependent on consumer subsidies. The pump prize of Petroleum Motto Spirit (PMS) is subsidized as the product is mostly imported within the context of rising inflation and fluctuating foreign exchange rate. Nigeria spends about NRN 4.5 trillion yearly on consumer oil subsidies, making it cheaper for the masses than RE alternatives [12]. The projected PMS subsidy in the Nigeria Medium Term Expenditure Framework (MTEF) plan for 2023 is put at NRN 6.7 trillion [52]. Electricity bill is also subsidized, as poor distribution system and low penetration of metered billing have frustrated proper prising. Energy subsidy has discouraged investment in the sector and made RE a non-competitive option [53].

xi. Data transparency (RB11). There is dearth of GHG emission data in Nigeria [36]. Accurate and timely climate monitoring and data acquisition is lacking. Most of the climate policies in Nigeria are based on projections raising doubt as to the veracity of the claims therein [36]. Moreover, the agencies of government involved in climate monitoring often find it difficult to make data available to stakeholders for planning purposes.

xii. Biomass economy (RB12). Biomass is the dominant source of energy in Nigerian rural communities, accounting for over 80% of energy needs [27]. It is a major economic driver sustaining jobs and daily income, and therefore overly critical to the decarbonisation effort. Getting the rural population of Nigeria to transit to RE options will have disruptive implications for their livelihoods; and this is the actual meaning of carbon neutrality for the average rural dweller in Nigeria. Managing this socio-economic deficiency is a big constraint to carbon neutrality especially in Sub-Saharan Africa.

xiii. Management of the energy system (RB13). The existing framework for the management of the energy system in Nigeria is weak, inefficient, and entirely driven by the public sector. The Nigeria National Petroleum Corporation (NNPC) is the major player in the downstream petroleum sector, and their operation is marked by high inefficiency. Though the Nigerian government has recently passed the petroleum industry law which is expected to unbundle the oil industry for private sector participation, misgovernment has made it impossible to operationalize the law almost 2 years after its passage.

3.1.2 The potential drivers and barriers at the niche level

The sociotechnical niche level of the Nigerian economy has some prospects that can drive low-carbon transition. These include:

i. Strong market for niche demand (ND1). The Nigerian population is presently more than 216 million with the annual growth rate of 3.2%, and a projected figure of 402 million by 2050 [2]. This translates to huge demands in the energy sector and other aspects of economic development. Strong demand guarantees the success and faster uptake of niche innovations [13]. Nigeria is the biggest telecommunication market in Africa, with 195,463,898 active voice subscriptions, and 12.61% GDP contribution in the 4^{th} quarter of 2021 [54]. The successes of the Nigerian telecommunication transition speak to the potentials of the Nigerian market for the RE sector if proper policies and the political will to drive them are put in place.

ii. The existence of many universities and research centres (ND2) in Nigeria is another enormous potential to drive niche innovation. The universities are hubs of Research and Development (R&D). They are vital in the process of creating new RE technologies and developing capacity to handle existing ones. The Nigerian government has underscored the need for a robust investment in research and innovation to facilitate energy transition in the country and has taken action to review the operational guidelines of the research centres in the various universities for the purposes of meeting the energy transition objectives of the federal government [55]. For this to yield the required result, the government must fully integrate the universities and research centres to the transition process through proper funding and international technical assistance.

iii. The renewable energy sector holds vast employment opportunities in Nigeria (ND3). The national energy masterplan recognized that employment opportunities in the RE sector can generate over 100 million jobs in 10 years [56]. Studies have shown that the global oil market is witnessing huge demand post COVID-19, and oil producing nations like Nigeria should leverage on it to mobilize needed funds to invest massively in the RE sector [57]. Currently, most of the Nigeria RE projects are in the rural areas providing jobs and off-grid electricity for communities which are not connected to the national grid.

iv. Nigeria has vast potentials for carbon sequestration through nature-based solutions (ND4). The nature-based solutions (NBS) are actions that ensure biodiversity protection and ecosystem restoration, while simultaneously contributing to the attainment of multiple SDGs, including national climate goals, disaster risk reduction, food security, water security, and livelihood [7]. Based on global dataset, Nigeria has an estimated mitigation potential of 115.52 Mt CO_2e/year via selected NBS. The top three NBS for climate mitigation are forest restoration, agroforestry, and improved forest management with a combined mitigation potential of 89 Mt CO_2e/year [7].

The MLP analysis identified four major barriers associated with the Nigeria's low-carbon transition at the niche level. (a) Expensive/complex RE technologies (NB1). The costs of RE solutions are high compared with cost of oil and gas in Nigeria. The initial installation costs for off-grid solar PV for example, is well above the financial capacity of a medium-income Nigerian; thereby making it a non-viable option for households. Requisite technical capacity for the installation and maintenance of RE infrastructure is grossly lacking [8]. For there to be considerable uptake of RE technologies, strategies such as tax incentives, solar subsidies, and promotion of local manufacture of RE systems need to be implemented [35]. (b) Weak infrastructural base (NB2). The infrastructural base for the energy sector in Nigeria is in short supply and obsolete. The refineries for the oil and gas sector are literarily in comatose [9]. Nigeria generates about 13,000 MW of electricity but unfortunately, is only able to evacuate 5,000 MW due to obsolete transmission infrastructure [18]. Poor infrastructural base hinders investment in RE options. (c) Technology transfer/

capacity building (NB3). Nigeria depends on technology transfer and capacity building from developed countries for most aspects of the economy. The Nigeria updated NDC [7] recognized technology transfer and capacity building from international partners as key drivers to realizing carbon neutrality. This is increasingly becoming problematic as the developed nations are either reluctant or slow to transfer innovative technologies and competences to poorer nations [4]. Most developed nations prefer to sell finished technological products and services to nations in the global south. (d) Gas flaring (NB4). Nigeria has an abundant natural gas reserve hence she is recognized as more of a gas than petroleum nation. Gas flaring has been a perennial problem of oil exploration in Nigeria for over four decades, adding billions of Tonnes of GHG to the atmosphere [58]. Nigeria has made several attempts including the enactment of different laws and deadline targets to end gas flaring without success. The Nigeria national energy masterplan increased the penalty for gas flaring from NGN 10 to NGN 5,000 per 1000scf to force oil companies to end gas flaring [59]; and that has been fully captured in the Nigeria PIA 2021, but gas flaring has continued unabated that notwithstanding. There is no way Nigeria can achieve carbon neutrality without first eradicating all sources of direct GHG emission including gas flaring.

3.1.3 Landscape-level drivers and barriers to carbon neutrality

The low-carbon transition process in Nigeria can benefit from the sociotechnical landscape potentials of the global climate fund (LD1). The achievement of carbon neutrality by mid-century requires a substantial ramp up of investments on power infrastructure and its end-use sectors [58]. This requires massive funding which most developing nations are not capable of; hence the provisions of the Paris Accord for USD100 billion climate funds to help developing country parties to deliver on climate mitigation and adaptation goals. This fund if properly administered is an enormous potential for Nigeria and other developing nations to actualize their emission reduction projects. However, the COP26 meeting noted with deep concern in the article 44 of the Glasgow climate pact that the goal of developed country parties to mobilize jointly USD100 billion per year in the context of meaningful mitigation actions and transparency on implementation has not yet been met [60]. This poses a serious challenge to the low-carbon transition process.

The identified Landscape-level barriers to Nigeria's transition to carbon neutrality include the following.

i. Impact of climate change (LB1). Climate change poses major threats to the socio-economic development, the energy system, agriculture, and food security of most Sub-Saharan countries (Adzawla, Sawaneh, & Yusuf, 2019). Climate change impacts have been projected to cost Nigeria 30% of its GDP by 2050, which translates to over USD 460 billion (Ati, 2018). For instance, the flood disaster of 2012 cost the country USD 17.3 billion [2], while the 2022 flood disaster which has been declared the worst in the history of Nigeria affected over 30% of the entire country, resulted to the death of over 600 persons and more than 2 million displaced, with the actual cost yet to be determined [61]. This is an active threat to the realization of Nigeria's carbon neutrality goals.
ii. Population growth (LB2). Nigeria is experiencing rapid growth at the rate of 3.2% with the current population of over 216 million [2]. The country is projected to have a population of 402 million by 2050 which may position Nigeria as the 3rd largest population in the world – behind India and China [2]. Considering the urbanization rate in the country – which is one of the highest in Sub-Saharan Africa [38], this will translate to massive energy demand. Nigeria's urbanization rate in the face of low economic growth and energy crisis will have a disruptive effect on the regime processes for transitioning to a carbon neutral economy.
iii. Carbon pricing and tax (LB3). There is dearth of literature on carbon pricing and tax in Nigeria due to lack off technical capacity for carbon monitoring and measurement [18]. A comparative study of carbon tax regimes in African countries showed a tax of USD 8 per t_{CO2} for Nigeria's oil and gas industry [62], which is insignificant compared to carbon prices in Europe and Asia. Scholars have noted that significant carbon prices, eventually reaching USD100 per t_{CO2} or more, will be required to drive carbon emissions reduction [63]. Daggash and Dowell [18] assessed the effect of carbon tax from the energy sector and projected that the implementation of USD50 per t_{CO2} in Nigeria will result to a significant increase in the deployment of intermittent RE sources. Therefore, ineffective carbon pricing is a deterrent to carbon neutrality. On the other hand, there is the danger that Nigeria's export opportunities may be highly reduced because of barriers that are posed by carbon taxes on imports by developed countries [5].
iv. Weak climate governance (LB4). COP27 held in Sharm el-Sheikh, Egypt in 2022 recognized that parties to the Paris climate pact have not done much to meet expectations and targets. This was also stressed in COP26 held in Glasgow in 2021. Article 5 of the Glasgow climate pact "stressed the urgency of enhancing ambition and action in relation to

mitigation, adaptation and finance to address the gaps in the implementation of the goals of the Paris Agreement" ([60]. 2). Scholars have noted that the UNFCCC lacks the governance capacity to enforce NDC pledges, whereas developed country parties like the US, China, France, and India wilfully block, reverse, or simply ignore the UNFCCC pacts without any possibility of sanction [5, 9].

v. Global disinvestment in fossil fuels (LB5). The overarching implication of the Paris climate pact is that fossil fuels which are major contributors to GHG must be phased out. However, technological advancements notwithstanding, gas (a part of fossil fuel) remains the least-cost option for providing affordable energy in most countries of the world [5]. On this basis, it may be economically unrealistic to expect poor countries which rely heavily on fossil fuels for socioeconomic development to prioritize carbon emission reduction over domestic competitiveness [5]. The call for global agencies to no longer support upstream oil and gas investments through multilateral institutions including the World Bank poses a great threat to many fossils fuel-dependent nations (especially in Sub-Saharan Africa) on their path to economic growth, energy sufficiency, and carbon neutrality [5].

3.2 PESTLE analysis of the drivers and barriers to carbon neutrality

PESTLE framework classified the potential drivers and barriers to carbon neutrality under Political, Economic, Social, Technological, Legal, and Environmental aspects respectively (Tables 2 and 3).

3.2.1 Political factors

The political factors which constitute potential drivers to carbon neutrality are: compliance with the UNFCCC requirements (P1); and the political will to drive transition (P2). Results from expert evaluations (Fig. 1) indicate high scores for P1 ($M=3.5$, $SD=0.6$); and P2 ($M=3.1$, $SD=0.7$) on a 5-point Likert scale. When compared with the global (overall) average ($M=3.7$, $SD=0.6$), P1 and P2 were considered strong factors to drive low-carbon transition. In this analysis, any factor that scores above the global average ($M=3.7$ in this case) is considered a strong factor (Table 2). However, a consideration of the proportion of experts who rated P1 and P2 as strong factors affirmed P1 (62%) as a strong driver of carbon neutrality but rejected P2 (25%). This finding agrees with Ofosu-Peasah et al. [6] who rated institutional dimensions of Nigeria's low-carbon transition high while downplaying the political will of the Nigerian government to drive carbon neutrality.

Nine political barriers to carbon neutrality in Nigeria were examined (Table 3). Amongst the factors, 'policy inconsistence' (P7) and 'weak policy implementation' (P4) scored 'very high' ($M=4.6$, $SD=0.5$), and ($M=4.6$, $SD=0.8$), respectively. Other factors which scored very high on a 5-point Likert scale are: P3—'poor governance support' ($M=4.5$, $SD=0.6$); P10 - 'management of the energy system' ($M=4.5$, $SD=0.8$); P8 – 'energy subsidies ($M=4.0$, $SD=0.7$); and P9 – 'data transparency' ($M=4.0$, $SD=0.5$). The other political factors: P11

Table 2 PESTLE score values for potential drivers

Code No	Potential Drivers of carbon neutrality	Socio-Technical Level	Strength of potential drivers				
			0.1–1.0 Very Low	1.1–2.0 Low	2.1–3.0 Medium	3.1–4.0 High [a]G.A 3.7	4.1–5.0 Very High
P1	Compliance with UNFCCC requirements	Regime				3.5	
P2	Political will to drive transition	Regime				3.1	
E1	Strong niche market demand	Niche					4.4
E2	Global Climate Fund	Landscape		2.4			
S1	Employment opportunities in RE tech	Niche					4.6
T1	Renewable energy resources	Regime					4.8
T2	Efficiency in Energy use	Regime	1.7				
T3	Existence of research/ innovation centres	Niche			3.1		
T4	Availability of Footprint area for RE	Landscape					4.5
L1	Climate Change Act/ policies	Regime				3.7	
En1	Potentials for Carbon sink/ NBS	Niche					4.7
	Total		1.7	2.4	3.1	10.5	23.0

[a] *G. A.* means global average = the overall mean of the scores

Table 3 PESTLE score values for barriers

Code No	Barriers to carbon neutrality	Socio-Technical Level	Strength of the Barriers				
			0.1–1.0 Very Low	1.1–2.0 Low	2.1–3.0 Medium	3.1–4.0 High G.A 3.9	4.1–5.0 Very High
P3	Poor governance support	Regime					4.5
P4	Weak policy implementation	Regime					4.6
P5	Strategic interest	Regime				3.2	
P6	Poor articulation of Landscape pressure	Regime			2.9		
P7	Policy inconsistence	Regime					4.6
P8	Energy Subsidies	Regime				4.0	
P9	Data transparency	Regime				4.0	
P10	Management of the energy system	Regime					4.5
P11	Weak climate governance	Landscape				3.3	
E3	Dependence on external funding	Regime					4.6
E4	Volatile international oil prices	Landscape					4.6
E5	Carbon tax	Landscape				4.0	
E6	Global disinvestment in fossil fuel	Landscape					4.5
E7	Cost of RE solutions	Niche					4.9
S2	Extreme poverty	Regime					4.6
S3	Energy poverty	Regime					4.7
S4	Biomass economy	Regime					4.7
S5	Population growth	Landscape					4.5
S6	Poor social inclusion	Regime					4.5
S7	Stakeholder participation	Regime					4.7
S8	Awareness of transition	Regime					4.5
T5	Expensive/ complex RE technologies	Niche					4.6
T6	Weak infrastructural base	Niche					4.9
T7	Technology transfer/capacity building	Niche					4.1
T8	Retrofitting old Energy systems	Niche					4.4
L2	Domestication of climate change Act/ policies at State/ Local level	Regime				3.7	
L3	Conflicting laws, conflict of interests	Regime					4.1
En2	Gas flaring	Regime					4.6
En3	Climate Change Impact	Landscape					4.6
En4	Deforestation	Landscape					4.7
	Total		0	0	2.9	22.1	105.0

- 'weak climate governance', P5 - 'strategic interest', and P6 - 'poor articulation of landscape pressure' all scored below the overall average ($M=3.9$, $SD=0.6$), hence, they are considered as weak barriers. These results were further subjected to expert evaluations, P4 (89%), P7 (82%), P3 (74%), P9 (72%), P10 (70%), and P8 (53%) were all rated as significant barriers to carbon neutrality by the experts (Fig. 2). These findings agree with other studies which identified certain barriers to low-carbon transition in Nigeria and other West African countries. Ofosu-Peasah et al. [6], Alaigba [11], and Dioha et al. [51] all identified policy inconsistence and poor implementation of public policies in Nigeria as barriers to low-carbon transition. Daggash and Dowell [18] observed poor management of the energy systems and lack of requisite data,while Edomah et al. [8] identified local oil subsidies as major barrier to energy transition. The other barriers examined (weak climate governance, strategic interest of the government, and poor articulation of landscape pressure) were all rated 'very low'. These findings slightly differ with other studies which identified ineffective climate governance framework [62], and divergent priorities/strategic interest of the Nigerian government [64] as barriers to energy transition. The variation between

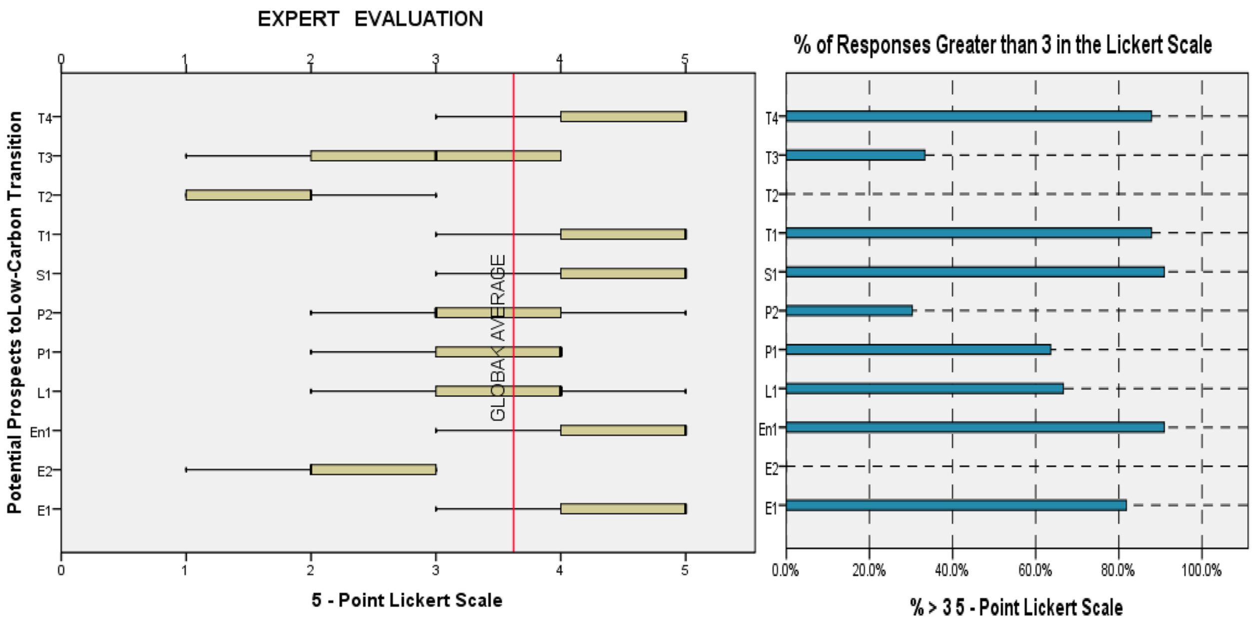

Fig. 1 Expert evaluation of potential drivers

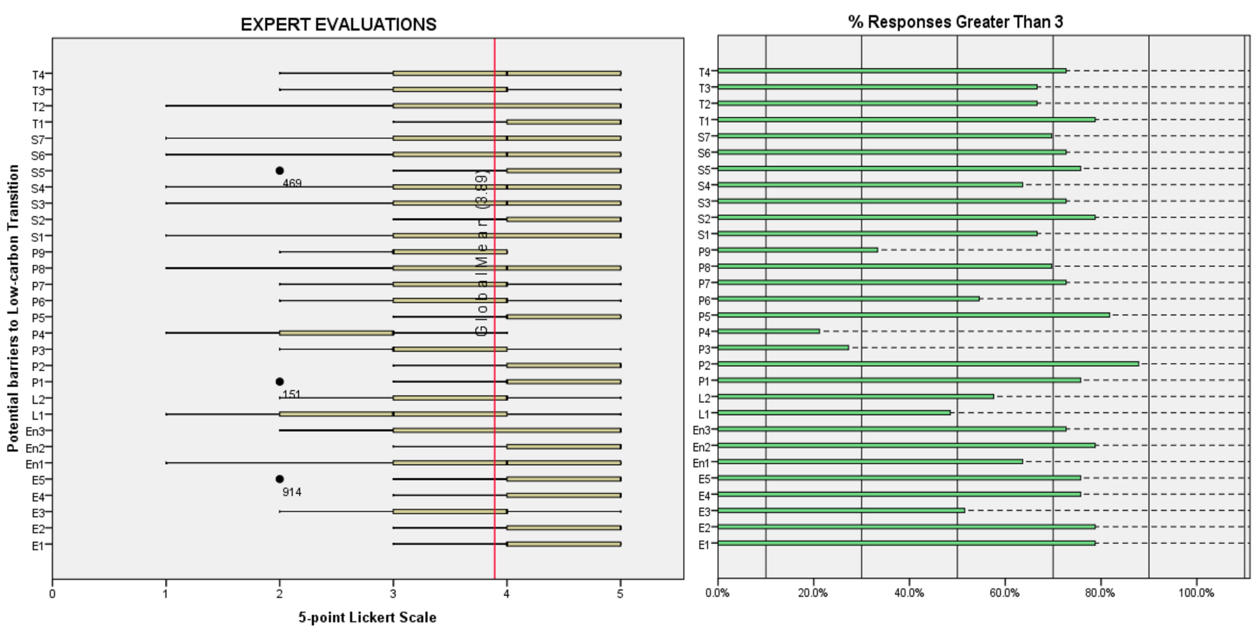

Fig. 2 Expert evaluation of barriers

the findings of these studies and the present one may be attributed to the fact that our study evaluated relative strengths of the identified barriers, whereas the previous studies simply identified those factors without interrogating their relative strengths as barriers to carbon neutrality.

3.2.2 Economic factors

The PESTLE analysis identified two economic factors: ‘strong niche market demand’ (E1) and ‘global green climate fund’ (E2) as drivers of carbon neutrality (Table 2). From expert evaluations, E1 scored ‘very high’ on a 5-point Likert scale ($M = 4.4$, $SD = 0.7$) and was also rated as a strong driver of carbon neutrality by experts (81%), but E2 scored 'low' ($M=2.4$, SD 0.6) with a very low rating (0%) by experts, affirming it as a weak factor to drive carbon neutrality in this region. In line with these findings, some previous studies [4, 35] have underscored the importance of strong niche market demand especially as it concerns emerging technologies in the RE sector as alternative to fossil fuels. The green climate fund was established by the UNFCCC to finance investments in developing countries towards the reduction of greenhouse gas, but studies [65] have noted that access to the fund by developing countries has been particularly challenging. This explains its low rating by experts in driving carbon transition.

Concerning the economic barriers, all five factors investigated scored high, above the overall average (Table 3), ranging from ($M=4.9$, SD 0.3) which was scored by 'cost of RE solutions' (E7), to ($M=4.0$, SD 0.7) which was scored by 'imposition of global carbon tax' (E5). Further analyses show that all the five economic factors (E3, E4, E5, E6, & E7) were rated 'very high' by more than 50% of the experts, affirming that they may constitute significant barriers to carbon neutrality. These findings are in line with different studies in this region. Ofosu-Peasah et al. [6] rated the economic indices of Nigeria's low-carbon transition low, meaning they constitute huge challenge to transition. Amo-Aidoo et al. [35] observed the need for subsidies to reduce the costs of RE solutions and make them affordable to the average Nigerian. Irma [43] observed the unreliable nature of international climate financing and its capacity to derail climate transition in developing countries. The IEA [47] noted that Nigeria's high dependency on fossil fuels coupled with the volatile nature of the international oil market have capacity to undermine the global fight against climate change, exacerbate poverty, and drive more people to unsustainable climate practices. Walsh et al. [5] also observed that global disinvestment in fossil fuels may stifle needed fund to drive energy transition in Nigeria.

3.2.3 Social factors

The major social factor identified as potential driver to carbon neutrality in Nigeria is 'employment opportunity in the RE technologies' (S1) with the score ($M=4.6$, $SD=0.5$). The strength of the factor (S1) was confirmed by expert ratings of 90% (Fig. 1). Other studies [6, 34] have also underscored the huge employment potentials in the RE sector in Nigeria. Seven other social factors: lack of stakeholder participation (S7),the Nigerian biomass economy (S4); energy poverty (S3); high poverty level (S2); low awareness of the transition process (S8); population growth (S5); and poor social inclusion (S6) all recorded high scores as barriers in that order, with the scores ranging from ($M=4.7$, $SD=0.6$) for S7, to ($M=4.5$, $SD=0.5$) for S6 (Table 3). Further analyses show a high proportion of experts ranging from 65 to 79% who rated all the seven social factors as strong barriers to carbon neutrality in Nigeria. Previous studies corroborate these findings. Edomah et al. [8] noted that lack of social inclusion, coordination, and engagements among various stakeholders pose a serious challenge to effective energy interventions that address the needs of people in Nigeria. Furthermore, economic poverty [46], energy poverty [51], and dependence of the greater proportion of the Nigerian populace on the biomass economy [64] have all been identified to constitute major barriers to energy transition in Sub-Saharan Africa.

3.2.4 Technological factor

Four technological factors: 'renewable energy resources' (T1); 'availability of footprint area for RE construction' (T4); 'existence of research/innovation centres' (T3); and 'energy efficiency' (T2) were evaluated as drivers of carbon neutrality in Nigeria (Table 2). Two of the factors (T1 & T4) scored high above the overall average ($M=3.9$, $SD=0.6$) and thus were considered strong drivers while the other two (T3 & T2) scored low and were considered weak to drive carbon neutrality. Greater proportion of expert (>84%) further rated T1 and T4 as strong drivers, while T3 and T2 were rated by insignificant proportion of experts. These findings agree with previous studies [18, 34] which observed that Nigeria's RE resources are massive to deliver enough energy to cater for the entire West African region if exploited sustainably. However, our finding that Nigeria's research and innovation centres are weak to drive carbon neutrality varies with the claims of Omolaoye [55] that the federal government of Nigeria has repositioned the Energy Research Centres (ERC) to drive innovation for energy transition. This variation is so because, experts are yet to see any competitive local innovations from the ERC and the universities for energy transition in Nigeria. On the other hand, four technological barriers: 'weak infrastructural base' (T6), 'expensive/complex RE technologies' (T5); 'retrofitting old energy systems' (T8); and 'technology transfer/capacity building' (T7) scored above the overall average ($M=3.9$, $SD=0.6$) and are consider strong barriers. Greater than 74% of experts rated all the four factors high thereby confirming them as strong barriers to carbon neutrality in Nigeria. These findings are in line with previous studies. Oladipo and Onyedinefu [9] observed that obsolete infrastructures have made the oil and gas sector unable to drive energy transition in Nigeria. Amo-Aidoo et al. [35] observed that the existing RE technologies in Nigeria are costly and beyond the reach of average citizens, requiring significant government subsidies for greater uptake. Edomah [4] also noted that developed countries are less disposed to transferring new RE innovations and capabilities to developing countries as they are to selling finished products.

3.2.5 Legal issues

Climate change policies (L1) is the only legal factor identified as a driver of transition to carbon neutrality with the score ($M = 3.7$, $SD = 0.5$), which when compared to the overall average and expert rating of 64% hold strong potentials. On the other hand, two factors (conflicting laws/conflict of interests – L3, and domestication of climate change policies at State and Local levels – L2) scored high as barriers compared with the overall average. Both legal factors were further validated by more than 50% of experts as constituting significant barriers to carbon neutrality. These findings align with previous studies [36, 66]. According to the National Climate Change Policy for Nigeria 2021–2030, there are over 23 policy and strategy documents targeted at climate change in Nigeria [27]. These policy documents also created multiplicity of agencies most of which have overlapping functions, making funding and implementation difficult [36]. Regarding collaborative approach towards carbon neutrality, Ati et al. [66] noted that any meaningful action against climate change will require a multi-sectorial approach and coordination as well as the political will to implement the numerous extant policies.

3.2.6 Environmental issues

The major environmental issue identified as driver to carbon neutrality is 'the potentials for carbon sink/nature-based solutions' (En1) which scored ($M = 4.7$, $SD = 0.5$). In agreement with this score, 85% of experts rated En1 as a strong driver of carbon neutrality. This finding also agrees with previous studies. The World Bank Group [67] stated that nature-based solutions can deliver 37% of the mitigation required until 2030 to realise the targets of the Paris Agreement. According to FGN (2021 b), NBS offer the most convenient pathway to addressing the impacts of climate change in a cost-effective manner considering its huge mitigation potentials. With regard to the environmental barriers, three factors: 'deforestation' (En4); 'impact of climate change' (En3); and 'gas flaring' (En2) all scored higher than the overall average, with at least 62% of experts validating the three factors as strong barriers to carbon neutrality. These findings corroborate past studies on the issue. Ofosu-Peasah et al. [6] observed that the impacts of climate change in Nigeria are multi-dimensional, including desertification, extreme heat, and flood. Ominabo [61] noted that the 2022 flood disaster in Nigeria was massive, covering more than 30% of the entire country, and has been described as a huge setback to Nigeria's climate transition efforts. FGN [27] stated that gas flaring is a primary source of GHG emission from the energy sector in Nigeria, which also constitutes second major source of emission next to AFOLU. Scholars have observed that Nigeria needs to completely eradicate gas flaring as a foremost measure towards transition to carbon neutrality [68].

3.3 The Impact/Uncertainty Grid

Having examined the strengths and weaknesses of the drivers and barriers to carbon neutrality following the PESTLE analysis, we constructed the Impact/Uncertainty Grid (IUG) to assess the co-evolutional effects of the potential drivers and barriers and to build scenarios that best describe the transition pathway on-going in Nigeria (Fig. 3). The red horizontal and the blue vertical grids which divided the matrix into 4 quadrants represent the global (overall) average for the expert evaluation scores of the drivers and barriers, respectively. The 1st and 2nd quadrants represent the secondary elements; the 3rd quadrant represents the predetermined trends while the 4th quadrant represents the critical uncertainties. The results show that most of the potential drivers (P1, P2, E1, E2, T1, T2, T3, T4, & S1), with few barriers (P5, & P6) fall within the secondary-elements category. These factors have insignificant impacts in developing the scenario that defines the transition pathway to carbon neutrality. On the other hand, the trend elements (P9, P10, P11, E6, S8, T5, T8, & En4), and the critical uncertainty elements (P3, P4, P7, P8, E3, E4, E5, E7, S2, S3, S4, S5, S6, S7, En2, & En3) have strong impacts in defining the transition pathway. The elements in the critical uncertainty region exert the most important effects in each scenario because they are more difficult to control. Most of the barriers identified in the PESTLE analysis (22 out of the 30 elements) fall within the critical uncertainty category. The identified barriers are more in number than the potential drivers at the ratio of 4:1. This means that the barriers to low-carbon transition play greater roles in defining the current transition pathway in Nigeria. The implication is that, for there to be a transformative change to the drive for carbon neutrality, there must be a significant effort to eliminate the inherent barriers or at least degrade them sufficiently.

The elements in the critical uncertainty region and the trend region were grouped into meta-categories based on the transition pathway/context they represent. Most of the elements examined fall into either of two transition pathways/contexts: the 'reconfiguration pathway' and the 'emergent transformation context' (see Section 2.2). The 'emergent transformation context' considers that the regime depends highly on external funding and technologies while it struggles with poor articulation of landscape

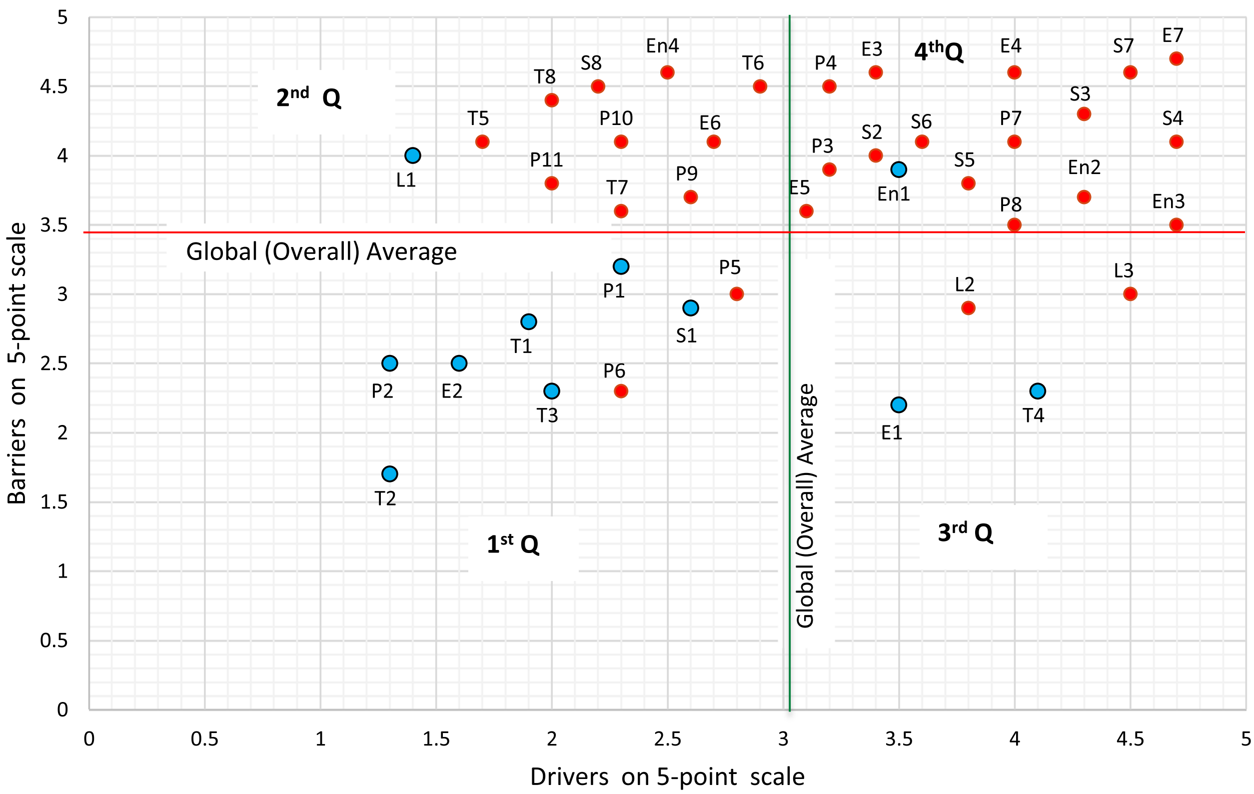

Fig. 3 Dependency structure matrix for drivers and barriers of carbon neutrality

(climate change) pressure and lack of coordination among the regime actors. These regime weaknesses translate to local deficiencies which the 'reconfiguration transition pathway' seeks to supplement through symbiotic adoption of niche innovations. Due to inherent political, economic, and technological deficiencies, Nigeria's transition process to carbon neutrality has symbiotically adopted gas (the basic transition fuel for the country) with RE options.

Thirteen elements from the critical uncertainty region satisfy conditions that characterize the emergent transformation context. 10 out of the 13 elements are issues connected with the sociotechnical regime actors of transition, and they are: poor governance support (P3); weak policy implementation (P4); policy inconsistence (P7); and energy subsidies (P8). Others are dependence on external funding (E3); extreme poverty (S2); energy subsidy (S3); predominance of the biomass economy (S4); poor social inclusion (S6); and lack of stakeholder participation (S7). The remaining 3 elements in this category relate to the sociotechnical landscape, and they are: volatile international oil market (E4); population growth (S5); and the impact of climate change (En3). We also found three other sociotechnical regime elements from the trends region of the IUG which also satisfy the emergent transformation context, and they are: data transparency (P9); management of the energy system (P10); and awareness of the transition process (S8). Two landscape elements from the trend region (global climate fund – E2; and deforestation - En4) also identify with the emergent transformation context.

Three elements from the critical uncertainty region and four elements from the trends region satisfy conditions that are inherent with the 'reconfiguration transition pathway' as follows: carbon tax (E5) and global disinvestment in fossil fuel (E6) which are landscape factors; cost of RE options (E7), complex RE technologies (T5), strong market for niches (E1), and challenges of retrofitting old energy systems (T8) which are niche factors; and gas flaring (En2) – a regime factor. A few other elements are associated with a third transition pathway – the 'reproduction pathway,' and they include: 'compliance with UNFCCC requirements' (P1) and 'availability of RE resources' (T1) which are regime factors; and weak climate governance (P11) – a landscape factor. This transition pathway (the reproduction pathway) was considered inapplicable to the Nigerian context because of the insignificant number of elements associated with it.

3.4 Implications of Nigeria's pathway to carbon neutrality for Sub-Saharan Africa

Nigeria shares common characteristics with most other countries of Sub-Saharan Africa in terms of resource endowment and potentials for transition. For instance, countries like Angola and Equatorial Guinea have significant fossil fuel reserves like Nigeria but also grapple with weak production capacities. Tanzania and Mozambique are fast becoming strong players in the natural gas sector with significant offshore discoveries in recent years but just like Nigeria, they require a lot of investments to leverage on the natural gas sector to achieve energy transition [5]. Regarding the role the solid mineral sector can play in driving transition, countries like South Africa, Democratic Republic of Congo, and Zambia have abundant potentials but are constrained by similar regime inefficiencies and weak niche innovations like Nigeria (Daggash &Dowell, 2021). The Sub-Saharan region by virtue of its geographical location has abundant renewable energy resources like solar, wind, and hydro-energy sources which can drive energy transition. Ecosystem-based resources of the region are equally massive. The vast tropical rainforests such as the Congo Basin (the second-largest in the world) spanning across several countries including the Democratic Republic of Congo, Cameroon, Gabon, and Central African Republic; the Guinea forest of West Africa which cover parts of Sierra Leone, Liberia, Guinea, Cote D'Ivoire, Ghana, and Nigeria; and the Eastern Arc mountains and coastal forests which stretch across several countries including Tanzania, Kenya, and Mozambique are all massive resources for carbon sequestration. Nature-based solutions hold strong prospects as drivers of carbon neutrality across the nations of Sub-Saharan Africa.

Nigeria also shares a lot of similarities with other countries of Sub-Saharan Africa in terms of the socio-technical regime and processes of niche innovation. While these countries contribute little to global emission, they bear greater burden of climate change with impacts of landscape proportion across the region. The political governance in Sub-Saharan Africa is marked by inconsistent policies, weak regulatory frameworks, and a lack of long-term planning which create uncertainties for investors and developers. Socio-economic challenges which manifest in unemployment, poverty, and limited access to education negatively impact transition. High upfront costs of renewable energy technologies are unaffordable for many, while lack of awareness and technical skills hinder their deployment and maintenance. Inadequate energy infrastructure especially in rural areas constitutes a challenge for deploying and integrating renewable energy solutions. Insufficient transmission and distribution networks, grid instability, and limited technological capacity hinder the adoption of low-carbon technologies [40]. The 'emergent transformation context' considers that the regime depends highly on external funding and technologies. Many countries in Sub-Saharan Africa face financial constraints limiting their ability to invest in low-carbon technologies and infrastructure. Their dependence on external funding for energy transition and climate change mitigation has proved unreliable over the years (UNFCCC, 2021). These barriers are common with energy transition in most countries of Sub-Saharan Africa [5], hence, the relevance of the finding from this study to achieving a sustainable pathway to carbon neutrality in the region.

4 Conclusion

This study applied the MLP and PESTLE analytical framework to assess Nigeria's transition pathway to carbon neutrality. Two complementary transition pathways/contexts (the reconfiguration transition pathway, and the emergent transformation context) have been identified to be underway in Nigeria based on the considerable number of their inherent elements which characterize Nigeria's low-carbon transition process. Nigeria's transition pathway to carbon neutrality is characterized by poor articulation of the landscape pressures (specifically, climate change) with an uncoordinated political/local-industrial responses which are heavily dependent on external resources. The regime responses primarily constitute a symbiotic adoption of some niche innovations in the RE sector to supplement gas as the primary transition fuel in other to solve the massive local deficiencies in the energy sector; with the possibility of triggering a complete transition to carbon neutrality in the future. The on-going transition process is typified by few potential drivers and many barriers with critical uncertainty effects. Some of the drivers with strong prospects include Nigeria's potentials for carbon sink/nature-based solutions; huge renewable energy resources; and massive footprint area for RE construction. The study identified many barriers with critical uncertainty effects some of which include: policy inconsistence/weak implementation framework; the dominance of fossil-fuel economy; dependence on external funding; difficulty in retrofitting old energy systems; volatile international oil market; energy poverty; and impacts of climate change. The barriers with critical impacts outweigh the potential drivers at the ratio of 4:1 suggesting that the barriers play greater role in defining the current transition pathway in Nigeria. It therefore means that for there to be a transformative change in the on-going transition process, there must be a significant effort to eliminate the inherent barriers. It is important to note that majority of the identified barriers belong to the regime level while fewer barriers are associated with the niche and landscape levels of the structural domains for transition. Though Nigeria may not have much control over the landscape and niche level barriers, she has the capacity to eliminate or, at least, degrade most of the regime level barriers. There is the need for the country to target and eliminate the identified regime barriers in other to create an efficient pathway that would deliver the low-carbon targets and attain carbon neutrality by 2060. Considering the huge mitigation potentials of Nigeria's vast forests and natural ecosystem for carbon sink, nature-based solutions offer the most convenient pathway to addressing the impacts of climate change in a synergetic and cost-effective manner, and to achieving a timely transition to a low-carbon economy. Policy makers may consider grounds for synergy between energy system management and ecosystem management to drive a sustainable transition to carbon neutrality. The authors, therefore, recommends further study on specific ways by which nature-based solutions can be applied to drive transition to carbon neutrality.

Appendix 1

Transition pathway and contexts

Transition pathway

Scholars have identified five different pathways that transitions can take depending on the mode of interaction of the three elements of the MLP, i.e., either reinforcing or disruptive effects of the landscape on the regime; and either symbiotic or competitive relationships between the niche-level and the regime [14, 69]. The following are the five transition pathways.

a. The reproduction pathway: when there exist niche innovations capable of transforming the regime but there is no sufficient pressure from the landscape on the regime, hence the regime is stable [14].
b. The transformative pathway: when moderate landscape pressure is exerted on the regime, but the niche innovation is in the incubation process, not ready for adoption hence regime actors are left with the option of modifying existing technologies to accommodate landscape pressure [70]. This pathway gives rise to new regimes out of the old through reorientations and cumulative adjustment [14].
c. De-alignment and realignment: when there exists strong and disruptive landscape change while niche innovations are immature resulting in de-alignment and a vacuum on the regime. To fill the vacuum, multiple niche alternatives coexist and struggle for dominance until one innovation dominates leading to the re-alignment and formation of new regime [14, 70].
d. Technological substitution: when disruptive landscape changes exert enormous pressure on the regime while viable niche innovations exist also, then the niche innovation is easily adopted and replaces the incumbent regime [14].
e. The reconfiguration pathway: when a niche innovation is symbiotically adopted by the regime as a supplementary component to solve local deficiencies and barriers, and the innovation triggers further changes in the regime configuration [14].

Transition contexts

Smith et al. [21], realising that niche innovations alone may not provide all that is needed to bring about transition, approached transition pathways from the perspective of the sociotechnical regime. The general submission of these scholars is that radical changes at the regime level are fundamental for a sustainable transition. They conceptualized regime transformation as a function of (i the degree to which regime actors can articulate the landscape pressure on it; (ii the degree to which regime actors coordinate their responses to pressure across the regime spectrum; and (iii the extent to which needed resources for effective transition are available within or outside the regime. Following this, Smith et al. [21] identified four transition contexts as follows.

i. Emergent transformation – this occurs when poorly articulated landscape pressures meet with uncoordinated regime response which depends on external resources.
ii. Purposive transition – these are transitions intentionally engaged to achieve societal interests, but which draw from capacities and resources external to the regime.
iii. Reorientation of trajectory – this occurs when an uncoordinated regime responds to a poorly articulated landscape pressure with regime's internal resources.
iv. Endogenous renewal – this is a transition context whereby regime actors make conscious, well-coordinated efforts to respond to a clearly-articulated landscape pressure using regime internal resources and following an incremental process.

The transition context model with its emphasis on the regime's adaptive capacity, stresses that proper articulation of landscape pressure, coordination of regime capacities, and resource endowments are vital to a successful transition and results in different transition contexts. In this study, we adopted the concept of transition pathways and contexts to examine the low-carbon transition dynamics in Nigeria as to determine the kind of transition in progress and ways of ensuring it is successfully carried through.

Appendix 2

Table 4 Selection of experts for expert elicitation survey

ID code	Sex	Category	Organization	Field of Specialization	Qualification	Position
R01	M	FM	Department of Climate Change, FME	Environmental Engineering	PhD	Deputy Director
R02	M	FM	Department of Climate Change, FME	Physics	PhD	Director
R03	F	FM	Department of Climate Change, FME	Marine Engin	MSc	SRF
R04	M	GA	Office of the National Focal Point to the UNFCCC	Climate studies	BSc	Deputy Director
R05	M	GA	Office of the National Focal Point to the UNFCCC	Law	PhD	Director
R06	M	GA	Office of the National Focal Point to the UNFCCC	Computer Engin	MSc	Executive Sec
R07	M	GA	Nigeria Renewable Energy Agency	Environ Sciences	MSc	Asst. Director
R08	M	GA	Nigeria Renewable Energy Agency	Environ management	PhD	Deputy Director
R09	F	CSP	African Climate Foundation	Mathematics	BSc	Executive Sec
R10	M	GA	Energy Commission of Nigeria	Electrical Engineering	MSc	Deputy Director
R11	M	GA	Energy Commission of Nigeria	Electrical Engineering	PhD	Deputy Director
R12	M	IR	Nigeria Midstream & Downstream Petroleum Regulatory Authority	Petroleum Engineering	MSc	Executive Sec
R13	M	CSP	Nigeria National Petroleum Corporation	Chemistry	PhD	Asst. Director
R14	M	CSP	Nigeria National Petroleum Corporation	Chemical Engineering	MSc	Assistant R. Manager
R15	F	CSO	Civil Society Legislative Advocacy	Law	LLB	Executive Sec
R16	M	CSO	Civil Society Legislative Advocacy	International Relations	BA	Program Officer
R17	M	CSP	Nigeria Liquefied Natural Gas (LNG) ltd	Economics	MSc	Deputy manager
R18	M	RI	Centre for climate change and development, Alex Ekwueme Federal University Ndufu-Alike	Petro-chemical Engineering	PhD	Professor
R19	M	CSP	Renewable energy association of Nigeria (REAN)	Civil engineering	MSc	Executive Sec
R20	F	CSP	Renewable energy association of Nigeria (REAN)	Architecture	PhD	Vice Chairman
R21	M	IR	National Electricity Regulatory Commission	Law	LLB	Senior Legal Adviser
R22	M	IR	National Oil Spill Detection & Response Agency (NOSDRA)	Environmental Sciences	BSc	Executive Sec
R23	M	RI	Shell Centre for Environmental Management and Control (UNEC)	Chemical Engineering	PhD	Professor
R24	M	RI	Shell Centre for Environmental Management and Control (UNEC)	Environmental management	PhD	Professor
R25	M	CSP	Independent Petroleum Marketers Association of Nigeria	Economics	BSc	Manager
R26	F	FM	Federal Ministry of Power Abuja	Electrical Engin	PhD	Director
R27	M	FM	Federal Ministry of Power Abuja	Physics	PhD	Asst. Director
R28	F	CSP	ECOWAS Centre of Renewable Energy and Energy Efficiency	Environmental Engineering	PhD	Executive Sec
R29	M	CSP	ECOWAS Centre of Renewable Energy and Energy Efficiency	Geography	PhD	Senior Data Analyst

ID code	Sex	Category	Organization	Field of Specialization	Qualification	Position
R30	M	AC	Department of Environmental Management Federal University of technology Owerri	Environmental Sciences	PhD	Professor
R31	M	AC	Department of Environmental Management Federal University of technology Owerri	Environmental Engineering	PhD	Professor
R32	F	AC	Department of Environmental Management Federal University of technology Owerri	Chemical Engineering	PhD	Senior lecturer
R33	M	CSP	Nigerian Environmental Society	Environmental Sciences	MSc	Vice chairman

GA Government agency, *FM* Federal ministry, *CSP* Corporate service providers, *IR* Industry regulators, *CSO* Civil society organizations, *AC* Academia, *RI* Research institutesAppendix 3

Seven-step procedure for the expert elicitation survey

i. We defined the objectives of the expert survey by aggregating the potential drivers and barriers to low-carbon transition following the MLP analysis.
ii. Selection of experts was made based on the guidance on energy transition stakeholders from the National Energy Master Plan (ECN, Energy Commission of Nigeria, Federal Republic of Nigeria, 2018). Following the guidelines, 33 experts were drawn from different fields including federal ministries, government agencies, corporate service providers, industry regulators, civil society organizations, the academia, and research institutes. Detailed information concerning the selected experts is contained in Table 4 in Appendix 2.
iii. We structured the survey and developed the assessment protocol based on probability trend and uncertainty expressed in a five-point Likert scale.
iv. Experts were provided with detailed background of the study and specific expectations of the elicitation survey.
v. The actual elicitation was then conducted, and experts were provided with feedback about the assessment results, which afforded them the opportunity to revise their assessments.
vi. Individual expert responses were collated and integrated to create aggregate assessment and analysis of the variables of interest.
vii. Result documentation.

Abbreviations

AFOLU	Agriculture, Forestry and Other Land Uses
CTCN	Climate Technology Centre and Network
GHG	Green House Gas
IPPU	Industrial Processes and Product Use
IPG	Impact Uncertainty Grid
MLP	Multilevel Perspective
NAP	National Adaptation Plan
NCCP	National Climate Change Policy
NDC	Nationally Determined Contribution
NNPC	Nigerian National Petroleum Corporation
NREEEP	National Renewable Energy and Energy Efficiency Policy
PESTLE	Political, Economic, Social, Technological, Legal, and Environmental framework
RE	Renewable Energy
UNFCCC	United Nations Framework Convention for Climate Change

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1007/s43979-023-00065-5.

Additional file 1. Questionnaire.

Acknowledgements
The authors sincerely thank the director and staff of the department of climate change Federal Ministry of Environment Nigeria and the National Council on Climate Change for their assistance with policy documents and other materials.

Authors' contributions
CGO conceptualized the study, developed the methodology, coordinated the surveys, carried out data analysis, and wrote the original daft. CCN participated in literature review, document analysis, data collection, data analysis, and reporting. OIO assisted in the surveys, literature review, validation of data, and review of the manuscript. OAF participated in the surveys, data coding and entry, data visualization, and editing of manuscript. All the authors read and approved the final manuscript.

Funding
Open access funding provided by Shanghai Jiao Tong University. No funding was received for conducting this study.

Availability of data and materials
The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests

The authors declare that there are no competing financial interests or personal relationships that may influence the work reported in this paper.

Received: 27 December 2022 Revised: 24 August 2023 Accepted: 4 September 2023
Published online: 19 September 2023

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