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# Transcending energy transition complexities in building a carbon-neutral economy: The case of Nigeria

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A B S T R A C T

Nigeria seeks to transition to a low-carbon economy through the use of renewable energy resources and technologies. However, while some of the Nigerian government's recent policies have emphasized the need for the relative decoupling of energy systems in order to maximize renewable energy, others have concurrently bolstered fossil-fuel power generation as the country's energy system's centerpiece. This paper employs the Long-Range Energy Alternatives Planning Tool (LEAP) and the Announced Pledges Scenario (APS) to evaluate Nigeria's progress toward a carbon-neutral economy. The findings indicate that the transformation to a low-carbon economy offers enormous opportunities for enhanced energy access and the future expansion of fossil fuel infrastructure. Nevertheless, institutional inertia and coordination lapses create barriers within the energy systems, while inconsistent policy priorities and political-economic calculations generate further bias in favor of the currently dominant oil- and gas-based development. Renewable energy will ensure Nigeria reduces its reliance on fossil fuels, but the transition will be fraught with formidable obstacles. Therefore, accelerating carbon neutralization necessitates a suite of energy mitigation pathways at scales that allow for the flexible integration of all energy systems, particularly modern bioenergy and natural gas.

## 1. Introduction

Climate change is unquestionably a 'code red' alert for humanity (Intergovernmental Panel on Climate Change [IPCC], 2018). In 2019, greenhouse gas (GHG) emissions reached 59.1 gigatonnes of $CO_2$ equivalent (GtCO2e), according to the Emission Gap Report of 2020 (UNEP, 2020). The recently released IPCC report reaffirms a temperature increase to 1.1°C, with an alarming rate of temperature rise that could reach or exceed 1.5°C over the next 20 years (IPCC, 2021). In order to limit greenhouse gas (GHG) emissions, carbon emissions are projected to peak in 2030 and then decline precipitously until 2050, when the amount of Carbon Dioxide ($CO_2$) emitted will equal the amount removed (IPCC, 2018). The energy sector (including electricity and heat, transportation, buildings, manufacturing and construction, fugitive emissions, and other fuel combustion) which heavily relies on oil and gas produces the most greenhouse gas emissions, with emissions from energy consumption accounting for a staggering 75.6% or 37.6 gigatonnes of $CO_2$ equivalent (GtCO2e) worldwide in 2019, and heating and electricity generation accounting for the majority of GHG emissions (31.8% or 15.8 GtCO2e) (Ge, Friedrich and Vigna, 2020; Dewar, et al., 2022).

Fossil-fuel-related mitigation action is therefore the most effective method for reducing GHG emissions, and achieving this objective. This is one of the principal commitments of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC), with an agreement to limit the global average temperature to below 2oC or, ideally, 1.5oC, in order to reach the acceptable level by 2050 (UNFCCC, 2020; IPCC, 2018). In accordance with the global climate goal, a significant number of countries have pledged to fundamentally transform their energy consumption and production systems by 2050 in order to accomplish net zero emissions.

An increasing body of research has highlighted efforts to reduce global energy-related CO2 emissions in order to reach the Carbon Neutral (CN) objective (Zhao et al., 2022; Zou et al., 2021; Relva et al., 2021). Carbon neutrality is attained when the amount of CO2 emitted into the atmosphere through economic activities is equal to the amount of CO2 absorbed in carbon sinks such as soil, forest, and ocean through a process known as carbon sequestration (European Parliament, 2019). According to Zou et al. (2021), carbon neutrality is the point at which human economic interference with global climate systems has negligible discernible consequences. Reaching this threshold requires cultural, technological, and energy transformations, particularly the challenge of

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enhancing energy access through the widespread diffusion of renewable energy technologies in a manner that promotes energy security (IEA, 2020; Zou et al., 2021). It involves politics as well (Zou et al., 2021). For example, debates on the topic of CN have centered on its nature and form, and the pace of the process (whether rapid or gradual) especially given the varying energy access challenges of countries in the Global North and South.

We could question whether transitioning to net zero is even necessary, especially for resource-based African countries with low or moderate incomes, such as Nigeria, where government revenues and foreign exchange are highly dependent on the oil and gas sector and where fossil fuels play a predominate role in energy generation. In this paper, we argue that such a transition is necessary and imperative, especially given the vulnerability of these countries to climate change. Even though most African countries, with the exception of South Africa, are generally low carbon emitters and have made negligible contributions to climate change, they "stand out disproportionately as the most vulnerable [countries] in the world" (UNEP, 2022). According to the UNEP (2022), "in West and Central Africa, climate change is manifested in the form of rising temperatures, droughts, and destructive floods, which have a significant impact on the well-being of the population." The number of cyclones in the Sahel region nearly doubled between 2015 and 2020, and climate hazards in this region exacerbate gender inequality, food and water scarcity, forced migration, and resource conflicts such as violence between farmers and herders, which have been on the rise in some of these countries over the past decade (UN Humanitarian, 2021). Decarbonizing Africa's energy systems will not only stop the catastrophic effects of climate change, but it will also foster the development of renewable energy systems that will increase the continent's access to electricity and stimulate economic competitiveness and growth.

In light of the urgency of the climate crisis, African nations should prioritize the transition to net-zero emissions by utilizing their abundant natural resources to generate renewable energy. Therefore, the crucial question is not whether the transition to carbon neutrality is necessary, but rather which path is optimal for attaining this goal. Given the global nature of the climate crisis, is there a singular path that all nations should follow, despite their varying energy access situations, degrees of economic reliance on fossil fuel revenues, and access to finance for renewables investment? For instance, African governments have proposed a carbon-neutral future based on gas as a 'transition' resource, contending that this will allow them to simultaneously improve their energy access and security while combating climate change (Harvey, 2022).

However, opponents of the continued use of fossil fuels argue that "gas exploration and gas-fired power infrastructure in Africa are robbing [the continent] of crucial time to switch to clean energy" and that fossil fuel development has negative environmental and livelihood repercussions for the locals, despite the fact that these fuels are exported rather than used for domestic energy generation (Nakate, 2022). It has also been argued that continuing gas investment or development by African countries is a wasteful endeavor that will overstretch the economies of most of these countries and may result in stranded assets, which are defined as "those assets that at some point prior to the end of their economic life (as assumed at the investment decision point), are no longer able to earn an economic return..., as a result of changes associated with the transition to a low-carbon economy" (Carbon Tracker, 2017).

Such divergent perspectives on energy transition are a source of stalemate in both policy circles and international climate negotiations. Reaching the threshold at which the net CO2 removal is equal to the net emission can result in unequal transition (Carbon Trackers Initiative, 2017; Relva, et al., 2021) if energy access declines so drastically that the transition risk either exacerbates energy poverty or limits fossil-fuel power generation in low income countries (LICs) (Gimenes, Udaeta, Ashworth & Peyerl, 2021; McCollum, Zhou, Bertram, De Boer, Bosetti, Busch & Fricko, 2018; Carbon Trackers Initiative, 2021).

According to Okoh (2021), the complexity of decreasing the global economy's energy intensity renders the energy transition a carbon catch-22. The primary challenge of energy transition is meeting global climate goals without compromising energy access for countries suffering from severe energy access deficits. Overcoming this challenge is the context of this study, which examines the challenges of decarbonizing energy system in Nigeria through just transition pathways. This work promotes the linkages of energy carriers in the transition process and seeks to establish long-lasting CN attainment structures in Nigeria with the goal of ensuring technological shifts to prevent climate change and reduce energy access shortfall.

This study compares favorably to other longitudinal studies on achieving carbon neutrality, such as Yang et al. (2021) investigation of the complex relationship between energy consumption and structural adjustment in China's pursuit of carbon neutrality. This study concurs with Yang et al. conclusion that countries must implement mitigation measures in order to achieve carbon neutrality, and that these measures must be implemented under reasonable economic conditions that do not compromise their economic growth potentials. In addition, these studies concur that an increase in energy consumption is necessary to meet the energy needs of a growing population, although they differ significantly regarding the changes required. For example, we highlighted Nigeria's use of gas as a bridge fuel to ensure economic competitiveness and a smooth transition, whereas Yang et al. emphasized the importance of structural change in China's energy consumption.

In a similar vein, Pe˜na et al. (2022) examines various temperature scenarios, such as the Gradual Transition Scenarios (GTS) and the Rapid Transition Scenarios (RTS), as a vehicle for energy transition in an effort to identify environmentally friendly means of achieving carbon neutrality in Mexico. Based on the objective of reaching 87103 Mt CO2 in 2050 by prioritizing Renewable Energy Sources (RES), enhancing energy efficiency improvements, and phasing out the use of coal, their study concludes that the RTS scenario is the optimal pathway for achieving carbon neutrality. Similarly, this article uses the Announced Policy Scenario (APS) to examine progress towards reaching net zero by 2060. However, the papers differ in that Pea et al. emphasized the phasing out of coal in Mexico, whereas our paper agrees that Nigeria should gradually 'phase down' rather than 'phase out' petroleum resources. The ultimate objective of reducing the energy intensity of these economies is the point of convergence for both studies, while both nations face the threat of stranded assets.

### *1.1. Reframing carbon neutrality in Nigeria*

Nigeria's long-term climate objectives are to limit the economy's carbon intensity, generate new impetus for the establishment of a new energy-efficient system, increase power generation, enhance energy sufficiency, and capitalize on new business opportunities prompted by global decarbonization (Federal Government of Nigeria [FGoN], First Biennial Update Report [BUR1], 2018; FGoN Third National Communication [TNC], 2020). Accordingly, the primary goal of the 2050 Long-Term Vision (LTV-2050) is to guarantee that transition enablers expand access to energy, boost energy security, and slow the accumulation of carbon dioxide through environmentally friendly technologies that can reduce carbon intensity and scale up low-carbon solutions.

Yet, Nigeria's energy transition objective is not linear, as the country's policies also target high-carbon electricity generation sources, as evidenced by the recently enacted Petroleum Industry Act (PIA), which outlines the government's plan to increase revenue generation by optimizing its hydrocarbon resources. The contradictory policies on energy transition and hydrocarbon production raise the important question of whether the low carbon development policies enumerated in the Nationally Determined Contribution (NDC) and LTV-2050 blueprints are merely rhetorical actions or posturing (Okoh, 2019). This is an important question since the energy transition is subject to competing demands from human progress, technology, the environment, and energy security (Akuru, Onukwube, Okoro, & Obe, 2017, Okoh, 2021).

Moreover, while Nigeria's Zero GHG emission policies are consistent with the extensive energy decarbonization pathway advocated internationally, they have only succeeded in raising the profile of low carbon development on the political stage without securing its implementation on the ground (Osunmuyiwa, Biermann, Kalfagianni, 2018; Nwozor, Oshewolo, Owoeye, & Okidu, 2021). Others contend that the expansion of fossil fuel assets is occurring at the same rate as the decarbonization push, therefore the process of attaining a carbon-neutral future is biassed towards a high carbon emission trajectory, not low carbon development, as has been asserted (Nwozor, Oshewolo, Owoeye, & Okidu, 2021, Okoh, 2021).

On the basis of these controversies, achieving an energy-efficient future while concurrently enhancing energy access has sparked lively debates among energy sector stakeholders. Academic discourse has centered on the potential obstacles that decarbonization-aligned policies can pose to the expansion of energy production (Ojo et al., 2020). Again, it is argued that the line between energy transition and optimization of hydrocarbon is still hazy, and as such, it must be clearly delineated for Nigeria to reach its climate goal (Okoh, 2021). According to Okoh (2019), Nigeria's goal of achieving zero carbon emissions could potentially eliminate the energy access/energy transition/energy security trilemma through supply-side policies that shift the energy emission trajectory towards the 1.5-degree objective in a manner that optimizes both fossil energy assets and renewable energy to increase energy generation.

In other climates, a combination of structural and non-structural measures is proposed as a solution. For example, low carbon technology is gaining traction as a result of the structural shift that is causing a technological revolution. In the majority of High Income Countries (HICs), the widespread implementation of Electric Vehicles (EVs) is one of the routes to carbon neutrality by 2050. For instance, the EU, USA, China, India, and a number of other nations have established deadlines for phasing out fossil fuels through the use of Electric Vehicles. In Africa, Cape Verde has designated 2040 as the date to eliminate Internal Combustion Engine Vehicles (ICEVs) (Gaventa, 2021). In addition, the UN Environment Programme (UNEP), in collaboration with partners such as the Global Fuel Economy Initiative and the Climate and Clean Air Coalition, is supporting the transition to electromobility in 19 African countries, including zero and low-emissions transit systems (e.g., Senegal and Seychelles), Electric Light Duty Vehicles (e.g., Ghana and Mauritius), and Electric two and three wheelers (e.g., Kenya and Rwanda) (UNEP, 2023).

In Nigeria, however, decarbonization is problematic due to a variety of socioeconomic factors and the political entrenchment of the fossil fuel system (Okoh, 2019; 2021). Resolving this carbon impasse is a difficult task given the current trend of UNFCCC negotiations that attach serious urgency to the 'phase down' of fossil fuels (UNFCCC, 2021) as the primary goal of energy transition despite the benefits of oil to fossil-fuel economies and the potential for further inequality between developed and developing economies (Papadis & Tsatsaronis, 2020). In this context, Ojo et al. (2020) discuss how removing hydrocarbons from the energy supply mix could undermine long-term energy access, potentially leading to the disentanglement of public finance from petroleum resources in a situation where the ability to pay for other issues relating to energy generation depends on profits from this industry. Nkoro et al. (2019) explain how the energy transition may affect financial stability in the short term but will not improve macroeconomic stability if political limitations are not resolved. While Okereke (2021) emphasises the relevance of gas in the near future, noting that the sector is critical to improving energy security and efficiency, and that effective energy access needs the use of existing energy resources to create power generation infrastructure.

In light of this, Nigeria's energy approach has as its strategic goal the promotion of eco-efficient development using petroleum resources, such as gas, rather than the elimination of these resources from the country's energy mix. This broadly agrees with McCollum, Zhou, Bertram, De Boer, Bosetti, Busch, and Fricko's (2018) position that limiting the role of hydrocarbons as the primary source of energy will not only undermine efforts to promote energy transition, but can also prevent the achievement of universal energy access as outlined in the Sustainable Development Goals (SDGs).

It has been suggested that energy transition should be bolstered by utilizing available resources, with hydrocarbon progressively phased out while a low-carbon system is developed to promote eco-efficient resource utilization in a way that enables short-term climate change mitigation (Toledano, Brauch, Mebratu-Tsegaye, & Favela, 2020). However, the long-term effects of economic uncertainty include a high transition risk that could impede decarbonization efforts (Okoh, 2021). The gradual 'phase out' of hydrocarbons appears to resonate within the policy community, as the current policy of relative decoupling designed for the energy sector seeks to increase climate resilience but cannot surmount the constraint of insufficient funds. However, this policy's primary drawback is its promotion of contradictory development trajectories, rendering the transition an additional dead end for Nigeria's plan to achieve net zero emissions (Osunmuyiwa, Biermann, & Kalfagianni, 2018; Okoh, 2021).

### 1.2. Aim

Nigeria's revenue levels as a proportion of GDP are one of the lowest in the world, despite the fact that it is Africa's largest economy with extensive hydrocarbon deposits (Aisen et al., 2021). The country relies heavily on oil and gas for 90% of its foreign exchange earnings and 80% of its government revenues in the first quarter of 2022 (Ekeghe, 2022), while non-renewable energy supplies 77% of its power generation capacity (IRENA, 2022). Natural gas plays a significant role in the generation of electricity in Nigeria due to its abundance of fossil fuels. Still, gas flaring is high, with 7.4 billion cubic feet of its associated gas production, or 10% of its gross production, being flared in 2018 (PriceWaterhouseCoopers, 2019). Along with projected population growth to reach 400 million by 2050, energy demands are increasing (The Economist, 2020).

Despite this, Nigeria has one of Africa's lowest energy access rates. In order to meet its development goals, it intends to increase energy production from its vast reserves of fossil fuels. In its long-term plan outlined in Agenda 2060, Nigeria aims to become the world's twenty-first industrialized economy. In order to achieve this objective, the Petroleum Industrial Act (PIA) of 2021 seeks to maximize petroleum resources. However, the effects of climate change are being felt across Nigeria's six geopolitical zones, hindering sustainable development. To overcome this, concerted decarbonization measures in line with the international community's goal of zero carbon emissions are required. Thus, carbon neutrality is at the intersection of a number of complex issues involving climate change, energy security, energy poverty, widening energy access gaps, insufficient power supplies, system losses, aging fossil fuel infrastructures, and potentially stranded assets (Oyewo, Aghahosseini, & Breyer, 2017; Osunmuyiwa, Biermann, & Kalfagianni, 2018; Okoh, 2021).

Various continental and international instruments, including the Sustainable Development Goals, the Africa Union's Agenda 2063, and the Paris Agreement/Glasgow Climate Accord, aim to resolve these problems. Nevertheless, access to energy and energy security in Nigeria has not improved. In recognition of the complexities of constructing a climate-resilient economy in an era of socioeconomic, sociopolitical, and technological change, Nigeria formulated series of policies designed to strengthen energy security while transitioning away from fossil fuels (FGoN, Nigeria Climate Change Act [NCCA], 2021). In Nigeria's 2021 updated NDC, the country committed to reducing emissions by 47% by 2030, with 20 percent of emissions unconditional, and has developed a long-term emision development strategy (LT-LEDS) aimed at achieiving net zero emissions by 2050 (NDC Partnership, 2021). In the LTV-2050, Nigeria proposes ambitious programs for the widespread diffusion of new energy sources, but these require additional technological costs and market incentives to encourage investment in low-emission products. This long-term development vision's ultimate objective is to scale up Nigeria's energy system to increase energy access while simultaneously attaining carbon neutrality (FGoN, LTV-2050, 2021). Nigeria unveiled an Energy Transition Plan (ETP) in 2022, reiterating a commitment made at the United Nations Climate Change Conference (COP26) in 2021, to achieve net-zero emissions by 2060. The ETP requires substantial emission reductions in five essential sectors, namely power, cooking, oil and gas, transportation, and industry, which collectively account for 65% of Nigeria's emissions (Nigeria Energy Transition Plan, 2022). Nevertheless, resolving the dyadic relationship of energy access, energy security, and energy transition is a horror for policymakers, given the financing implications. For instance, as noted in the Nigeria Energy Transition Plan (2022), to achieve net zero by 2060, a total of $1.9 Trillion is required, including $410 Billion above projected normal expenditures. This additional expense amounts to approximately $10 billion per year.

This article investigates this complexity by addressing the following questions, which then enable identifying the most equitable route to a zero-carbon future that will not further strain the vulnerable economy. The questions are:

Q1: Is Nigeria's energy access on track to provide power for everyone in the transition to a carbon neutral world?
Q2: Which peculiar barriers to energy transition make the technological shift an arduous task?
Q3: How can the energy sector shift to a decarbonized polity in which sustainable energy solutions are adequate for all?

In order to answer these questions, the remainder of the study is divided into four sections, expanding on the introduction and context of carbon neutrality in Nigeria. The following section investigates the resources and techniques used to reveal the intricate relationship between energy access and energy transition in the context of achieving carbon neutrality. The second section of the report contains the investigation's findings. In the third component, the study examines the feasibility of the current energy transition regime in order to determine if the roadmap can ensure Nigeria's climate objective is met. The fourth section discusses policy implications, allowing the sixth and final section of the study to reach a conclusion and make policy recommendations for promoting CN despite complex socioeconomic and technical conditions and policy contradictions.

## 2. Materials and methods

### 2.1. Data and data sources

Data in this study are both qualitative and quantitative. Published documents were used to establish the interconnectedness of key variables on inclusive transition to a carbon neutral future. These collated data come mainly from national and international institutions engaged in energy related issues. The initial data are derived from domestic sources, such as the Economic Recovery Plan (ERP), LTV-2050, updated NDC, TNC, and BUR1, and are supplemented with data from international sources, such as the IPCC, World Bank, IEA, and IRENA. These published documents were supplemented by an in-depth interview with energy sector experts.

### 2.2. Methodology

In accordance with the sociotechnical and political contexts of this study, we identified the initial issues surrounding Nigeria's energy transition in order to accomplish our research objective. Then, we conducted stakeholder mapping to identify survey participants who were pertinent. The stakeholders or Key Expert Interviews (KEIs) consisted primarily of Ministries, Departments, and Agencies (MDAs) involved in policy formulation and implementation of energy and climate change policies, as well as private sector practitioners and civil society actors with relevant experience to the study. A total of forty-two (42) KEIs were conducted using the virtual snowball sampling technique, which was used to reduce time for establishing trust between interviewer and interviewee, thereby increasing the degree of confidence to achieve higher response rates (Baltar and Brunet, 2012). Christopoulos (2009) suggests that KEI can be conducted with snowball sampling, and this method is consistent with that suggestion. Different participants proposed other knowledgeable experts/actors for subsequent interviews, allowing for qualitative insight into the problem.

Between 4 December 2021 and 15 December 2021, only twelve (12) preliminary interviews were conducted via Zoom. This allowed us to compile additional queries and contact new participants identified in the initial cascade operation, who in turn suggested additional participants. Between 4 January 2022 and 22 February 2022, interviews were conducted with an additional eighteen (18) samples, and between 23 and 28 February 2022, interviews were conducted with the third and final set of interviewees. The data were subsequently compiled, analyzed, and interpreted using straightforward percentages based on predetermined themes.

### 2.3. Modeling approach

According to the Transforming Energy Scenario (TES) devised by the Energy Commission of Nigeria (ECN) and International Renewable Energy Agency (IRENA), Nigeria anticipates a radical improvement in energy access, with a proposed 30% share of renewable energy by 2030 and a rise to 92% by 2050 (IRENA, 2023). Using historical data derived from the Low Emissions Analysis Platform or LEAP (previously the Long-Range Energy Alternatives Planning system (LEAP), renewable energy opportunities capable of enhancing energy access and reducing greenhouse gas (GHG) intensity were evaluated. This is consistent with the Business as Usual (BaU) strategy and the Low Carbon Development (LCD) program implemented in the Third National Communication (TNC) to the UNFCCC. Taking into account the GHG emission and mitigation pathways of the NDC in order to extend the forecast to 2050 as consistent with the LTV-2050 climate objective, the projection of emissions is extrapolated from the base year of 2015 to 2035, with the projection ending in 2050. The BAU and LCD allowed the study to determine if Nigeria is on schedule to fulfill its climate goal and energy access goals.

The Announced Pledges Scenario (APS) was utilized to analyze various energy transition trends. The APS is the IEA's energy modeling toolkit that determines whether and to what extent a country's proclaimed energy ambitions and commitments, including all low carbon development targets outlined in the NDCs, will result in net zero emissions by 2050 (IEA, 2022). In evaluating the long-term effects of reducing the energy intensity of the economy on energy security, the themes of the interviews are framed by existing literature and data, as well as convergences and divergences of energy transition ambitions and gaps in achieving the 1.5°C climate objective. Based on sectoral mitigation actions envisioned in the updated NDC, the APS assists in establishing each level of energy access and emission reduction targets. This is evaluated against demographic projections for the remainder of the century prior to determining the optimum for achieving Nigeria's 2060 goal of creating a carbon-neutral society.

**Table 1**
Mitigation measures in the energy sector

| Sector | Measure |
|---|---|
| Residential | 48 % of population (26.8 million households) using LPG and 13 % (7.3 million households) using improved cookstoves by 2030 |
| | Elimination of kerosene lighting by 2030 |
| Energy efficiency | 2.5% per year increase in energy efficiency across all sectors |
| Transport | 100,000 extra buses by 2030 |
| | Bus Rapid Transport (BRT) will account for 22.1 % of passenger-km by 2035 |
| | 25 % of trucks and buses using compressed natural gas (CNG) by 2030 |
| | All vehicles meet EURO III limits by 2023 and EURO IV by 2030 |
| Electricity generation | 20 % of electricity from renewables (12 GW additional large hydro, 3.5 GW small hydro, 6.5 GW Solar PV and 3.2 GW wind) |
| | 13 GW off grid solar |
| | Reduce transmission and distribution losses to 8 % in 2030 |
| | 100% of diesel and single cycle steam turbines replaced with combined cycle |
| | Elimination of diesel generators by 2030 |
| Oil and gas | Zero gas flaring by 2030 |
| | 60% reduction in fugitive methane emissions by 2031 |

**Source:** FGoN, Update NDC (2021)

## 3. Findings on energy access and energy transition complexities

### *3.1. Nigeria's energy status*

Nigeria has the second largest proven petroleum oil reserve in Africa (Kamer, 2023) and an estimated 5,848 billion cubic meters of proven gas reserves (OPEC, 2002). Despite these abundant natural resources, access to and production of energy remain low. Nigeria's per capita electricity consumption of 140 kWh is one of the lowest in Sub-Saharan Africa and is almost three times lower than the average for the continent (Enerdata, 2022). Paradoxically, Nigeria's shockingly low per capita electricity consumption is 79% below what its income level alone would predict (Todd Moss and Portelance, 2017). In fact, despite the Nigeria's massive hydrocarbon reserves, the country still has significant difficulties meeting its energy needs. In terms of quality of electricity supply, it ranks 136 out of 137 countries in the Global Competitiveness Report of the World Economic Forum (2017-2018). Although the country is adequately endowed with fossil fuels, wind, solar, and hydro power resources, there are frequent power disruptions and 45 percent of the population lacks access to electricity (World Bank, 2019; (Okoh, 2021).

With the formulation of the REEMP, ERP, and NDC blueprints, various zero-carbon solutions such as solar PV, wind, and Clean culinary ovens have proliferated, and the use of renewable energy is rising steadily. In the updated NDC, the Nigerian government attempts to reduce greenhouse gas emissions by increasing renewable energy generation (Table 1). Other measures to reduce the carbon intensity of the economy include the use of CNG for vehicles and liquid petroleum gas (LPG) for heating, with the development of modular supply units increasing gas consumption from 5,000 metric tonnes in 2007 to 600,000 metric tonnes in 2017 (Banner Energy Limited, 2018; Corfee et al., 2019).

From the Table 1, Nigeria's emission currently at 347 $MtCO_2eq$ should drop by 100 $MtCO_2e$ in 2030 and drastically reduce to 244$MtCO_2eq$ in order to achieve net zero emissions in 2060 (Fig. 1).

From Fig. 1, it is clear that practical decarbonization policies consist of mitigation actions in the energy (transportation) and agriculture sectors, where emissions are most prevalent. Expectedly, the updated NDC mitigation actions to reduce greenhouse gas emissions by 36% by 2030 and 70% by 2050 are not feasible. With total energy-related emissions estimated at 253,892.54 $GgCO_2e$ in 2020 and expected to reach 3,30387.31 $GgCO_2e$ by 2030, reducing emissions by 36% is a monumental undertaking due to the political entrenchment of fossil fuels. Therefore, the transportation transition will play an important role in reducing the energy intensity of the economy. Nigeria may implement the Kenyan paradigm for multi-scale interventions in the energy and transportation systems.

### *3.2. Energy transition implementation*

55% of respondents agree that achieving a net zero emission economy is a continuous process rather than a final state, and that this requires strong policy signals and social constructs to reach the desired goal, whereas 45% believe that the best solution is the promotion of technological and cultural shifts that will result in a gradual transition away from fossil fuels and towards low carbon development. 55% of the participants, however, insist that a hasty transition away from fossil fuels will hinder socioeconomic development. While the proposed actions and measures on transitioning to an energy efficient future (Table 1), such as the Solar Homes Schemes (SHS) of the ERP, are set to connect 5 million homes or 25 million individuals to the solar mini-grid, and the capacity to reach carbon neutrality will be high with the provision of 30 million homes with clean cook stoves based on LPG (FGoN, ERP, 2021; FGoN, updated NDC, 2021), sixty percent and twenty-five percent of the participants are of this view. In contrast, 15% of respondents believe that achieving carbon neutrality is primarily political posturing due to a lack of political commitment to LCD.

### *3.3. Closing the energy transition and energy access divide*

Regarding the current state of energy access and transition, 35% of respondents agree that leveling off energy consumption with cost competitiveness has improved energy access, 60% contend that such leveling has not yet had a significant impact on energy transition, and 5% argue that although cross-sectoral efficiency measures are steadily increasing, efficiency has not yet taken root. In addition, energy demand is expected to increase by more than 50 percent in the coming years (FGoN, BUR1, 2018), while electricity demand is estimated at 40,000 Megawatts. Nigeria has a total electricity generating capacity of 12,522 MW, but on most days it can only distribute around 4,000 MW (USAID, 2022) to its population of over 200 million people. Of Nigeria's total installed generation capacity of 16,384 MW, gas accounts for 11,972 MW, hydro for 2,062 MW, wind for 10 MW, and solar for 7 MW, while diesel and heavy fuel oil (HFO) account for 2,333 MW.

55% of respondents agree that access to solar power (particularly solar Pico devices with a capacity of 1W-10W, Solar Homes Systems (SHS) between 10W-200W, and solar hybrid grids which are part of the mini grid and have a capacity of 1KW-1MW) has increased, and that this has led to a steady increase in the share of low-carbon systems in the total energy supply. In 2018, an estimated 300,000 off-grid solar panels were sold, a significant increase from the 150,000 units sold in 2017. Nonetheless, 45% of respondents cautioned against optimism that electricity access is spreading and that the adoption of solar renewable energy systems will usher in a radical shift in Nigeria's power landscape,

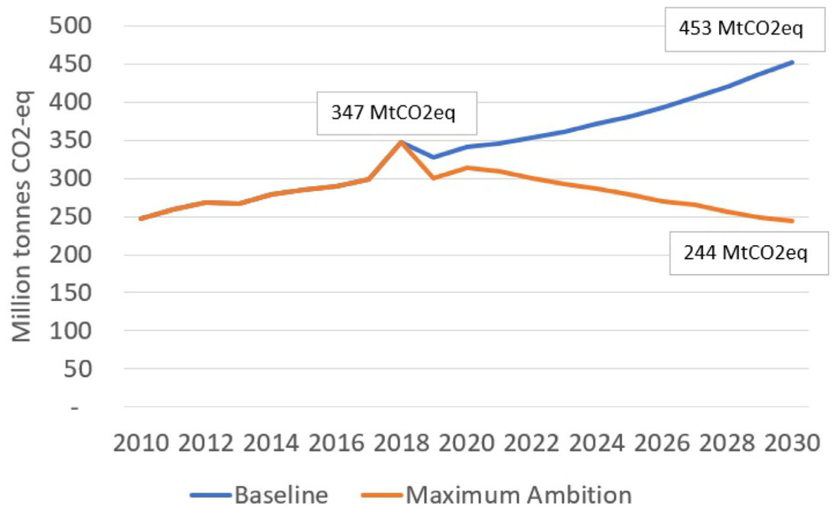


**Fig. 1.** **GHG Emissions in MtCO2eq under BaU scenario (blue line) and conditional contribution (orange line). Source**: FGoN, Updated NDC (2021).

given that Pico devices used at the individual level, rather than government policies or support, are the primary cause of this gradual increase in energy access.

Moreover, Nigeria's abundant fossil fuel resources, especially gas, continue to play a crucial role in meeting domestic and industrial energy needs. Nevertheless, the optimization of petroleum-powered infrastructure has not significantly improved the reliability of connections to the national grid. There are plans to increase the use of LPG/CNG for transportation by 40% by 2030, and 5 million gas-based cooking stoves have been distributed to combat deforestation.

### *3.4. Barriers to energy access and energy transition*

All respondents (100%) agree that implementing Nigeria's energy transition plan will be an arduous undertaking. They argue that while the country has the potential to achieve zero carbon development, there is a wide gulf between low carbon transition policy and improvement in energy access, and the realization of the net zero carbon goals will be hampered by a wide range of technological, socioeconomic, and political issues. Literature has identified barriers to energy access and transition in Nigeria, such as weak institutional capacity, lack of inter-sectoral synergies, high system losses, absence of proper grid infrastructure, supply chain, consistency in regulation and permitting, unfavorable investment climate, cultural bias, and quasi-centralization of energy generation and distribution.

Nigeria's renewable energy circumstances show that distributed renewable energy systems such as mini-grids and off-grid solutions are the most cost-effective means for providing electricity access in rural and remote regions, with the potential to "electrify an estimated 14% of the population and generate annual returns of $3bn for investors by 2023" (Oxford Business Group, 2018), this potential is yet to be realized. Sure, important progress has been made with the launch, in 2019, of a five-year Nigeria Electrification Project (NEP), supported with credit facility from the World Bank ($350m) and African Development Bank ($150m), aimed at incentivizing private sector led off-grid systems development which could solve the problem of electricity access for rural populations, as well as public educational institutions, and underserved micro, small and medium enterprises (Africa Development Bank, 2018; The World Bank, 2018). Another project is the mini-grid acceleration scheme (MAS), with funding support from the European Union (EU) and the German government via its Nigerian Energy Support Program, for the construction of "isolated mini-grids up to 1 MW" in generation capacity to be operated on a commercial, public-private partnership basis (Tsagas, 2019). There is also the *Solar Power Naija*, developed as part of Nigeria Federal Government's Economic Sustainability Plan (ESP) in response to the COVID-19 pandemic aimed at creating 5 million new solar-based connections in communities that are not grid connected through the provision of Solar Home Systems (SHS) or connection to a mini grid (Rural Electrification Agency 2022).

In addition to these government-regulated and subsidized off-grid solar initiatives, Pico devices are acquiring popularity, as previously mentioned. However, despite the progress achieved, only a small percentage of Nigeria's energy originates from renewable sources. So far, 30 operational mini-grids (mostly based on solar PV-Battery, solar PV, Diesel, and only one based on biogas) with 1 MW of installed capacity capable of providing electricity to 6,000 clients have been developed (Zebra et al., 2021), whereas 359 solar mini-grid projects with the potential to provide electricity to 1.1 million people are under development under this scheme. Thus, although ongoing measures have aided the expansion of off-grid energy development, they are still minuscule droplets in the ocean given the country's extreme energy poverty, particularly in rural areas where only 22.62 percent of the population has access to electricity (Hansen, 2021). Indeed, the small proportion of renewable resources in Nigeria's energy blend means that the country will rely heavily on gas as the cornerstone of its decades-long decarbonization endeavor, with some estimates placing the proportion of gas in the energy mix at approximately 85%.

### *3.5. Mitigation pathway to achieve improved energy access and energy transition*

To enhance energy accessibility, energy generation would need to encompass both supply and demand side utilization. All study participants (100%) concur that this would necessitate the coexistence of renewable energy and energy-efficient fossil fuel systems as the primary energy carriers, but a robust bioenergy component is necessary for a low-carbon economy to take root. 70% of the participants agree that enhanced access requires a sustainable bioenergy supply, whereas 30% believe that this will primarily depend on the distribution of innovative technology to reduce the energy intensity of bioenergy sources. Biomass reliance would double by 2050 (IEA, 2009), further impeding the energy transition as revenues from fossil fuels decline in the future. Bioenergy production and use will account for two-thirds of Nigeria's greenhouse gas emissions, as the country's energy demand has increased by more than fifty percent since 1990. The biomass sector is expected to develop exponentially (FGoN, BUR1, 2018), necessitating standardization by means of biofuel technology scaling up. Through carbon tax, grants, and subsidies, fiscal incentives to promote renewables will encourage investors to catalyze carbon neutral emission. The vast majority of study participants (55%) suggested that in order to drastically reduce

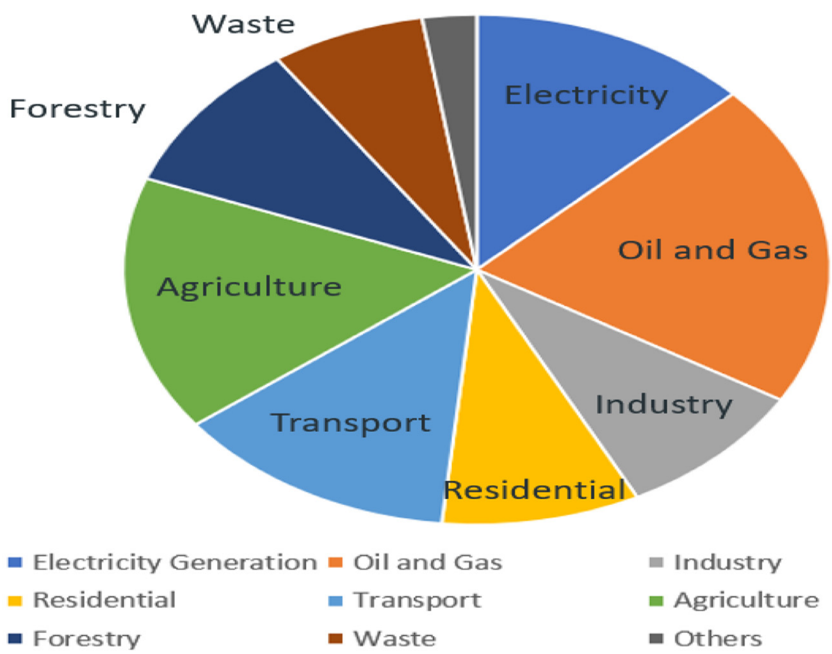


**Fig. 2. Major GHG emitting sources in the economy of Nigeria. Source:** FGoN, LTV-2050, 2022

**Table 2**
GHG emissions under the BaU scenario for year 2020, 2025, 2030, 2035 and 2050

| SECTOR | 2020 | 2025 | 2030<br>Gg $CO_2$ eq | 2035 | 2050 |
|---|---|---|---|---|---|
| **National Emissions** | 683237.73 | 764873.56 | 843200.01 | 966673.69 | 1,039,171.69 |
| **Total Energy Sector** | 253892.54 | 297515.94 | 330387.31 | 3 98993.17 | 698,238.05 |
| **Transport** | 43557.98 | 50698.41 | 59125.31 | 69097.88 | 120,921.29 |
| **IPPU** | 16126.29 | 20581.69 | 26268.03 | 33525.41 | 58,669.46 |
| **AFOLU** | 387306.02 | 417229.13 | 452854.35 | 495740.19 | 867545.33 |
| **Waste** | 25912.88 | 29546.80 | 33690.80 | 38414.92 | 67,226.11 |
| **Manufacturing Industries and Construction** | 14303.58 | 18255.40 | 23299.03 | 29736.212 | 52038.21 |

**Source:** Adopted from TNC, 2020 projections to 2050

industrial emission rates, fossil fuel subsidies that drain the economy's resources should be eliminated, while others (45%) suggested that emission taxes and eco-labels should be incorporated into fossil fuel production and consumption as market-based disincentive policies to force businesses in energy intensive sectors to reduce GHG emissions.

## 4. Discussion

Nigeria is fast urbanizing, requiring additional power generation to meet the growing needs of its young population. Reliance on hydrocarbons will rise, but the share of the global energy supply represented by hydrocarbons will gradually drop. These predictions are set against the backdrop of the projection to reduce emission from high polluting sectors of the economy, as shown in Fig. 2.

Paradoxically, these sectors are also the main growth drivers of the economy, where increase in energy intensity is still required to improve the pace of development. The high energy demand points towards further increases in carbon intensity, equally connected with the high carbon sources needed for electricity generation, as reflected in Table 2.

Energy consumption would double by 30% in the following 13 years (FGoN, updated NDC, 2021). Thus, the gradual uptake of energy efficient products to achieve annual 2% efficiency gains is not really feasible. Indeed, GHG emission under the BaU scenario in 2035 is estimated at 966673.69 Gg$CO_2$eq. Even then, energy transition would still be a major concern as the need for securing additional energy assets to scale up power generation is high, yet the country also plans to cut emission by 36%, as contained in the updated NDC (FGoN, updated NDC, 2021).

With the total energy-related emission estimated at 253,892.54 Gg$CO_2$e in 2020 anticipated to reach 330387.31 Gg $CO_2$**e** by 2030, cutting emissions by 36% as projected would increase the energy access deficit, since the major action to be taken targets fossil energy assets but without the commensurate infrastructure put in place in renewable energy. Moreover, the expectation of providing 30% renewable energy by 2030 in the APS scenario would result in increased energy access, yet implementation constraints mean that the plan to improve the energy supply is yet mere political posturing. To overcome the rising trend, different measures have been elaborated in the updated NDC targeting 2% annual efficiency gains to achieve 30% GHG cuts by 2030, and reach 70% reduction in 2050. This requires adopting the LCD scenario (Table 3), if Nigeria must reach the zero carbon goals.

There is an obvious mismatch between emission reduction target and the energy supply. Evidence of this can be gleaned from the implementation of the plan to improve solar-based power generation in the ERGP and ERP, which is still grappling with implementation problems. Evidence from the BaU scenario also points to the total energy demand of 4,961.3 Gg $CO_2$e, as indicated in Table 3, projected by 2030.

According to the BaU scenario, the total energy demand in the industry sector will double by 2030, reaching an estimated 2,384,5 Gg CO2e. In the most recent version of the NDC, only 30% of energy supply is anticipated to come from renewable energy sources. As a result, the much-desired transformation of the power generation sector

**Table 3**
Energy demand in 2030 (BaU and LCD Scenarios)-CASE A

| Economic Sectors | Business as usual (Million GJ) | Low Carbon Development (LCD) Demand (Million GJ |
|---|---|---|
| Households | 2,139.4 | 1.177.0 |
| Agriculture | 1.7 | 1.1 |
| Commercial | 33.2 | 20.9 |
| Industry | 2,384.5 | 1,833.4 |
| Transport | 400.1 | 244.6 |
| Other Electricity Uses | 1.8 | 1.4 |
| Total | 4,961.3 | 3,278.5 |

Source: Adopted from FGoN, TNC (2020).

cannot occur. To close the deficit in electricity generation with the rest of the world, Nigeria proposes a 2% annual increase in energy efficiency until 2030, when it will have reached a 30% efficiency rate through increased investments in gas-powered electricity generation. The issue with this is that the estimated cost of enhancing electricity from 2021 to 2030, which is $177bn (FGoN, updated NDC, 2021), will cause additional fiscal constraints, rendering the plan to address energy generation and transmission unresolved. As a result, the disparity between energy access and energy transition, which should narrow as a result of the adoption of renewable energy, would widen, as the generated power would continue to be insufficient.

Gas is considered a bridge resource and a climate solution, but its development is fraught with significant obstacles, particularly in Nigeria. A persistent issue is gas flaring, characterized by Chukwumereje Okereke as the “largest single source of climate pollution in Nigeria, contributing approximately 55 million tonnes of carbon equivalent per year” (Adelana, 2022). While the Nigerian government has pledged in its climate change document to eliminate gas flaring by 2030 (FGoN, Updated NDC, 2021), the government’s previous policy commitment records do not inspire confidence that this goal will be met. For instance, since the first legislation to regulate the oil industry through the Petroleum Act of 1969, 10 deadlines to end gas flaring have been missed (Adelana, 2022). It is due to these previously unmet deadlines and other problems such as regulatory weakness to implement policies while government is intensifying fossil fuel production that environmental activists such as Tijah Bolton-Akpan have described the Nigerian Climate Change Act and its emission reduction targets as “a feel-good illusion” with “an energy transition blind-spot” (Adelana, 2022).

In addition to facing this transmission handicap and challenge of relying on gas as the primary energy source, demographic growth would erode the narrow gains in energy access since inadequate provisions for exponential population growth have been made. Though Nigeria is aware of its population growth, the closing of energy access gap is hamstrung by the implementation challenge.

In the APS, Nigeria aims to make energy accessible to 70% of the people by 2020 and 85% by 2030, with the intent of reaching the whole population in 2050. This is not feasible, given the levels of ERGP, ERP, and REEMP that have been implemented. Furthermore, the duration of electricity provided for the people in a day, a major criterion for assessing energy access, is still low. The duration of service from the national grid per day in Nigeria is 6.8 hours (National Bureau of Statistics [NBS], 2020), whereas the cost of electricity at 60.67 Naira per kWh is not affordable to a vast majority of the population. On the basis of this, a vast majority of the people are reliant on other alternatives, notably biomass, for their primary energy supply. Reliance on biomass will be high in 2050, consistent with IEA findings of the doubling of biomass consumption in 2050 (IEA, 2009). A positive development is that the regulation of electricity access is improving with reforms in the electricity sector (Abah, 2017). Still, very few communities have access up to 250 kWh per year in rural households and up to 500 kWh per year for urban households (Okoh, 2021).

Under the APS, the plan to increase energy access to 750 kWh per person, considered the appropriate energy access level, by 2030 (IEA, 2015) is not feasible due to the emergent constraints of stranded assets and lock-in inertia linked with the fossil fuel exit plans of developed economies (Okoh, 2019; 2021). The number of households with reliable and affordable access to electricity that is adequate to supply a basic bundle of energy services will be low. Given the current trend, it is not only inadequate, but also not on track to increase in subsequent years to a significant level to curb energy poverty specified in the IEA and World Bank criteria for effective energy access.

Carbon conversion, emission reduction, and transfer are some of the strategies targeted at achieving carbon neutrality, although many of them are still poorly defined or executed in Nigeria. A move from petroleum to gas for transportation and cooking is part of Nigeria’s NDC, but it has been stalled, and even blocked by institutional and technological barriers. For instance, in 2015 the Federal Executive Council approved the contract for 750,000 cooking stoves and 18,000 wonder bags to span over 5 years which was targeted at a total number of 20m cooking stoves over the contract life span. Yet despite the disbursement of the fund the scheme was not fully implemented (Okoh, 2021). The country also intends to implement Nature-Based Solutions (NBS) to reduce Agriculture, Forestry, and Other Land Use (AFOLU)-based emissions in the updated NDC. However, mitigation strategies for curbing climate risk, such as biofuel production, carbon tax, BECCS, and Carbon Capture and Storage (CCS), have not been fully operationalized.

The long-term phase, consisting of the period between 2035-2050, considered the last stage of the LCD scenario, requires emissions decline after peaking in the medium term by 2030 (NDC scenario) to reach carbon neutral growth. The ideal scenario is the electricity demand estimated at 3,278.5 Gg $CO_2e$ (Table 3), which is realizable with minimal carbon upload recorded. Yet, it is predicted that by 2020, 75% of Nigeria’s population will live in urban areas, and that the country’s per capita electricity consumption, which is currently at 151 kWh per year, should be four to five times higher than the current level, taking into account latent and suppressed demand (FGoN Third National Communication [TNC], 2020).

## 5. Policy implications

Decarbonization strategies, manufacturing techniques, and investment objectives impact Nigeria’s energy system. It has become embedded in political manoeuvring by fossil-fuel interests, owing to the fact that some of the most substantial acts the government might take to address climate change challenges, such as stopping petrol flaring, would run against these powerful interests or political constituencies (Adelana, 2022). Due to a lack of political will, there is a hiatus in implementation. Efforts to attain net zero emissions are also undermined by the inability to conceive a concrete plan for removing excess emissions. The greatest achievement of promoting zero-carbon solutions therefore is raising awareness of the climate risk, which, despite marginally improving environmental quality and drawing more political attention to the decarbonization drive, has not resulted in greater energy access or a reduction in carbon intensity. In the coming years, energy access will increase, but this will have little effect on emissions due to demographic pressures and unsustainable oil and gas production practices, such as gas flaring and oil spills.

Adopting the LCD scenario removes the barrier to energy access, allowing for an accelerated adoption of renewables after 2030 to meet NDC commitments and guarantee energy access for all. This therefore depends on the availability of funds from concessional grants and not primarily from DFI loans. Building a carbon-neutral society requires Nigeria to reorganize its energy production so that bioenergy is optimized for profit in a post-carbon world. Achieving the 1.5°C temperature target necessitates vast quantities of energy- and climate-efficient technologies. This extends beyond the current BaU scenario of energy sustainability rhetoric in the direction of a technological transition in which inclusive bioenergy achieves dominance and national acceptability. Bioenergy penetration can be assured by bolstering the country's biomass sector, but in order for Nigeria to make the most of the potential presented by decarbonization, it must embrace Bioenergy with Carbon Capture and Storage (BECCS) and launch carbon offset and carbon sequestration programmes. To assure energy access and achieve a carbon-neutral economy by 2060, Nigeria should implement the use of gas for industrial and residential purposes as a bridge technology. However, there are impending indicators of fossil fuel's entrenchment, rather than its use as a transition fuel. For instance, despite the fact that the new crude oil discovery in the north of the country in 2022 may appear to be in line with the government's goal of using natural gas as a bridge fuel for the transition to net zero, it serves the political objective of diversifying away from the country's primary oil producing region (Okpanachi, 2017). While diversifying the regional basis of the country's oil production makes economic and security sense, it nevertheless creates a new political economy constituency with a vested interest in the industry that will struggle to keep oil production beyond the period to 2030 that the government has declared as the "Decade of Gas." This has the potential to undermine the country's net zero goal for 2060 if not well managed.

## 6. Conclusion and recommendations

Due to the potential for the escalation of energy poverty if the transition is not managed more strategically, it is economically prudent for a heavily fossil-reliant economy like Nigeria to pursue two inversely related paths toward a carbon-neutral future. The optimization of bioenergy and natural gas as bridging technologies is necessary to close the energy supply and transition gaps. The implementation of Bioenergy with Carbon Capture and Storage (BECCS) will reduce greenhouse gas emissions at a low cost (Vandermel, 2020), but this and the provision of subsidies for other low-carbon technology are yet to be operationalized or gain traction. Transitioning from rhetoric to action, Nigeria must utilize its extensive biomass for bioenergy to meet its rising energy needs and generate additional income. In the updated NDC, Nature-Based Solutions (NBS) with a total potential of 115.52 MtCO2e (FGoN, updated NDC, 2021) will reduce GHG emissions in absolute terms and free up emission reductions from gas-based electricity generation. Due to lock-in inertia, the NDC's policy instruments cannot eliminate the issue of extant industries' supply-side energy generation burden. In many ways, the transition to a future with sustainable energy will therefore require the use of modern bioenergy production. This is contingent upon the improvement of agricultural productivity through loans, reskilling and training in bio-energy development in order to herald in a new era of food security in which bio-energy serves as an alternative to fossil fuels. BECCS is not a magic device for transitioning to net zero, and while BECCS "has the potential to be a valuable step towards a low-carbon energy system," it risks compromising the natural ecosystem and social equity (Pour et al., 2017: 6045). The government must therefore provide an environment conducive to sustainable BECCS practices.

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## Declaration of Competing Interest

None.

## Data availability

Data will be made available on request.

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