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Original research article

Exploring the dynamics of socio-technical transitions: Advancing grid-connected wind and solar energy adoption in Nigeria

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ABSTRACT

Globally, countries are transitioning their national electricity grid system to meet the obligations of the Paris Agreement. National grid-connected renewable electricity provides an opportunity to reduce greenhouse gas emissions. Specifically, in a developing country like Nigeria, renewable energies such as solar and wind power can play a critical role not only in transitioning away from fossil-fuel based electricity systems but also to address prevalent energy security challenges, electricity supply deficit and gaps in energy access. Policies, plans, and strategies to ensure grid-connected renewable energy have been put in place, but these measures have proved ineffective. Likewise, there are limited studies that investigate these transition problems, including drivers and enablers from a developing country perspective. This research fills that gap in knowledge by investigating these transition dynamics through a qualitative approach applying the multi-level perspective framework. Thirty-one (31) key energy and non-energy actors were interviewed, and the transcripts thematically analysed. Findings indicate that there is prospect for Nigeria to transform its electricity system. However, there are major deterrents including institutional, infrastructural, incumbent electricity system instability and economic barriers. The paper highlights that there is a level of regime stability/instability that will enable renewable energy development. In addition, practical and policy insights are offered to overcome identified challenges towards accelerating electricity system transformation. Future studies should also explore the degree of instability, stability and change in developing country settings necessary for energy transition to occur. Finally, this paper advances debates in energy transition and socio-technical system studies.

1. Introduction

Recently, there has been a heightened drive globally to decarbonise energy systems and transition to cleaner energy sources such as solar and wind for electricity generation. Energy transition has become a salient agenda for governments worldwide as they seek pathways to tackle climate change and air pollution [1]. According to the International Energy Agency [2], decarbonisation of the electricity system is integral for energy transition. It plays a pivotal role in combating climate change and reducing greenhouse gases (GHG), which have increased since the pre-industrial era.

Despite these concerns, electricity is still primarily generated from fossil-fuel sources for commercial, industrial (manufacturing) and residential (cooling, lighting, cooking) purposes in many countries [2,3]. It directly links socio-economic advancements and sustainable development in modern societies [4]. To harness these energy services and benefits from cleaner sources, renewable energy technologies for electricity generation, such as wind and solar, have been embraced for mitigating and reducing greenhouse gas emitted into the atmosphere [5] and to boost energy access, security of supply and sustainable development [6–9].

In developing and developed countries, there has been evidence of adverse climate-related outcomes and vulnerability to global warming impacts. Research has indicated that temperature and sea-level rises, increased flooding, drought, land degradation and freshwater challenges which threatens agricultural production, food, and human security as some of the impacts [10–12]. Like so many developing countries, Nigeria is currently (and will continue to be) impacted by challenges due to climate change [13,14]. Also, the current state of energy poverty (access and security), similar to most developing countries, is a

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challenge that would need to be resolved, albeit sustainably, to reduce the expected emissions from fossil-fuel sources and meet international obligations, especially the Paris Agreement. Therefore, a panacea to the Nigerian grid-based electricity system would serve as a direct template for other developing countries that mostly share similar socio-economic and governance structures to Nigeria but in a reduced format due to the lower population density of these countries [15]. Nigeria's potential for both solar and wind has been widely analysed. The country's daily solar density is between 3.5 kWh/m2/day (usually in the south) and 9.0 kWh/m2/day (in the north) [16,17], while the monthly mean speed varies from 4.0 m/s to 5.2 m/s; however, the actual measured data in some areas was as high as 7.0 m/s especially in the north-west and north central [18,19]. Currently, there is no installed wind for electricity in Nigeria and only 112 MW of solar installed capacity (off-grid) [20,21]. Furthermore, based on IRENA's estimates, the total solar PV potential is 210 GW and the potential for concentrated solar power (SCP) is 88.7 GW [17,22].

Despite Nigeria's vast renewable and non-renewable energy sources, only fossil-fuel-based sources have been explored extensively, with 80 % of power generation coming from natural gas connected to the national grid [23]. There are projections that the dependence on fossil fuels will increase as energy demand increases, with Nigeria's population of about 200 million projected to double by 2050 [24]. Aside from reliance on fossil fuels, the country experiences energy poverty and is among the world's poorest in energy consumption because, despite the vast population (6th largest in the world) [23,25], the electricity generated through its network is considerably low. For example, according to IEA [26], the energy consumption for Nigeria was 0.16 TWh/capita compared to 0.9 for Morocco, 1.6 for Egypt and Algeria, 4.0 for South Africa, 4.8 for the UK, 4.9 for China, 6.7 for Germany, 7.6 for Japan and 12.8 for the USA. Hence, Nigeria's energy consumption is one of the lowest in the world, principally due to governance and institutional issues that require urgent resolution.

Recent studies aver that energy security challenges are prevalent, which are in two dimensions: on the one hand, there is an energy access issue in Nigeria, as about 40 % of the nation's population (i.e., approximately 80 million) are without access to power [26]. On the other hand, there are deficits in power supply; the average energy supply of around 4000 MW (peak generation capacity of 5300 MW) is inadequate to meet the current demand of approximately 6000 MW [26]. Furthermore, those connected to the grid have zero (0) to twenty (20) hours of electricity supply daily. Hence, there are incessant power outages and regular grid collapses [27–29]. This has resulted in the large-scale use of fossil-based generators [26] for industrial and residential purposes, which are expensive to maintain and operate and contribute to carbon emissions, noise and air pollution [30]. Also, some industries have had to relocate their operations to neighbouring countries to mitigate the absence of constant power and avoid the high electricity cost. Consequently, these have impeded Nigeria's economic development, prosperity, and quality of life [31–33].

Against this backdrop, Nigeria has created renewable energy policies, plans, strategies, and policy support mechanisms to stimulate the development of on-grid and off-grid renewable energy to address these energy security and poverty issues and tackle climate change. The policies, such as the National Renewable Energy and Energy Efficiency Policy (NREEEP) instituted in 2015, aim to develop renewable energy on the national grid, a centralised system responsible for most of the electricity used in Nigeria. Renewable energy is expected to contribute about 30 % of the 30 gigawatts of proposed electricity generation by 2030 on the national grid [34]. However, despite the measures in place from 2015, novel renewable energy technologies such as solar and wind have yet to be introduced to the natural gas-dominated electricity system, and critical milestones have been missed. This is owing to the complexities and challenges that need to be overcome to develop large-scale solar and wind technologies on the Nigerian national grid system. Nevertheless, the off-grid space, which the Rural Electrification Agency (REA) oversees and has executed renewable electricity projects to contribute to Nigeria's remote and off-grid power development.

Previous studies and literature have discussed energy transition and renewable energy development from a holistic industry perspective or rural electrification/community energy perspective [35–37]. Some authors investigated the hindrance to energy transition in Nigeria from an economic standpoint [38,39] technical analysis of the integration of solar and wind technologies [28] and financial perspectives [40–42]. Several pieces of literature explored the policy and governance domain for green energy systems [34,43] and renewable energy development in Nigeria, such as Akinyele et al. [44] who investigated Nigeria's challenges and policy direction for solar-thermal energy. Similarly, Ogbonna et al. [45] assessed the Nigerian low-carbon transformation using the Multi-Level Perspective (MLP) and Pestel analysis, though from a political context. However, there is scant focus specifically on grid-connected renewable energy technologies development and a need for more analysis from a socio-technical perspective by applying MLP in developing countries context which is a gap this research fills. Most studies in this domain are typically published in developed countries such as the United Kingdom (UK), United States (US) and Netherlands [6,46,47]. The MLP is useful for understanding transition dynamics and serves as a lens to understand transition problems and barriers taking consideration of actors, niche innovation and the specific context [48–52], necessitating studies from a developing country viewpoint. Though the MLP has been extensively applied to assess energy transition process in developed countries, it is still unclear from a developing country's perspective and using Nigeria as a case study, (1) what barriers need to be surmounted for grid renewable energy, in terms of solar and wind, to develop on the Nigerian national grid; (2) what drives grid renewable energy development; and, (3) what are the enablers for solar and wind technologies to be installed on the Nigerian electricity grid?

Various elements, such as economic, technical and financial, policy and governance, have been considered. However, to steer the transition, it is essential to delineate these influences from a socio-technical perspective, constituting major impetuses such as supportive policy design, institutional arrangements, regulatory frameworks, market instruments, social actors, political processes, and technological dimensions, which are critical to understanding energy transition [53–56] and renewable energy development. Furthermore, Nigerian literature has limited socio-technical perspective for renewable energy development, application and analyses. Andersen et al. [57] argued that the speed of transition, including the breadth and depth, needs to be studied to understand the tensions and relationship to obtain lessons learnt especially in the deployment of large-scale systems such as the grid to achieve net zero. While the MLP has gained popularity and application in developed countries, especially in Europe [58], this has been applied only in a few contexts in Nigeria's energy domain (see Osunmuyiwa et al.'s work [59]). Moreover, the applications do not involve conceptualising barriers, drivers, and enablers of energy transition, which are crucial to elicit solutions to accelerate transitions [60]. Hence, this study fills the gap and contributes to the existing literature by exploring these influences; barriers, drivers, and enablers of on-grid renewable energy transition in a developing country context and forms a basis for further investigation in developing countries with similar socio-technical, techno-economic, and political considerations to Nigeria. Barriers, in the context of this study, refer to factors that impede the effective implementation of on-grid renewable electricity strategies. Likewise, drivers are defined as factors that necessitate the development of renewable energy in the Nigerian grid system. In addition, enablers are factors put in place to facilitate and actualise on-grid renewable energy transitions.

From a socio-technical perspective, this study aims to empirically address the gap by applying the MLP to comprehend and analyse the existing dynamics of the uptake of on-grid renewable energy in Nigeria. A socio-technical perspective is selected as it provides a comprehensive dynamic pattern of the interactions between the landscape, regime, and niche levels to understand persistent transition problems. Hence, the research question is: what are the renewable energy strategy implementation barriers, drivers, and enablers on the Nigerian electricity grid?

The sections of this paper are structured as follows: Section 2 describes the Nigerian electricity system and renewable energy development in Nigeria, including policies, with Section 3 introducing the theoretical underpinning of facilitating socio-technical transitions and the MLP. The methodology is outlined in Section 4, where the data collection and analysis process are presented. In Section 5, the results of the empirical investigation are discussed based on the three analytical lenses of MLP (landscape, regime, and niche levels). The conclusion and policy recommendations for stimulating niche technology and accelerating the energy transition in Nigeria are discussed in Section 6.

2. Nigerian electricity system and renewable energy development

2a. Nigerian electricity system

Historically, electricity was first introduced in 1896 in Lagos, more than a decade after the establishment of England's electricity sector [31,32]. Later, other colonies (now major cities) began generating electricity and building individual power stations in silos. Cities such as Port Harcourt, Kaduna, and Enugu were some of the first cities to generate their electricity. They were overseen by the Nigeria Electricity Supply Company (NESCO) and the Public Works Department (PWD). However, as Nigeria developed and the electricity demand increased, these individual cities' power stations were connected to form a grid network to distribute electricity across the country and ensure electricity is enough for those with purchasing power in all cities [32,61]. Hence, the Nigerian grid system emanated from the need to meet the electricity demand in the country. The Nigerian Government Electricity Undertaking (NGEU), a spin-off of PWD, was then established to manage the new grid system but was later replaced with the institution of the Electricity Corporation of Nigeria (ECN), which was vested with authority in 1951 to control and coordinate all electricity operations in the country. The Niger Dams Authority (NDA) was founded in 1962 to oversee the activities of hydroelectric power in the country. By 1972, ECN and NDA merged to become the National Electric Power Authority (NEPA). Therefore, the Nigerian Electricity Supply Industry (NESI) had a vertically integrated structure constituting Generation Companies (GenCos), Transmission Company of Nigeria (TCN) and Distribution Companies (DisCos) as shown in Fig. 1 and was managed and controlled by monopolistic NEPA, statutorily mandated.

By 2000, the electricity sector, which was government-owned, regulated, funded and controlled through the NEPA, was characterised by ineffectiveness, inefficiencies and unreliable services, poor management, frequent power outages, blackouts, low energy access, and increased demand from a growing population [29,62]. Furthermore, the deficiencies were across the value chain (GenCos, TransCo, DisCos), creating an underserved population. Therefore, the inefficiencies and inability of NEPA to fulfil its statutory requirement resulted in the commencement of privatisation and sector reforms to encourage Public-Private Partnership (PPP) through a Public-Private Agreement (PPA). The privatisation encouraged private sector participation and fostered an enabling environment for the electricity market and was enacted by the Federal Government through the Electric Power Sector Reform Act (EPSRA) 2005. This resulted in the unbundling of the Power Sector into six (6) GenCos, a TransCo, and eleven (11) DisCos and restructuring of NEPA, now Power Holding Company of Nigeria (PHCN). The government still owns total stakes in the TransCo and none in the GenCos while keeping 40 % of the DisCos. After the unbundling, a total of twenty-three (23) generating plants are operating, comprising of the former GenCos, the Independent Power Producers (IPPs) – private sector managed power plants, and from the National Integrated Power Project (NIPP) - generating stations built through public sector emergency intervention funding [63,64]. Furthermore, the Nigerian Bulk Electricity Trading PLC (NBET) was instituted as an intermediary to purchase electricity from the power generating companies at agreed pricing and sell to the DisCos, as constituted in the PPA to streamline the power sector [64]. This is described pictorially in Fig. 1 above.

Moreover, this led to the creation of the Nigeria Electricity Regulatory Commission (NERC), as a regulator of the Nigerian Electricity Supply Industry (NESI). Aside from improving the sector's performance and encouraging private participation, the reforms also stimulated renewable energy electricity generation. This is contained in the NREEEP document by the Ministry of Power to account for 30 % of a planned 30 GW of electricity by 2030; however, key milestones have been missed.[41,] [65,66] This was done through support mechanisms such as introducing a feed-in tariff (enabling the sale of electricity to the national grid by renewable energy producers), a renewable energy electricity purchase guarantee, and a five-year investment tax exemption. NERC also sets the price of electricity through the Multi-year Tariff

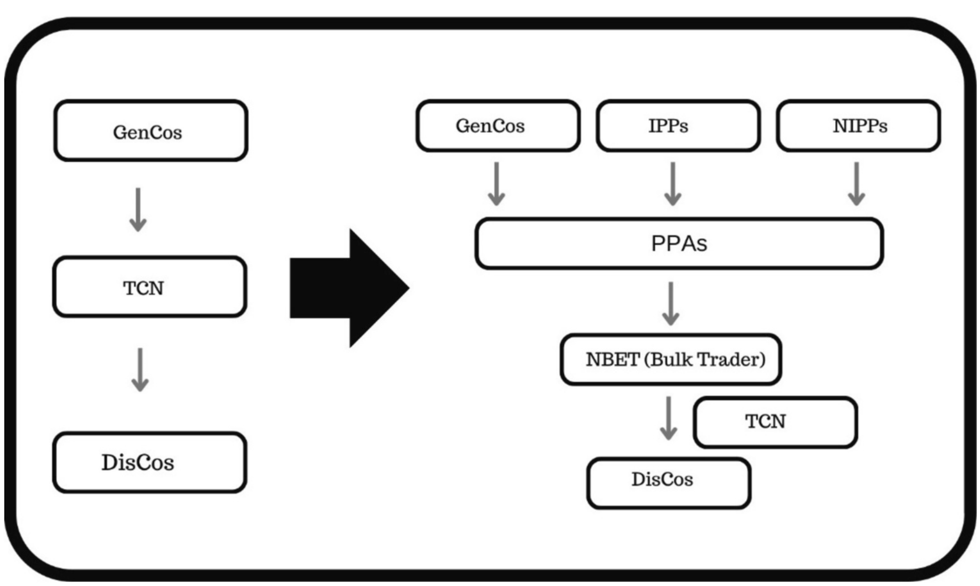

Fig. 1. Unbundling of the Nigerian electricity sector.

Order (MYTO) 1 and then revised to MYTO 2, which was aimed at ensuring a cost-reflective tariff to foster social equity and improve the attractiveness of the electricity market (for national and international investors). The MYTO 2 was introduced for fifteen (15) years to encourage renewable energy development. This includes opportunities for minor reviews bi-annually and major reviews every five (5) years [67]. However, Edomah et al. [68] argue that there are policy uncertainties around renewable energy buyback schemes and technical requirements for residential and commercial feed-in-tariff that are inhibiting execution.

Despite the progress of privatising the sector and encouragement of renewable electricity generation on the national grid, renewable energy (in terms of solar and wind) has had no success, though identified as a panacea by the Nigerian government and academia to tackle electricity challenges, satisfy the growing demand and address climate change and other environmental problems of fossil fuel usage.

2b. Renewable energy development in Nigeria

The Nigerian government created various measures to boost the development of renewable energy on the grid in the form of policies, plans, strategies, and policy support mechanisms to address the energy security challenges and achieve sustainable development. Table 1 below summarises the key policies for attracting foreign investments to boost economic development [43]. However, despite the numerous policy documents, plans and strategies to steer the development and implementation of renewable energy, the grid-connected options have made no notable progress. In contrast, the off-grid system has had some successes [66,69]. Nonetheless, communication gaps remain in these successes, as was the case of the Shape Community Renewable Project [35].

As shown in Table 1 above (based on the NREEEP), the plan is to generate 9100 MW of electricity from renewable energy with 800 MW from wind, 5000 MW from solar PV, 1000 MW from thermal PV, with Biomass 1100 MW, hydroelectric 1200 MW and the rest from thermal gas.

Furthermore, the progress of renewable energy development on the grid has been stalled due to the misalignment between the government and investors. Adeniyi [40] identified that the inability of the fourteen (14) solar project developers to reach financial closure has inhibited further grid renewable energy investments. This is a result of the companies being unable to gain two critical guarantees; firstly, the Put-Call-Option Agreement (PCOA) from the Nigerian government, which is an agreement that guarantees that solar plants will be purchased by the government where the project is unsuccessful due to conditions outside the control of the developers but in control of the government and vice versa. However, the government requested that the agreed tariff be reduced from $0.115/kWh to $0.075/kWh to bear the PCOA liability. Notwithstanding, only two developers proceeded with the agreement, but the government halted the PCOA due to the sector's challenges. Secondly, the companies could not secure the Partial Risk Guarantee from the government to guarantee the financial commitments by the Development Finance Institutes to NBET, which was supposed to hedge against NBET liquidity issues but could not be achieved.

Mohammed et al. [70] identified various challenges for renewable energy development, which include financing challenges, high upfront cost, lack of technical know-how, maintenance, lack of knowledge and benefit awareness by end users, concerns around theft and vandalisation, and ineffective renewable energy generation policies. Also, Ovwigho [29] found that inadequate management and policy, immaturity of renewable energy technologies, market inefficiencies and investment relating to renewable energy development inhibit the development of the Nigerian national grid system. Furthermore, Isah et al. [71] identified governance failure concerning corruption and lack of transparency in the electricity market with multiple market inefficiencies which proliferate risk in renewable energy project investments, lack of good policy design and implementation, financing challenges, lack of cost-reflective tariffs, land issues and economic challenges, insufficient political will, and lack of a working public-private partnership.

3. Theoretical framework

In the last decade, socio-technical transition theories have gained significant popularity for understanding trajectories of large or small infrastructural systems, such as power and transportation systems, to more sustainable systems to reduce greenhouse gases and tackle climate change. Geels [72] and Sovacool et al. [56] opined that transitions entail a process of transformation and reconfiguration of elements of a socio-technical system. Geels [51] avers that socio-technical changes could be radical or incremental. Similarly, Geels [55,72,73] argued that transitions could be steered or triggered incrementally. However, Batinge et al. [6] reasoned that the structural transformation pathway of the societal system should be sustainable and long-term oriented. Kern and Smith [46] described energy systems as socio-technical, critical to the core functioning of societies and the provision of basic human needs such as electricity. Energy and electricity systems are described as socio-technical systems. The sustainable transition literature has focused extensively on developed countries such as the UK, the US, Germany, Sweden and the Netherlands [6,46,47,74–78]. Several studies have employed transition theories to explore transforming fossil-fuel-based electricity systems into cleaner technologies.

Similarly, the MLP is a well-established theoretical framework that has been applied extensively and is primarily used in understanding and investigating major transitions [79,80] in the electricity sector. For example, Verbong and Geels [81,82] investigated the Dutch electricity system using the MLP. Also, Geels et al. [83] investigated the UK's and Germany's transitions to low-carbon electricity. Batinge et al. [6] proposed an energy transition framework from MLP and Transition Management Framework (TMF) for the unmet electricity market. Likewise, Rosenbloom and Meadowcroft [84] and Rosenbloom et al. [85] investigated the transitions in the electricity sector using the MLP, while Geels et al. [86] applied it in the context of the German electricity transition. Flynn [87] analysed the stalled transition related to offshore wind power in the North Sea. Furthermore, Andersen and Geels [88] posit that transformation of large energy system such as the grid is faced with significant hurdles due to the interactions with other systems and subsystems; therefore, requiring an understanding of the dynamic forces and close management to ensure alignment with the transition objectives. The MLP conceptualises the dynamics of society's interaction with technology [72]. Geels [49] asserts that transitions are non-linear processes and occur based on the alignment of elements that drive transition at three nested hierarchical levels. Three MLP conceptual analytical levels are: socio-technical landscape (an exogenous environment), regime (an environment characterised by dominant practices, rules, and culture) and niches (an environment where innovative ideas and innovation emerge), presented in Fig. 2. Geels [72] and Geels and Schot [48] argue that socio-technical systems have existed for a long time (decades), such that they have become resistant to change, as they have developed paths and co-dependency that could create a lock-in.

Fig. 2 represents the socio-technical landscapes (external elements, environments or events that affect regime configuration) exert pressure on the socio-technical systems and create a window of opportunity for niche development [82]. At this level, the socio-technical regime cannot influence the landscape in the short run [3]. The landscape houses the regime and involves spatial configurations and structures, societal values, macroeconomic trends, and geo-political pressures. Exogenous environment and changes at this level occur gradually [49]. The regime layer is the heart of the socio-technical transition [89,90]. It is referred to as a meso-level and is the most dominant level of the three analytical layers. This level consists of a set of normative (values, norms), cognitive (belief systems) or regulative (regulations) rules and practices that govern the activities of the social groups, multi-actor network (users)

Table 1
Key policies, plans, strategies and programmes related to the Nigerian electricity sector.

S/N	Policies	Policy year	Background	Energy objectives	Deliverables	Target date
1	National Energy Policy (NEP)	2003, revised 2006 and 2013	Nigeria's energy utilisation was increasing; therefore, a need arose to ensure an "optimal, adequate, reliable and secure supply of energy for economic development."	1. To develop and diversify energy resources for energy security and efficiency. 2. To generate income from energy production. 3. To ensure energy supply is affordable, "adequate, reliable and sustainable". 4. To encourage national and international investments in the energy sector etc.	75 % energy access and 40 GW power generation.	2020
2	Renewable Energy Master Plan	2005, revised 2012	The country continues to seek avenues to improve electricity supply and increase the reliability and security of the grid.	Increased installed capacity of: - Small-hydro: 600 MW in 2015 and 2000 MW by 2025; - Solar PV: 500 MW by 2025; - Biomass-based power plants: 50 MW in 2015 and 400 MW by 2025; and - Wind: 40 MW for wind energy by 2025.	Increase renewable electricity from 13 % of total electricity generated in 2015 to 23 % in 2025 and 36 % by 2030.	2030
3	Renewable Energy Policy Guideline (REPG)	2006	This is a combination of renewable electricity strategies described in the Nigerian constitution, NEP, REMP, etc.	1. Electricity diversification. 2. Increase energy access. 3. Enhance technology development. 4. Reduce pollution.	Same as NEP and REMP.	2030
4	Renewable Electricity Action Programme (REAP)	2006	The REAP was set up to enable the implementation of REPG.	Same as REPG.	Same as REPG.	2030
5	Vision 20:20:20	2010	The Nigeria Vision 20:20:20 is the country's plan for growth and development to be among the 20 largest economies in the world.	1. Improving power supply. 2. Efficient delivery of sustainable, adequate, qualitative, reliable, and affordable power.	35,000 MW of electricity generation by 2020 (6000 MW by 2009, 20,000 MW by 2015). Include renewable energy generation in the long-term targets.	2020
6	National Renewable Energy and Energy Efficiency Policy (NREEEP)	2015	The energy access to rural areas is low, and further development of the grid system will not cater for all the rural communities that are hitherto unreached. Hence the NREEEP provides a comprehensive renewable energy policy for urban and rural areas, i.e., grid and off-grid development.	1. Set-up a framework to address energy access and security. 2. Increase the proportion of energy generated from renewable sources. 3. Incorporate energy efficiency in the energy plan. 4. Develop an integrated resource plan (IRP).	At least 10 % of hydroelectricity. At least 3 % solar energy by 2020 and 6 % by 2030.	2030
7	Sustainable Energy for All (SE4All) Action Agenda	2016	Nigeria's Sustainable energy for all action agenda is an offshoot of the global SE4ALL incorporated with other national energy agenda.	1. Increase electricity access. 2. Improve energy efficiency. 3. Invest in renewable energy technologies.	Increase energy access from 40 % (urban = 65 % and rural = 28 %) in 2015 to 75 % (urban = 90 % and rural = 60 %) by 2020 and 90 % by 2030. Increase electricity generation on the grid from 5000 MW in 2015 to at least 32,000 MW by 2030.	2030
8	National Renewable Energy Action Plan (NREAP)	2016	A comprehensive document that provides a detailed roadmap for renewable energy development in Nigeria. It is an offshoot of the NREEEP.	Same as NREEEP.	Same as NREEEP.	2030
9	Nigeria's Nationally Determined Contributions (NDC)	2015, Updated 2021	As part of its contribution to the Paris Agreement, Nigeria presented the Nationally determined contribution in 2015, and updated the document in 2021.	1. To ensure a 2.5 % per year energy intensity reduction in all sectors. 2. Continue plan to achieve 30 % of on-grid electricity from renewables (12GW additional large hydro, 3.5 GW small hydro, 6.5 GW Solar PV and 3.2 GW wind). 3. Also develop 13 GW of off-grid renewable energy (i.e. 5.3 GW mini-grids, 2.7 GW Solar home systems and streetlights and 5 GW self-generation). 4. Stop the use of fossil fuel generators.	Unconditional emission reduction of 20 % below business-as-usual by 2030 and 47 % reduction conditional on international support (initially 40 %).	2030
10	Climate Change Act (CCA)	2021	After COP26 (Glasgow 2021), Nigeria committed to achieving net-zero by 2060. So, an act was signed to solidify the plan.	1. Ensure the creation of plans to achieve the goals on climate change mitigation and adaptation. 2. Set a target to achieve net-zero between 2050 and 2070.	To provide a framework for achieving low GHG emissions and to mainstream climate change actions into national plans and programmes.	2060

(*continued on next page*)

Table 1 (*continued*)

S/N	Policies	Policy year	Background	Energy objectives	Deliverables	Target date
11	Energy Transition Plan (ETP)	2022	This is Nigeria's strategic pathway to achieving carbon neutrality by 2060.	To transition away from diesel/petrol generator through incorporating renewables to meet the demands and ensure decarbonisation.	A strategic plan to address 65 % (179MtCO2e) of Nigeria's emissions from the power, transport, oil and gas, cooking and industrial sectors.	2060
12	Electricity Act	2023	The Act repealed and replaced the Electricity and Power Sector Reform Act (EPSRA) 2005 and provides a holistic integrated plan that recognises all sources for the generation, transmission, and distribution of electricity, including the integration of renewable energy into the energy mix.	1. To provide a legal and institutional framework to enjoy the gains of privatisation, increase power supply and upgrade current infrastructures. 2. To produce a plan to develop further renewable energy sources in the energy mix. 3. To encourage indigenous capacity development for renewable energy development. 4. To promote public education on renewable energy.	To provide a comprehensive framework to guide the operation of the electricity market in Nigeria and attract private sector investments in the power value chain.	

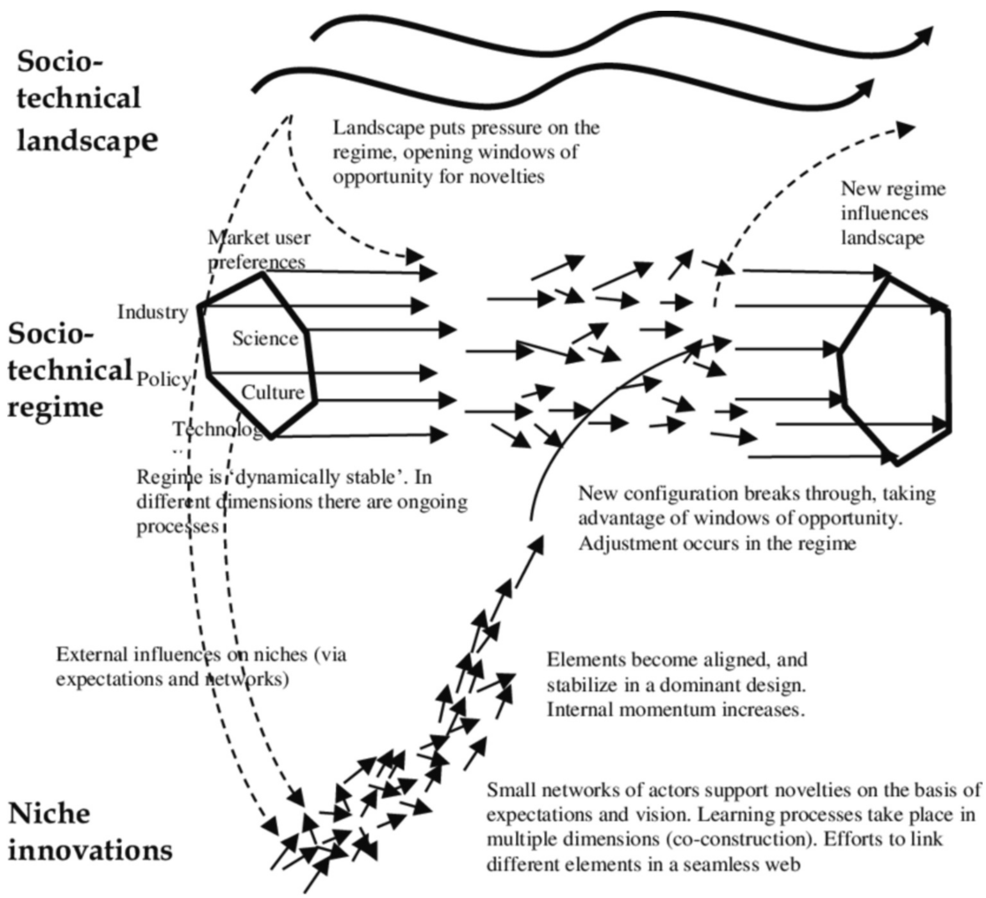

Fig. 2. Multi-level perspective for transitions [48,72].

and material and technical elements (technologies, resources, infrastructures of existing systems) [52,55,81]. The regime is often challenging to change or transform as incumbent regimes are characterised by lock-in [91], path dependency, and inter-relationship among actors as gradual changes occur along the established pathway, resulting in a stable trajectory [49]. These paths are multi-dimensional (technology, socio-cultural, industry and market) and controlled by various sub-regimes which interact and co-evolve.

However, the elements within the sub-regimes are only familiar to some socio-technical regimes. According to Geels [72], the extent of alignment of the sub-regimes influences the stability of the socio-technical regime and the tension present that could trigger the transition. Transitions occur when tension at the regime level creates destabilisation and provides a window of opportunity for niche technologies to emerge [49,92]. Lastly, niches are at the lowest level of the MLP structure. Niche technologies are innovations that emerge and have the potential to disrupt existing regimes by competing with or complementing them with support from the socio-technical landscape [48,93]. These are 'protected spaces' or 'incumbent rooms' to develop new technology, shielded from market pressures of the existing system

[3,72].

Furthermore, three processes are required to provide sufficient protection to niches. The first is the shielding phase, which refers to fencing off selection pressures from various dimensions, such as politics, infrastructure, and market, to foster experiments external to the niche [94]. Secondly, the nurturing phase introduces three transition processes for niche development. It pertains to the internal activities of niches: a) guided and articulated expectations; b) social and actor networks; and, c) stimulating learning [95]. The last relates to empowering niche innovations to enhance the competitiveness of the niche for path-breaking from the incumbent regime in two ways: firstly, through a fit and conform approach, empowering niche innovation to compete with the existing regime and selection environment and secondly, through a stretch and transform approach; destabilise existing regime by introducing 'niche-derived institutional reform' into a reconfigured regime [5,92,96]. The space is developed by an interested network of actors who might be outsiders [97]. However, transitions might be challenging for actors if the regime's analytical dimensions do not support niche innovations [49,55].

This study builds on Markard and Truffer [98] stance and Konrad, Voß and Truffer [99] suggestion that regime definition should be based on the study's perspective, the coupling of the socio-technical configurations and societal function. We adopt the descriptive delineation approach focussed on answering the research purpose and questions by defining the regime in this study as the Nigerian centralised grid energy system dominated with fossil-fuel and constituting actors, institutions and processes to address electricity supply gap. Hence, the MLP is contextualised in this study to firstly identify stabilising and destabilising forces of the centralised fossil-fuel dominated electricity regime and secondly the landscape elements are based on elements supporting and resisting new niche development (renewable energy on the national grid system) due to the peculiarity of the developing countries context and lastly, the barriers and driving forces of niche renewable energy relating to the grid development [48,100].

Furthermore, we argue that the transition characteristics of developed and developing countries vary, requiring the reframing of the MLP definition of regime. Although MLP is a popular framework applied to understand transitions, it has been criticised for being geographical-location sensitive, as different characteristics emerge from application in various contexts [60,101]. Hence, it is important not to transfer the characteristics of developed countries to developing countries that are institutionally and technologically different from other societal, cultural, and social norms. Therefore, we define regime in this research as transformation of a sub-optimum and dysfunctional incumbent electricity system with higher potential to resist landscape pressure, to shorten rein and hinder the speed of niche innovation development, limiting replacement potential of the regime. This is due to the energy poverty, low energy access, limited infrastructure and immature institutions, which depicts a developing country's regime, leading to the inability to fulfil societal functions which is contrary to developed countries context, where societal function of such incumbent systems are met and fulfilled. This is a unique nuance in the operationalisation of MLP in developing countries requiring in-depth consideration and has been articulated in studies [6,98] and therefore this study advances this line of argument.

Additionally, this study contributes to MLP application in developing countries, especially Africa by advancing the understanding of MLP in this geographical region. To achieve the aim, this study, from a socio-technical perspective, applies the MLP to comprehend and analyse the existing dynamics of the uptake of on-grid renewable energy in Nigeria to understand the persistent transition problems. However, MLP has been criticised for its lack of focus on the politics of transitions [101,102]. There are usually several competing systems of values and beliefs on the regime level.

4. Methodological approach

This section describes the methodology employed in the study to investigate and analyse the existing dynamics of the uptake of on-grid renewable energy in Nigeria to understand persistent transition problems.

4.1. Data collection

An interpretivist philosophical stance is adopted to analyse the barriers, drivers, and enablers to on-grid renewable energy adoption and implementation in Nigeria, as it provides an avenue to elicit experiences from multiple perspectives [103]. This approach is consistent with previous research utilising the MLP to understand the socio-technical transition. This study conceptualises the findings to MLP and draws on the MLP to gain insights on the transition implication for Nigeria's on-grid renewable electricity system. Findings from the study were conceptualised to the MLP. Empirically, data were obtained through interviews. Adopting an interview method enabled an in-depth understanding of informants' experiences, opinions, and viewpoints with regard to national grid renewable energy in Nigeria [8,9,104,105]. Due to the critical role energy plays in the Nigerian economy, coupled with cultural and educational considerations and the calibre of informants, it was perceived that a semi-structured interview would foster more trust and openness than other forms of data collection (cf. Rowley [8]). Semi-structured questions were formulated (see Appendix 1) which aligns with the expectations of socially useful research, and these were used as a guide for probing and discussions to improve understanding of the development of renewable energy on the national grid [106,107]. However, not all the interview questions pertain to this article, as this article is one of a three-part series.

Also, the technique combines the strength of structured and unstructured approaches, enabling predetermined questions from the literature reviewed and interviewees' theoretical perspectives [103]. Yin's [108] work on case study design influenced the selection of the Nigerian electricity sector as a case study, as it availed the opportunity to explore the intricate context to identify external and internal stabilising and destabilising pressures and processes for accelerating grid renewable energy. This aided the achievement of the research aim, which focused on understanding the barriers, drivers, and enablers for the transition to cleaner energy and deriving policy implications to drive and stimulate a low-carbon transition in Nigeria.

Thirty-one (31) participants were recruited through the purposive sampling and snowballing technique, which enables the recruitment of participants with in-depth knowledge or experience of the on-grid renewable energy sector. Confidence in the sample size was reached, and data collection was discontinued when data saturation was attained [103,105,109–111]. For this study, the research participants were selected based on the aim to address the central purpose of this research, which is to ascertain the barriers, enablers and drivers for renewable energy implementations on the Nigerian grid. Hence, the quality of data was ensured by the eligibility of the informants being executives, directors, managers, researchers or other experts in Nigeria's energy/non-energy sector who possess in-depth knowledge of the Nigerian electricity sector and renewable energy technologies. Also, the initial sample size was set at twenty-eight (28) participants, and the 28th respondents identified no other new theme; however, probing continued, and three additional interviews were conducted to ensure and confirm data saturation and enhance the validity of the research. The study garnered information on the research subject from actors in the Nigerian electricity value chain (Generating Companies, Transmission Company and Distribution Companies), public authorities, independent researchers, research and development institutes, climate change groups, funding and donor companies, energy associations, consultants, and universities. This approach provided rich, robust and diverse exploratory data on the barriers, drivers, and enablers to low-carbon technologies in the

Nigerian electricity sector, as represented by Table 2. This design is similarly to the study by Edward [112]. But the choices made in this research were based on the study's research aim, participant characteristics, domain, and cross-sectional nature [113].

The interview was conducted online, as it was during the covid-19 pandemic and global national lockdown and social distancing were enforced, which inhibited field visits to obtain in-person data. Though there were strengths from adopting this approach there were also some limitations due to the nature and social impact of the research including the cultural and political sensitivity and interviewing of elite groups who have considerable responsibilities in the energy sector. A limitation was the power dynamics and the reluctancy of some interviewees to discuss openly on some aspects and our inability to obtain non-verbal clues which would have been possible in a field visit. The researchers addressed this by being adaptive and reflective, for instance, phone calls, WhatsApp messaging and email communications were maintained with interviewees before the interview day and informal conversations were had prior to starting the interviews to build rapport and trust (see Saricca et al. [114]). Also, the interviewer moved between questions to ensure objective views and opinions were obtained with ethical considerations observed to protect the informants and, in some instance, there were frequent re-statement and re-assurance of the confidentiality of respondents, companies, institutions and projects identities. Although there were notable strengths to this approach, as the opportunity for interviewees to take part in the interview online from home or a comfortable location provided a safe space for some respondents to discuss their thoughts freely on the phenomenon, which might otherwise be difficult in an in-person approach, as respondents would have conducted the interview from their offices or a formal setting. Furthermore, this approach avoids in-person interview hurdles and eases the burden of frequent field visits with interviewees not being available or interview appointment being called off at last minute despite long waiting time which is typical to Nigerian research [115]. Also, it reduced contribution to CO_2 emissions from flight travels to conduct interviews and also kept research costs within constrained limits.

4.2. Data analysis

The interviews were conducted across eight months, from April to December 2022. The participants were issued the research information sheet containing the study's details, including the interview's purpose. Subsequently, a consent form was given to participants to indicate their voluntary acceptance to participate in the study. The interviews were conducted online via Zoom/Teams for approximately 30 to 90 min. This approach to interviewing was adopted because the research occurred during "Lockdown". The discussions were recorded with the interviewees' permission, transcribed to text data, and anonymised to ensure the respondents' identities were confidential. Notes and critical points were taken during the interview to keep track of questions directed to a particular participant category.

Furthermore, the data were analysed inductively, and the process started as soon as the first interview was conducted [116]. This involved a reiterative process of listening and reflecting on each participant's responses to the interview questions and was maintained after the verbatim transcription from audio to text data to identify themes. This aided the familiarisation and understanding of various informants' perspectives on the focus of the study [113]. Each transcript was saved based on the sequence of interviews and represented as IR01, IR02, etcetera, with time stamps and interview duration indicated on each file.

Thematic analysis was utilised to analyse the data, which provides an objective view or perspective on the research question, that is, what are the barriers, drivers, and enablers of renewable energy implementation on the Nigerian grid using interpretation, and it is compatible with the theoretical underpinning of the study [117,118]. Marshall and Rossman [119] posit that this phase is the most "intellectually challenging phase". Hence, to ensure the rigour is guaranteed, Braun and Clarke's [120] six

Table 2
Interview participant categories.

Public Authorities	Research and development institute	Association	Climate change movement	Non-governmental organisations	Universities	Electricity generation companies	Electricity distribution companies	Electricity transmission companies	Renewable energy Investment company	Independent researchers	Renewable energy businesses
Regulatory IR11, IR16 Policymaking IR08, IR15, IR17, IR22, IR25, IR27 Government ministry and parastatal IR09, IR20, IR23, IR31	IR29	IR30	IR24, IR28	IR18	IR02, IR07	IR01, IR14	IR03, IR05, IR06	IR10, IR19	IR26	IR12, IR21	IR04, IR13

(6) steps for thematic analysis were adopted (see Fig. 3).

Fig. 3 shows that the process involved familiarising the text data; 182 codes were generated after the initial coding and reduced to 112 codes that closely represent the notion of the respondents while searching for themes based on phenomenon under study. Subsequently, the categorised themes were reviewed, defined, and written as a paper. NVivo, a qualitative data analysis software, was used to organise, sort, and systematically structure the data [121]. Braun and Clarke [120] assert that the researcher's role in this phase is critical in identifying and reporting the themes. Therefore, the emerging themes were carefully documented and presented in Fig. 3. Fifty-one (51) themes were initially identified and then reduced to twenty-seven (27) as they were merged based on similarity.

The next section presents the results from the interviews conducted with the thirty-one (31) individuals on the factors for grid renewable energy implementation.

5. Discussion on the multi-level perspective of on-grid renewable energy in Nigeria

This paper aims to investigate and analyse existing dynamics on the uptake of on-grid renewable energy in Nigeria by exploring impeding and facilitating factors. The MLP is used to analyse findings, gain insight, and understand the transition implication of the grid renewable energy electricity systems. This section presents a conceptual framework identifying the dynamic pattern of the interactions between the multi-level landscape, regime, and niche levels. It discusses these patterns and interplays, including the transition implications, with the support of literature on energy transitions. Table 3 and Fig. 4 below capture these dynamics, complexity, and challenges of renewable energy (solar and wind as niche innovations) in the Nigerian electricity sector.

This approach is consistent with previous research utilising the MLP to understand the socio-technical transition. This study draws on the MLP to gain insights into the transition implication for Nigeria's on-grid renewable electricity system.

5.1. Landscape supporting and resisting forces to niche development

The government aims to achieve 30 % renewable energy of 30 GW proposed electricity generation by 2030. To achieve this goal, the findings in this study show that landscape elements exert pressure on the electricity sector's regime configurations. In the socio-technical landscape, several forces are encouraging the development of renewable energy on the Nigerian grid. The drivers of renewable energy development are mainly classified at the landscape levels as forcing and supporting on-grid renewable energy development and transition other than the other two levels (socio-technical regime and niche levels). These drivers include international pressures on the Nigerian government through the Paris Agreement obligations and the country's commitment to achieving the Nationally Determined Contributions, thereby adopting a pathway through the development of renewable energy technology on the national grid and the need to maintain global relevance in the energy domain.

Based on the interviewees' perspectives, grants and funding of green

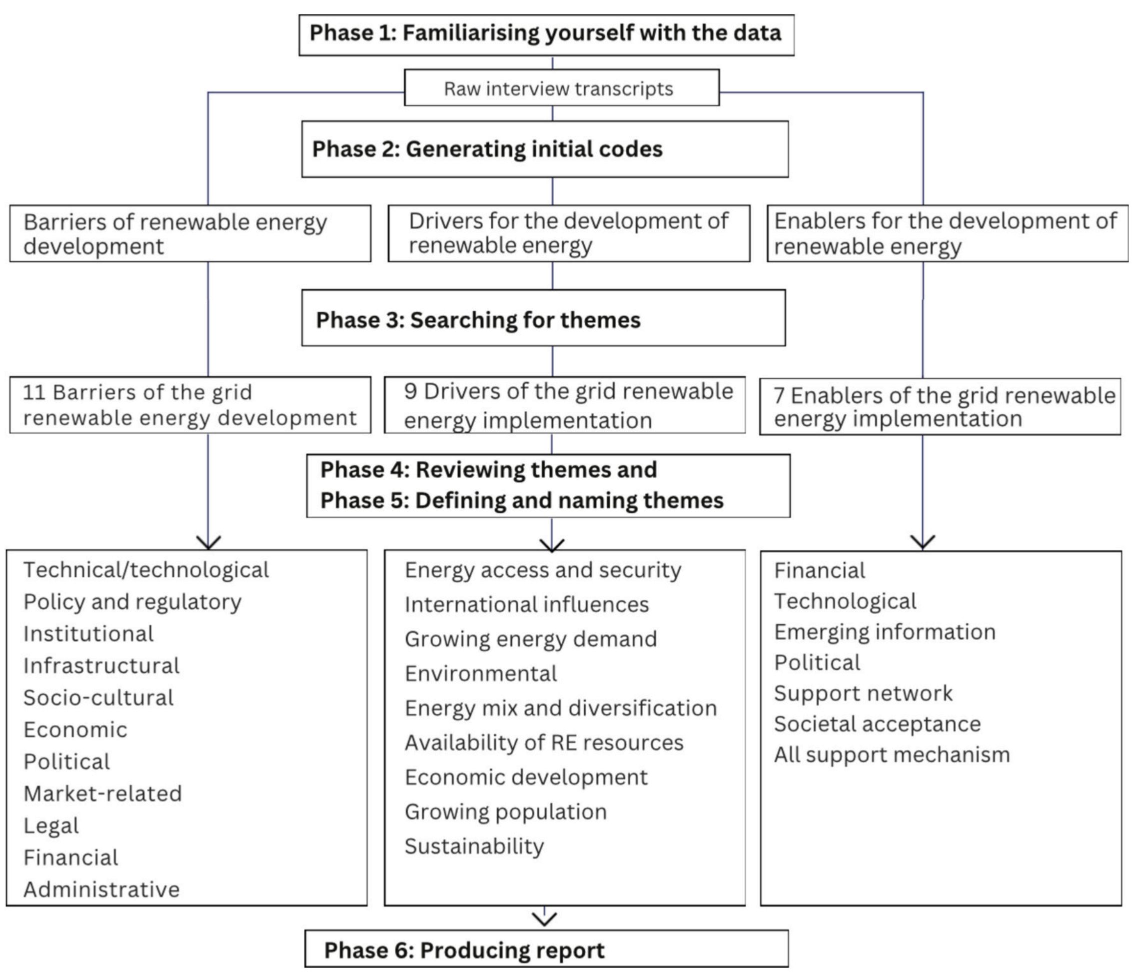

Fig. 3. Six steps for thematic analysis.
(Adapted from Braun and Clarke [120].)

Table 3
Elements and forces represented in the conceptualisation of the Nigerian on-grid renewable energy development using MLP in Fig. 4.

No	Elements	Forces
1	International agreement, trends and pressure i.e. Kyoto protocol, Paris agreement Economic development Growing population International grants and funding Sustainability Energy access and security Growing energy demand Climate change and low carbon driver Economic development	Supporting on-grid renewable energy development
2	Policy and regulatory Institutional challenges Management challenges Market related challenges Infrastructural challenges such as transmission capacity Economic and financial issues Socio-cultural issues i.e. land use challenge Political barriers Legal barriers	Resisting on-grid renewable energy development
3	Comparable advantages of other energy sources (fossil fuel) Resistance and sabotage from current energy producers Social budgeting Petroleum subsidies and support Favourable gas policies – PIA- confused signal Obsolete infrastructure such as electrical equipment Government's control of transmission line	Stabilising forces
4	Lack of cost-reflective tariff/ unattractive feed-in tariff Ineffective revenue collections plus liquidity challenge Transmission and distribution challenges of gas Lack of metering Grid unreliability (inefficiencies)	Destabilising forces
5	Technology implementation challenge Lack of infrastructure such as storage facilities Narratives from off-grid systems Lack of research and development initiative No clear implementation action plan for the policies Lack of enforcement of the legal framework Unreliability of the renewable energy technology due to their variability Lack of expertise and renewable energy technology capacity in the sector Renewable energy investments drawback (security of investment) Socio cultural issues	Problems and barriers
6	Government policies Private investment arrangement Government partnerships Policy support mechanism Support network such as Renewable Energy Association of Nigeria (REAN) Emerging information Standards and regulations One-stop investment shop Societal acceptance Technology advancement such as battery capabilities for solar and wind turbine blade improvements	Driving and enabling forces

projects by the international community such as the German Agency for International Development (GIZ) and World Bank/African Development Bank (AFDB) in Nigeria for off-grid and prospect of future large-scale deployment that connects to the grid is creating momentum and drive towards maintaining low greenhouse gas emissions to mitigate climate change. However, the government's need to meet increasing energy demand and address the issue of energy access are priorities, as some respondents argued that the political regime needs to fully embrace the shift to renewables for environmental and sustainability goals. Energy access and security of supply were themes of significant importance to all participants; most informants stated that the motive for adopting renewable energy in Nigeria was to resolve the country's energy poverty issue. For instance, the following statements were made by interviewees:

> "...the real reason for it is just basically because of lack of access..."
> IR08

IR21 supported this;

> "...for me is based on the context of Nigeria, or Sub-Saharan African countries where majority of the people are lacking electricity, they do not have access to basic electricity. So Nigeria thought is the right thing to do to look into renewable energy..."
> IR21

The aforementioned is further accentuated as, according to some interviewees, the growing population and energy demand necessitate exploring clean energy means such as solar and wind as the existing sources for electricity generation cannot satisfy the populace for residential, industrial, or commercial usage. Most respondents suggested that Nigeria is endowed with abundant renewable energy sources, which propels the exploitation of these natural resources to satisfy electricity demand and diversify the existing system, which is dominated by fossil fuel sources.

Interestingly, a few respondents recognised that the benefits of renewable sources vary from location to location and technology to technology. Regarding the economic and social dimensions as drivers, some respondents alluded that renewable energy technology has been identified as a universal remedy to improve economic profit, productivity, human capital development and standard of living in Nigeria. Geels [73,79] argues that socio-technical landscape (macro-level) forces could cause deviation and misalignment in existing regime configurations, creating windows of opportunities for niche development. However, though the finding is indicative that there are pressures driving energy transition relating to the grid, these pressures are much lower than anticipated. They are faced with opposition from the inefficiencies in the electricity sector, therefore resisting the deviation and misalignment of the regime system.

Respondents had a collective perspective on these inefficiencies, which cuts across various domains. One of which is policy and regulatory challenges. However, Vision 30:30:30 lays out the policies for renewable energy development; there are policy continuity and somersaults, including a need for deep thinking and an implementation plan. The lack of legal backing for the existing renewable energy policies deters enforcing the policies unless the legal and institutional frameworks are legislated and approved. There are also challenges with the management and structure of the institutions. The unaligned positioning of the Energy Commission of Nigeria under the Ministry of Science and Technology poses difficulty in coordinating with the Ministry of Power over grid renewable energy affairs. Furthermore, the economic crises have had financial challenges on the country, with the government prioritising essential development needs. Other resisting forces are land use challenges and market-related hindrances to niche development.

These inefficiencies are common in other African/developing countries [6,122] and less common in developed countries [123] due to institutional maturity, accountability and transparency.

5.2. Stabilising and destabilising forces of incumbent regime configurations

In the socio-technical regime, landscape pressures influence the configuration, destabilising or reinforcing the system [72,88]. There is a

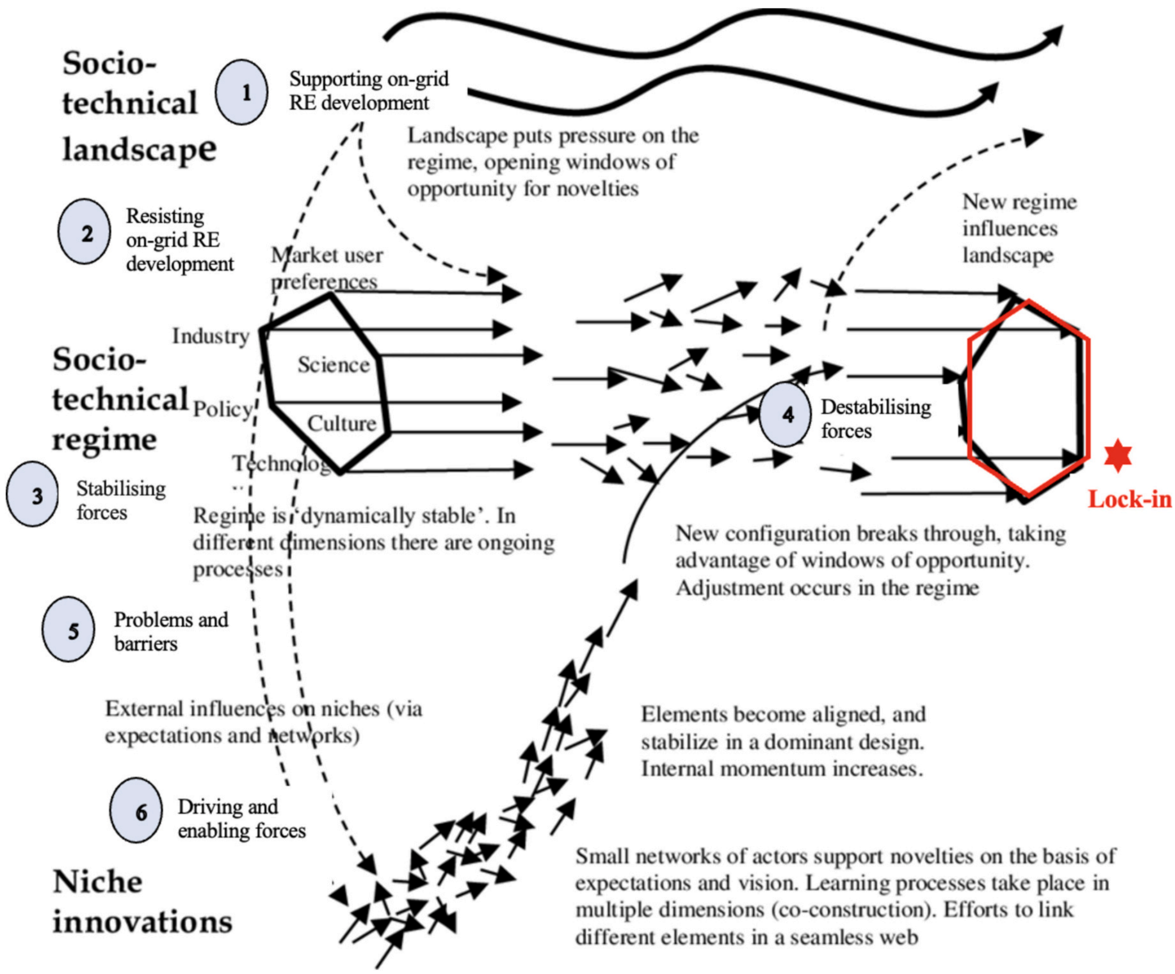

Fig. 4. Conceptual representation of the Nigerian on-grid renewable energy development using MLP. Adapted from Geels [100].

suggestion of multiple influences which dominate and reinforce the incumbent regime, which is mainly based on fossil fuel, creating technological and institutional lock-in and preventing cracks and weak spaces for grid renewable energy to develop in Nigeria. Some of these influences are favourable gas policies, existing petroleum subsidies, the comparative advantage of fossil fuels and revenue dependence for social budgets, which makes fossil fuels more competitive and renewable energy less attractive.

In addition, there is resistance from incumbent generating and distribution players as they perceive renewable energy producers as threats since they have invested immensely in the existing power plants and are yet to recoup the investments. In the same vein, the market and fiscal incentives which are to act as support mechanisms for renewable energy development are considered ineffective and not yet been fully effected. For instance, lack of implementation of the feed-in tariff, financing challenges owing to high renewable energy costs, paucity of up-front capital subsidy and tax relief for installation equipment reinforces the regime. A quote from IR11 is used to illustrate this point:

> "…they wanted the NBET, who they think has more capacity, to pay them or has more backing of government and World Bank partial guarantee, you are more inclined to sign in with NBET, not the DISCOs… "
>
> IR11

On the other side, our study shows destabilising forces of the incumbent regime, such as grid unreliability (inefficiencies), lack of metering, transmission and distribution challenges of gas, ineffective revenue collections plus liquidity challenges, and lack of cost-reflective tariff are regime systems challenges creating a green window of opportunities. While it can be argued that the tension is primarily from the landscape forces, an interesting finding is that the incumbent regime's inefficiencies, which contribute to the opportunity for the consideration of renewable energy technology, are also a significant deterrent for the penetration of niche innovation on the Nigerian grid. For example, the infrastructural issues, specifically the transmission capacity, are also a significant hindrance to investing in the grid. Isah et al. [71] aver that the investment risk is higher for renewable projects due to the weak grid system and high transmission and distribution losses attributed to gas in the sector. They perceive that they would not recoup their investments due to existing transmission losses [40]. They argue that due to the intermittent nature of renewable energy, it is essential that power generated is adequately accounted for and used up by the end users, or it will lead to power supply losses.

Furthermore, some participants indicated that the grid is obsolete and cannot take more electricity generated beyond a particular limit due to its fragility; otherwise, it will collapse. An interesting finding was, "as far as I know, nobody can fully tell you what capacity of renewable energy can be integrated on the grid without no issue as we speak" IR20.

However, the government MYTO 2 regulation that obligated distribution companies to source 50 % of all electricity procurement from renewables is projected to contribute to reconfiguring the fossil fuel-dominated regime when in operation. Hence, it seems reasonable to infer that path-dependence and lock-in effects are stabilising the on-grid system, which might encourage the acceptance of incremental changes within the system [124].

5.3. Driving forces and problems/barriers of niche development

At the socio-technical niche level, societal acceptance of renewable energy sources of electricity, emerging support networks and information are fundamental niche mechanisms that promote the development of renewable energy technologies. There are positive perceptions and attitudes of the population towards the technologies mainly to address the power shortages in Nigeria. This is explained further by IR22.

> "Nigerians are totally embracing renewable energy…if we could quantify the number of Nigerians that have gone on their own to invest in renewable energy, you will see that there is definitely a shift in paradigm, a paradigm shift in attitude."
>
> IR22

On the contrary, some respondents have a divergent view that there needs to be more awareness of the benefits of renewable energy. A participant explained:

> "I am still surprised, with all the awareness that we have been creating up until now, a lot of people do not really see the need for alternative energy sources"
>
> IR13

The advent of information, such as from the SE4ALL website and support networks in Nigeria, is driving the adoption and acceptance of renewable energy initiatives in Nigeria. Government policies, partnerships and support, technological advancement, and cost reduction are some factors that have contributed to the development of renewable energy. The Vision 30:30:30 contains renewable energy policies which propel the actualisation of 30 % of the 30 GW electricity generation target for 2030. On the other hand, there are barriers and challenges to the maturity of niche technology, such as lack of investment, limited R&D, technological challenges, narratives from off-grid renewable energy systems, and lack of actionable government plans, to mention a few. A significant hindrance articulated by respondents is the deadlock with the Put Call Option Agreement (PCOA) around the feed-in tariff structure and Partial Risk Guarantee (PRG) involving the World Bank and African Development Bank (AfDB), which is to operationalise the Power Purchasing Agreement (PPA). Nigeria signed with IPPs (14 solar companies) to generate 1125 MW of grid solar electricity, but these concerns have caused a transition slowdown.

Moreover, this study shows that the political actors' involvement is significant for development, as it requires 'protected spaces', a network of powerful actors' buy-in, and resources that support the development to mainstream and possible replacement of the incumbent regime (cf. Geels [100]). According to some interviewees, there needs to be more buy-in from stakeholders and political actors to foster development. Also, there is limited support for transition through the national grid pathway due to all these complexities. Still, there is substantial encouragement for a smart grid system pathway to be considered to encourage community and societal engagements, improve resilience and address inefficiencies of the national grid. Smart grids enable renewable energy integration by addressing issues around solar or wind energy supply variability. This enables a decentralised generation pathway for PV rooftops, which the government is committed to deploying through the Solar Home System Programme [125]. This will encourage private investment and participation in power generation from investors and individual, commercial, and industrial users. Though the willing buyer and willing seller regulations exist, this can further be expanded to actualise the grid renewable targets and objectives. Niche innovations have a more extensive prospect of becoming mainstream and replacing regimes with the support of an extensive network of actors and resources [79]. However, penetration is difficult due to regime lock-in and misalignment of niche elements with regimes [126]. This study hints that most barriers to niche development have significant financial implications that impede progress. Correspondingly, the window of opportunity created by the landscape pressures is not large enough for on-grid renewable energy (solar and wind) to penetrate the fossil fuel-dominated regime. The internal momentum for the innovations is insufficient to propel the penetration into the grid.

This exploratory research focuses on renewable energy development on the Nigerian grid relating to solar and wind technologies. Therefore, findings cannot be generalised to all renewable energy technologies. Also, a limitation of the study is that the two niches (solar and wind) are not differentiated in the interview instrument as it was out of scope of this study. Future research could differentiate between these two niche innovations and how they interact with the incumbent regime systems in a developing country context. However, this is a foundation for assessing other technologies captured in the Nigerian Renewable Energy and Energy Efficiency Policy (NREEEP) documents. Furthermore, this study finds that inefficiencies of an incumbent regime system could be a major deterrent for niche development. Further study could focus on the dynamics of the regime in a transition pathway where incumbent regime systems are inefficient.

6. Conclusion and policy implication

Nigeria has numerous renewable energy policies to achieve 30 % renewable energy of 30 GW power generation by 2030. However, implementing these policies has stalled, with missed short-term (2015) and mid-term (2020) targets and milestones. As contained in the NREEEP document, the policy aimed to generate through PV and solar thermal in the short term and long term 117 MW and 1343.17 MW, respectively, and wind, 50 MW and 57.40 MW in the same time scale [77]. Despite these policies to accelerate the sustainable energy transition, there is no account of these renewable energy technologies being incorporated into the Nigerian grid to date.

This paper aimed to empirically investigate and analyse existing dynamics on the uptake of grid renewable energy in Nigeria by exploring the barriers, drivers, and enablers of the renewable energy target of 30 % renewable energy on the Nigerian electricity grid by 2030 by adopting the concepts of transition theory to understand the persistent transition problems. This was based on applying the MLP and a qualitative approach through the interviews of thirty-one (31) energy and non-energy actors. The Nigerian electricity system faces complexities in the socio-technical transformation to renewable energy. There is the prospect for Nigeria to transform the electricity system by incorporating renewable energy sources, as there are supports at the landscape level and destabilising forces at the regime level.

This study indicates that renewable energy is pivotal in increasing energy access and addressing energy poverty [34]. Moreover, the quest to diversify to sustainable options for economic, environmental, and international reasons necessitates renewable energy grid developments. Nevertheless, while there are numerous policies for renewable energy deployment on the grid, the lack of institutional synergy reinforces the policy misalignment, thereby hindering a clear implementation strategy and action plan coupled with other challenges spanning from the political hurdle to lack of government synergies, commitment, and political will to accelerate transition to renewable energy. Additionally, socio-cultural issues concerning land use challenges, insecurity, kidnapping, banditry and vandalism, lack of awareness of the benefits and distrust in the management of the national grid. Also, financial and economic hindrances and market-related and infrastructural issues create resistance to the penetration of renewable energy on the grid.

In addition, the grid system's inefficiencies have created tensions and cracks and destabilised the incumbent regime; nevertheless, the existing inefficiency is considerable, such that it serves as a barrier to niche innovation development coupled with enforcement of existing configuration by stabilising forces such as resistance and sabotage from current energy producers. Though the pressure from landscape trends is significant, the resistance from the regime is equally substantial. Therefore, the socio-technical environment and niche innovation are insufficient to trigger the necessary transformation of the system and need to be addressed to trigger transitions.

This study establishes that government commitment and political will through policy implementation are significant to achieving the targets of grid renewable energy coupled with the reduction in the political influence and risk in the power sector to translate into a practical and realistic agenda. The government needs to play a pivotal role in facilitating and influencing the transformation of the energy systems from the various governmental levels: Federal, State, and Local. Also, there is a need for an explicit institutional mandate, governance arrangement and synergy with an independent agency instituted and charged with the leadership to handle the implementation of on-grid renewable energy. Thus, it is vital to have an actionable roadmap for executing renewable energy projects on the Nigerian grid. Presently, the Ministry of Power presides over grid renewable energy; establishing a specific agency to handle this would promote effective monitoring of projects, accountability, and transparency and encourage new investors into the sector. An example of notable success with tasking a specific agency was the establishment of the Rural Electrification Agency (REA), mandated to electrify rural communities using off-grid solutions, which has recorded notable successes [125].

To further attract domestic and international investors, policymakers and planners need to give strong signals for renewable energy support by prioritising renewable energy expenditures in the national budget and upgrading obsolete infrastructures which are currently designed for electricity sources mainly from crude oil therefore stabilising the incumbent fossil fuel regime system. In addition, tackling grid unreliability and expansion challenges around metering will provide an enabling environment for renewable niche innovation to thrive. Also, there is a need for an effective cost-effective feed-in tariff and promotion of investment security, PRG, and PCOA to encourage renewable niche innovations. Moreover, market-led transitions can be embraced by introducing flexible policies to encourage the participation of companies, corporations and industries committed to purchasing power from renewables. Also, there is a need for the energy industry actors, government, communities, consumers, and other key stakeholders to work collaboratively to address the issue of insecurity of energy systems and infrastructure to foster an environment where various clean energy business models can succeed.

Solar technology has more support from regime actors at the Niche level than wind technology. However, the momentum for both is insufficient to spur resource supply or upscale renewable energy development. More powerful actors, such as the investment community, political actors, and existing electricity generating and distribution players, are needed to support the transition to overcome resistance from the incumbent regime players, systems, and subsystems. Lastly, for the acceleration of transitions, there is a need for the creation of favourable business models that encourage smart grid development and new business opportunities for prosumers for the renewable energy targets and visions to be reached. However, respondents' opinions on attaining the target by 2030 were described as ambitious.

This study provides a robust understanding of the dynamics of the Nigerian electricity sector, providing policy implications and recommendations. This informs policymakers on the on-grid renewable energy policies to overcome existing energy challenges and accelerate plans on the variables impacting the actualisation of renewable energy targets and visions and niche innovation or pathways that could foster transitions. While most of the recommendations would have financial implications, some are low-cost, aimed at breaking out of the fossil fuel-based regime lock-in. Furthermore, the study provides insights into developing countries with a socio-technical, techno-economic, political, and energy poverty panorama similar to Nigeria's.

For academic debates, drawing on the MLP analysis, it provides insights into the complexities of regime system in developing countries setting; specifically, it agrees with Hansen et al [127] and Wieczorek [128] arguments that there is a level of regime stability that is required for niche to flourish in developing country contexts. Our study establishes that the incumbent electricity regimes instability plays a significant role in deterring renewable energy development, growth and diffusion due to extreme weaknesses in the system which is contrary to the findings of developed countries. This brings up the question for future research that could be theoretically explored "what degree of stability, instability and change in developing country settings, is necessary for energy transition to occur?" This is in line with Wieczorek's [128] argument that while we know that, from a transition lens, destabilisation of the regime system is a pre-condition for niche innovation to emerge, it is still unclear in developing country contexts which of the elements hinders and which needs to be destabilised.

In addition, while it was beyond the scope of this study, understanding how informal regimes such as large-scale fossil-based back-up generators regime influences the renewable energy generation on the national grid would provide more insights on niche development challenges in developing countries, which supports Hansen et al.'s [127] observation that the need for more research on multiple regime systems that exists within the developing country contexts. This could be relating to policy, policy support mechanisms, industry and market dynamics of these regime systems.

CRediT authorship contribution statement

Racheal Adedokun: Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Peter A. Strachan:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Anita Singh:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Fredrik von Malmborg:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix 1

Lead questions

What are the drivers and enablers for the development of renewable energy on the Nigerian national grid?

What do you think are the inhibitors/barriers of renewable energy development on the national grid?

What are the objectives and visions for introducing renewable energy on the grid?

What is the strategy or pathway for their actualisation? In your opinion, what strategy or pathway can be adopted to achieve renewable energy on the grid?

How do Nigerians perceive this energy mix initiative? What is the outlook of Nigerians towards this plan?

Who are the major actors/stakeholders in renewable energy governance relating to the grid?

Which stakeholders are involved in implementing the strategy of grid renewable energy?

What role does the government play in facilitating stakeholder alignment, and how is this done?

What support mechanisms are you aware of for grid renewable energy development?

How effective are these support mechanisms in fostering development?

In your view, what support mechanisms should be introduced?

What are the determining factors for the successful planning process of grid-based renewable electricity generation?

What are (or should be) the procedures for the implementing renewable energy on Nigerian national grid and how is/should this have been enforced?

What are the renewable energy planning process and governance for sustainable development in Nigeria?

In your view, what should the process of planning for renewable energy on Nigeria national grid entail?

Who are the major actors/stakeholders in the planning of renewable energy on the grid?

In your opinion, which important stakeholders were excluded in the process of planning for grid renewable energy?

What role(s) does the incumbent energy generating players play in the development of grid renewable energy?

Are you aware of any ongoing renewable energy projects or experiments on the grid?

What can you say about the direction of the projects/experiments?

Who are involved in this projects/experiments? key actors or stakeholders?

In your view, what is (or should be) the process of monitoring and reviewing these projects/experiments? Is the learning from these processes effected or how can it be effected?

How accountable are the processes?

What is your view about the level of transparency in planning, governance or implementation of renewable energy on the national grid?

In your opinion, what role does transparency play in actualising the goal of renewable energy on the grid?

Who should be responsible for ensuring the entire process is transparent?

What can be done to ensure the process is more transparent?

What are the similarities and differences in the comparison of on-grid and off-grid generations?

Are the challenges of introducing renewable energy on the national grid similar to the off-grid issues?

Is the planning and governance of renewable energy on the national grid similar or dissimilar to the off-grid process?

How do the stakeholders/actors' involvements compare with the off-grid and grid-based electricity generation projects?

How does the societal acceptance of renewable energy on the national grid project compare to the off-grid project?

In your opinion, what could be the impact of the Covid-19 pandemic on RE development in Nigeria?

Appendix 2

List of abbreviations

AfDB	African Development Bank
CCA	Climate Change Act
COP	Conference of Parties
DFI	Development Finance Institutes
DisCos	Distribution Companies
ECN	Electricity Corporation of Nigeria
ECN	Energy Commission of Nigeria
EPSRA	Electric Power Sector Reform Act
ETP	Energy Transition Plan
FIT	Feed-in Tariff
GenCos	Generation Companies
GHG	Green-house Gases
GW	Gigawatt
h	hour
IEA	International Energy Agency
IPPs	Independent Power Producers
IR	Interviewed Respondent
KWh	Kilowatt-hour
MLP	Multi-Level Perspective
MW	Megawatt
MYTO	Multi-year Tariff Order
NBET	Nigerian Bulk Electricity Trading PLC
NDA	Niger Dams Authority
NDC	Nationally Determined Contributions
NEP	National Energy Policy
NEPA	National Electricity Power Authority
NERC	Nigeria Electricity Regulatory Commission
NESCO	Nigeria Electricity Supply Company
NESI	Nigerian Electricity Supply Industry
NGEU	Nigerian Government Electricity Undertaking
NIPP	National Integrated Power Project
NREEEP	National Renewable Energy and Energy Efficiency Policy
PCOA	Put-Call-Option Agreement
PIA	Petroleum Industry Act
PPA	Public-Private Agreement
PPP	Public-Private Partnership
PRG	Partial Risk Guarantee
PWD	Public Works Department
RE	Renewable Energy
REA	Rural Electrification Agency
REAP	Renewable Energy Action Plan
REMP	Renewable Energy Master Plan
REPG	Renewable Energy Policy Guideline
SE4All	Sustainable Energy for All
TCN	Transmission Company of Nigeria
TW	Terawatt
UK	United Kingdom
US(A)	United States (of America)

Data availability

The authors do not have permission to share data.

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