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Review

Moving beyond fossil fuel in an oil-exporting and emerging economy: Paradigm shift

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Abstract: The next transformation in human civilization is occurring in the energy sector. The transition is supported mostly by concern for environmental safety (climate change). Other factors such as energy security and economics also dictate the shift. The transition will be more disruptive to oil-exporting economies such as Nigeria, which depend heavily on it for economic growth. Historical inferences from past energy transitions reveals that discovery and massive acceleration of new energy resources alters mode of production, energy consumption, economic innovation and unlocks multiplier effects on the society. Technology and availability of energy resources is the critical enabler of past transitions. Renewable energy technologies are becoming more cost-competitive relative to fossil fuels. The increasing transition will have serious socioeconomic and political implications, if the country does not diversify its economy. For example, contraction in oil export because of global transition to renewable energy will reduce Nigeria government's revenue, increase unemployment, decrease capacity to finance infrastructure and development projects, and increase poverty rate. Nigeria has enormous renewable energy potential—solar, wind, biomass, etc. The use of renewables will improve environmental quality. For example, increased use of biomass (organic wastes) for energy production will advance Nigeria solid waste management system and vice versa. All these are associated with sustainable resource management.

Keywords: energy transition; renewable; fossil fuels; climate change; energy efficiency; economic diversification; economic growth; sustainability; Nigeria

Abbreviations: ET: energy transition/energy transformation; RE: renewable energy; VRE: variable renewable energy; PV: photovoltaic; Bpd: barrel per day; Mbpd: million barrels per day

1. Introduction

Environmental issues are one of the major problems facing humans today. Emissions from energy use, resource depletion and waste generation from production and consumption activities and many other anthropogenic activities impacts the globe adversely. Consequently, the growing attention on energy transition and circular economy. This involves a comprehensive transformation—"decoupling" of energy and material use from negative externalities. To accelerate the sustainable transitions, the importance of policy mixes (economics, technology, governance) cannot be over-emphasized. The Policy mixes include adoption of renewable and low-carbon energy sources [1,2], bio-circular economy [3]; circularity of "wastes" for both material and energy production [4]. The energy system can either be centralized or decentralized, or integration of both [5]. Finance and new business model is critical to the growing energy transition (sustainable energy), as it entails new infrastructure or modification of existing ones [6]. Fossil fuel has played a critical role in socioeconomic development and international relations of countries over the last 120 years. Globally, the major factors that supported the demand for oil are demographic changes (population and urbanization) and economic growth [7]. Global sectorial consumption of oil shows the following—transportation (55%), petrochemical feedstock (12%), buildings (8%), steam and process heat (6%), electricity generation (6%), and others (12%) [8].

Climate change and air pollution has increased concern of the use of fossil fuels. Major problem with fossil fuel use is greenhouse gas (GHGs) emissions. The GHGs—N_2O, carbon dioxide (CO_2) and methane (CH_4) have increased by 20%, 40% and 150% above pre-industrial level. In the 1880s (during the industrial revolution), the atmospheric concentration of CO_2 was about 280 parts per million (ppm). In 2015 and 2016, it was 399 and 403.9 ppm, respectively, representing 30% increase above pre-industrial level. Emissions from combustion of fossil fuel account for 65% of the global anthropogenic CO_2 emissions. Residence time of CO_2 in the atmosphere varies between 50 to 200 years [9]. About two-thirds of global GHGs emissions comes from energy production and consumption. Between 1880 and 2012, the average temperature of the globe increased by 0.85 °C. Presently, there are increased variation in temperatures and severe weather, resulting to increased degree and incidence of hot days across most regions of the globe. Relative to pre-industrial levels, a temperature increase of between 1.5 °C–4.8 °C is estimated by the year 2100 [10]. Consequently, the present emphasis on renewable energy. Actions that support sustainable development and advancement throughout all segments of human environment are critical to human civilization. Transition from "hydrocarbon molecules to electrons," (fossil fuels to renewable and low-carbon energy) is growing globally [8].

Energy transition follows when an economy changes from one significant source of energy to another. Past transitions largely occurred at national and sometimes regional level. Conversely, because of globalization, the present energy transition will likely encompass many regions of the globe [8]. Some researchers prefer the term "low-carbon transition" to "energy transition" [11]. It is a much wider categorization and reflects the present observed reality. Low-carbon transition emphasizes reducing greenhouse gas emissions from the energy sector, independent of fuel or technology. Regardless of the terminology used, transition from fossil fuel to renewable energy sources is the future of decarbonized energy system.

In accordance with environmental objectives, most of the developed countries have established legal structure to strengthen the use of renewable energy (RE) sources. Another factor that has encouraged increasing use of RE is the insecurity associated with fossil energy supply and demand [12,13]. Decreasing cost of renewable-generated power, market penetration of electric vehicles (EVs), numerous technological innovations, issue of energy security and oil price volatility are the other factors supporting the present energy transition [8]. The timeframe for the transition is largely dependent on country's socioeconomic and technological capacity. For example, it took Great Britain more than 200 years to transition from wood to coal in heating of their homes, whereas France transited from oil to nuclear in about 15 years [14].

Energy establishment analysts underestimate the haste and penetration of the transition. The same observation is true for many oil producing countries, especially the lower and middle income countries like Nigeria, which has continued on business-as-usual scenario. Conversely, the financial industry recognizes the depth of penetration and is taking the transition seriously [14]. Energy transition is not a new phenomenon. Fuel wood used to be the major source of energy across the globe, until development of steam engines. The U.S. and most western (developed) countries transited from wood to coal between the late 19th to early 20th century. The transitions were encouraged by market disruption and technological developments. The oil shock of 1973–74 made France to shift the bulk of their electricity generation from oil to nuclear power [8]. The same scenario presents itself today. However, the major factor supporting the current energy transition is environmental concerns.

The pursuit of sustainable energy is strongly associated with political will and the necessary socio-economic structure, which differs across the regions of the world. Advancement of RE development is central to Nigeria's National Energy Master Plan (NEMP), but the pursuit has been very slow. This is based on weak political will, poor legislative framework and socioeconomic support towards the development [12]. For Nigeria to continue in business-as-usual scenario is to its disadvantage. If the transition occurs rapidly than energy industry expects, the consequences for oil-exporting countries and their geopolitics (especially OPEC members) will be very disruptive [8]. Accordingly, the importance of this paper. The paper is basically sectioned into two. The first part discusses the brief introduction, historical energy transitions (globally, and in Nigeria), energy consumption in Nigeria and expected impact of the ET on Nigeria. In the second section, future directions—renewable energy development, economic diversification and energy-efficiency were discussed.

2. Energy transition

2.1. Generalized energy transition

Energy transition (ET) is a major change from a dominant model to a different paradigm in energy system [15]. It means moving from a socioeconomic and technological system to a different one, as regards energy supply and use [16]. It is the diffusion of energy use from 5% to 80% (or the peak, if it did not attain 80%) in a particular sector. Since industrial revolution, the average period for the diffusion from invention of the core technology to 80% portion of energy use (or peak) is 95 years [14,17]. ET characterizes various period of human history. For example, the harnessing of fire by people of the medieval age transformed the course of humankind. Use of wind power for oceangoing ships made possible trans-maritime trading and movement of people across the oceans. ET is complex and exceeds mere substitution of one source of fuel with another. It is multi-faceted, non-linear and very uncertain. Though, ET is usually evaluated based on the speed of changes in the noticeable elements—energy source and technologies, it is a comprehensive development with several actors—institutions, society and agents [15]. According to [18], three ETs have occurred in primary energy mix. They are:

i. transition from wood (biomass) to coal,
ii. transition from coal to oil and gas (hydrocarbon), and
iii. transition from tradition fossil fuel to non-fossil fuel (renewable energy).

Organic fuels—firewood, charcoal—were the major energy sources during the middle ages. Majorly, energy consumption in the 1700–1800s was for residential use—heating and cooking. As towns grew, and the supply region extended, transport cost increased very high. The development increased the prices of wood fuels, which has relatively the same per energy unit with that of coal. Conversely, when the price per energy unit of wood became twice that of coal, the motivation to use coal enlarged. Accordingly, the populace made an effort to replace wood with coal. This accelerated development which gave rise to invention that produced the shift to coal. However, the shift from wood to coal was not a simple process, as it posed complex technological difficulties. First, the use of coal in heating emits sulphur which makes home unlivable. Secondly, coal requires a confined small space, different from open fireplace of the medieval house. Therefore, the use of coal requires a new house design, incorporating chimneys. Chimneys were costly to build and only the wealthy could afford it for hundreds of years [19].

Between fourteenth and fifteenth century, the use of coal for energy production rose from 10% to 35%, in Britain. In 1760, commonly assumed as the start of the industrial revolution, use of coal in energy generation attained 64% [19]. Watts' invention of steam engine in 1769 and development of the first coal-fired steam engine in France, in 1875 increased the growth of coal industry [18]. It brought about industrial growth, and resulted to Britain's control across the globe in the 19th and early 20th centuries. It also produced the "Fossil-Fuel Age," which has extended for more than 200 years now [20]. In 1780s, coal exceeded wood as the major share of primary energy mix for the first time in history. This point marked the transition from wood to coal or the first energy transformation [18]. By 1860, coal accounted for 93% of the energy consumed. The shift was very slow and much of it occurred before the occurrence of industrial revolution [19]. Though the nineteenth century may be considered the 'great age of coal,' global consumption of wood was 100% higher than that of coal. Similarly, though, the 20th century is highly regarded as the 'great age of oil,' global consumption of coal was 15% higher than that of oil. Accordingly, the rise of coal and oil did not mean the end of wood and coal, respectively [15].

The second energy transition is the shift from coal to oil and gas, in the primary energy mix [18]. Following after the coal steam engine, was the invention of internal combustion engines (ICE). ICE was used by vehicles and gas turbines to generate energy to drive machines [20]. Consequently, the portion of oil and gas in the primary energy mix rose tremendously to more than 50% in 1965.

Estimation factoring in several factors shows that oil production will reach its peak around 2040, at about 45 × 10^8 tons, while that of natural gas will peak around 2060 [18]. Transition to new energy sources are usually slow, and even at that the use of the older energy sources still continued along with the new ones. Factors that have shaped the shifts across the world include the complex relationship between economics and supply and demand, and technologies associated with the consumption of specific forms of energy. Our paper conceptualized historic ET in Figure 1 below.

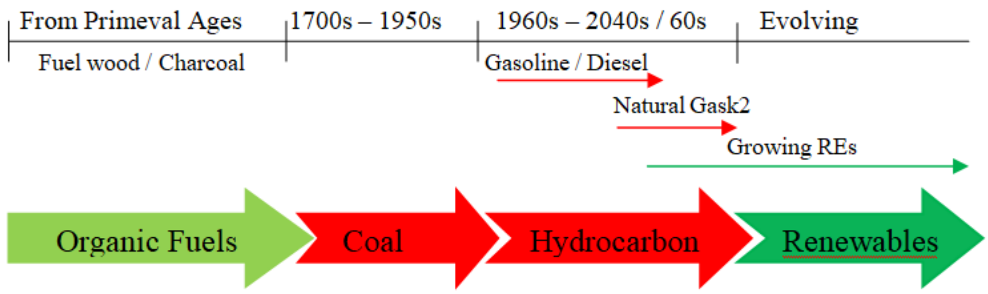

Figure 1. Basic representation of energy transition eras.

The third energy transition is transformation from fossil-fuel to renewable energy. Environmental considerations account most for this energy transition [19]. Past transitions happened naturally or by chance without strong policy support [15]. Conversely, current transition is driven by well-defined. According to [21], the current transition of the global energy system is supported by three related factors viz:

i. economic factor of supply and demand, and of national competitiveness;
ii. security factor rationalizing the tactical implication of reliance on trade in oil and gas; and
iii. sustainability which focuses on the search for a low-carbon energy mix.

Growth in renewable energy development is stronger in the power sector than other sectors such as transportation. For example, more than 181 gigawatts (GW) of renewable power were installed in 2018. In the same year, more than 90 countries have added at least 1 GW of variable renewable energy (VRE) electricity generating capacity; while 30 countries surpassed 10 GW capacity. Presently, many countries have more than 20% variable renewable in their electricity mixes. Solar energy (photovoltaic) accounts for 55% of the newly added REs, followed by wind power (28%) and hydropower (11%). RE now account for about 33% of the total installed electricity generating capacity across the globe [22]. In 2019, primary energy consumption grew by 1.3%, and the increase was driven by renewables (3.2 Exajoule) and natural gas (2.8 Exajoule). Combined, the two sources accounted for 75% of the increase (BP 2020). From 2010 till present, renewable energy (power sector) has been growing at an average of 8% per year [23]. In 2010, there were 750 million passenger cars in the road worldwide. The growing middle class in emerging economies will increase the demand, and consequently it is estimated that about 1.5 billion cars will be on the road by 2030 [24]. Focus on the transition is more on transportation and energy generation. Estimate show that full penetration of EV will reduce global fuel consumption by 25 million barrels per day (mbpd) [7]. Many countries—Norway stated its plan to ban fossil-fueled car by 2025; Germany (2030). Similarly, China, Japan and many developed countries are pushing for a phased ban of fossil–fueled cars. Electric vehicles (EV) are increasing globally. In 2012, number of EVs increased by 100% above 2011 level.

In 2012, total stock of EV in thirteen major EV markets was 180,000. The United States accounted for 38%, followed by Japan (24%), nine EU countries (11%), China (6.2%) and India (0.8%) [25]. In 2018, number of EVs across the globe increased 63% above 2017 level. 3.3% of the global transport sector was fueled by RE sources in 2018. Most of the RE source of the sector is supplied by liquid bio-fuels [22]. These growing trends will unsettle and dislocate oil-exporting countries, especially those that rely heavily on it for foreign exchange, like Nigeria.

Economics interrelated with the other two factors (energy security and sustainability) have steadily made renewable energy sources very viable. Forecast shows that global cost of renewable energy has been declining steadily. For example, in the US, the cost of wind and solar power per kilowatt-hour were $11c and $17c (US cents) respectively, in 2013. Globally, average cost of wind and solar energy is presently $5c/kWh and $6c/kWh, respectively. It is estimated that wind power will further decrease to $4c/kWh in 2020. Therefore, renewable energy has become very competitive across the globe [15]. Estimate show in 2018, RE sources supplied more than 26% of global electricity generation [22]. The ability of oil-exporting countries to highly diversify their economy will determine how rapid the global energy transition will occur. Among the primary energy mix, only renewable and gas showed a positive increase in 2019 [26]. Table 1 presents global primary energy consumption in 2019.

Table 1. Fuel shares of primary energy and contributions to growth in 2019.

Energy source	Consumption (Exajoule)	Annual change (Exajoule)	Share of primary energy (%)	Percentage point change in share from 2018 (%)
Oil	193	1.6	33.1	−0.2
Gas	141.5	2.8	24.2	0.2
Coal	157.9	−0.9	27.0	−0.5
Renewables*	29.0	3.2	5.0	0.5
Hydro	37.6	0.3	6.4	−0.0
Nuclear	24.9	0.8	4.3	0.1

* Renewable power (excluding hydro) plus biofuels

Source: [26]

Per unit calorific value of different fuels are: coal (26.3 t/TJ), crude oil (20.1 t/TJ) and natural gas (15.3 t/TJ). Hydropower, wind power, nuclear and solar energy are practically carbon-free. The shift from coal to fossil fuels; and from fossil fuels to the presently growing RE sources has moved from higher carbon-content fuel to lesser carbon-content fuel [18]. Although calorific value of fuels may have steadily decreased through the transitions, population increase, industrialization and its associated energy requirement, urbanization and expanding transportation systems has increased energy consumption, and more GHGs emissions. For example, in a one-year period (2015–2016), the atmospheric concentration of CO_2 increased by 4 ppm, to 404 ppm. By May 2019, the atmospheric CO_2 level has reached 415 ppm [9]. The global temperature is now 1.2 ℃ higher than pre-industrial revolution level [20]. Economic activity depends on efficient supply of energy. Estimate shows that in 2030, energy demand will increase by 21%. Therefore, accelerating transition to RE system provides opportunity to achieve Paris Agreement climate objectives and sustainable development goals—economic growth, employment and improved human welfare [27].

Past energy transition revealed "S"-shaped curve during their lifetime. At the start of the transition, the performance of the new fuels and technologies expands and penetrates the market gradually. It sped up at certain point afterward, and finally contracts when technology development advances. The speeding up is very critical to the development cycle of the technology. It is the critical inflection point after which the rate of diffusion will develop at a more rapid speed. The issue confronting decarbonizing or pursuing low-carbon energy in global economy is not non-availability of cost-competitive alternatives, nor scarcity of renewable or low-carbon primary energy sources. Rather, it is poor geopolitical cooperation across the globe to achieve the transition through strategic mechanisms such as carbon pricing, public-private partnership in research and development, and effective government regulations [20].

2.2. Energy transition in Nigeria

Nigeria has also experienced transition in its energy system. According to [28], five energy transition periods have taken place in Nigerian. They are: (i) pre-industrial (agricultural) era—mid 1800s; (ii) early industrial (advanced metallurgy) era—late 1800s; (iii) industrial (steam engines) era —early to mid-1900s; (iv) late industrial (dynamo, ICE) era—mid to late 1900s, and (v) information (microprocessor) era—early 2000s onwards. Four major characteristics that influenced the country's energy transition are—energy resources consumed to meet demand for energy; technological intrusion that made possible production and use of energy; commercial and end-use activities that created and patterned demand for energy; and establishments governing energy infrastructure and supply [28].

Based on these characteristics, and past transitions in other regions of the world, our paper distinguishes broadly three comprehensive energy transition periods in Nigeria. It is based on available energy sources and technology evolution. They are: (i) ancient era to late-1800s; (ii) Late 1800s to mid-1900s; and (ii) post-colonization era till present

2.2.1. Ancient era to late 1800s

The first energy transition is the transition from ancient days (largely agrarian society) to early industrial age. Agriculture was largely the only economic sector of the society, and it was mainly subsistence farming. Manual labour was what is required to create agricultural produce. Transportation of the produce to markets is mostly local. The crude implements used in the era are hoes, cutlasses which required minimum technology and skill of blacksmith. From agriculture, other crafts and arts evolved. They include dishes made from wood carvings, furniture made from timber. Cultural ceremonies largely depend on agriculture, such as new yam festival [28]. The major energy used were traditional biomass, agriculture wastes, residues and solar. Energy consumption was largely sustainable, as resources, energy and environment are used carefully. Even when organic fuels such as firewood or fuel wood are used, the source (forest) are exploited sustainably. Human needs were very elementary consisting of food, shelter and security. Household energy needs consists primarily of lightings, cooking, and were met by firewood and biomass. There was absence of technological enablers in production and consumption of energy. Available technologies were rudimentary, for example, goldsmith, blacksmith and other craftsmen. The system of commerce was mostly trade by barter. The need of life was very basic. Therefore, there was no society-wide demand for energy to drive production, since technological development was very minimal at best. This is comparative to what was obtained in western countries (e.g., Britain) before the industrial revolution. There were no institutions responsible for energy infrastructure and supply. There was inter-city and even regional commerce, driven mostly by animal-powered transport (in the northern Nigeria)—camels, donkeys, and in the southern Nigeria, by canoes, trekking, etc.

In the mid-1800s, the widespread use of metallurgical implements furthered energy use dynamics. It does not mean that metallurgy has not existed in the area before now, but rather it shows how understanding of metallurgy supported far-reaching mechanization beyond agriculture to production of machine and agricultural tools. The tools aided local small industries especially in transportation needs, for example wheel barrows, bicycles, mechanisms coupled with draft animals [28].

2.2.2. Late 1800s to mid-1900s

Colonialism followed strongly behind industrial revolution, as British industries need raw materials. The industrial revolution—which started in Great Britain—and diffused into Nigeria howbeit minimal (through colonization) changed the system of production, commerce, transportation and other sectors. Lagos was invaded by British forces in 1851 and annexed in 1865. However, contacts between Nigeria and Europeans date back as far back as 1472 when the Portuguese purchased pepper and ivory from Benin City. Colonization brought minimal technological intrusion into Nigeria, and altered energy infrastructure system over time. First, was the use of steam engines (late 1800s to early 1900s), coal fired power plants from 1920s to mid-1900s), construction of rail line from Lagos to Ibadan which started in 1898 and was completed in 1901. International trade grew. For example, in 1893, 446 ships called on Nigeria harbor, up from 99 ships (in 1863). Palm oil produce significantly increased the economy of the country [28].

The increase in trade activities requires ports and harbor infrastructure. In 1896, the first electrical power plant was constructed, to supply power mostly for lighting uses. The plant installed capacity was two 30 kW, 100 V single-phase supply. Increased demand led to building additional 60 kW. Use of electricity was rapidly replacing traditional oil lamps for lighting. It was within this era, that coal was discovered in Enugu, southeastern Nigeria (1909). In 1916, 24,500 tonnes of coal was produced. Similarly, there was a gradual but substantial shift in energy use in transportation (increasing use of railroads) and energy production. In 1923, coal-fired power plant was commissioned, with a total installed capacity of 3.6 MW. Coal-fired power plants were built in Enugu (1924), and the city was lighted. By 1929, generation at the plant is 936 MWh [28]. These transportation systems (rail) were constructed to enable conveyance of commodities (raw materials, agricultural produce) from the hinterlands to the coastal towns of the country, for onward transport to the UK [29]. Road infrastructure development came much later in the 20th century. By 1930, urban areas like Zaria, Port-Harcourt, Makurdi, Ilorin, Jebba, Minna and Gusau were connected by railway. In 1955, railway, initially a government department was later transformed to Nigerian Railway Corporation (NRC), by an act of Parliament. The Act granted NRC control of rail transport in Nigeria. At NRC establishment, there was 3,505 km narrow gauge single-track railway network. By Nigeria independence, railway transportation controls more than 30% of freight market in Nigeria. It was lucrative for farmers involved in production of cash crops (cocoa, groundnuts and cotton) which were very much in demand by British industries [30]. At the end of colonial rule (1960), Nigeria rail network totals 2,286 km. Only 1,542 km have been added since then [29].

The era witnessed widespread use of primary energy, driven by ICE as the main technology. Colonial administration was the main factor responsible for the increase. Different institution enablers—Nigerian Electricity Supply Company (NESCO), were in charge of developing electricity generation infrastructure [28]. Another is Nigerian Coal Corporation. There was available technological intrusion that gave rise to demand for energy (mostly coal), economic considerations for the provided technology and energy requirement, governmental control of the energy-driven system (transport, power plants, etc). Without technology, available energy remains dormant. For example, though coal has always existed in the southeastern Nigeria, there was no increased demand for it. Similarly, Nigeria has abundant RE sources, but technological incapacity and poor institutional framework has highly limited the ability to harness it and provide energy access for millions of the citizens. Though there was increased demand for primary energy, household and industrial energy needs were still rudimentary, and coal and biomass supplied it.

2.2.3. Post-colonization era till present

Toward the end of British rule in 1960, oil was discovered in Nigeria in 1956 [31]. Decline of coal production and consumption in Nigeria (between 1944–1948) preceded oil discovery and focus on hydroelectricity production. Oil exploration in Nigeria started in 1937, with award of concession rights to an Anglo-Dutch consortium -Shell D'Arcy—predecessor of the present Shell Petroleum Development Company. The concession right extended throughout the country. They suspended their operations at the commencement of the Second World War. Normal activities (exploration) resumed in 1947. In 1956, almost 20 years after the initial concession was granted, oil in commercial quantity was discovered at Oloibiri (Bayelsa State). In 1958, production started at 5,100 barrel per day (bpd). By late 1960s and early 1970s, Nigeria was producing more than 2 million barrel per day (mbpd). In the 1980s, because of economic contraction, production decreased. However, in 2004, a record new production level of 2.5 mbpd was attained. The availability of natural resources—coal, crude oil and natural gas supported the enlarged utilization of those resources. Resource availability is the main driver of energy use. Increasing demand for energy is the secondary reason [28]. Growing demand and resource availability led to transitions in energy use. The era saw increased use of hydrocarbons—petroleum, primarily because of diffusion of ICEs, in transportation, electricity generation, use of petroleum by-products in petrochemical industry for production of plastics, polymers and other compounds. Post-independence saw increased road construction. It was occasioned by oil boom which enlarged demand for goods and services, as wages of public and private sectors increased. Within 1976–1982, number of vehicles in Nigerian road increased by more than 100%. This factor led to rapid urbanization [29]. The increase in road transportation was huge. At independence, Nigeria road network consist of 66,000 km; then 86,136 km (1980) and 200,000 km (2014) [32]. Manufacturing activities, construction and real estate, energy generation and consumption also increased [28].

2.3. Policy mix in energy transitions

The importance of policy to energy transitions is critical. Policymakers frequently depend on policy instruments such as price mechanisms to set out sustainable energy without considering the issues of justice and greater political and economic concerns of ownership of the energy system, the technologies that are employed and how the energy is utilized [5]. Policy mix towards sustainability transitions (in this case RE) should include nature of the future energy systems, circularity and financing instruments.

There is no doubt that to meet sustainability goals, transitions to sustainable energy must proceed together with the concept of circular economy. The association between energy transitions and circular economy is very strong. Both concepts are geared towards "decoupling" energy system and production-consumption function from negative externalities. The two sustainable models are concerned with decreasing ecological impact of anthropogenic activities. Present ET encompasses a very limited element of CE objectives—waste-to-energy, while circular economy emphasizes the utilization of low-carbon and renewable energy sources. The present production-consumption system which is largely linear, requires energy supply which is most often (for example, in Nigeria) supplied by fossilized sources. Similarly, the linear economy produces waste. The integration of both offers pathways towards reducing greenhouse gas emissions and achieving resource efficiency. Landfill are the third leading source of anthropogenic emission. It produces about 223 million metric tons of carbon equivalents (MMTCE) per annum. Landfills (or dumpsites) in Nigeria accounts for 1% (or 2.23 MMTCE) of global methane emissions from landfills. Exploiting this energy sources will improve energy supply in the country. In 2018, for instance, the US generated electricity of approximately 14 billion kWh from 30 million tons of municipal solid waste. This supports the importance of adopting circular economy principles in pursuit of sustainable energy transition [33,34]. Further, biowaste-based energy transition will increase energy production, decrease greenhouse emissions, conserve natural resources and create new businesses [3]. A good example is the transformation of a disused petrochemical refinery in Gela, a city in southern Italy into a second generation biorefinery. The biorefinery will produce about 530,000 tons of biofuels per annum from first and second generation raw materials, including food wastes and animal fats [1,2]. Therefore, it is imperative that ET be increasingly linked with CE.

Future energy system will partially be a two-dimensional association between the social framework (ranging from democratic to monopolistic) and scale ranging from centralized to decentralized. The above two factors social framework and scope of the energy system gives rise to basically four broad future energy system viz: (i) democratic energy centralism, (ii) technocratic (monopolistic) energy centralism, (iii) democratic energy decentralism and (iv) libertarian (monopolistic) energy decentralism. In centralized energy system, energy production (generation, transmission and distribution) is detached from end consumers. For decentralized system, energy system is focused at local (micro) levels, and energy production and use takes place at a highly closer space. A good example is nano- or micro-grid involving distributed technologies that serve a building. In democratic centralism, just like a proper democratic society, bureaucratic institutions are accountable to the public, and decision-making are produced through democratic pathways. An example may be large-scale central renewable energy cooperatives (production-transmission and distribution) system controlled by consumers in a defined geographical location. Technocratic (monopolistic) energy centralism refers to the largely present energy system where decisions are made solely by utility corporations and state regulatory bodies. In democratic energy decentralism, energy system functions at decentralized levels—building complex or neighborhood—which uses distributed-generation technologies and energy storages, linking production to consumption. In libertarian (monopolistic) energy decentralism, the energy system is decentralized by hold by a monopoly [5].

Whichever pathways, it is clear that finance (for new or modified infrastructure development) is critical to the ET. This is challenging for an emerging economy such as Nigeria. Both the public and private sector has a part to play in financing of low-carbon and renewable transitions. This is very necessary as "green ventures" are capital intensive, have a high technology risk profile and unclear exit chances for investors. Thereby, creating finance gap for RE and low-carbon investments. This is because initial phase development of RE projects may not have past information that provides investors with information/data required to evaluate the risks of the venture. Therefore, the information asymmetries escalate the risk of RE development. Time scale also increases the finance gap, as RE requires long time scale. Investors are always out for profit, and therefore always prefer to medium term time scale [6]. All these have serious consequence on countries such as Nigeria, where most Foreign Direct Investment (FDI) and investment flows into hydrocarbon production, there is no meaningful large scale RE venture yet to provide finance and risk analysis for investments, and where political and economic orientation are still geared towards fossil economy. There is therefore need for both public and private funding of green innovation technology enterprise. Legislation and financial incentives (such as tax breaks) are critical enabler for this to happen. Steep first-mover cost and costly risk-return profiles for private investors are also barriers to deployment of solar PV-grid connected infrastructure in Nigeria [35].

Factors such as oil subsidies which have largely made oil to be cost-competitive related to renewables should also be critically addressed, to scale RE and low-carbon energy financing. Therefore, any financing policymaking instrument must address this critically. In Italy, re-introduction of subsidies for PV plants with a nominal capacity above 20 kW through FER 1 Decree showed profitability and increase in investments [36]. Thus, the role of public sector in green financing ecosystem (RE and low-carbon energy) include subsidies, grants, early stage equity investment, debt financing and lending, etc. Another supporting policy environment is regulatory and tax regime for sustainable energy ventures, which should incentivize long-term investments. Considering the high technological risk of 'green' ventures, there needs to be constancy in policy to ensure continued financing [6]. To support biofuel development, Italy implemented tax exemptions from all excise duties which are usually placed on petroleum products, biofuel support scheme which supports blending quota on petrol and diesel; special treatment and incentives for biofuels produced from raw materials, wastes, residues, cellulosic and lingo-cellulosic materials [1]. This is instructive for Nigeria where capital and legislative framework are major hurdle to scaled RE and low-carbon energy development.

3. The study area

3.1. Demography and economy

Nigeria, located in West Africa, is the most populous country in the continent. National Population Commission (NPC) census of 2006 recorded the population of the country as 140,431,790. At a growth rate of 2.7% growth per annum, the population in 2019 is estimated at 198.6 million. Globally, Nigeria is 7th most populous country. It has a total area of 923,770 km^2, with land accounting for 910,770 km^2 and water bodies, 13,000 km^2. The national gross domestic product (GDP) and GDP per capita are \$478 billion and \$2,702, respectively. The average age of Nigerian population is 18 years, making it one of the countries with very young population. The urbanization rate is 3.5% per annum, and presently 51.16% of Nigerians live in urban areas. 84 million hectares of Nigerian land are arable. Also, Nigeria has 34 solid mineral resources [37].

In the 1960s, agriculture accounts for 80% of Nigeria's total export (and foreign exchange). It was the sole support of the country's economy. However, in less than 10 years (mid-1970s), oil accounted for about 94% of total export and foreign exchange. Ever since then, oil has been the major export commodity and foreign exchange earnings for Nigeria. The single commodity economy makes Nigeria highly exposed to the impacts of global oil price shock. For example, global contraction of oil price in 2015 pushed Nigeria economy into recession from 2016–2018. Accordingly, export is not only crucial for the economic growth, but the composition of the total export is very critical [38]. This is supported by [39] report that though the oil sector accounts for 8.4% of the country's GDP in 2016, the reduced foreign exchange earnings from oil export in the year had widespread implication on the non-oil sectors, which rely on importation of input and raw materials. This was more particularly seen in manufacturing and trade.

Although the oil sector accounts for significant portion of Nigerian export, non-oil sectors are responsible for considerable share of the GDP. Nigerian Bureau of Statistics (NBS) showed that in 2019, non-oil sectors contributed 91.2% to Nigeria GDP, while oil sector accounted for 8.78%. Non-oil sectors that drive the GDP growth are agriculture, financial and insurance services, manufacturing and information and telecommunications. In 2019, the GDP of the country grew by 2.27%, a 0.17% increase above 2018 level [40]. Consumer expenditure accounts for about 70% of Nigeria's GDP, and therefore drives the economy. Population increase, economic growth, increase in household income, and urbanization will result to about household spending of $1.1 trillion by 2030. It represents an increase of 71.2% above household spending in 2014 ($317 billion). Put another way, Nigerian household spending is expected to increase by 9% per annum from 2014 to 2030 [37].

In pursuit of economic diversification, import substitution strategy have been employed basically across agriculture and manufacturing. It is geared towards duplicating the success in cement production, which is currently above domestic consumption. Consequently, since 2012, duties have been imposed on specific agriculture produce. The duties are applied to wheat, rice and sugar. The duties have also been extended to automobile sector [37].

Apart from hydrocarbons, Nigeria has abundant natural resources. Yet, number of people living in poverty is very high. In 2019, 40.1% Nigerians lives in poverty (earns ≤ $2 per day) [41]. The phenomenon has given rise to what is commonly called "resource-curse." Comparatively, emerging economies that have abundant natural resources performed poorly economically relative to those that have scarce natural resources. It suggests an inverse association between natural resources and economic growth. GDP per capita of resource-deficient countries grew three times the rate of resource-abundant countries. The growth rate enlarged extensively since 1970s. The poor economic growth of resource-abundant developing countries may be related to diminished returns on human investments occasioned by natural resource development, economic mismanagement and inept resource distribution [42,43].

Nigeria contributes about 1% of global GHG emissions. Per capita GHG emission of the country is about 2tCO_2e. The country is grouped among the ten most climate-susceptible countries. It is estimated that climate change effect on the country's economy will lead to about 2–11% losses in GDP by 2020 if adequate mitigation measures are not taken. The estimate is assessed moderate considering economic losses produced by incidences such as contraction of Lake Chad, flooding disasters of 2012 and 2018. The 2012 flooding amounted to about 2% of the year's GDP [44].

3.2. Energy consumption

Estimated primary energy consumed in Nigeria in 2017 was about 1.5 quadrillion British thermal units. Natural gas, petroleum and other liquid fuels accounted for 97%, while biomass (firewood, charcoal, compost and produce residues), coal and renewables accounted for insignificant use (3%). Accordingly, Nigeria energy supply largely comes from fossil fuels. Out of total installed electricity generating capacity of the country (12,664 megawatts); 10,522 MW (83%) is from fossil fuels, 2,110 MW (17%) is hydroelectricity; and only 32 MW (<1%) is solar, wind and biomass. Actual generated electricity is about 3,495 MW, representing 27.6% of installed capacity [45]. Table 2 shows Nigeria RE potential.

Table 2. Renewables potential and their current utilization in Nigeria.

Resources	Amount	Current Use
Large hydropower	11,250 MW	1930 MW (17.1%) used
Small hydropower	3,500 MW	64.2 MW (1.83%) used
Solar	4.0–6.5 kWh/m^2/day	27% Capacity Factor (Negligible)
Wind:	2–4 m/s @ 10 m hub height	
- Onshore wind	1,600 MW	Negligible use
- Offshore wind	800 MW	Negligible use
Geothermal	500 MW	Negligible use
Biomass (Non-fossil fuel):		
Municipal waste	30 million tonnes/year	0.5 kg/capita/day
Fuel wood	11 million hectares of forest	43.4 million/tonnes/yr consumed
Animal waste	1.05 tonnes/day	Negligible use
Agricultural residues	91.4 million tonnes/yr produced	Negligible use
Energy crops	28.2 million hectares of arable land	8.5% cultivated

Source: [13]

The table clearly shows that renewables utilization is highly negligibly in the country. For example, while solar PV is accelerating in many countries, it is still extremely poor in Nigeria. Factors such as oil-dependent economy, technological incapacity, poverty level, political and socio-technical inertia [12], and the initial cost of deployment of the technologies (for households) presently militates against its wide-scale adoption in Nigeria. Other factors include unproven marketability in Nigeria's local market, and exorbitant risk-return profiles for private investors [35]. For example, though the average cost of solar power is $6 c/kWh [15], the initial cost for installation of 4 kW solar PV system for an average 3-bedroom apartment is about $9,090 [46]. Considering that greater number of Nigerian earn less than $2 a day [41], the issue becomes clear.

3.2.1. Coal

Coal is found mainly in the Middle-Belt (Kogi, Benue and Gombe States) and Southeastern (Enugu State) regions of the country. A realistic estimate show that identified 17 coal fields in

Nigeria has a reserve of 3 billion tons, and more than 639 million tons of proven reserves. The coal which are low rank are approximately, 49%, 39% and 12% sub-bituminous, bituminous and lignite coals, respectively [47,48]. Coal was first discovered in the country around 1909 and production started immediately. Generally, there are two production period—the pre-civil war and the post-war era. Rate of production grew slowly until 1958 when it noticeably increased to meet the demand of the then coal-powered generating plants. Immediately after Nigeria civil war which took place between 1967–1970, production started at less than 10,000 tonnes per annum. After that, production generally has been decreasing. Maximum consumption was around 1972 [49]. Figure 2 shows Nigeria coal production and consumption from 1980 to 2013, adapted from [50].

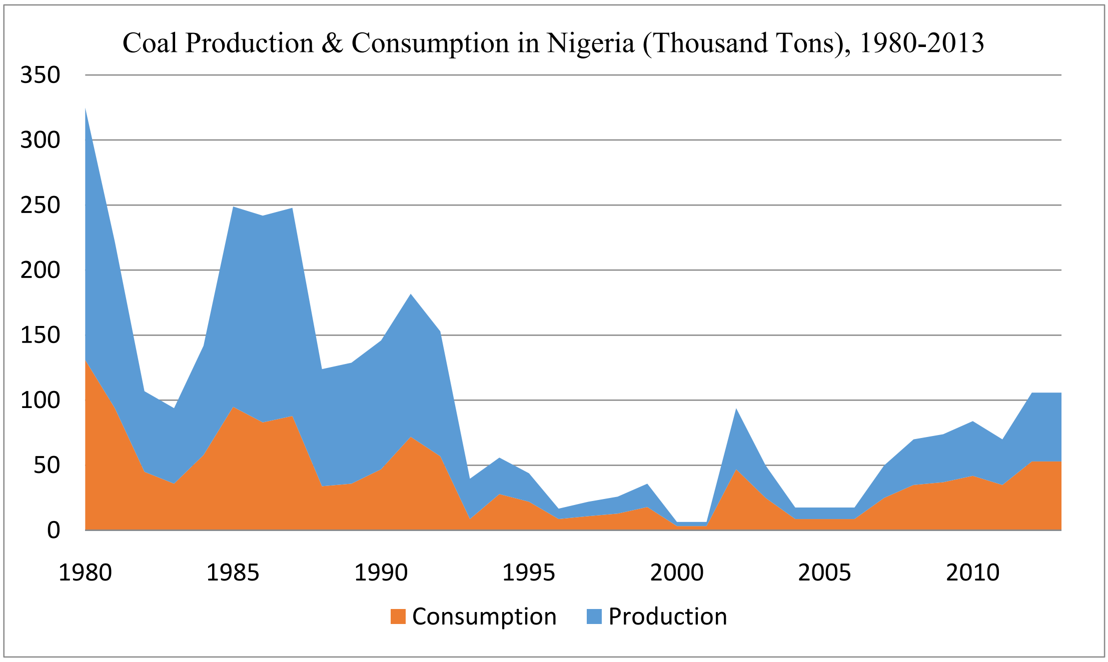

Figure 2. Coal Production and consumption in Nigeria, from 1980–2013.

The figure above shows that production and consumption of coal have significantly decreased over the years. It can be safely argued that coal is now a 'stranded resource' in Nigeria, as efforts over the years to revive its production has not succeeded.

3.2.2. Oil

Nigeria is the major producer of crude oil in Africa. Globally, the country is 22nd largest economy. It is projected that in 2050, the GDP of the country will be about USD6.4 trillion, situating it among the ten largest economies [37]. The country's economy is largely dependent on oil exportation. It has the second largest reserve in Africa after Libya. The estimated crude oil reserve is 37 billion barrels. In 2019, daily production of oil and natural gas was about 2 million barrel per day (mbpd). Currently, in accordance with its commitment to OPEC, the country's oil production is pegged at 1.41 mbpd from 1st May, 2020 to 30th April 2022. Nigeria's oil production is affected by intermittent supply interruptions. Over-dependence on oil means that the country's economy is significantly affected by fluctuation in global oil prices. Non–oil revenue accounts for only 3.4% of the country's GDP, which is among the lowest in the world [45]. Based on comparative analysis of resources and non-oil sectors contributions of ten major oil-producing and emerging economies, [51] argues that Nigeria's economy is diversified. The contribution of resources sector to their economy showed the following Kuwait (61%), Saudi Arabia (45%), UAE (37%), Iran (26%), Venezuela (24%), Russia (11%), Mexico (8%), China (6%), and Brazil (4%). For Nigeria, it is 14%, which is far below the average of 23.6% of the total contribution of resources to the ten economies. Nevertheless, the country's reliance on oil is still high. For example, taxation of oil and gas sector accounts for about 75% of federal revenue.

3.2.3. Natural gas

Nigeria has the largest reserve of liquefied natural gas in Africa, ranking 5th in exportation of liquefied natural gas (LNG) globally. By 2019 ending, the estimated volume of Nigeria natural gas reserves is about 200.4 trillion cubic feet (Tcf). In the same year, 1.6 Tcf of natural gas production was marketed [45]. Natural gas is reputed to be the cleanest fossil fuel, and have the "3As" of energy security—availability, affordability and acceptability. In pursuit of cleaner energy, natural gas production and consumption is increasingly being adopted as a bridge towards decarbonization. In the last 50 years, natural gas contribution to global primary energy mix has increased from 15.6% to 23.7%. It is the fastest growing fossil fuel [18]. Since there is still opportunity for growth in natural gas, the best buffer for Nigeria against the growing transition and decreasing demand for oil will be to increase gas production, at least in the intermediate future. By 2040, estimate shows global energy use will increase by 24% above today's level. Developing countries will account for most of the consumption. Relatively, natural gas is low-carbon. It is projected that it will experience rapid growth, and global consumption will increase by 36% above its 2018 level [52]. Substantial amount of Nigeria's gross natural gas production is flared. Though [53] report that Nigeria has reduced gas flaring by about 2 billion cubic meters from 2012 to 2015, about 8 billion cubic meters of gas are flared annually, flaring an estimated 700 million standard cubic feet of gas daily. The country ranks among the seventh largest gas flaring country. In 2018, 261 billion cubic feet (Bcf) of natural gas was flared. It amounts to financial loss of USD11 billion per annum. Nigeria cannot adequately address the issue of GHG emissions without tackling gas flaring [45].

Nigeria should reduce the enormous economic loss and ecological degradation associated with gas flaring, by enforcing existing regulations and improving it where necessary. That is the focus of energy resource management (ERM), which aims at using available energy resources for maximum benefits. Adequate investments on efficient gas fired electricity generating technologies will lead to production of sufficient amount of energy. Building a viable market demand for gas will greatly improve return on investments (ROI) made on gas infrastructure. Studies on industrial and economic viability of flared gas-to-generate electricity demonstrate that efficiently regulated gas industry will raise electricity production by 7500 MW per day. Also, successful recovery of gas will result to huge transformation in the transportation sector [13].

The growing transition away from fossil fuel raises a critical concern for Nigeria, and oil industry. How can Nigeria manage or survive a changing setting, while also providing (or increasing) social amenities and services to the citizens; and also become a participant in the global energy changing scenario? To move around this challenge, the country has to diversify the economy, including development of low-carbon energy and technologies.

3.3. *Overview of the impact of the growing energy transition on Nigeria*

The growing global energy transition will affect oil-exporting countries like Nigeria in three major ways [20]. They are:

i. Capital losses, as hydrocarbon reserves are abandoned beneath the ground;
ii. secondary economic losses, as treasury may no longer be able to fund the public sector from oil revenues; and
iii. loss of competitive geopolitical advantage, as hydrocarbons are replaced by global or regional energy access to VRE sources—solar, wind, hydro, etc.

The impact of the transition will be advantageous for oil-importing countries that are able to innovate as regards renewables. It will decrease their vulnerability to oil geopolitics, energy insecurity, and national energy bill. It will also produce industrial and economic gains, creating jobs and stimulating economic growth. Renewables have its own geopolitical risks—the issue of security of raw materials supply associated with the production of RE systems. For example, cobalt, used in batteries is critical to EVs and RE fueled transportation system. In 2008, China imposed a limit on the supply of rare elements leading to panic-buying and increase in prices. Another example is the cobalt crisis induced by internal conflict in Katanga (Zaire) in 1978. It increased greatly the price of the mineral. Accordingly, transition to renewables does not mean absence of energy geopolitics, but instead a change [20]. Geopolitical issues with the transition will be about control of the technologies and intellectual property rights, over the physical resources, their setting and transport course [16].

The growing transitioning to low-carbon energy sources is unsettling the global energy structure, affecting economies and altering the inter-governmental relations inside and among countries [20]. It is usually argued that economic growth of most oil-producing countries (including Nigeria) will lead to increased domestic consumption of their energy, thereby reducing their oil export and curtailing the considerable economic impact of energy transition [15]. Presently, the scenario is far unlikely for Nigeria where domestic consumption has peaked at 440,000 bpd [37,45]. Over the years' Nigerian domestic oil consumption has significantly lagged behind total production. So at present, it can be said the argument does not apply to Nigeria. Figure 3 shows Nigeria oil production and consumption [54,55].

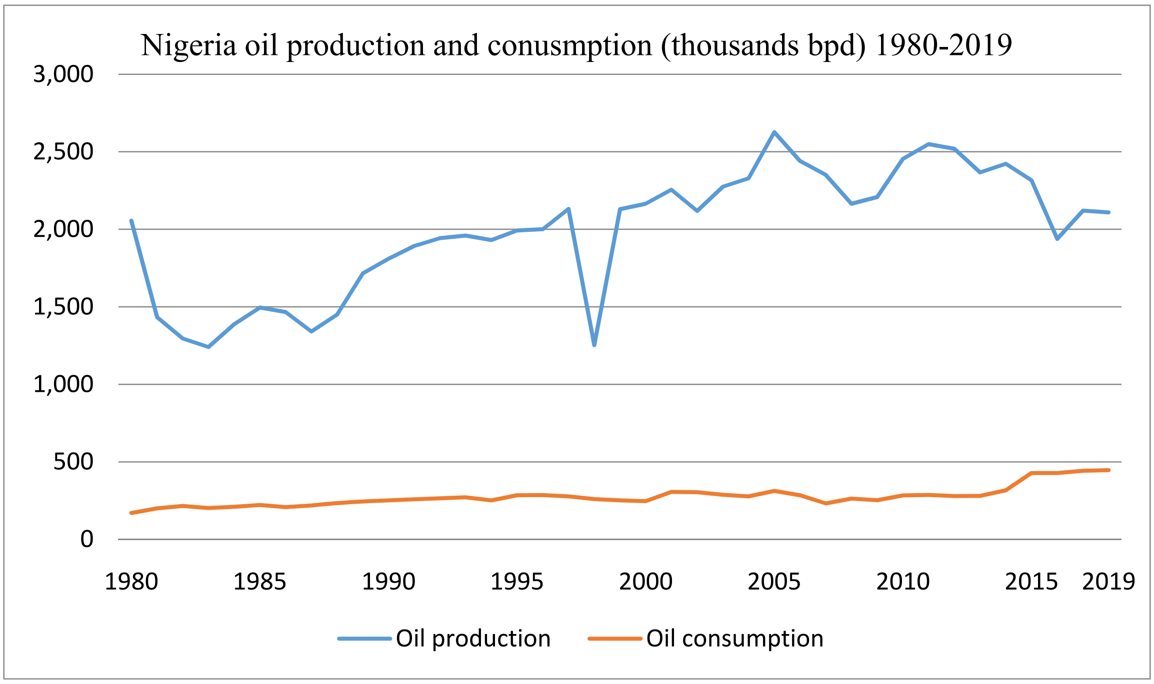

Figure 3. Oil production and consumption from 1980–2019.

If there is no deep economic diversification, energy transition induced reduction in oil-export will curb the country's economic development. There is a positive correlation between economic growth and energy consumption. Without energy, economic growth which increases the purchasing power of the people will not be achieved. Oil accounts for the bulk of Nigeria revenue. It finances critical infrastructure that provides opportunity to achieve economic growth. Non-oil sectors account for the largest contribution to GDP, but oil is the major export. Oil sector attracts the highest foreign direct investment (FDI) to the country. The significance of FDI in the growth dynamic of economies has produced great interest among researchers. Resource-seeking FDI aims to extract natural resources, export and sell the commodity(ies) in international market. FDI are the net inflows on investment to obtain a long-term management interest in a venture operating in an economy that is not of the investor's origin [56]. From 1970–2000, 30% of FDI flowing into Africa is accounted for by Nigeria. The trend was associated with the country's oil sector. Conversely, in 2007, even with the oil boom, the country accounted for only 16%. The decrease was attributed to oil development in countries such as Angola and Sudan. Other factors include enhanced FDI performance of other large African countries like Egypt and South Africa, which are successful in drawing FDI to their various economic sectors [57,58]. Put another way, the average value of FDI as a portion of Nigeria GDP from 1970 to 2018 was 1.52%, with a minimum of −1.15 (1980) and maximum of 5.79% (1994). In 2018, it was 0.5%, whereas global average (180 countries) was 3.36% [56].

Presently, Nigeria ranks third highest host economy for FDI in Africa. In 2019, the total FDI inflow to the country was $3.3 billion, which is lower than that of 2018, by 48.5%. It was estimated that Nigeria's total FDI stock by 2019 was $98.6 billion. The major countries investing in the country include the US, China, the UK, Netherlands and France [59]. The aforementioned countries are also the major buyers of Nigerian oil, except the US which in recent years has reduced importation of Nigerian oil. France, Netherlands, India and UK purchased almost 50% of the country's crude oil export in 2017. The countries are strongly pursuing elimination of fossil-fueled vehicles and integration of RE in their energy mix. For example, the UK and France have stated that by 2040, fossil-fueled cars will be banned. Similarly, India is pursuing electrification of all vehicles by 2030. Consequently, it can be argued that post-2040, some of the present consumers of Nigerian oil may have moved towards other energy sources. The loss of export and resource-seeking FDI will critically dislocate Nigerian economy, with attendant micro and macroeconomic implications—foreign exchange earnings, GDP, per capita GDP, employment, FDI - and other important sectors—power, manufacturing, etc. All these inter-related factors may impact the welfare of the citizens; reduce the inadequate social safety nets, increase poverty, lead to political unrest, and socio-political agitation.

To attract non-oil FDI, emphasis should be laid on: (i) the enormous size of the country's domestic market, (ii) its highest GDP in Africa, (iii) strong agriculture potential, (iv) comparatively low public and external debt, (v) government's program on liberalization of the economy, (vi) joint public-private ventures and strategic agreements with foreign corporations. Dismantling of controls and limits on FDI in 1995 and establishment of Nigerian Investment Promotion Commission Act of 1995 opened almost all the sectors of the economy to foreign investment. Excluding the petroleum sector, all the other sectors provides 100% foreign ownership of investments. Similarly, the Nigerian Foreign Exchange Monitoring and Miscellaneous Provisions Act allow unlimited relocation of dividends or profits resulting from FDI. It also allows unrestricted transfer of proceeds (after tax) in the occurrence of sale or liquidation. For the oil sector, FDI is limited to joint ventures or production sharing agreement [59].

4. Future directions

Technology, supporting regulations, economic instruments—tariffs, price regimes—and change in consumers' behaviours are important for the change towards cleaner energy systems and economy [17]. Total replacement of fossil fuels may not occur any time soon. In the near future, the energy mix will consist of hydrocarbons and renewable energy [60]. Transforming the country's socioeconomic system is a necessity if the transition will be achieved. It is also critical to ameliorating the anticipated impact global energy transition will have on the country. Energy transition cannot be approached separately from the socioeconomic system in which it is positioned. It should consist of all the social and economic composition and relationships present in a society. Diverse transition path can be followed, as well as different transition of the socioeconomic system [23]. Consequently, the transition is dependent on Nigeria's target and socioeconomic configuration.

Nigeria, a tropical country has abundant RE sources. However, technological incapacity, poor management and policy initiative (or implementation) have limited the country's adoption of RE. This is more important as continuing with business-as-usual scenario portends huge challenges to Nigeria. Present investments in carbon-intensive energy system and hydrocarbon production facilities may translate to "stranded asset/infrastructure" which implies lost economic opportunities in the near future. Continuous drop in the cost of RE [8,15,22,23] unlocks the scenario where energy supply is controlled by renewables. The rate North America, Europe, Asia and South Africa are accelerating their share of RE, demands serious recalibration of Nigerian economy. Acceleration of

EV markets also supports the urgency of the adaptation. An estimated 1.2 million new EVs were sold globally in 2017, representing 1.5% of all the cars sold that year [61]. With the compound growth rate of 52% (2012–2017), more than one billion EVs will be on the road by the year 2050 [23].

By 2018, nearly all countries (168) of the world have a RE policy and targets. However, the scope and range of the frameworks vary across different geographical regions of the world. Setting target is very necessary for any RE plan, as it identifies, engages and communicates with relevant stakeholders. It reduces the possibility of replication and opposing policy goals. Target assures confidence to stakeholders (utilities, investors) to make huge investments. Increased investment confidence and strong commitment to achieving set target also attracts local and international investors. In addition, targets assist in creating awareness among the people. Awareness is very essential to building support among the general public and businesses so as to facilitate achievement of the objective. Setting target is not enough to make successful implementation. There is need for efficient regulatory mechanism and a simple but progressive plan with measurable indicators and acceptable development reports. Policies and targets selected should reflect the situation in Nigeria [22,62]. A good example will be practical oriented, but well monitored training center where young Nigerians (secondary school leavers, engineering and technical university/polytechnic students, etc) will be trained on installation and construction of RE technologies—solar PV, biomass composting technologies, etc. The training should also be integrated with National Directorate for Employment programme. Seed capital, grants and soft loans should be devised to enable start-up of ventures by trainees of such programmes. Indigenous and local construction will likely reduce the cost, increase its use and build a niche form of development.

Developed countries advanced their economies through carbon-intensive energy use, and now want developing countries to give it up in their quest for economic growth. For example, Nigeria's 2018 per capita GHG emission was 0.565 tCO_2/Cap, Brazil (2.372 tCO_2/Cap) while that of US and UK are 16.14 tCO_2/Cap and 5.587 tCO_2/Cap, respectively [63]. This argument is at the heart of climate change politics. It militates against political action towards cutting GHGs emission in developing/emerging economies. Recognizing the argument, *Paragraph 47* of COP 15 (Paris Agreement) required Green Climate Fund to provide support for developing country Parties. The support should ensure formulation of national adaptation plans. It also called for implementation of policies, projects and programmes identified by them. Similarly, *Paragraph 46* requires the Adaptation Committee and the Least Developed Countries Expert Group, in cooperation with the Standing Committee on Finance and other relevant institutions to take the needed steps to support mobilization for adaptation in developing countries in the context of limiting global average temperature increase. *Paragraph 72* also *Decides* to set up the Paris Committee on Capacity-building whose goal will be to tackle gaps and needs, both current and emerging, in implementing capacity-building in developing country Parties, with regard to capacity-building activities under the Convention. Accordingly, developed countries (under the Agreement) pledged to provide US$100 billion (climate finance) annually from 2020. The fund will support RE, energy-efficiency, natural resources conservation and other GHGs emissions abatement projects. The funds will also aid developing countries mitigate the effects of climate change.

The support is important because future growth in GHG emissions will come from developing countries. By 2030, more than half of global goods consumption will occur at developing world. They will account for about 60% of global GDP in terms of purchasing power parity, and their share in volume of trade globally will be almost 50% [64]. Economic growth and population increase means that energy use will grow in countries like Nigeria. If RE is not actively pursued, most of the demands will be met by fossil fuels use. The increments have implications for any future climate regime.

Sub-Saharan African countries accounts for small proportion (2.3%) of global CO_2 emissions. But climate change will impact the region higher, more than other regions of the world [16]. It therefore present Nigeria the possibility of receiving 'adaptation support' provided by developed to developing countries within the framework of international climate agreements.

The paper adopts three important components which will help the country move beyond the current heavily-dependent oil-exporting economy. They are economic diversification, renewable energy development and energy-efficiency. These three factors are premised on the "energy triangle"—(i) economic development and growth, (ii) energy access and security; and (iii) environmental sustainability. The need to bring about the energy triangle is motivating basic transformation in the way humans' source, transform and use energy at various levels—local, national, regional and global. Consequently, the triangle is leading to what [65] called "New energy architecture". Our paper conceptualizes the integration of economic diversification, scaled-up RE and energy-efficiency, in Figure 4 below.

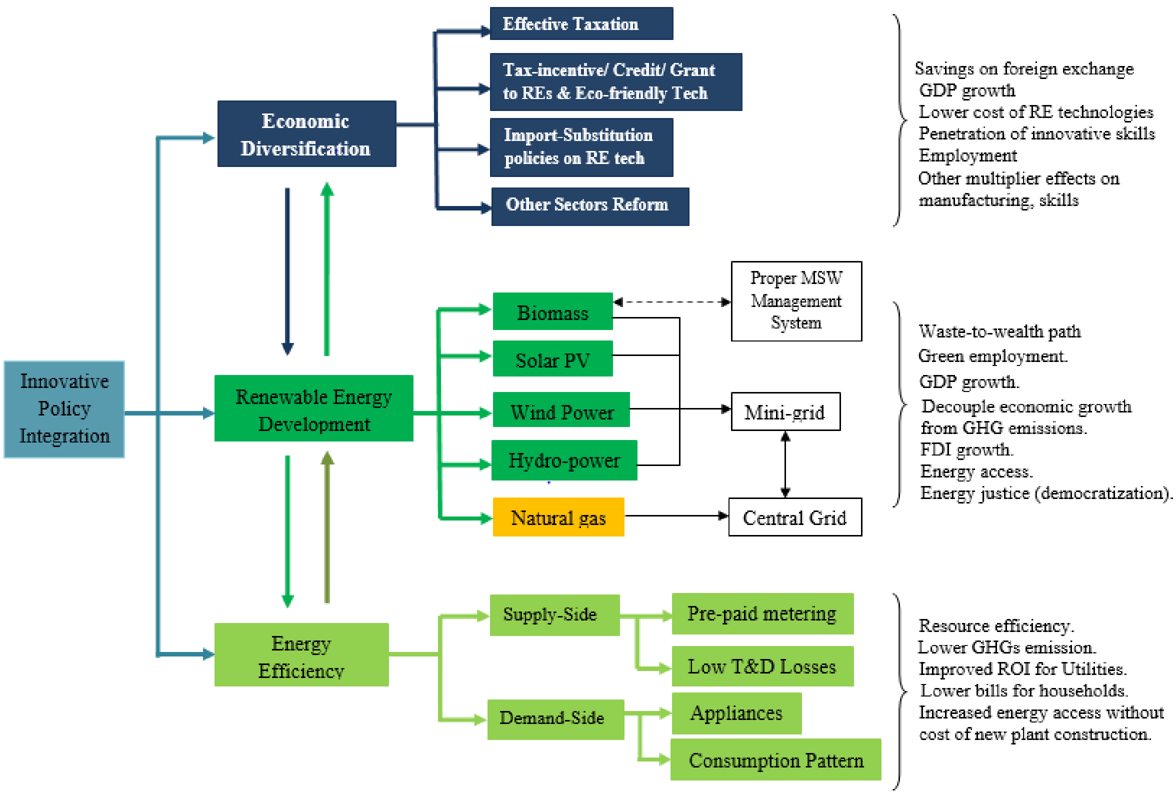

Figure 4. Integration of Economy, RE and Energy-efficiency.

4.1. Renewable energy

Any adaptation approach to energy transition involves fundamental changes in the energy sector, the general economy and the distribution of scarce capitals to innovative sectors—including renewables—which do not produce substantial revenues like oil and gas industry does [15]. Both centralized and decentralized energy system has its own sustainability issues. For centralized system, the issues include fixed infrastructure and demanding land and resource use, and the tendency to be monopolized by the privileged and bureaucratic bodies. Decentralized energy also system have substantial issues such as providing equal access to energy resources for marginalized populace. It can also be monopolized by bureaucratic and the privileged. Accordingly, there are features of each scale that can reduce the issues of the other. Centralization will enable transformation much quickly across space (for example, shifting to RE and decreasing fossil fuel), while decentralization will support developments for direct and self-governing control between people and groups. Therefore, energy transition requires some arrangement of centralized energy design at regional and national level using decentralized technologies (solar, wind, biomass, etc) [5]. This does not negate the coexistence with decentralized system, as the future entails the two of them working side by side. Therefore, in the near future, Nigeria's energy mix policy should pursue integration of decentralized RE systems and technologies in the present largely centralized energy system operating on fossil fuels. This is important since RE tends to be geographic-specific (for example, solar, wind, biomass, etc).

Renewables are regenerative and cost-effective in proffering solution to our current energy challenges. The potentials for RE production are great in Nigeria. Though the harvesting technologies are expensive, RE sources are free, the feedstock cost is practically zero. Operating costs are limited to maintenance once the initial investments are made. Further, the enhanced energy-efficiency produces the odd that lifecycle savings in costs will be larger than the costs of installing it [66].

If Nigeria does not attain universal energy access, many of the 2030 Agenda for Sustainable Development will continue to be out of reach. It will divest the country of the chance to build a successful future. Consequently, to ensure total energy access, it is expected that the increasing electricity demand will met by adopting a mix of natural gas and RE sources, decreasing the utilization of oil in generating electricity. Further, alternatives to biomass have to be strongly deployed as clean cooking choices. The alternatives include better biomass cook stoves and liquefied petroleum gas (LPG) [16].

In 2006, Nigeria created the Renewable Energy Master Plan. It aims to increase renewable electricity supply from 13% of total installed electricity production capacity to 23% by 2015 and 36% by 2030. However, that has not been realized. Despite privatization of generating (Gencos) and distribution companies (Discos), establishment of a grid management company and associated legislations, Nigeria have a very poor policy environment to increase energy access. Still, market for renewables, both on and off-grid are growing in the country. For example, in 2016, fourteen solar PV companies reached a power purchase agreements (PPAs) with Nigerian Bulk Electricity Trading (NBET) to build and generate a combined capacity of 1,125 MW infrastructure. However, none of the project has been commissioned [44,67]. In [68], the CBN reported that scaling pay-as-you-go (PAYG) off-grid technologies will provide $2 billion market opportunity for Nigeria annually. It will solve the issue of energy access, provide financial inclusion and reduce poverty. Scaling RE in the country will not only increase economic growth, the sufficient, reliable and reasonably priced power will enhance transformation of agriculture and increase quality of life [66].

There is strong association between poor energy supply and poverty indicators such as illiteracy, life expectancy, infant mortality, total fertility rate [69]. Carbon-intensive energy and its externalities on the long run pose limitation to economy. Diversifying economy implies charting a new, viable and feasible solution and technologies which have significant benefits for the country. Developing RE will not only improve energy access and low-carbon energy, it also contributes to economic growth of the country. In [13], the five objectives of sustainable energy production are—CO_2 emissions abatement, eco-friendly process, and security of energy transition, reduced cost of energy production and substantial inclusion of green energy technologies. These improves environmental quality and economic security. Therefore, access to reliable, cheap and clean energy is at the core of socio-economic growth, industrial development and sustainable environment of Nigeria. Achieving significant growth in provision of energy and energy access will impact positively on other components of socioeconomics.

Although potential for RE is great in Nigeria, they are unexploited. The critical barriers to RE development include oil and gas production, government oil subsidies; scarcity of data/information on market opportunities for private sector; knowledge gap relating to fiscal support instruments available in the country. Nigeria has great solar potential, with sunshine of about six hours a day. Nigeria's solar irradiation is about 19.8 MJm^2/day, and the estimated potential for concentrated solar power and PV generation is about 427,000 MW [67]. In the southern part of the country, daily solar energy density is about 12.6 MJ/m^2/day; while in the distant northern part closer to Sahara Desert; it is 25.2 MJ/m^2/day, with a mean generation capacity factor of 27%. Capacity factor is estimated generation efficiency of energy systems. Allocating 5% of suitable land in the central and northern Nigeria for solar PV farm will make available a theoretical generation capacity of 42,700 MW. Therefore, great advantages for developing solar energy as an efficient and viable RE exists. Insignificant amount of this resource has been exploited. Nigeria's research and development programs on variable renewable energy (VREs) are focused more on solar energy, relative to other sources. This is not unconnected with the comparatively simple technology and ample capacity factor of solar energy. Minimum requirements are needed for setting up and maintaining Solar PV. Also, recent fall in global cost of PV system parts has increased its prospect. Consequently, in 2017, the federal government of Nigeria provided about US$20 billion for new solar projects. Similarly, a private company plans to build a 30MW solar farm in Kaduna State [13].

Wind energy is produced by temperature differentiation at the surface of the earth due to influence of sunlight. Wind energy can; be used to generate electricity. However, it needs widespread aerial coverage to produce considerable amount of energy. Wind energy is also constrained by factors such as availability of wind all year round. Wind energy is used to revolve the blades of windmills or wind turbines and drive generator to produce electricity [70]. Some parts of northern and coastal region of Nigeria have reasonable potential for wind energy production [13].

Biomass is one of the efficient paths for energy resource management. It provides waste-to-energy models for sustainable removal of agricultural and organic wastes from households and industrial sources. Energy resource management requires using available energy resources for greater application. A typical example is the recently built 100 kVA refuse-derived fuel (RDF) gasification plant at University of Nigeria, Nsukka campus [13]. On a larger scale, the challenge that must be scaled to achieve adequate and consistent supply of biomass is related to Nigeria's poor waste management system. There is lack of separation at source and indiscriminate disposal. This attitude is reinforced by poor waste management policy and regulation, inadequate monitoring and control, absence or non-existence of properly engineered landfills. What are obtainable in Nigeria are open dumpsites, and this does not encourage efficient waste disposal-collection system critical for successful harnessing of energy from waste. Sustainable waste management practices such as recycling, reuse, resource recovery is dependent on proper solid waste management system [4,71]. An eco-friendly approach to biomass energy use was initiated by Lagos State government in December 12, 2012, in its "Waste-to-Energy Scheme". The scheme is directed towards producing 50 MW from the different dump sites in the states [67]. This path offers great ecological, social and economic advantage considering poor waste management system of the country. Another waste stream which has huge energy production potential, especially for cement and allied industries is tyre-derived fuels (TDF). TDF is achieved by pyrolysis of rubber. A unit passenger car tyre produces 7.6 liters of low-sulphur oil. Further, the calorific value of tyre rubber is 3,400 kilojoules per kilogram (KJ/kg), which is higher than bituminous coal (26,000 KJ/kg) and urban wastes (5,800 KJ/kg), and is slightly lesser than that of crude oil (39,500 KJ/kg) [4].

Of the 1.5 quadrillion British thermal unit (Btu) TPEC consumed in Nigeria in 2017, traditional solid biomass (fuel wood, charcoal, compost and agricultural produce residues) accounted for only 3% [45]. Fuel wood is mostly found in the southern rainforest belt of the country, and is source of fuel for many Nigerians. However, the ecological implications of deforestation have driven government to discourage its use as energy source.

Hydro accounts for about 15% of Nigeria's power generation. The three major sources of hydropower in Nigeria with total installed capacities of 1,930 MW are Kainji Dam (760 MW), Jebba Dam (570 MW) and Shiroro Dam (600 MW). In all parts of the country, there are large rivers. These provide a theoretical capacity for 70 micro dams, 126 mini dam and 86 small sites, with potential to provide 11,250 MW. Yet, only 17% are utilized. Consequently, Nigerian government targeted increasing hydroelectricity generation capacity by 5,700 MW in 2020. The target is to be achieved by improving old hydropower plants and installing new ones [67]. Table 3 presents hydropower plants under development in the country.

Table 3. Hydropower projects under development in Nigeria.

Power station	Capacity (MW)	Location (State)
Zungeru	700 MW	Kaduna
Mambilla	3050	Niger
Gurara II	360	Taraba
Gurara I	30	Kaduna
Itisi	40	Kaduna
Kashimbilla	40	Taraba

Source: [67]

RE has ushered in 'democratization of energy and resources'. It offers cities, local governments and states opportunities to generate, use and trade their own energy, and also enlarge energy access. The democratization focuses on consumers and allows DISCOs to increase capacity by buying power from individuals, cities, local governments, etc. Micro-grids are most effectively situated to deliver demand-side energy-efficiency, support more sustainable energy sources and relatively lower energy costs. At the same time, it provides grid flexibility and ease of installation. Relatively, they can be built more easily than national grids. For example, India, in its effort to lessen energy poverty and generate electricity from renewable sources, initiated a plan to establish 10,000 micro and mini-grids, with total capacity of 500 MW, by 2021 [63]. Provision of RE and 'democratization of energy' requires policy, regulatory and financial reforms. Presently, the power sector of Nigeria operates a centralized grid system.

Failure of national grid supply led to gasoline and diesel self-generation, which is very common in Nigeria. Relatively, standalone solar PV systems are more cost-competitive over its lifetime, though the initial cost may be substantial. In addition, gasoline and diesel generators are easily accessible for households and enterprises [44]. Hence, to increase adoption of RE in the country, the following issues must be critically addressed in power sector—infrastructure investment, industry capacity building, efficiency and economic sustainability. Two instruments which can foster massive capital accumulation to drive infrastructure and boost RE investment is Nigeria Sovereign Investment Authority (NSIA) and Nigeria Renewable Energy and Energy Efficiency Policy (NREEP). The two instruments incorporate RE infrastructural development and fostering of resource efficiency management. NSIA act was established in 2011 and commenced operation in 2018. It manages Nigeria Sovereign Wealth Fund (SWF). The surplus earnings (difference between budget and actual market price of oil) from Nigeria's excess oil reserves are deposited in the fund. It was planned that NSIA administer and invest these funds. Initially, $1 billion (seed principal) was allocated to the fund. The fund acts as stabilization or protection against future economic volatility, contribute towards the expansion of Nigeria's infrastructure, and acts as reserve instrument for future generation. It is the third largest in Africa. The SWF consists of three separate funds, each of them with definite investment and growth goals. They are stabilization fund (20%), future generation (40%) and the Nigeria infrastructure funds (40%) [72,73]. Energized effort should be made to use the fund to scale RE infrastructure and diversification of Nigerian economy. Mechanism for accountability and monitoring should be established.

Investment in low-carbon energy and technology can be a means to diversify Nigeria economy and achieve her Nationally Determined Contributions (NDC) to the Paris Agreement. Though RE aims at 100% carbon emission abatement, increased utilization of low-carbon technologies such as natural gas (which is abundant in Nigeria) is a good step towards decarbonization of Nigerian economy. Oil is expected to reach its peak by 2040. For natural gas, it is around 2060. Therefore, natural gas should play an important role in pursuit of low-carbon energy transition. Gas will increase to be a vital component for decades to come in the US, India and China- the three highest GHGs emitters [16]. Nigeria should develop her gas infrastructure and market, so as to remain competitive globally. Factors unique to Nigeria means that gas development should be integrated into energy portfolio, away from energy-intensive oil. It will provide time to scale adequate RE in the country. Also, "energy democratization" which allows cities, states and regions to develop their unique RE sources should be pursued strongly. This is antithetic to the current centralized energy governance in Nigeria—electricity (national grid), and hydrocarbon resources (owned by federal government). Energy democratization will enable development of these sources which are largely unexploited. For example, the northern region can invest on solar, while the southern section integrates geothermal, biomass and wind (especially in the coastal areas).

Scaled-up RE will provide diffusion of required skills, technologies and opportunities for Nigeria, which has high proportion of young people. RE can offer the same trajectory for Nigerian youths and entrepreneurs, which penetration of ICTs is currently providing in the country.

Energy-efficiency shares almost the same objectives with REs—lower GHG emissions, resource-efficiency, and their other associated socioeconomic and ecological benefits. Accordingly, RE cannot be pursued without energy-efficiency. RE and energy-efficiency are important tools to solve the issue of energy-poverty and access, which is a major challenge to under-performance of Nigerian economic sectors. There is need to synergistically address economic diversification, together with the growing technologies in order to curtail the impact of global energy transition on the country. Oil will enter into decline after 2040 [16,18]. Thus, it can be safely argued that Nigeria have almost 20 years to put policies, targets and goals, infrastructure, and other factors in place to critically withstand the impact of energy transition.

4.2. Economic diversification

The largely oil economy poses a critical barrier to transformation in Nigerian energy sector, thus the need for diversified economy [39,44]. The speed of the energy transition is not even across the globe, but the transitioning process is predicted to cause structural disruptions in global energy markets and economy. This is more serious for countries that exports oil. In Nigeria, the shift will disrupt socioeconomic welfare of the people. Hence, the crucial concern is how can Nigeria situate itself in this shift period so as to guarantee future sustainability? Unlike other past 'unrealized' goals, for example Vision 2020 which targeted 40,000 MW at a rate of 4000 MW every year with an annual cost of $3.5 billion [47,74], there is no time to waste. The transition defines the future of Nigeria—economic stagnation or unlocking of the country's potential in terms of renewable resources. What is needed is a synergy between socioeconomic, political and legislative framework to address the challenges it poses to Nigeria.

A critical challenge confronting Nigeria and oil value chain companies located here is how to move beyond hydrocarbon. Wait-and-see approach may be very damaging. Hence, there is need for development and integration of other economic sectors. The speed of the transition is occurring faster in European countries and some Asian countries which are major buyers of Nigerian oil. The evolving energy transition suggests urgent need for diversification of Nigerian economy. COVID-19 pandemic supports this position. The country is entering into the worst recession in 40 years, adding new 7 million Nigerians to poverty in 2020 alone [41]. COVID-19 produced global economic inactivity which reduced oil demand and prices. Diversifying the economy is not going to be an easy undertaking, but it is mandatory if sustained economic growth should be achieved. It is easier to create a program than accomplishing it, as past and present government has done so. Re-positioning Nigeria will involve wide-ranging transformation in the economy, and will have implication on the people's welfare and distribution of national resources. For example, it requires economic reforms such as reduction/elimination of subsidies of oil products, and strengthening our taxation framework. These changes will bring difficulty. For instance, elimination of oil subsidy will increase the cost of petrol and impact the people adversely, but it is a needed measure. This is supported by [66] that over-reliance on subsidized oil and gas as primary energy sources has slowed down the growth of RE in Nigeria.

Four critical issues are hindering business environment of Nigeria. They are: corruption, poor infrastructure, poor capability (proficiency) of labour and macro-economic volatility. Out of 189 countries surveyed in 2015 and 2016 Ease of Doing Business, Nigerian ranked 170th and 169th, respectively. Economic and regulatory environment should be made favorable for industry to succeed. In pursuit of that, regulation and procedure should be made less complex. Barriers that limits scaling up of larger and more dynamic private sector should be eliminated [37].

Before the discovery and commercial production of oil, Nigerian economy was firmly established on agriculture. For example, in the early 1960s, Nigeria is the largest producer of palm oil, controlling 43% of the global market. Presently, it is the 5th largest, accounting for less than 2% of global production, and depends on import to meet the supply gap. If Nigeria has accelerated palm oil production, estimate shows it will be earning the country $20 billion per annum [75]. Agriculture accounted for 72% of the total national output in 1950, compared to 1.1% from mining and crude oil. In a decade (1960–1971), crude oil contribution to the country's revenue grew from 2.7% to 73.7%. Since then, oil has accounted for the most of the country's export [31]. In 2016, agriculture (19.8%) and services (63.6%) contributed 83% of the GDP. However, this substantial non-oil sectors needs to develop revenue and export-generating capacity. To achieve this, tax collections from non-oil sectors should increase so as to enhance government revenues. Another way is to improve productivity in services and agriculture directed towards export; and also increase self-sufficiency in agriculture to curtail imports [76]. Export is one of the major sources of foreign exchange for a country. It improves the balance of payments and produces employment opportunities. Exportation achieves this by increasing the association between production and demand, and economics of scale due to bigger international markets.

Compared to other emerging economies, Nigeria is a low-taxed economy. Nigeria's tax receipts are very poor [76]. To shield the economy against fluctuation in global oil prices and the growing transition, it is important to develop better tax collection and administration framework. Improving tax administration efficiency is not enough if there is no corresponding efficiency in government spending. There is opportunity to achieve huge savings in capital expenditure and operating costs across the tiers of government.

The productivity of Nigeria workforce has been improving, however, it still lags behind that of other developing economies. The average output per Nigeria worker is 57% less than those of seven large emerging economies. Further, at 29%, the country has a very poor employment-to-population ratio. Comparatively, it is 45% for Indonesia, Brazil (49%), and Russia (51%). The poor productivity of workforce and low employment-to-population ratio is one of the factors accounting for the country's low per capita GDP compared to seven other peer economies [51]. The low workforce and economic performance is related to Nigeria's pitiable educational and skill development setting. A determinant of technological innovation is number of patents secured. Globally, China, has the highest patent related to RE technology (150,000) followed by the US (above 100,000) and Japan. In Africa, South Africa holds 63% of the regions' patents, followed by Egypt (8%). Energy transition is dependent on technology and innovation [16]. If Nigeria fails to innovate and develop in the area of technology, the situation currently observed in the oil industry will be witnessed in the evolving transition.

Though, Nigeria have a large oil and gas reserve, and produces about 2 mbpd, the technology, manpower and control of the companies involved in the sector are mostly multinationals. Repetition of the same in the transition scenario will expose Nigeria to shocks and disruption that will be produced by the transformation. It is therefore very important and urgent that Nigerian government (national, state and local) invest in building human capacity and capability in this sector. The very young age of Nigeria's population (average, 17.9 years) is a promising factor that can drive economic growth, if properly harnessed. By 2030, the number of working-age population is expected to grow by 50% above 2014 level (56%). This factor alone could add more than 0.8% annually to the country's GDP. Many countries have achieved significant economic advancement by the contribution of their 'demographic dividends' [51]. Hence, the need to improve our educational system and the financing. It is more cogent as [37] report that the service sector is estimated to be the prime driver of the Nigerian post-oil economy. Therefore, grants and funding should be provided to universities, polytechnics, technical secondary schools to scale technology, knowledge and skill transfer in this area. An all-inclusive approach that will provide the relevant skills is required. Cooperation among all stakeholders is required.

An alternative to forestalling 'stranded asset and resource' of oil is to considerably increase the production and market of Nigerian oil. Such windfall should then be used to fund critical infrastructure needed to industrialize the economy. However, this approach has a limiting barrier. OPEC set limits to each member's daily production. Currently, Nigeria's daily quota is pegged at 1.4 mbpd from May 2020 to April 2022 [45].

To achieve success, capital is central to enterprises. 85% of SMEs in Nigeria are financed with personal savings. Only 10% of the SMEs startups access bank credit or loans. 98% of the SMEs are totally uninsured. Consequently, most Nigerian businesses don't have the capacity to survive a shock or spend towards productivity and growth. As at 2014, 32 million Nigerians were employed by SMEs, at an average of 1.9 employees per business. SMEs accounted for more than 25% of the country's GDP [51]. Accordingly, deepening the scope and depth of Nigerian economic diversity must address the following issues—infrastructure investment, industrial capacity building, efficiency and economic sustainability.

Five critical factors that affect the success or cost-competitiveness of Nigeria's businesses are inadequate access to funding, macroeconomic situations and economic volatility, poor electricity supply, political instability and high operating overheads. Corruption (bribery) alone raises the cost of doing business by 3.2%. SMEs and households spend between 200–300% more on fossil-fueled (gasoline and diesel) self-generation, compared to grid-supplied electricity. Consequently, products made in Nigeria are 33% more expensive than imported ones [44,51]. In 2011, 35% of power generators imported (estimated at $152 million) into Africa was accounted for by Nigeria. It was estimated that it will reach $951 million by 2020 [77,78]. The valuation did not include the cost of fuel. Adding the cost of fuel will greatly increase the economic implications. These inefficiencies pose serious economic challenges. These can be tackled by developing RE technologies, since the existing barriers towards realizing the goal of 100% RE are neither technical nor economical, but social and political [70].

4.3. Energy-Efficiency

Recognizing that gas will play a role at least in the near foreseeable future [18], especially in developing countries such as Nigeria, where adoption of renewables is very sluggish [12,35,44,67], energy efficiency is critical to mitigating emissions, and promoting sustainability in Nigeria energy sector. Two major pillars of the present energy transition are energy-efficiency and renewable energy.

Although alternative pathways (carbon capture and sequestration, etc) can mitigate climate change, RE and energy efficiency offers the best possible way to bring about the bulk of emission abatement required at the needed pace. Deploying adequate technologies that are reasonably priced and broadly accessible, RE and energy efficiency can provide more than 90% of the energy-related CO_2 emissions cut that is required in Paris Agreement. Energy efficiency is more critical in the building sector. The relaxed pace at which energy efficiency is growing in the sector (1% per annum) is a serious challenge to decarbonization. High energy demand of some industries and households, intensive carbon content of some goods and high emission processes, demand new solutions and lifecycle methodology [23]. Hence, the importance of achieving energy efficiency across all sectors of Nigeria. Energy-efficiency is also important towards Nigeria achieving Nationally Determined Contributions (NDC). Nigeria can meet 60% of the NDC pledge through power sector reform [44].

Meaningful RE objectives cannot be achieved without improving energy efficiency at the same time. Energy efficiency makes achieving RE plan easier, cost-effectively, and more sustainable in the long-term. It decouples economic growth from increase in energy consumption [62]. Energy efficiency has both supply and demand side. For example, though electricity generation increased from 14 to 27 billion kWh between 2000–2011, energy losses in transmission and distribution (T&D) was 22.8%. This inefficiency implied loss of energy access to millions of consumers [79]. Inefficiency from supply-side (utilities) is a serious limitation which should be addressed, if energy access will improve in Nigeria. Figure 5 shows generation, transmission and distribution losses in Nigeria electricity industry. Adapted from [79].

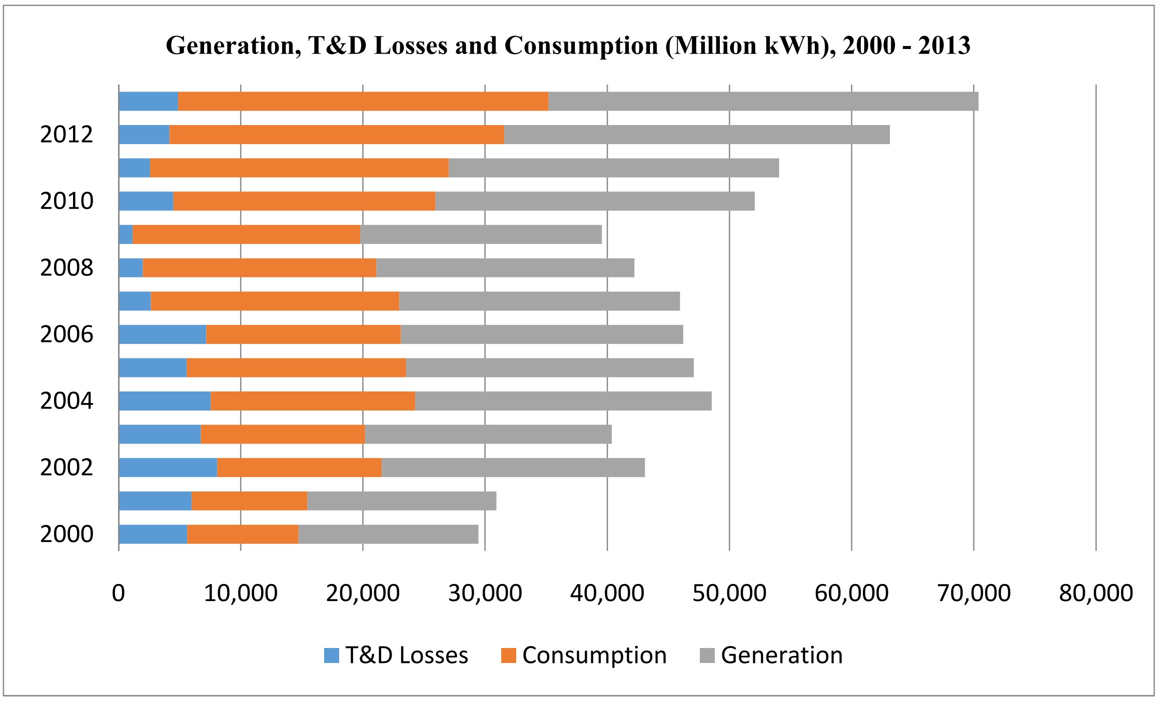

Figure 5. Generation, T&D Losses and Consumption (Million kWh) from 2000–2013.

A T&D loss of 13% will be a better figure for Nigeria. This is the case in Peru which has similar electricity structure like Nigeria [76]. Achieving energy-efficiency means technological transformation must be achieved at both the supply (energy producers) and demand side (consumers).

Out of 39 countries (including Nigeria) power sector surveyed by World Bank in sub-Sahara Africa, only Uganda and Seychelles entirely recovered their operational and principal investment costs from consumers. The huge loss which is about 1.5% of GDP constrains the power utilities from providing adequate electricity to their existing consumers, much more increasing supply to new customers. The financial losses prevent utilities from accessing credit because of their capital risk; and impacts public finances since government most often have stakes in the entities. The below average performance prevents private investments in the electricity industry, even though there is demand for increased capacity to ensure adequate supply to consumers [16]. Hence, there is a relationship between efficiency and sustainability.

Nigeria exports most of the petroleum products it produced. However, domestic consumption is on the increase. The increase in domestic production is related to population growth, urbanization and economic growth. A critical fiscal tool that is related to inefficient consumption and which keeps afloat the strong use of fossil fuel is subsidies. Globally, subsidies for fossil fuel increased 11% in 2018. In Nigeria, fossil fuel subsidies have been a complicated issue [22]. Economic growth and development requires increased energy consumption. The reliability and cost of energy is an important factor that determines the competitiveness and growth of SMEs, and comfort of households. Compared to income inequality, the unequal difference across countries in energy consumption is far extensive. For example, in the US, per capita energy consumption per annum is 12,000 kWh, while in India, the average is 1,200kWh per annum [80]. In Nigeria, it is 151 kWh per annum [76]. Higher consumption of electricity is strongly correlated to industrialization and economic growth. The converse is the case for low energy consumption. For example, [74] reported that 10% improvement in power supply will increase GDP by 2–3% annually. Even though Nigeria is the largest oil producer in Africa, and has the ten largest gas reserves globally [45], it has not been able to meet the electricity demand of the people and industries. Accordingly, any energy and developmental policy of Nigeria must, first of all, address adequate supply of electricity to firms and households. Renewable energy and energy-efficiency provides reliable and cost-effective means to achieve it.

Nigeria pledged to unconditionally reduce 20% of GHG emissions under its business-as-usual (BAU) scenario. With conditional fiscal, technological and capacity building assistance, it targets to reduce GHGs by 45%. More than 60% of these cuts are expected in the power sector [44]. Besides changes in energy use after an energy transition, historical development show there is also changes in production processes. These have most times transformed social composition which may put stress on political structure. All things being equal, energy transitions can be a catalyst for socioeconomic and political transformations. For example, the invention of steam engines provided further flexibility to the location of industrial activities, as enterprises don not have to be proximate to power sources (e.g., water) to function [14].

Hence, the need for multi-sectorial cooperation to scale and deepen the scope of RE and energy-efficiency in the country, and also diversify the economy. Financial institutions, universities, R&D, entrepreneurs, government and non-governmental organization and other stakeholders must be involved. Import tariff should be waived or highly reduced for energy-savings and energy-efficiency appliances, so as to make it cost-competitive. For example, many Nigerians use incandescent bulbs—in Cross Rivers and Bauchi states, 60% and 53.7% of the households uses incandescent lightings, respectively. It is cheaper cost compared to LED and CFL. Apart from cost, un-metering or estimated billing system which does not capture the actual energy consumption is also implicated. The trend pervades the whole country [81,82]. Import tariff should be waived for RE technologies such as solar panels, PVs and its components. Funding of solar technology development hub in the country should be intensified, so as to produce technology diffusion, contribute to self-reliance and economic growth. In [69], Central Bank of Nigeria (CBN) estimated substituting importation of solar PV components with locally manufactured alternatives will produce an annual saving of $10 million and ₦7 billion tax receipt. Accordingly, CBN reported that it will not finance projects (in Nigeria Electrification Project and Rural Electrification Agency) with imported solar balance of system (BOS) components. BOS encompasses all components of a PV system excluding PV panels.

5. Conclusions

Historical deductions from past energy transition reveals that discovery and massive acceleration of new energy resources alters mode of production and energy consumption, innovates the economy and unlocks multiplier effects on the society. The discovery of coal in 1909, and oil in 1956 enlarged the economic activities of the country and propelled massive infrastructure development (1975–1980s), though at the disadvantage of over-reliance on single commodity export economy. The next paradigm shift is occurring, and it is the transition from fossil fuel to RE. Timely and efficient transition of the economy of Nigeria to this energy sources will decouple the country's growth and advancement from vagaries of environmental pollution, oil geopolitics and global price fluctuations, which are disruptive. Our paper show that Nigeria has enormous RE potential—solar, wind, biomass, etc. An association exists between use of RE and quality environment. For example, acceleration of the use of biomass for energy production will lead to a quality municipal solid waste management system and vice versa. Technology and availability of energy resource is the critical enabler of past transitions. RE technologies are becoming more cost-competitive relative to fossil fuels. There is a strong global demand to cut emissions. If Nigeria fails to implement strong diversification of the economy, the country will be vulnerable to energy transition with severe socioeconomic and political consequences. Contraction in oil export because of global transition to REs will lead to fall in government's revenue, increase in unemployment, incapacity to finance important infrastructure and development projects, reduction in the poor available social safety nets, and substantial spike in the poverty rate. The ability of Nigeria to mitigate the impact of growing global energy transition is premised on developing economic capacity (highly diversified economy), resource management and adoption of renewable in its energy mix. In pursuit of renewable energy, the paper strongly emphasized the need for distributed and embedded generation—distribution, as opposed to the current model of centralized energy grid.

Limitation and future research

The paper is a review and a qualitative one at that. Thus, there is no statistical analysis or empirically generated data. There is therefore need for technical and economic studies (empirical research) to assess factors that supports viability of the different renewable and low-carbon energy sources. The study should include comparison of the costs of renewable generated electricity and the current situation. Factors such as installation costs, maintenance costs and other associated externalities should be included in the analysis. Also, there is need for studies on socio-technical system elements that supports or hinders sustainable transition. Energy transition is driven by society transformation (with its governance, social structure and behaviours) and technological innovation, both of which are critical enabler for “cleaner” energy system.

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Conflict of interest

The authors declare no conflict of interest in this paper.

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