An Overview of the Exploitation of Renewable Energy Resources in Nigeria, South Africa, and the United Kingdom

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Abstract- In this study, the current perspective of renewable energy utilization as an alternative energy source and viable energy option were examined and discussed from the standpoint of sustainable development in Nigeria, South Africa, and the United Kingdom. The challenges and drivers impacting the development and implementation of renewable energy (RE) in these countries were identified and discussed in the comparison between the countries. Amongst the numerous factors, the effect of energy policies, policymakers, its implementation and supporting financial backing, and conventional energy associated demands were predominant features of the RE development strategy of these countries. This article gives an overview and a conceptual framework of how these key factors influence RE development. It also aims to contribute to the debate on how to promote renewables, influencing decisions of the policymakers, contribute to policy formulation and attract funding in the countries considered with particular emphasis on Nigeria.

Keywords Renewable energy; Nigeria; South Africa; United Kingdom.

1. Introduction

Renewable energy (RE) sources and its enabling technologies have been the focal point of most research on the sustainability of the ever-growing, energy-dependent global population. With the global human population of 1 billion in the 1600s rising to 7.6 billion in 2018 and which is projected to increase to 9.7 billion by 2050 [1], there has been a corresponding increase in energy consumed. Energy consumption has risen from ~2,000 Mtoe (~23,260 TWh) reported in the 1950s to ~14,000 Mtoe (~162,820 TWh) in 2017 and is projected to further increase to ~17,000Mtoe (~197,710 TWh) in 2035 [2] and 19,000 Mtoe (221,000 TWh) in 2050 [3]. It is eminent that the exploration of alternative energy sources is required to meet global energy demands. The British Petroleum's annual outlook (2017 edition) depicted skewness in the global energy resource consumed with the dominance of fossil fuels ~85%, while nuclear power contributes about 5% and less than 10% being generated from renewable energy resources [2]. Given the adverse effects of non-renewable energy sources such as the ozone layer depletion, greenhouse gases (GHGs) emission, depletion of fossil fuel reserves, scarcity of the elements/compounds used to fuel nuclear plants and the disposal of their by-products, the energy consumption trend cannot be sustained without increased catastrophic effect [4,5] relative to the increasing energy demand. Hence, the necessity for a commensurate carbon-neutral energy source with energy resources equal to or greater than the present-day energy demand is pertinent. The establishment of RE based energy system is an effective way for the global long-term energy transformation.

Understanding and mitigating the adverse effect of the use of non-renewables has led to research and development (R&D) focused on energy optimization and RE technological advancements. This is in addition to the formulation of national policies and several international treaties such as the United Nations Framework Convention on Climate Change (UNFCCC) of 1992 [6], the 1997 Kyoto Protocol and the Paris Agreement of 2015 which are all channeled towards combating global warming through the reduction of GHGs concentrations in the atmosphere. Unfortunately, these agreements and treaties are not been upheld by some parties to the agreement, while most developing countries that account for 80% of the global population are not making such emission reduction concessions [7].

To achieve the set marks by these treaties, developed countries such as Canada, the United States of America, the United Kingdom amongst others have set up their own RE targets in their Intended Nationally Determined Contributions (INDC) in response to climate change [8]. These countries achieved this through policies, legislation, increased investment in R&D on RE generation and storage, among others. The approach adopted involved transitioning from fossil-based energy systems to sustainable (renewable) energy through the combination of low carbon and sustainable energy systems [8,9]. The work presented in this paper focuses on the comparative analyses of the developmental framework for adopting and implementing RE technologies by developing and developed countries, taking a case study of the United Kingdom, South Africa, and Nigeria.

The scope of this study is limited to desktop study; with data sourced from a review of literature to provide a descriptive overview on how renewable energy resources has been exploited in the United Kingdom, South Africa, and Nigeria.

2. RE for Sustainable Development, Situations, and Projections

There is an established nexus between access to energy and the quality of life. Such energy must be safe, clean, and affordable for it to make any meaningful and desired impact. The inadequate energy supply system is considered a constraint to human and economic development. Over the years, the exploration, exploitation, and utilization of energy from fossil fuels has inflicted avoidable consequences on man and our planet. Continuous and increased use of fossil fuels as a result of population explosion, increased urbanization and industrialization without corresponding remedial measures to mitigate GHGs, has continued to negatively impact the environment. Harnessing renewable energy sources is believed to be a veritable means of achieving zero GHG emissions, thereby assuaging climate change and its attendant effects. The volatility of the oil market and the hike in world oil prices since the late 1990s triggered the search for alternative and affordable sources of energy [10,11].

In other to put this into perspective, the international community through the United Nations General Assembly, in 2015, proposed and adopted a set of 17 goals and 169 targets, tagged the "Sustainable Development Goals" (SDGs) to be achieved by 2030. The adopted 17 SDG goals focuses on addressing issues relating to poverty, hunger, good health and well-being, quality education, gender equality, clean water and sanitation, affordable and clean energy, sustainable cities, life on land, life below water, climate action, responsible production and consumption, peace, justice and strong institutions, etc. The general intention of the SDG goals is to end poverty, protect the planet, ensure peace and prosperity for all. [12]. The 7th goal specifically focuses on affordable and clean energy with five targets (see Fig. 1). Target 7.2 seeks to increase substantially the share of renewable energy in the global energy mix by the year 2030. Targets 7a and 7b, respectively, aims to enhance RE access and upgrade infrastructure for the supply of sustainable energy services for developing countries [13]. In order to achieve these ambitious goals and targets, particularly goal 7, different countries set up RE policies with specific timelines towards the year 2030 with a view of improving the living standards of their citizens.

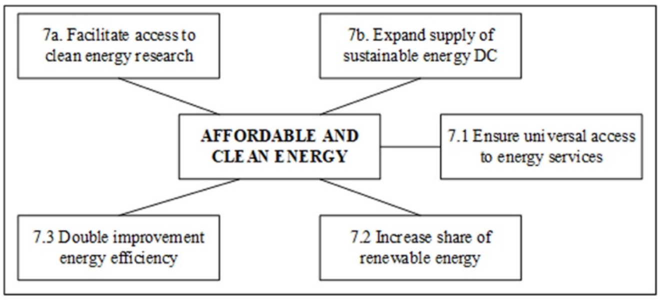

Fig. 1. The 7th SDGs and targets [13].

2.1. Country specific RE policies

It is no longer news that the fossil fuel-based economy is not sustainable and is foreseen to end. The negative effects of exploration and exploitation of fossil fuel on the ecosystem have continued to hasten the need to decrease its use and explore green technologies and techniques to meet global energy demand. These technologies and techniques include the use of efficient RE opportunities which themselves are governed by policies that are setup by different countries.

2.1.1. RE policies in Nigeria

Nigeria's RE policy instruments and targets are encapsulated in about three major documents namely, Renewable Energy Master Plan (REMP), National Renewable Energy Action Plans (NREAP) and Sustainable Energy for all Action Agenda (SE4ALL-AA). These documents not only set targets, but it also provides modalities for achieving the targets.

Renewable Energy Master Plan: Produced in 2006 with the active support of the United Nations Development Program (UNDP), Nigeria's Renewable Energy Master Plan (REMP) seeks to articulate the development of renewable energy in all its ramifications including setting the targets, goals, policies, legal framework, technologies, as well as manpower and infrastructural requirements. The specific objectives of REMP, among others, is to provide plans and roadmap for making RE a substantial element of the national energy mix and improve research and development, techniques, and technologies for the exploration and exploitation of RE for sustainable development [14]. The main focus of REMP is to widen the application and utilization of RE technologies, namely, wind power, small-scale hydropower, improved wood stoves, and solar energy, by the year 2025 as shown in Table 1.

Table 1. REMP targets. Adapted from [14]

RE resources	2007	2015	2025
Wind power (MW)	1	19	38
Small scale hydropower (MW)	56	600	2,000
Cook stoves	300,000	500,000	1,000,000
Solar home system	40,000	400,000	4,000,000
Solar cookers	1,500	50,000	150,000

National Renewable Energy Action Plans: The National Renewable Energy Action Plans (NREAP) was produced by different stakeholders and tiers of government, adopted by Inter-Ministerial Committee on Renewable Energy and Energy Efficiency (ICREEE) and approved by the National Council on Power (NACOP) in July 2016. The document seeks to promote the utilization of RE to achieve energy security, environmental protection, energy access, improved technology, and innovation. It spelt out modalities to achieve Nigeria's target to contribute 23 % and 31% RE to the overall ECOWAS target in 2020 and 2030 respectively, as stipulated by ECOWAS Renewable Energy Policy (EREP). The NREAP document stipulated targets for small, medium, and large hydro powers, solar PV, solar thermal, tidal, wave, ocean, wind, bioenergy and geothermal RE resources. The document also specified measures for achieving the targets and market development indicators for the policy. Table 2 shows major targets as stipulated by NREAP [15].

Table 2. NREAP targets. Adapted from [15].

RE resources	2010	2015	2020	2025	2030
Large hydro (up to 30 MW)	916	1,097	2,540	4,000	4,700
Small and Medium hydro (> 30 MW)	0	15	265	625	1,200
Solar PV	0	0	2,000	3,500	5,000
Solar thermal	0	0	50	600	1,000
Tidal, wave, ocean	0	0	0	0	0
Wind	0	0	170	370	800
Bioenergy	0	0	300	600	1,100
Geothermal	0	0	0	0	0
Total	**916**	**1,112**	**5,325**	**9,695**	**13,800**

Sustainable Energy for all Action Agenda (SE4ALL-AA): Approved by Inter-Ministerial Committee on Renewable Energy and Energy Efficiency (ICREEE) and approved by the National Council on Power (NACOP) in July, 2016, the Sustainable Energy for all Action Agenda (SE4ALL-AA) seeks to ensure universal access to RE technologies and techniques, improve the global energy efficiency, and double the 2010 share of RE in global energy mix by 2030. As stated in the policy document, the vision of SE4ALL-AA is to attain a technology-driven RE sector with a view to moving Nigeria away from a fossil fuel-based economy and ensuring energy sufficiency and security. Specifically, by exploiting RE technologies, the electricity generation mix is expected to receive contributions of 27% and 20% of hydroelectricity (both large and small hydro) by 2020 and 2030 respectively, 2.5% from wind energy by the year 2030, 20% and 19% from solar energy (PV and Solar thermal) by 2020 and 2030 respectively, and 10% from biofuel blends by 2020 [16].

The main thrust of these policies is to achieve and maintain more RE technologies by the year 2030, thereby moving away from fossil fuel-based economy and ensure a cleaner environment. The policy document specified roles expected from various stakeholders and all levels of government with specific timelines for both on-grid and off-grid connections. This agrees with the aspirations of the national energy agenda that prioritize access to clean, safe, reliable, and affordable energy to both rural and urban dwellers.

Nigeria wishes to generate 30 GW of power by 2030, with 30% expected to come from renewable sources. Also, the country targets 5.4 GW and 2.8 GW from mini-grids and solar home system in 2015, respectively. The overview of Nigeria RE policies targets are summarized in Table 3 [17].

Table 3. Overview of Nigeria other RE targets

Renewable	2020	2030
Solar PV, MW (home + streets)	360	2,786
Biomass, MW	300	1,100
Mini grids, MW	180	5,414
All Renewables, MW (incl. off-grid PV)	3,325	17,200
All Renewables, MW (on-grid PV)	2,785	9,100
All Energy, MW (incl. off-grid PV)	17,527	45,100
Renewables incl. Off-grid PV (% of All Energy)	19	38

2.1.2. *RE policies in South Africa*

With the inauguration of democratic government and promulgation of a new constitution in South Africa in 1994, the white paper on energy policy was adopted in 1998. The white paper on energy policy seeks to, among others, ensure economically feasible energy technologies, ensure investment in RE technologies and techniques, and address constraints on the development, exploitation, and utilization of RE [18].

But it was not until 2003 that the white paper on RE was adopted as the first policy document of RE. This white paper on RE [19] set a 10-year target to achieve 10 000 GWh (0.8 Mtoe) RE contribution to be produced from biomass, wind, solar and small-scale hydro to be utilized for power generation, solar water heating and biofuels by 2013. This was to diversify the source of electricity generation from coal which is associable with GHG emissions. The policy document identified the requisite financial, legal, technology development, together with the need for raising awareness, capacity building, and education to achieve the policy objectives of the document [20].

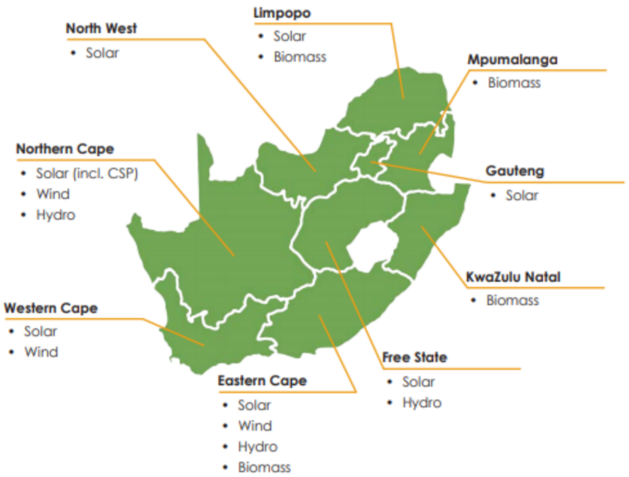

Fig. 2. Provincial distribution of RE resources [20].

The Department of Energy (DoE) of South Africa initiated an Integrated Resource Plan (IRP) in June 2010, and the Revised Balanced Scenario (RBS) in October 2010 to set targets for RE technology for the period 2010 to 2030. The document is a product of public participation, government agencies and international consultants based on a cost-optimal solution to build new solutions and improved policy considerations. This led to the adoption of adjusted IRP codenamed Policy-Adjusted IRP which encompasses the installation of solar PV, concentrated solar power (CSP) and wind. The Policy Adjusted IRP thus accounts for the uncertainties associated with the costs of renewables, emission constraint of 275 million tons of carbon dioxide (CO_2) per year after 2024, and energy efficiency demand-side management (EEDSM) measures. The outcomes of public consultations and review of policy parameters have thrown up four policy issues, namely nuclear options, emission constraints, import, and energy efficiency [21]. The South Africa RE targets as compiled by the South African Institute of International Affairs are shown in Table 4, while Fig. 2 shows the provincial distribution of RE resources in South Africa.

Table 4. South African RE targets [22].

RE Technology	Target
Electricity	Total installed wind capacity to reach 8.4 GW by 2030.
Electricity	Total installed CSP capacity to reach 1 GW by 2030.
Electricity	Total installed Solar PV capacity to reach 8.4 GW by 2030.
Electricity	Total installed renewables capacity to reach 18.2 GW by 2030.
Electricity	Total installed wind and solar PV capacity to increase by 20% by 2030.
Electricity	Total added hydropower capacity to reach 2,609 MW by 2024.
Electricity	Total electricity generation from renewables to increase by 13% by 2020.
Electricity	Total added installed renewable capacity to reach 3,200 MW by 2020.
Electricity	Total added installed onshore wind power capacity to reach 1,470 MW by 2020.
Electricity	Total added installed CSP capacity to reach 400 MW by 2020.
Electricity	Total added installed Solar PV capacity to reach 1,075 MW by 2020
Non-sector specific	Total added installed biomass capacity to reach 47,5 MW by 2020.
Non-sector specific	Total added installed biogas capacity to reach 47,5 MW by 2020.
Non-sector specific	Total added installed hydropower capacity to reach 60 MW by 2020.
Non-sector specific	Total added installed capacity of wind and solar PV to increase by 10% by 2020.

2.1.3. RE policies in the United Kingdom

Continuous depletion of domestic fossil fuel reserves, projected astronomical increase in global energy demand, the threat of climate change, among others, have given the United Kingdom (UK) government no better option than to develop her RE resources. The UK evidently needs to play its international role and fulfil its commitments by developing carbon capture and storage systems, decarbonizing the economy, and drastically reduce the emission of GHGs. The National Renewable Energy Action Plan (NREAP) contains the UK's RE target by the year 2020. As of 2005, only 1.5% of the UK's energy is from RE. The 2009 Renewable Energy Directive, therefore, targets 15% of the UK's energy will be from RE sources by 2020 [23]. The policy framework consists of three key components namely, financial support for renewables, unblocking barriers to delivery, and developing emerging technologies. The national overall RE targets are as shown in Table 5. The targeted proportion of RE consumption in each sector is 12% of heat, 10% of transport, and 30% of electricity demand, including from small-scale sources. These targets are being coordinated by the Office of Renewable Energy Development (ORED) which an office within the Department of Energy and Climate Change (DECC) [24]. In all, the UK's RE regulatory and support policies can be summarized in Table 5 and Table 6.

Table 5. The National overall target for RE in 2005 and 2020 for the UK.

Share of energy from renewable sources in the gross final consumption of energy in 2005	13%
Target of energy from renewable sources in the gross final consumption of energy in 2020	15%
Expected total adjusted energy consumption in 2020 (ktoe)	136,700
Expected amount of energy from renewable sources corresponding to the 2020 target (ktoe)	20,505

2.2. RE availability and utilization

Global RE penetration has continued to increase, particularly in the last decade. This may be attributed to increased concerns about the effect of the exploitation and utilization of fossil fuels on the environment. There has been increased awareness of the harmful effects of fossil fuels leading to tighter emission restrictions, and urgency to supplement the inadequate energy available through non-renewable sources. Increased urbanization, population, and industrialization have not been met with the increased availability of energy, rather, non-RE sources are believed to continue to dwindle and are inadequate to meet the growing global energy needs. Available statistics show that total RE capacity and production for Nigeria, South Africa, and the UK have been on a steady increase in recent years, as shown in Fig. 3 and Fig. 4, particularly for the off-grid and total production capacity [26]. This may not be unconnected to the implementation and meeting of the respective country RE policies and targets.

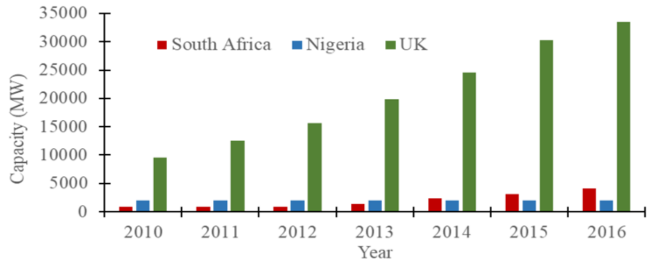

Fig. 3. Off-grid capacity of Total RE. Adapted from [26].

Table 6. RE support policies for Nigeria, South Africa, and the UK [25].

	Nigeria	**South Africa**	**UK**
RE targets	Power	Power	Energy, Power, Transport, Heating, or cooling
RE in [1]INDC or *NDC	Yes	Yes	
Feed-in tariff/premium payment	Yes		Yes
Electric utility quota obligation	Yes	Yes	Yes
Transport obligation/mandate		Yes	Yes
Heat obligation/mandate		Yes	
Tradable [+]REC			Yes
Tendering	Yes	Yes	Yes
Reductions in sales, energy, CO_2. VAT or other taxes	Yes	Yes	Yes
Energy production payment			Yes
Public investment, loan, grants, capital subsidiaries or rebates	Yes	Yes	Yes

[1]INDC - Intended Nationally Determined Contribution
*NDC - Nationally Determined Contribution
[+]REC - Renewable electricity certificate

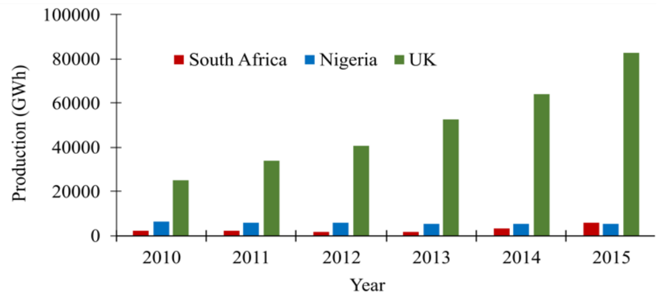

Fig. 4. Total Production of RE. Adapted from [26].

Here, the utilization of RE resources will be discussed under three subheadings, namely electricity generation, transport fuel, and heating and cooling. As shown in Fig. 5, RE resources like wastes, agricultural products, forest products, and industrial by-products are converted to heat, electricity and transport fuels through various chemical and biological processes associated with various energy conversion techniques.

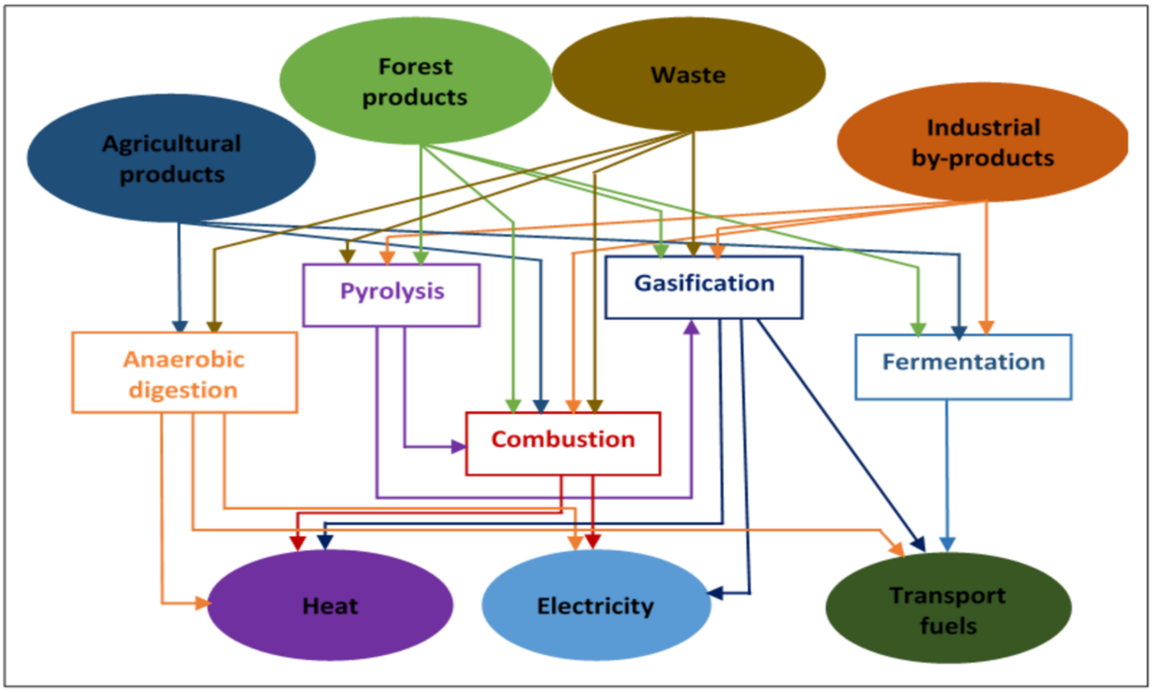

Fig. 5. Conversion of feedstock to heat, electricity and transport fuels.

2.2.1. RE for electricity generation

Access to electricity is one of the measurement indices for the measurement of the quality of life. The availability of electric power is an important factor for industrialization, civilization, and urbanization. The use of non-renewable sources of power has inflicted devastation in our environment and society. The exploitation of RE for electricity generation has continued to increase in recent years and will continue to increase. As shown in Fig. 6, access to electricity has continued to increase for both rural and urban populations for both Nigeria and South Africa from 1990 to 2016, while all citizens of the UK have access to electricity since 1990. As of 2016, more than 50% of rural dwellers in Nigeria have no access to electricity [27]. This fact has continued to fuel the rural-urban migration in Nigeria which has caused the resources in the cities to be overstretched.

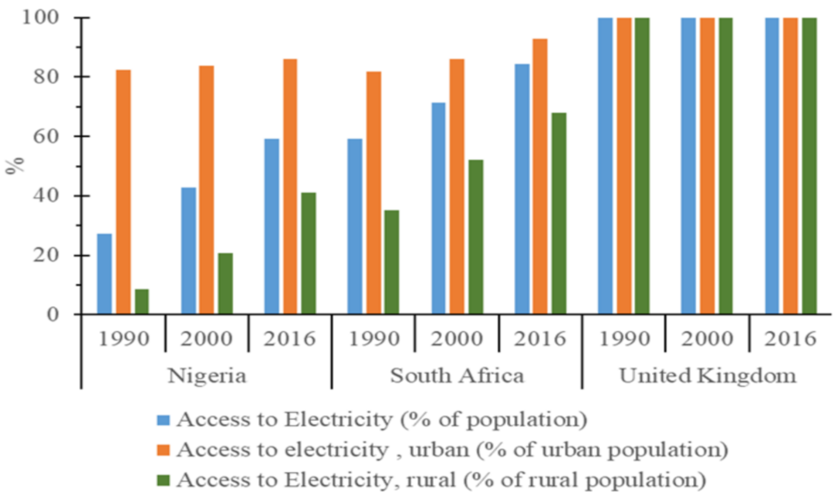

Fig. 6. Access to electricity. Adapted from [27].

One of the advantages of RE is the provision of low-carbon energy, with renewables-based electricity generation increasing by 6.3% (380 TWh) in 2017. Available statistics show that RE accounts for about 25% of global electricity generation [28]. The total RE for the UK for 2016 and 2017 was reported to be 83.2 TWh and 98.8TWh respectively while South Africa recorded 8.6 TWh and 9.6TWh for 2016 and 2017 respectively [29]. Nigeria looks forward to generating 10% of her electric power from RE by 2020 while South Africa targets 9% by 2030. The UK targets to generate 39 GW from off-shore wind power by 2030 while South Africa is targeting 17.8 GW of electricity from renewable power by 2030. By 2025, Nigeria hopes to generate 400 MW, 2 GW, 500 MW, 5 MW, and 40 MW from bio-power, hydropower (small scale), solar PV (large scale), CSP, and wind power respectively [25].

With the faithful and diligent implementation of RE policies and power targets for the individual countries, more clean and renewable sources will be added to electric power, both as off-grid and on-grid energy systems. Prominent of these sources are hydropower, wind power, solar power, and bio-power. These will not only increase access but also improve the quality of life. It will also lead to a reduction in the emission of GHGs and predominantly lead to a safer environment.

2.2.2. RE for Internal Combustion engines and transport vehicles

Despite the improved penetration of fuels from renewable, the transport sector is still dominated by the use of fossil fuel. Available statistics showed that only 4% of the global road transport fuel was met by conventional biofuels in 2016. Though there is a substantial increase in the number of transport vehicles globally, the growth in consumption of liquid transport fuel is being hampered by tightening emission and vehicle efficiency standards, increased in the number of electric vehicles [30,31]. In the UK, the share of RE in transport vehicles was recorded as 4.7%, 5.4%, and 4.4% in 2013, 2014, and 2015 respectively [32]. The need to meet the stringent emission benchmarks and improve engine performance is at the heart of the adaptation of alternative fuel for transport vehicles.

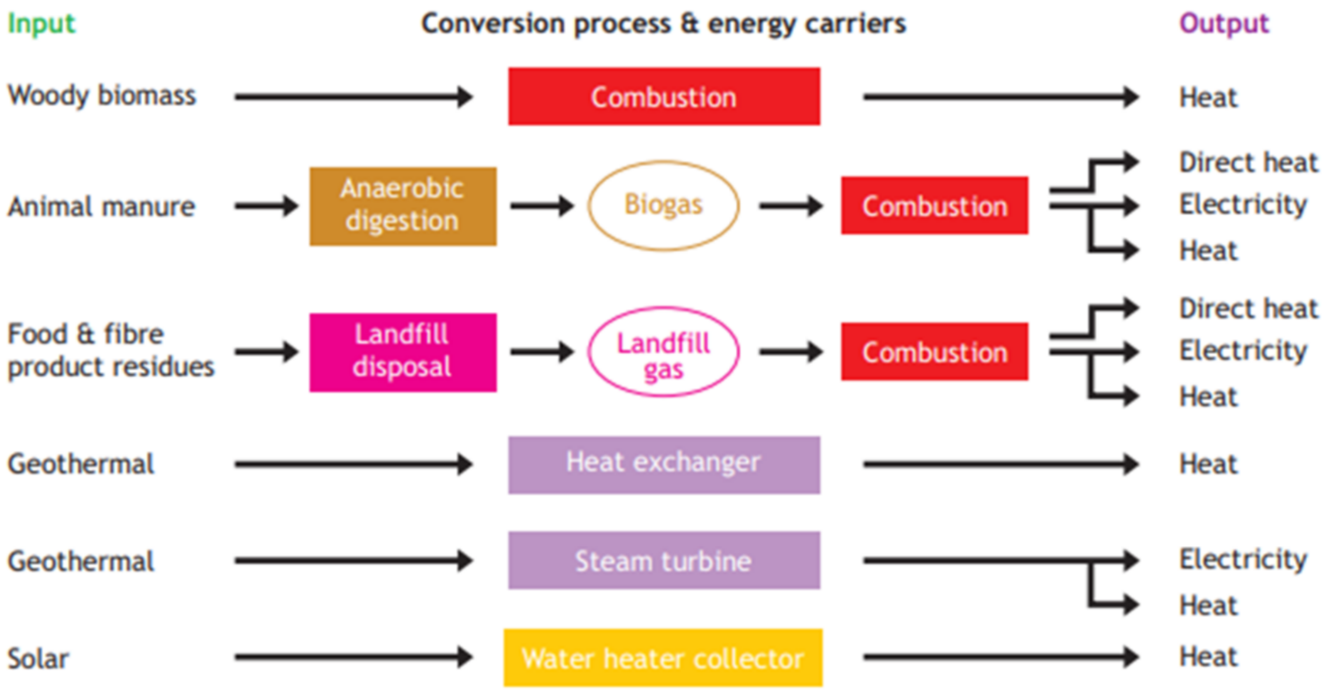

Fig. 7. Conversion process and energy carriers for RE heat. Adapted from [33].

2.2.3. RE for household heating and cooling

RE provides a veritable avenue for heating and cooling. Renewable heating and cooling convert RE source to useful heat. RE heating and cooling possess untapped potentials globally through the application of solar, biomass, and geothermal resources by producing cost-effective and efficient means of providing heat at reduced carbon dioxide and GHG emissions. Demand for heating accounts for a substantial portion of global total energy demand. In the household and building sectors, heating consumes about 48% compared to transport and electricity which are reported to be 20% and 32% respectively. These can be higher during winter seasons and in temperate regions. To generate heat from biomass, anaerobic digestion, pyrolysis, gasification, fermentation, and combustion are commonly employed to convert feedstock-like waste, forest products, agricultural products, and other industrial by-products into heat, electricity and transport fuels as shown in Fig. 7. However, until recently, RE has not being explored for household cooking and other forms of heating and cooling due to high cost and other technical constraints [33].

3. RE Driving Factors and Constraints

In relation to the countries considered in this study, RE drivers and challenges can be summarily categorised under RE policies, market demand, and fossil fuel subsidies, infrastructure and RE technology (see Table 7).

Immediately clear in Table 7, many issues concerning RE advancement in Nigeria and South Africa are similar with few peculiarities compared to the UK. The sub-sections that follow discusses RE policies, financial mechanisms, and fundamental infrastructure relating to drivers and challenges for RE in individual countries considered here.

Table 7. Drivers and challenges for RE.

#	Factors	Country	Drivers	Challenges
1.	RE policies	Nigeria	Internal policies and treaties on RE. Prominent Nigeria Energy Policies and Strategies: - National Energy Policy (NEP), 2003, 2006, 2013 - Renewable Electricity Action Programme (REAP), 2006 - Nigerian Biofuel Policy and Incentives (NBPI), 2007 - Renewable Energy Master Plan (REMP) 2005 and 2012 - Sustainable Energy for all Action Agenda (SE4ALL-AA), 2016 Ensuing RE market and renewable industry	Inadequate or weak policies [34–36] Market entry (Crude oil-\based power plants). Uncertainty and ambiguity regarding procurement regulations. Inconsistency in political support at the federal, state and local government levels [37]. Economic challenges – Crude oil-dependent economy. Bureaucratic challenges [34]. Political instability and low political interest in RE [37].
		South Africa	Internal policies and treaties on RE Prominent South African Energy Policies and Strategies - White Paper on RE, 1998 - White Paper on RE, 2003 - The National Environmental Air Quality Act, 2004 - the Integrated Resource Plan (IRP2010) - National Climate Response White Paper, 2012 - Integrated Resource Plan (IRP2013) Ensuing RE market and renewable industry [41].	Lack of political commitment [38]. Lack of adequate and stable government policies [39]. Bureaucratic challenges [40]. The fall and removal of RE Feed-in-Tariff (REFIT), (2009-2011) [40].
		United Kingdom	Internal policies and treaties on RE. Prominent UK Energy Policies and Strategies: - Energy Review, 2006 - Energy White Paper, 2007 - Climate Change Act 2008 - Electricity Market Reform (EMR), 2013 - Feed-in Tariffs for renewable electricity for PV and non-PV technologies 2010, 2015 - National Renewable Energy Action Plan (NREAP), 2010	Instability of RE policies due to political competition and interest alignment. The exit of Britain from the European Union [42].

#	Factors	Country	Drivers	Challenges
2.	Market Demand and RE Innovation	Nigeria	Values added by renewables; - Economic - Environmental - Socioeconomic [43]. The inadequate and epileptic power supply in Nigeria. Concerns about climate change and dependence on fossil fuels.	Competitiveness with well-established crude oil power plants [43]. Inadequate Tax Incentives, low or interest-free loans [44]. Inadequate local demand [35]. Comparatively high initial cost of installation of the system [34]. Perceived higher cost of energy integration. Needed accessories for backup and energy storage. Lack of funding of R&D related to RE generation, storage, and installation [44]. Misconceptions on renewable energy [25,45]. Low awareness by the uneducated populace [35].
		South Africa	Values added by renewables - Economic - Environmental - Socioeconomic Concerns about climate change and dependence on fossil fuels	High initial capital cost [38,46]. Low funding of R&D related to RE generation, storage and installation within the country [41]. Lack of consumer awareness to technology [38,46]. Needed accessories for backup and energy storage. Comparably inefficient technology.
		United Kingdom	The populace is largely supportive of renewable energy [47]. Concerns about climate change and dependence on fossil fuels. Values added by renewables [47]; - Economic - Environmental - Socioeconomic	The initial cost of RE systems and the length and complexity of application procedures [48].
3.	RE Subsidies	Nigeria	Enlightenment of the populace. International policies on RE. Foreign and local investors interest.	Low political interest for renewables. High reliability of national economy on crude oil. Bureaucratic ineffectiveness [49]. Low incentives on renewables [50]. High subsidies for fossil fuel [37,50].
		South Africa	International policies on RE. Foreign and local investors interest [38,41].	High subsidies for fossil fuel [51].
		United Kingdom	International policies on RE Foreign and local investors interest [37,53].	High subsidies for fossil fuel [52].

#	Factors	Country	Drivers	Challenges
4.	Infrastructure and Innovation	Nigeria	Location and development of remote communities in proximity with natural resources. Standalone capabilities and possible income generation.	Undeveloped road, energy, transport and housing infrastructure [49,50] High up-front costs of procurement and developing infrastructure to support renewable sources [34]. Lack of economies of scale. Theft and vandalization of solar energy systems infrastructure [35]. Huge investment and good maintenance culture required [34,35].
		South Africa	Slow implementation pace of RE projects [54].	Lack of infrastructure [39,46,55]. Low investment in renewables.
		United Kingdom	National and international policies of RE. Investment in RE by the government and investors [56].	High initial cost [37]. Constant improvement in infrastructure [57].
5.	Renewable Energy Technology (RET)	Nigeria	A vast range of available RE resources. Values added by renewables; - Economic - Environmental - Socioeconomic Large market potential for both local and foreign investors.	Technological challenges [35]. Weak R&D culture. Not conceived as viable solutions. Inadequate funding for R&D by the government and stakeholders. Disjoint of town and gown. Bureaucratic challenges. Inadequate government or policy support and implementation [44]. Perceived higher cost of energy integration. Misconceptions on renewable energy [25]. Comparably inefficient technology. Low political interest for renewables.
		South Africa	A vast range of available RE resources Values added by renewables - Economic - Environmental - Socioeconomic Large market potential for both local and foreign investors [46].	Lack of awareness by the populace [46] Inadequate funding for R&D by the government and stakeholders [46].
		United Kingdom	A vast range of available renewable energy resources. Investment in RE by the government and investors [56,57]. Values added by renewables - Economic - Environmental - Socioeconomic	Continued investment [56,57].

3.1. RE policies

Globally, an increasing number of countries are adopting and supporting the RE policies with a record of 173 countries at the end of 2015 [9,45] at the provincial/state or national level. This is mainly due to the global effort channelled towards mitigating the effect of climate change as discussed during the COP21, Paris summit in 2015. As documented in the literature, one of the key demands of investors in RE sources is the implementation of long-term stable policies that decrease the uncertainty level [37] and promote further investments [58,59]. As shown in Table 7, the energy policies and strategies are summarized to provide intuition on the current situation of renewable energy policies in Nigeria, South Africa, and the UK.

The sole dependency of the national economy for a country like Nigeria on fossil fuels represents the major barrier to the effective implementation of the RE supportive legislation and policy. The implementation of RE policies does not have a strong and consistent political push [36,37], which could either have been through easy bureaucratic procedure and consistency in the tenacity to follow the RE policy master plan of the country no matter the political affiliations. In addition, the implementation of the policies at the state and national levels in Nigeria is primarily been hampered by the complications associated with monitoring and enforcing the dictates of RE supporting legislation [35,36]. In addition, local regulatory bodies often lack sufficient funds, know-how, tools, transparency, consistency, and capacity to carry out outlined policy [35,50]. The lack of timeliness, accuracy, and accessibility of data for statistical data analysis and detailed review of the status of RE production impedes the implementation of a more-precise policy, in addition to new investment [9,36].

A stack similarity in the policy drivers and challenges observable between Nigeria and South Africa has been documented in the literature [38,41,46]. The main drivers for RE policies are the internal policies and treaties on RE, the emergence of RE market and the renewable industry amongst others. While the major challenge is the lack of adequate and stable government policies on RE. South Africa RE policy can be considered to be more successful due to the considerable progress made in addressing both the energy access and sustainability challenges as a result of the inclusion and implementation of RE initiatives in broader long-term rural electrification programs that are supported politically and backed by adequate funding [43]. This challenge is associable with the political instability within both Nigeria [36,60] and South Africa [38,46]. Asides the present plans for the UK exiting the European Union (BREXIT), the policies associated with RE in the UK can be comparatively stable but still has political influence [61].

3.2. Financial mechanism

3.2.1. Subsidies on energy sources

Nigeria is one of the foremost countries blessed with a variety of fossil fuel resources such as tar, coal, natural gas, and crude oil; and the country's economy is 90% dependent on crude oil [62]. But due to vandalisation of pipeline, poor maintenance amongst other factors which has caused refineries within the country to function below par, the importation of refined petroleum product is being necessitated. The high dependency on subsidies for fossil fuel has been documented to cost Nigeria about USD4 billion (~NGN1.2 trillion (at USD 1.00 = NGN 306.35)) per year in the last five years [45,63]. This has been one of the germane factors debarring the competitiveness of RE. The uproar leading to nationwide strikes and protests because of the total removal of the subsidy in 2012 forced the government to retain partial subsidy [45]. The main benefit of the partial subsidy is the increased availability of funds for capital development, removal of energy market distortions which is skewed towards fossil fuels energy sources and the development of renewables technology and project [45].

South Africa's economy on the other hand is mainly based on the exportation of rare earth metals and other materials but she has spent about \$3.5 billion on fossil fuel subsidy in 2016 [51]. For South Africa, it is often argued that the subsidy required for the competitiveness of renewable electricity with the conventional energy sources is substantial given the nation's budgetary constraints [41,46]. It is suggested that unless the subsidy on fossil fuels in the country is reviewed, competition with conventional energy sources cannot be achieved even if this is strongly opposed by both powerful interest groups and the general public [41,46].

In the UK, there are direct subsidies for the introduction of RE – it is an integral part of energy production and price establishment which is special in the UK. The introduction of the feed-in-tariff which is designed to support small-scale RE generation has been one of the motives for the surge in the investment of about £400m on RE projects in 2014 [64]. A fall in RE investment has been observed following the decision of the UK government to abolish feed-in tariffs [64], while, subsidy for fossil fuel is still ongoing [52,65].

For the cases of the countries considered in this study, the primary issue connected to the existence of the subsidies for fossil fuel is the presence of vested interests of powerful players such as the multinational petroleum companies. However, the policy actions and financial mechanisms pertaining to RE in the countries considered still require strengthening to improve RE competitiveness.

3.2.2. Administrative bureaucracy

Complex bureaucratic procedures for RE projects has been a bane in the advancement of renewables. The involvement of numerous actors and institutions in the decision-making process in energy-related issues makes the advancement of RE projects difficult in Nigeria [37,60] and South Africa [41,66]. For both Nigeria and South Africa, the responsibilities, and roles within a RE project can be divided among many governmental parastatals (both federal/state and local) and different organizations [37,66].

3.2.3. Inadequate financial resources

One of the core challenges of the advancement of RE technology, infrastructure, and RE associated solutions is the lack of consistent funding in Nigeria by the government, as a result of policy and political instability within the country [37,44]. While the same can be said for RE investors due to poor incentives [44]. This has been one of the reasons for the stagnation of Nigeria's RE resource development in an emerging stage [37]. For South Africa, the public capital available is limited, therefore, private funding bodies and RE investors are needed to leverage for the construction, maintenance, and operation of new infrastructure [46,66]. The financial support of the UK government for RE development is enough, but some RE technologies, such as photovoltaics (PV) still require further financial support [37].

3.3. Fundamental infrastructure

Nigeria is rich in diverse RE resources which is enough to accommodate its present and future energy requirements [67]. Even with the existence of substantial RE resources, the nation is entrenched in an energy crisis. About 60% of the Nigerian population do not have access to the public electricity supply with all the required infrastructure [50], while only a few percentages of the rural households in Nigeria have access to electricity either by government electrification projects or through the stand-alone power generating sets. Extending the power grid for rural household electrification is usually deemed not economically sustainable especially in localities with rough terrains and far away from preinstalled grid infrastructure [35]. Efforts channeled towards substantial expansion by the government on the electric power quantity generated are not concurrently complemented by strategic expansion of the infrastructure, transmission distribution and maintenance systems [49]. It can be categorically said that the presence of embedded infrastructure supports rapid development in RE by integrating it into their existing infrastructure [36]. Nigeria is lacking the required infrastructure that can fully cater even for the present electrification demand [49], while infrastructure to cater for large-scale RE generation is lacking [50,68]. The lack of good road network and required infrastructure coupled with the fact that components of RE technologies are not locally produced make the transportation of RE technology modular parts costly and difficult, without locally available technical know-how. These characteristics present both challenges and opportunities for an energy transition toward renewables and investment opportunities for both the government and RE investors to explore the RE market.

On the other hand, the challenges in South Africa can be characterized by high initial capital cost, lack of financing mechanisms, lack of awareness of technology and lack of sufficient infrastructure in the establishment of RE projects [38,39,46,55]. Pegels (2010)[46] opined that significant investment is required to get the necessary infrastructure to the location of the RE power plant. The associated initial cost of such infrastructures and possible upgrades has been documented in the literature to be a major scare for investors which are passed down to the RE project developers [37,40,53]. Therefore, the percentage of private investors in the RE sector is still relatively low due to barriers such as the infrastructure amongst others [66]. Within the RE sector, South Africa can boast of locally available skills of ancillary part RE project due to the fabrication of those parts within the country. But skills, technical know-how, and formal tertiary education aimed specifically at the RE industry are still lacking [40,46].

In terms of energy infrastructure in the UK, the effort is constantly channeled towards developing, upgrading and reconfiguring the energy grid with the aim of achieving a highly efficient system [57]. The sustainability of RE projects and systems are not hindered by financial constraints as more financial assistance is available at an investment level for energy infrastructure and at a domestic level via disposable income [56]. This is as a result of the UK's growing economy, strong RE policy and policy backing, regulations and new environmental targets [56] even asides other international treaties.

4. Exploring RE for Energy Efficiency and for Cleaner and Safer Environment: the Way Forward

This section presents recommendations on how RE technologies can be explored to attain energy efficiency and ensure a cleaner environment in Nigeria.

4.1. Bridging the Energy Demand Gap

With the ever-rising population and the gradually increasing economic development over the past 20 years, the energy demand in Nigeria has been on a rapid increase. In a study conducted by the Energy Commission of Nigeria (ECN) using the Model for Analysis of Energy Demand (MAED) that considers demography, economy, energy intensities, and energy efficiencies, it was projected that Nigeria energy demand under a 7 % GDP growth rate will be 120 MW by 2030 [69]. The same study also showed that the energy demand would be 300 MW under a 13 % GDP growth rate if Nigeria hopes to be among the first 20 economies of the world in the same year. Unfortunately, there is currently an energy crisis in Nigeria as she is unable to meet the energy demand with commensurate supply. As mentioned earlier, the energy supply system is largely dominated by the use of fossil fuels (oil and natural gas) for electricity generation which is itself not enough to meet the energy demands.

As an alternative energy source, RE technologies when integrated into the supply system, either as off-grid or on-grid systems, can bridge the energy demand gap. However, despite the abundant energy resources available in Nigeria, RE technologies have neither received significant attention nor have the available RE technologies been properly managed. This shortfall in the development of alternative sources of energy has largely been due to the over-dependence on fuel fossils despite the apparent energy needs [62].

To bridge the Nigerian energy demand gap, in what follows, we discuss three key areas of interventions that promote the development and adoption of RE technologies as part of the energy supply system.

4.1.1. Energy policies and funding

Bridging the demand energy gap in Nigeria largely depends on implementing existing energy policies. The most recent energy policies in Nigeria are the aforementioned NREAP, REMP, SE4ALL-AA, and the Nigeria Feed-in Tariff for Renewable Energy Sourced Electricity (2016) [70]. These policies which rely on fiscal/financial incentives, Feed-in tariffs/premiums, or tax relief, are targeted at RE sources such as Bioenergy, Solar, wind, and hydropower. The policies are largely aimed at national development through the efficient utilization of the nation's energy resources to achieve an adequate, reliable and sustainable supply of energy to the various sectors of the economy. Although there has been a sluggish application of RE technologies for power generation in Nigeria, effective and sustained implementation of the energy policies will lead to improvement in the use of RE to help meet the power demands.

Implementing the Nigerian energy policies largely requires funding from the public or private sector to drive investments in RE technologies and in extension the energy supply system. Corporate establishments can be encouraged to invest in renewables as part of their corporate social responsibilities to their host communities. Also, an increment and unhindered disbursement of yearly budgetary allocation by the Federal Government for successful implementation of the energy policies together with proper monitoring of the allocations, will not only facilitate growth in alternative energy sources but will encourage direct foreign investments in RE technologies.

4.1.2. Implementing a decentralised RE mix for electricity generation

With Nigeria being ranked within the 10 worst performing countries in terms of quality of electricity supply in Africa [71], a large proportion of her population reside in rural and secluded areas where access to electricity is either non-existent or is in a deplorable state. Nigeria has mainly adopted a centralized power generation scheme which is characterized by large plants in remote locations and from which electricity is transported over wide distances for use in urban and rural centers. Due to the high energy demands, the current systems for energy transportation are not reliable as only about 46% of the homes in Nigeria have access to electricity [72] and only 2% of homes in rural communities have access to electricity [73]. Significant attention has not been paid by the government to establishing power generation systems in rural areas where residents depend largely on petroleum for electricity using standalone power generating sets.

One way to circumvent this situation is to implement a decentralized RE mix in these isolated rural communities. The decentralized energy technologies, for example, roof-top wind turbines, small hydropower (SHP), solar power systems, are beneficial as they provide electricity where they are needed. Some of these technologies can be deployed as standalone setups for individual homes or as local utility-scale power generation and transmission systems. While roof-top wind turbines and solar power systems can be used for the former, the latter can be implemented by exploring solar farms, wind turbine farms, SHP and thermal-based technologies like biomass-fired engines or steam turbines for micro-grid power generating schemes. Community-based renewable power generating systems could be exploited for a strong energy mix comprising of various RE technologies. In some cases, to reduce the total reliance on fossil fuel, hybrid isolated micro-grid RE technologies can be deployed [74].

4.1.3. Research and Development (R&D)

R&D in the deployment and utilization of RE technologies, is necessary for bridging the energy demand gap. By strengthening existing educational institutions and research centers, the required knowledge, expertise, and transfer of technology in the energy sector can be enhanced. This is particularly useful in developing, managing, monitoring, and evaluating RE projects as the viable additions to Nigeria's energy supply system. The end goal is to attain efficient and reliable solutions to the growing energy needs. Given the current global inclination towards promoting RE over conventional fossil fuel-based energy stems, R&D institutions focusing on RE technologies can attract foreign investments or grants for research that are tailored towards the local environment or peculiarities in the immediate society in need of energy.

4.2. Affordability and Accessibility of RE Technologies

One of the key advantages of RE is that it aids the economic growth of any nation. Though renewables are very cheap to operate with small maintenance requirements, one of the impediments to the deployment of RE is the initial expense required in building and setting up RE technologies for electricity generation. Fortunately, there has been an impressive fall in RE capital costs since the early 2000s [75]. For example, compared to the cost in 2009, solar photovoltaic (PV) modules are now more than 80 % cheaper and wind turbine prices have fallen by about 50 % over the period 2010-2017 [76]. For residential solar PV total systems, the costs decreased by 68.5 % from an average cost of USD 8900/kW in 2007 to an average cost of USD 2800/kW in 2017 [76]. Table 8 shows a recent (as at 2017) global cost of some selected RE technologies. As seen, costs of solar PV systems and onshore wind farms have significantly decreased over the period of study according to IRENAs database. Among other things, the reduction in RE costs is driven by technological improvements and the competition between a wide base of experienced project developers and suppliers of RE technologies.

In contrast, from the same IRENAs database, the cost of offshore wind farms increased potentially due to the significantly higher lead times, and the use of advanced technologies for the offshore facilities. The increased cost for hydropower projects over the 7-year period of study was attributed to installations in less ideal sites which are far from existing transmission infrastructure and will require additional cost to transport power generated.

For the cost of biomass power generation, the type of technology deployed for construction, fuel handling, and equipment for feedstock preparation, largely determine the cost of this RE technology. Cost of equipment for various biomass power generation technology can vary widely and this depends on the location of the biomass plant, the availability, and type of feedstock, and where the feedstock preparation or conversion is performed [76].

Table 8. Global weighted average of cost of selected RE technologies [76].

RE Technology	Cost as at 2017 USD/kW	Comment on current cost
Residential solar PV system	2,800	68.5 % decrease compared to cost in 2007
Total installed cost of a hydropower project	1,558	33 % increase compared to cost in 2010
Total installed cost of onshore wind farms	1,477	70 % decrease compared to cost in 1983
Total installed costs of offshore wind farm	*4,487	4 % increase compared to cost in 2010

*Cost as at 2016.

To consider the cost of RE technologies in Nigeria, a study was recently carried using the concepts of Levelized cost of electricity (LCOE) and Society's cost of electricity (SCOE) as tools to evaluate the costs of power generation in Nigeria [77]. These tools allowed RE cost analysis from the perspective of a private investor and a societal-based standpoint respectively. It was established that to acquire the needed power on a lifetime basis, RE technologies offered the most cost-competitive means compared to fossil-fuel based options. This cost competitiveness also considered the costs to society; that is, costs of climate change damage and health costs from air pollution. Using a Hybrid Optimization Model for Electric Renewable (HOMER), Okedu et. al (2015) [78] similarly showed the cost-competitiveness of deploying RE technologies compared to fossil-fuel systems in mountainous and riverine environments.

The solar PV system is the major RE technology often deployed as an off-grid system in Nigeria. This system is usually custom-made to the appliances with various load requirements that are powered by it and the different storage configurations employed. As with other RE off-grid power systems, a person investing in the solar PV systems is usually the consumer of the electricity. Over the last 5 years, there has been a proliferation of solar energy companies and suppliers of PV systems for residential and office buildings, and for Small and Medium Scale Enterprises (SMEs) in Nigeria. So, solar PV systems are readily available and depending on the load requirements of households or SMEs and the solar energy system supplier, the costs of a solar system for 24-hour electricity may vary from few hundreds of thousands of Naira to millions of Naira. Today in Nigeria, a solar system can be installed for as low as about NGN 150,000.00 (USD 490.00 (at USD 1.00 = NGN 306.35)) for a conventional household that has about 3 - 4 energy-saving bulbs, an LCD television, a small fan, and gadgets. For a typical urban household which require a 1.5 kW solar system that comprise of solar panels, inverter, deep cycle battery and other accessories to power light bulbs, Fans, laptops, phones, large fridge (300 W), TVs and sound systems, the cost of the solar system including installation may be up to about NGN 1,300,000.00 (USD 4,250.00 (at USD 1.00 = NGN 306.35)).

There is much potential for wind energy in Northern Nigeria [79], thus giving support to calls for deployment of micro-wind turbines in those areas for power generation. Micro-wind turbines are not as common as solar PV systems, however, these wind turbines are available in Nigerian markets and are used to provide energy for lighting or other low energy demand applications. A typical cost of a micro-wind turbine is about NGN 450,000.00 (USD 1,470.00 (at USD 1.00 = NGN 306.35)) which provides 40 kWh of energy per month.

Costs of the RE technologies are generally high for most of the population as 61 % of Nigeria's population lives in poverty, and about 100 million people live on less than a USD 1 a day [80]. These numbers are expected to be higher considering the recent economic recession faced by Nigeria. Therefore, only a small percentage of the population can afford any of the RE technology to use for their households or businesses. It is hoped that with government invention in terms of funding and implementation of appropriate policies, together with investments from the private sector, deployment of RE technologies to communities, individuals and SMEs lacking the financial capability of getting RE technologies, will be encouraged. Also, since most RE technologies and equipment are not manufactured in Nigeria but are rather imported into the country, costs of RE can be further reduced by removing or relaxing import duties on RE related shipment into Nigeria.

4.3. Protecting the Environment

Fossil fuels are the main source of supply of today's world energy and are mainly used for electricity generation, and transportation. However, the use of fossil fuels leads to the release of GHGs which cause climate change through global warming. The effects of climate change can be observed to have been manifested, for example in Nigeria as; rising year-round temperatures, flooding of coastal communities, and desert encroachment in northern Nigeria. In addition to atmospheric pollution due to GHGs, communities in the oil-producing Niger-delta region of Nigeria have at numerous times encountered the problem of environmental pollution due to oil spillage. The environmental degradation caused by this oil pollution has severely impacted on not only the ecology and ecosystem of the affected communities but also on the means of livelihood and the health of the residents the communities [81]. A well-known case is that of Ogoniland, Rivers State, in the Niger-Delta region of Nigeria, which yet remains to be cleaned up as at today, despite recommendations from the United Nations Environment Program (UNEP) report and promises from the past governments of Nigeria. Though the present Nigerian Government has shown great commitment to addressing this dire environmental and toxic situation by initiating the Ogoni clean-up project, the exercise is yet to commence.

Since Nigeria, largely depends on fossil fuels to meet energy needs, it is not uncommon to witness environmental pollution in the form of noise pollution from generating sets and atmospheric pollution in the form of emission of GHGs from these machines that are used to supply power to residential and public buildings. The practice of energy conservation and the use of energy-efficient appliances will lead to a reduction in demand for energy and thus constitute a means of combating climate change in Nigeria [50]. Though RE technologies have not been fully embraced in Nigeria, the use of RE sources is a major way to combat environmental pollution and climate change as they do not release GHGs like fossil fuels.

5. Conclusion

The development of RE in the energy sector has the potency of addressing capital development, reduce the dependency on fossil fuels, improve the energy mix and reduce the emission of GHGs. This paper critically explores the present state of RE in Nigeria, South Africa, and the United Kingdom. The paper also examined targets set by these respective countries to harness RE. Nigeria plans to generate 30 GW of power by 2030, with 30% (9 GW) coming from RE sources. Similarly, south Africa targets total installed renewables capacity to reach 18.2 GW by 2030. Though, only 1.5% of the UK's energy is from RE as of 2005, the UK targets this to increase up to 15% by 2020. Factors that drives and challenges the RE developments in these countries were identified. Amongst the numerous factors, the effect of the policy, policymakers, its implementation, supporting financial backing and conventional energy source associated demands seems to be predominant. This paper provides an insight into RE associated policies and practices in the countries considered. The competitiveness of RE and the continued improvements in the technology still require continuous improvements.

To harness the numerous benefits offered by RE technologies in meeting Nigeria's energy needs, it is important that commitment is shown by government towards implementing existing energy policies and then continuously monitoring their implementation to achieve the objectives of the policies. Also, the government should increase funding and encourage contributions from private investors in RE technologies. Owing largely to technological advancements, the globally decreasing initial costs of RE technologies should promote the drive in seeking for alternative energy sources which can be used as part of decentralized, off-grid energy systems for homes, businesses and rural communities. Nigeria should embrace smart grid technologies, where monitoring and control of RE systems via ICT allows for improvement of quality and safety of such systems [82, 83]. By exploring RE technologies, aside from contributing to meeting Nigeria's energy demands, Nigeria among the comity of nations would also move a step ahead in contributing its quota to combating climate change by reducing her dependence on fossil fuel based technologies which negatively impacts the environment.

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