

Adewuyi, Oludamilare Bode et al.

Article

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Research paper

Challenges and prospects of Nigeria's sustainable energy transition with lessons from other countries' experiences



Oludamilare Bode Adewuyi^{a,*}, Mark Kipngetch Kiptoo^a, Ayodeji Fisayo Afolayan^b, Theophilus Amara^{a,c}, Oluwatobi Idowu Alawode^d, Tomonobu Senjyu^a

^a Graduate School of Engineering and Science, University of the Ryukyus, 1 Senbaru, Nishihara-cho, Nakagami, Okinawa, 903-0213, Japan

^b Institute for Sustainable Development, First Technical University, Ibadan, 200253, Oyo state, Nigeria

^c Distribution Operation Section, Electricity Distribution and Supply Authority, Freetown, 32023, Sierra Leone

^d Department of Agricultural and Environmental Engineering, University of Ibadan, 200284, Ibadan, Nigeria

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ABSTRACT

Sustainable energy transition is generally understood as a concept of developing robust, effective and efficient energy sectors in a particular country or region without compromising the present and future socio-environmental security. In view of this, several countries have made remarkable efforts towards achieving this all-important objective in compliance with modern energy needs and supply requirements. Over half of the reported impoverished people globally reside in the sub-Saharan Africa (SSA) region and a sizeable portion of these people (up to 400 million) live in Nigeria, being the most populated country in Africa. The economic growth and social development of any nation depend remarkably on the sufficiency of its energy sector. Thus, the realization of the Sustainable Development Goals (SDGs) comes the year 2030, as projected by the United Nations, in Nigeria and the entire SSA region depends heavily on energy. In this study, the importance of an equitable right to sustainable energy adoption in Nigeria and other countries in Africa towards meeting United Nations SDG's deadline has been succinctly discussed. The reform activities towards improving the energy sector of Nigeria are discussed and appropriate recommendations are made taking clues from other developing countries' successful energy transition efforts.

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1. Introduction

Critical to the continued existence of our planet are actions that promote sustainable growth and development across all phases of the human environment. According to a common saying "when one party has not, corporate spending is like a burden", hence the reason behind the United Nations Program for Sustainable Development. Beyond the uncontrollable natural occurrences, the greatest threat to the peaceful, equitable and continuous co-existence of our world are the various unguided human activities; which are both political and apolitical. A situation whereby many has enough to throw away, while many lives in abject poverty constitute a gross imbalance in the scale of social egalitarianism. Hence, sustainability can be described, succinctly, as an act of getting the best out of the available such as the

human and natural resources widely distributed across all regions, while bringing the good out of the inevitable such as the socio-economic and political differences, etc..

Consequently, sustainable development was defined, adequately, as any action that helps to satisfy the present needs, across all the regions of the world, without compromising the future of our globe (Ozturk and Yuksel, 2016). In line with the above definitions is the formulation of the United Nation's Sustainable Development Goals (SDGs). These are 17 integrated goals set in the year 2015 towards having a better human society come the year 2030 (UNDP, 2015). However, as lofty and ambitious as these goals are, their attainment is deeply enmeshed in the desire to follow through with the necessary political will and the needed socio-cultural renaissances which differs from region to region. No doubt, Africa is the most impoverished continent and the worst-affected by the attendant problems that the sustainable development goals seek to address.

Putting all the SDGs into proper perspective, the achievement of goal (7) has been established as the golden link to the successful implementation of all the other SDGs. This is succinctly illustrated by the interrelationship network shown in Fig. 1. The triangular interdisciplinary model for sustainable development

* Corresponding author.

E-mail addresses: adewuyibode@gmail.com (O.B. Adewuyi), kiptoo.k.mark@gmail.com (M.K. Kiptoo), aayodeji1@yahoo.com (A.F. Afolayan), tioamara@gmail.com (T. Amara), oluwatobiidowu24@gmail.com (O.I. Alawode), b985542@tec.u-ryukyu.ac.jp (T. Senjyu).

Nomenclature

SSA	Sub-Saharan Africa
SDGs	Sustainable Development Goals
LMS	Learning Management System
HDI	Human development index
VREs	Variable renewable energy sources
DSM	Demand-side management
DR	Demand response
NREA	New and Renewable Energy Authority
WAPP	West African Power Pool
ISES	Integrated Sustainable Energy Strategy
FIT	Feed-in-tariff
R&D	Research and development
NNPC	Nigerian National Petroleum Company
NGC	Nigeria Gas Company
PIB	Petroleum industry bill
PHESS	Pumped hydro energy storage system
GIS	Geographical information system
AREMI	Australian Renewable Energy Mapping Infrastructure
RDF	Refuse-derived fuel
DG	Distributed generation
PACE	Partnership to Advance Clean Energy
CSP	Concentrated solar power
NCEEC	National Centre for Energy Efficiency and Conservation
NCEE	National Centre for Energy and Environment
GHG	greenhouse gases

shown in Fig. 2 further clarify the centrality of sustainable energy, sustainable environment and sustainable economy to the achievement of the SDGs at the expiration of the set year 2030. The correlation between the SDGs and the main socio-economic variables such as sustainable energy/electricity use and other day-to-day activities of a particular place is verified to be massive, using a spatial econometric analysis model (dos Santos and Balestieri, 2018). In case study reviews performed for different countries, researchers have established a robust correlation between sustainable energy production, socio-economic prosperity and environmental security from places to places around the world (Shaikh et al., 2017; Pietrosevoli and Rodriguez-Monroy, 2019; Oyedepo, 2012b).

The five cardinal targets from sustainable energy production point of view are identified in Vidadili et al. (2017) to be: reduced carbon dioxide emissions, ecologically friendly process, energy transition security, reduced energy production cost and massive integration of green energy technologies. All the listed five targets are directly promoting a better environment while improving economic security. Hence, at the center of (or surrounding) the socio-economic growth, industrial revolution and environmental sustainability of any nation or community of people is the access to reliable, cheap and clean energy. Achieving the energy goal will have a remarkable impact on all other goals; energy (goal 7) drives industry, innovation and infrastructures (goal 9), then responsible consumption and production (goal 12) are achievable under a decent work condition which promotes economic growth (goal 8). With buoyant economy comes collective prosperity which reduces poverty (goal 1), combats hunger (goal 2), and promotes quality living and well-being (goal 3).

Sustainable cities and communities (goal 11) are products of environmental-friendly and cheap energy production.

In a sustainable environment, clean water and sanitation (goal 6) is non-negotiable, and this directly affects the aquatic life (goal 14) and life on the land (goal 15). Quality of life in the water and on the land is a direct indicator of a healthy environment and active climate change actions (goal 13). The coupling between sustainable energy and quality education (goal 4) may appear evasive, but it is significant. Sustainable and reliable energy drives quality educational facilities and infrastructures such as modern Learning Management System (LMS), state-of-the-art classrooms, well-equipped laboratories, reading rooms and comfortable students' accommodation. An informed mind with quality and service-oriented educational training will understand gender equality (goal 5) as a fundamental right of creation and will promote peace, justice, and strong institutional values at all places of duty, and will also seek to reduce global income inequality among nations. Goal 17 is a unifying agent, for none of the goals succeeds alone and no one country, no matter how powerful, can meet even only one of the targets without the support of other countries.

The understanding of the past and present socio-political actions in a particular region/nation can significantly help to design a sustainable pathway for efficient SDGs realization in that region/nation (dos Santos and Balestieri, 2018). Hence, this study seeks to appraise some of the existing socio-technical infrastructures for sustainable energy transition in Nigeria; as well as analyze the attendant challenges in the sustainable development prospects of Nigeria. The social, technical and political reasons behind the fallout of the efforts of the Nigerian energy sector and how to benefit from the experiences of other nations in overcoming these challenges are empirically analyzed and discussed. Recommendations for relevant government and non-government agencies as well as concerned citizens on immediate actions that can be taken towards meeting up with the 2030 set year for SDG realization, from the energy (goal 7) point of view.

The remaining parts of this report are sectioned as follows: Section 2 discusses the energy impoverishment of Nigeria and other countries in Africa, Section 3 gives a detailed information of the demography, energy sector and socio-economic conditions of Nigeria. In Section 4, a case was made for natural gas utilization for sustainable energy and environment transition in Nigeria. Other notable all-inclusive pathways, which involves both government and private agencies involvements towards achieving sustainable energy transition in Nigeria are discussed in Section 5. In conclusion, the verified approaches of other developing countries in achieving a leap in their energy transition efforts are analyzed and sufficient inferences that can benefit Nigeria are drawn in Section 6.

2. Energy poverty and a call for energy justice in Nigeria and SSA region

The economic, social and solidarity implications of energy poverty are becoming massive, especially in regions where the income level is low and the average cost of modern energy technology is relatively high such as the sub-Saharan Africa (Meyer et al., 2018). As at 2017, approximately 1.1 billion of people globally were living without access to energy in its clean, socio-environmentally and directly usable form. The sub-Saharan African region is worst hit by the global energy deprivation; only one in every three individuals is connected to an energy source in its reliable, clean and affordable form. The small population that is connected to the grid experience unreliable services that shortchange their daily energy needs (Division for Sustainable Development Department of Economic and Social Affairs

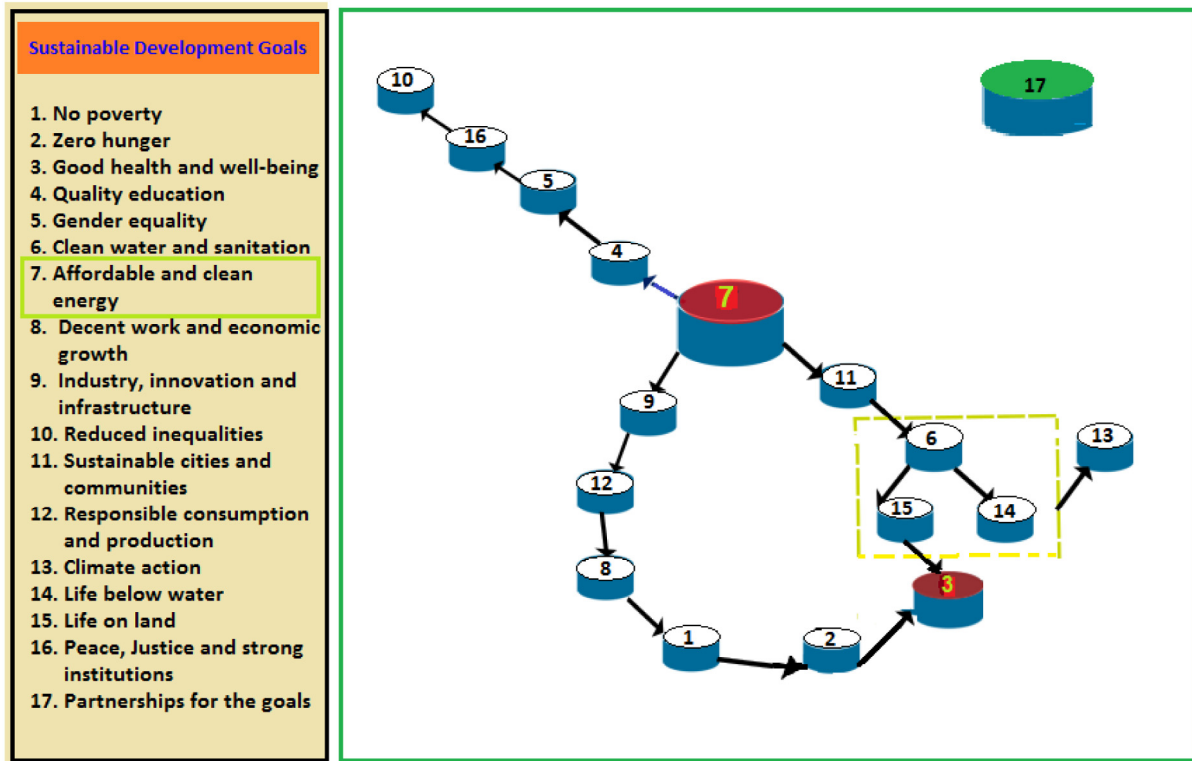


Fig. 1. SDGs interrelationship network (UNDP, 2015).

Table 1

Average power per capital for selected countries (CAS, 2018).

Countries	W/h/head	Countries	W/h/head
USA	1377	NIGERIA*	14
CANADA	1704	TOGO	16
CHINA	492	BENIN	10
AUSTRALIA	1112	GHANA	39
JAPAN	841	IVORY COAST	27
FRANCE	736	EQU. GUINEA	13
MALAYSIA	483	CONGO DR	21
ISRAEL	835	S. LEONE	3
SWITZERLAND	809	CAMEROON	28
INDIA	128	CHAD	1

United Nations, 2018; Lee and Callaway, 2018). In 2014, the total energy estimates of the whole of sub-Saharan Africa about 860 million residents, minus South Africa, was quoted to be 28 Gigawatts (Lomborg, 2016).

Significantly, issues that surround energy poverty analysis are broad as they also include the level of mass illiteracy and the socio-economic status of citizens. Hence, energy policies that will successfully address energy challenges in a specific region, country or state should be developed with significant consideration for the wide disparity that currently exists in the per capita energy availability from place to place all over the world. The average power per capita in SSA is about 32.6 Watts per hour per head; this reflects a gross case of energy poverty compared to other parts of the world as shown on Table 1 (CAS, 2018). Due to the huge energy imbalance and social infrastructure deprivation in SSA, most homes and businesses are either run using small diesel or gasoline generators or by direct/unhealthy bio-energy conversion for cooking and heating purposes. The negative impacts on the immediate environment and health are enormous (Avila et al., 2017); this is against the Kyoto 1997 protocol and Paris 2015 agreement which are centered on the need for global greenhouse gas emission mitigation (United Nations

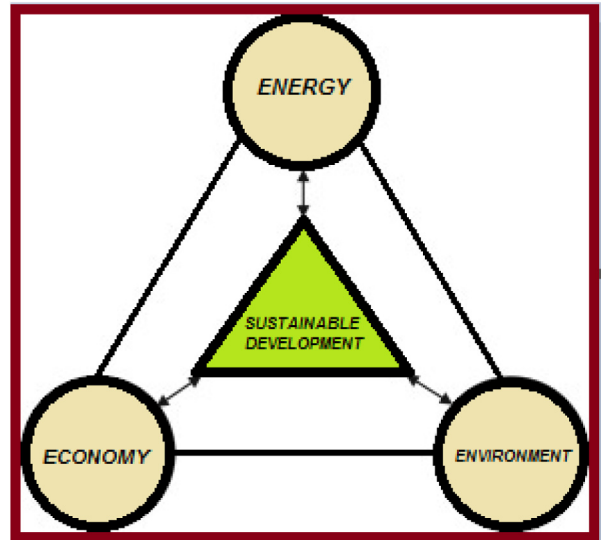


Fig. 2. Interdisciplinary triangle of sustainable development (Ozturk and Yuksel, 2016).

Climate Change, 2018). Countries all over the world are devising efficient technologies and formulating enabling policies towards encouraging significant levels of penetration of clean and cheap alternative energy sources into their energy mix. However, there is not yet an adequate and reliable approach for meeting the huge energy deficit of Nigeria and the entire SSA region as indicated in Fig. 3 (IEA (International Energy Agency), 2018; Akpan, 2015; IEA (International Energy Agency), 2014).

Most part of the SSA region falls out of the techno-economical credible zones for renewable energy exploitation due to low renewable potential access combined with huge investment cost,

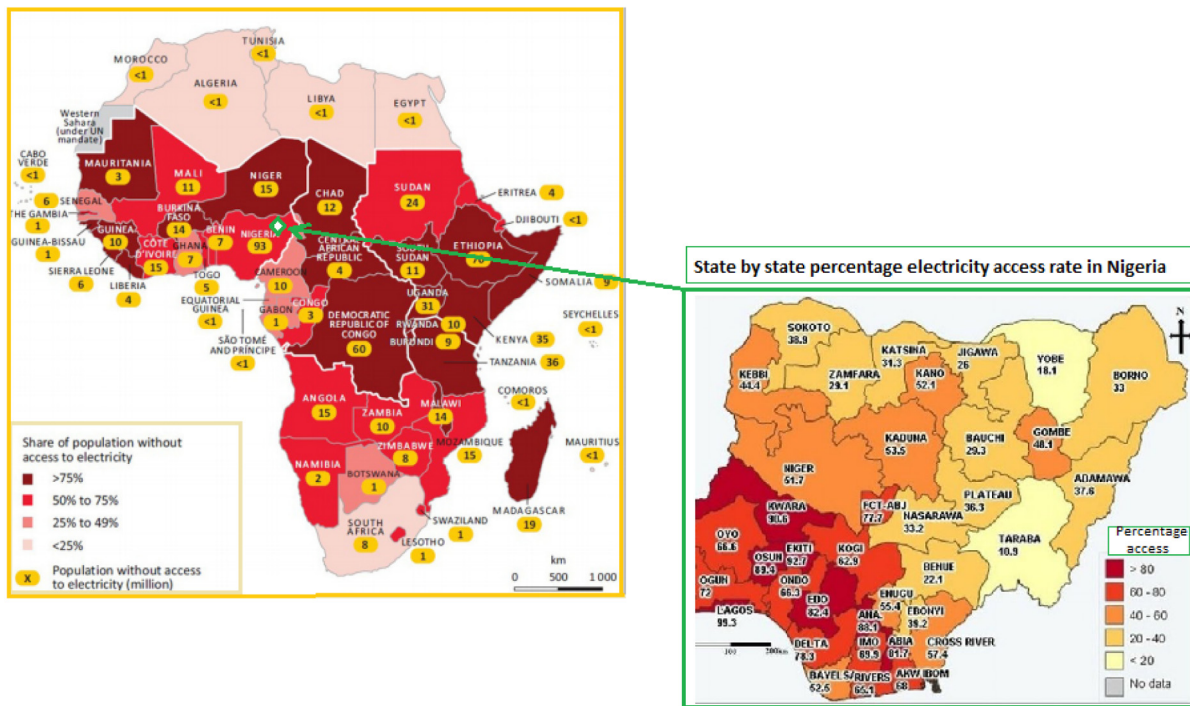


Fig. 3. Electricity shortage in African countries by percentage population (IEA (International Energy Agency), 2018; Akpan, 2015).

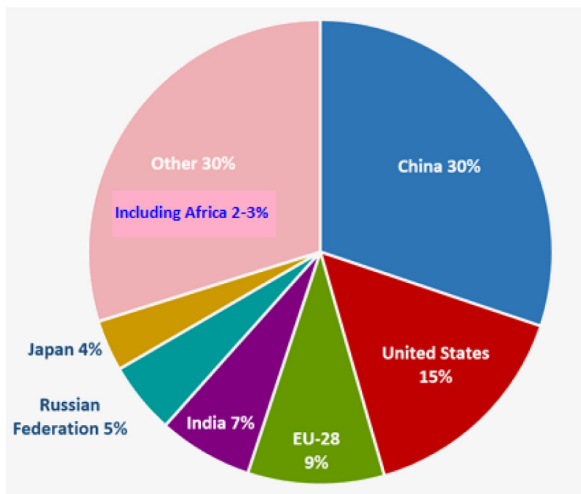


Fig. 4. Percent Contribution to global warming by countries (Fleurbaey et al., 2014).

lack of local technical know-how, lack or insufficient framework for environmental permit and energy trading (Avila et al., 2017). Hence, the cost of renewable energy generation in SSA remains as high as \$0.115 per kWh against \$0.07 per kWh from conventional sources (Pueyo et al., 2016). However, most of these countries are abundantly rich in several energy sources; most of which are currently not put to proper use due to lack of foresight. Remarkably, countries like Angola and Nigeria have a well-developed but poorly managed petroleum industry. Excess gas products from these countries are flared, mostly, as a result of the high requirements for gas transportation and storage. This energy fuel can be a credible solution to the energy needs of these countries if properly utilized, as other developed countries have done. The current combined contribution of the whole of Africa as a region to global climate change is low; and the energy

demand of Africa is increasing rapidly due to the continuous quest for industrialization and population growth (Schwerhoff and Sy, 2017; Fleurbaey et al., 2014; Wang and Dong, 2019).

Energy justice deals with the agreements and decisions on who bears the costs and the inevitable burdens of energy transition or integration of new energy facilities. The issue of energy justice should be more of an intrinsic concern in Africa compared to other industrialized and developing economy such as Indian, China, Japan, Taiwan and so on (Sovacool et al., 2019). The immediate call for all-green energy may be another form of energy injustice or unfairness to the African continent due to the huge financial implication and insufficient energy structure in the region. Countries like China and Indian are increasing their share of electricity production using coals, the United States is discussing pulling out of the Paris accord, and countries like Japan, Taiwan and South Korea are reinforcing specific portions of their nuclear energy production plants. Hence, natural gas, which is a clean-burning alternative energy source compared to other energy fuel sources such as coal, Bitumen, diesel, Lignite and so on, can provide an immediate way out for this region. An alternative source of energy may not necessarily be renewable in nature, but it has to be sustainable and a better substitute for fossil fuels in terms of cost and environmental-friendliness (Farret and Simoes, 2006); natural gas fit into this description. Hence, the gas flaring option, currently employed in most of the oil-producing regions of Africa, for disposing of this valuable energy resources is not only detrimental to human health and environmental sustainability; but also a waste of significant economic fortune.

Fig. 4 shows the percentage of countries contributions to global warming. Without compromising the need for environmental sustainability, the development and economic growth of most developing countries will need to be built on clean-burning alternative fuel sources such as natural gas and agricultural wastes. The continent of Africa, as of now, has the least financial and technical ability, as well as, market incentive for renewable energy investment. Adequate financing of the renewable energy project in Africa may be one of the key limitations

to achieving the United Nations SDGs within the stipulated period (Schwerhoff and Sy, 2017). Devising efficient technological and market policy model for the significant level of integration of clean-burning fuels such as natural gas and biofuels can help to meet the short term huge energy need of Africa, as further steps are being strategically devised and implemented towards a possible all-green energy future.

3. Overview of Nigeria: demography, energy sector activities and socio-economic implications

With an estimated population of close to 200 million people, as of late 2018, Nigeria remains the most populated African country. Located in West Africa sub-region along Latitudes 4°N and 14°N, and Longitudes spanning from 3°E to 8°E as shown on Fig. 3, Nigeria covers about 923,768 km² of the world area. The Federal capital territory is Abuja; and the country shares boundaries with Benin (773 km) to the west, Cameroon (1690 km) to the east; and Niger (1497 km) and Chad (87 km) to the North. The southern coast opens directly to the Gulf of Guinea in the Atlantic Ocean; which makes it a strategic location for international trade (Anon, 2017a). The population density is 204.28 per km² with a GDP of 375.77 Billion US dollars and per capita GDP of 2412.41 US dollars as at 2017. Nigeria is considered relatively wealthy judging by the value of the national income and financial/economic output but the minimal purchasing ability when it comes to international trading is among the lowest (Anon, 2018a). The weak economy is reflected directly in the nations' human development index (HDI), where Nigeria ranked as 157 out of 189 countries; with HDI value for 2017 being 0.5320 (Anon, 2018b). The potential of Nigeria as the most promising economy and the most viable market in the sub-Saharan African region is well-recognized all over the world going by its location and population advantage.

The most significant impediment to the maximization of Nigeria's potentials for adequate socio-economic growth is the poor condition of the power sector; according to the Transmission Company of Nigeria, the grid generating potential currently stands at 12,522 MW, Emodi and Dauda (2015) and NERC (2017). However, the consequences of ineffective operational management, poor maintenance, coupled with the irregular supply of primary fuels, have kept the country's average daily available generation to below 4,000 MW, as reflected on the operational status of each existing generation station. The all-time national peak generation of 5,375 MW was recorded in February 2019 (Mbah, 2019), and this is obviously inadequate considering the massive energy need of the nation. Going by this abysmal condition of the electricity sector, less than 50% of the population is being served by the grid (86% urban access and 41.1% rural access) and about 4% has access to clean energy for cooking in a country where there is about 49.6% urban population (Anon, 2016a). Nigerian electricity demand currently stands at above 20,000 MW, and it is projected to reach up to 90,000 MW by 2020, going by the estimated yearly economic growth rate of between 7% and 13%, and an urbanization rate of 3.8% (Salau, 2016). The existing Nigerian power system is highly unreliable both in content and in essence; the generation and transmission capacity is grossly insufficient, and the distribution network is outdated and inefficient. As a result of this, energy losses, planned outages (load shedding) and forced outages (voltage collapses) are everyday experiences (Oyedepo, 2012a; Adhekpukoli, 2018). With an average of 125 kWh per capita energy per head (Adedokun, 2016; Advisory Power Team, Office of the Vice President, Federal Government of Nigeria, 2015) and an estimated average occurrence of 23 system collapse over the past 31 years (Akinloye et al., 2016; Ogbuefi et al., 2018), the poor state of Nigerian grid is currently confounding. In Adewuyi

et al. (2019a), three cases of reliability-based optimal large solar PV investment models were investigated for the existing Nigeria national grid with adequate consideration for voltage stability improvement. At a load level of about 8000 MW, the current Nigerian grid is found to be highly susceptible to voltage collapse, and it can only support mean PV injection of less than 30% of this load level for it to be operated securely after an adequate grid enhancement has been ensured. In a bid to turn things around in the energy sector, the Federal Government embarked on the unbundling the power sector (decentralization process) and partial privatization of power infrastructures.

3.1. Nigerian Energy resource distributions, potentials and current utilization levels

There are sufficient reserves of variable renewable energy sources (VREs) and non-renewable energy producing resources in Nigeria, most of which are yet under-utilized (Adewuyi et al., 2019b). The distribution of energy resources and socio-economic activities in Nigeria can be characterized along with her geographical division, as shown in Fig. 5. The oil-rich south is highly industrialized and densely populated and credible renewable energy resources are available in the more commercialized and less dense north (Aliyu et al., 2015). However, inconsistencies of the government in terms of policy implementation and administration has grossly affected every region of the nation and this is reflected in the poor level of development all over the country. The oil rich coastal area are suffering from environmental degradation and poverty and the renewable energy rich commercial zone have the weakest electricity transmission and distribution network system.

Nigeria is the highest crude oil producer in Africa, as shown in Fig. 6; and it is ranked thirteenth in the world with an average production capacity of 2.40 million barrels per day, as at 2014. As of today, 90% of total exported products from Nigeria are crude oil-based, and this accounts for around 80% of the total revenue (Eravwoke et al., 2014). The current primary energy-mix for electricity generation of Nigeria is about 70% thermal, and it is predominantly from inefficient natural gas technology alongside some poor-burning coal-fired generating stations. The remaining electricity supply is from the hydro sources with negligible contributions from VREs (wind and solar). A large portion of the country's population depends on inefficient and costly diesel and petrol combustion engine generators to meet their inevitable energy needs. The daily solar energy density is around 12.6 MJ/m²/day in the southern part and 25.2 MJ/m²/day in far north close to the Sahara with a mean generation capacity factor of 27% (Ohunakin et al., 2014; Anon, 2015). The capacity factor, which is the estimates of the production efficiency of energy systems, for selected sites within the country, is calculated to be 25.85% and 28.67% respectively for Ilorin and Maiduguri (Adewuyi et al., 2019b).

The estimated generation capacity for solar PV in Nigeria is around 43,000 MW using the data obtained for the solar energy-rich northern and central regions (Africa-EU Energy Partnership, 2015), of which a very little portion has been yet utilized. Solar energy research and development (R&D) activities have been at the center of attention in Nigeria compared to other VREs as a result of its relatively simple technology and sufficient capacity factor (Giwa et al., 2017a). The installation and maintenance requirements are minimal; and the recent drop in the global price of PV system components has also made it encouraging (Ozoegwu et al., 2017; Ozoegwu, 2018). The federal government invested about 20 billion US dollar on new solar projects in 2017 and a private-owned 30 MW solar farm project has been planned to be sited in Kaduna state (Ayemba, 2017; Bulbulia, 2018). There

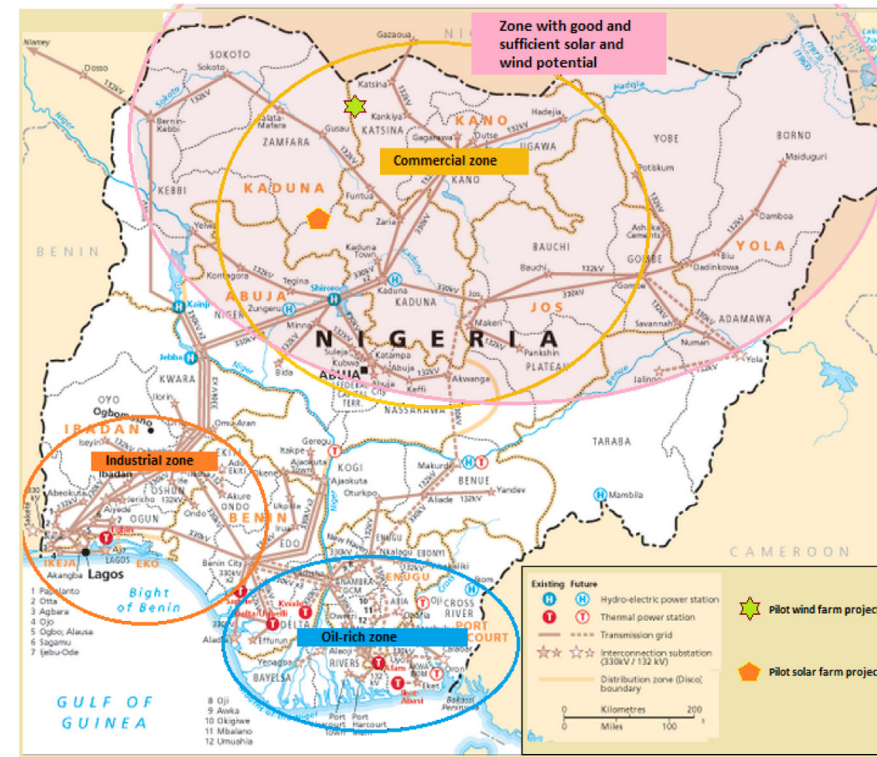


Fig. 5. Map of Nigeria showing energy resources distribution and socio-economic zones (GENI1, 2017).

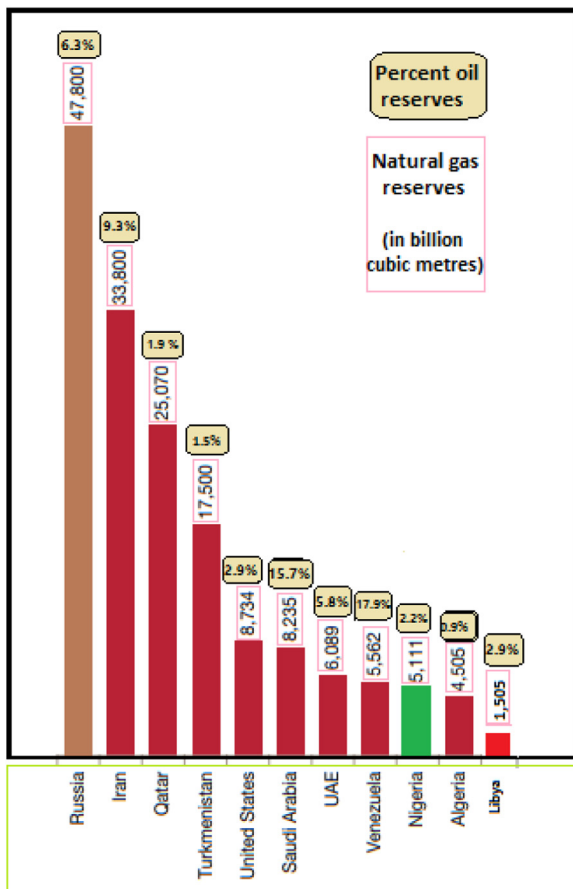


Fig. 6. OPEC proven world crude oil and natural gas reserves in 2017 (Wijeratne et al., 2016; OPEC, 2018).

is moderate potential for wind energy production in some part of the north and the coastal region of the country; with a pilot wind farm being constructed in Katsina as indicated in Fig. 5 (Oyedepo et al., 2012; Brimmo et al., 2017b). There are several other under-utilized energy resources such as coal and lignite, tar sands, small and large hydro, fuelwood, wastes from bio-agricultural produce and energy crops. The quantification and very poor utilization levels of some of the energy resources within Nigeria’s border are presented in Table 2.

3.2. Implementation status of Nigerian energy sector reform policies and effects

Another important area that needs to be analyzed in order to gain sufficient insight into the Nigerian energy industry administrative bottlenecks is the reform policies and implementation status. The vision 2020 for the Nigerian power sector as informed by the national technical group on energy is to achieve an energy sector that serves as the reliable engine for driving the nation’s pursuit for all-around sustainable growth and developments. The main focus is to ensure effective energy infrastructure management, efficient energy resource utilization and conservation, through the availability of cheap, reliable and sustainable electricity (National Technical Working Group, Federal Government of Nigeria, 2009; Wara Tita et al., 2009). Some of the short-term goals of the Nigerian energy sector reforms are the rejuvenation of the existing power system infrastructures, to encourage increased utilization of available energy resources and to promote investment on efficient energy management technologies.

Several phase-by-phase changes to the socio-political structure of the Nigerian electricity sector have been witnessed. Each of these phases is driven by some reforms and energy policies towards encouraging techno-economically efficient energy-mix, better energy facility management and effective energy industry regulations. Credible policies that have come from the Nigerian power sector reform actions with their year of formulation and

Table 2
Nigerian energy resources (Oyedepo, 2012a; Africa-EU Energy Partnership, 2015).

Resources	Quantification	Utilization characterization
Crude oil	37,062 billion barrels	22% utilization of refineries
Natural gas	182.3 trillion standard cubic foot	18% indiscriminately flared
Coal and lignite	2.7 billion tonnes	7% contribution to net GDP
Tar sands	31 billion barrels of oil equivalent	Negligible usage
Large Hydro	11,250 MW	1938 MW (17% utilized)
Small Hydro	3,500 MW	64 MW (2% utilized)
Solar	3.5–7.0 kWh/m ² /day	27% capacity factor; negligible utilization
Wind	2.0–4.0 m/s at 10 m height	Negligible utilization
Fuel wood	11 million hectares of forest	43.4 million tonnes/yr of consumption
Municipal waste	30 million tonnes/year	0.5kg/capita/day
Animal waste	1.05 tonnes/ day	Negligible utilization
Agricultural residues	91.4 million tonnes/yr. produced	Negligible utilization
Energy crop	28.2 million hectares of arable land	8.5% cultivated

re-formulations; as well as the government agencies involved are provided in [Advisory Power Team, Office of the Vice President, Federal Government of Nigeria \(2015\)](#), [Emodi and Ebele \(2016\)](#) and [Anon \(2018c\)](#). These policies cut-across all the significant levels of energy production from generation to the point of utilization. They involve both the technical and economic aspects for both the renewable and conventional energy system planning and operation. Four initial stages of energy sector reorganization are identified to enforce a competitive, efficient and private sector-driven power industry as shown in [Fig. 7](#). These stages are monitored by the Federal Ministry of Power under the direct regulation of NERC.

As of today, the major activities of the electricity sector are still carried out at the transitional electricity market stage. Some of the factors attributed to the current shortfall in effective policy implementation are poor tariff system which has led to huge cash deficits in the market, outdated metering and market monitoring structure which has contributed heavily to financial loss through illegal energy drain *etc.* ([Smart Energy International, 2017](#)). Also, some of the main challenges surrounding the implementations of all these lofty policies, as it has been the cases of other developing countries, are non-supportive political dynamics, poor rule of law and insufficient grid and market infrastructures ([Victor and Heller, 2007](#)). Poor physical and economic infrastructures have proven to be one of the most challenging areas for effective introduction of socio-economic and political reforms into the Nigerian electricity industry. The high capital cost and slow recovery/return on investment, as well as the tough regulatory and technical requirements involved, are also some of the identified bottlenecks affecting Nigeria and the whole SSA region.

To address these problems through R&D, six energy research centers have been established by the Federal Government of Nigeria in each of the six geopolitical zones to corroborate the efforts of other energy administration and management agencies towards devising sufficient structures for effective energy transition reforms and policies implementation ([Energy Commission of Nigeria, 2019](#)). However, the effectiveness of these centers of research excellence is still far from being significantly felt on the energy industry performances, so far. Reviewing the purpose of establishment of these research centers in line with the UN SDG energy goal, and providing adequate finance and monitoring, in line with their mission statements, can be a significant step towards empowering them to achieve their purpose of establishment.

4. Natural gas utilization for energy and environment sustainability in Nigeria

A crucial arm of the Nigerian energy sector which needs to be re-visited, strategically, in the nation's quest for energy sustainability and economic development, is the petroleum sector.

Gas flaring is a common issue that has contributed hugely to both economic losses and environmental degradation within the nation. Gas flaring involves the combustion of gas (including useful natural gas) in an open flame in oil production sites with no useful mechanism for harvesting useful energy. More gas is flared in Nigeria than anywhere else in the world, except Russia, due to insufficient gas markets and high cost of gas storage and transportation. On the average, roughly 2.5 billion cubic feet of produced gases from the crude oil refining process is reportedly wasted via gas flaring per year in Nigeria; this amounts to significant economic and environmental losses, ([Eboh, 2018](#)).

The effects of gas flaring on the pollution level and consequent poor living conditions of inhabitants (human and non-human) of the affected regions are detrimental. The atmosphere and aquatic life have been polluted, massively, and the available land areas are no longer suitable for agricultural processes, leading to a decline in socio-economic activities ([Fawole et al., 2019](#)). The economic and environmental impacts assessment of gas flaring in Nigeria reported in [Hassan and Kouhy \(2013\)](#) and [Anomohanran \(2012\)](#) shows that approximately 47% of the produced gases (with 18% of the total generated natural gas) is flared. In 2018 report of the Nigerian National Petroleum Corporation (NNPC), about 700 million standard cubic feet of gas was said to be being flared daily by all the oil and gas producing firms within the country; this amounts to a financial loss of about 11 billion US dollars annually. An estimated 215.9 billion standard cubic feet of natural gas was reported flared in nine months, from January to September 2018; this amounts to a total loss of about 641.22 million US dollars at \$2.97 per 1000 SCF of natural gas ([Asu, 2019](#)).

The Nigerian government can curtail the huge financial loss and environmental degradation that accompanies the process of gas flaring sufficient regulation of the gas industry ([Adekoma et al., 2016](#)). Sufficient amount of useful energy can be harvested from the flared gases by making proper investments on modern and highly efficient natural gas-fired electricity production technologies. With the recent state-of-the-art gas-driven energy technologies, adequate development of human resources and passing of the petroleum industry bill (PIB), Nigeria can rapidly be on her way to economic growth and sustainable development. Creating a competitive and lucrative market for gas sales will yield a better return on investments made on gas infrastructures, and this will encourage more interest in gas technology. Technical and economic feasibility analysis of flared gas to electricity potential in Nigeria shows that a well-regulated gas industry can help increase the daily direct electricity production by 7500 MW ([Ojjiagwo et al., 2018](#)).

The transportation Sector, just like the power sector, can also be massively transformed by efficient natural gas reclamation ([Otene et al., 2016](#)). The reclaimed natural gas reduces the greenhouse gases emission footprints when deployed for

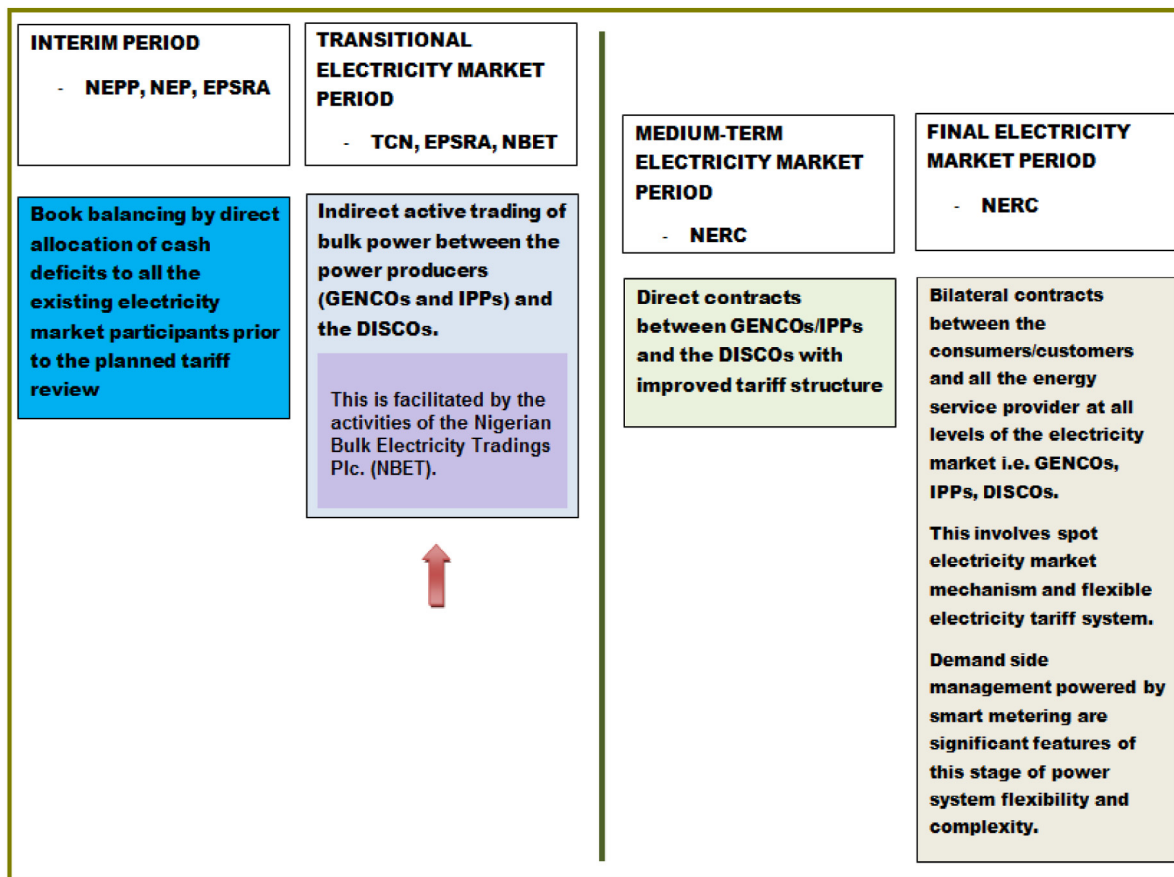


Fig. 7. Stages of Nigerian power sector reforms and the involved policies and sectors.

Table 3
Lifecycle CO₂ emission intensity (Farret and Simoes, 2006; WNA, 2011).

Primary source	CO ₂ emission (tonnes/GWh)		
	Low	High	Mean
Lignite	790	1372	1054
Coal	756	1310	888
Oil	547	935	733
Natural Gas	362	891	499
Solar PV	13	731	85
Biomass	10	101	45
Nuclear	2	130	29
Hydro	2	237	26
Wind	6	124	26

powering clean-burning and efficient natural gas-driven vehicles (Giwa et al., 2017b). There are about 12 million vehicles used for different activities in Nigeria, and most of these vehicles use fuels with high carbon contents (Alade, 2018). The lifecycle CO₂ emission content of natural gas as primary fuel compared to other energy sources and the available utilization options for clean natural gases for the Nigerian situation is illustrated in Table 3 and Fig. 8.

Fig. 9 shows the comparison between the levelized costs of natural gas-based energy system and energy technologies. The criteria for comparison are the economy of scale and the investment requirement. Except for solar PV and onshore wind, the world's investment performance of natural gas power generation infrastructure is encouraging than most of the other sources. One of the largest refineries in the world is scheduled to be in operation in Lagos, Nigeria by the end of the year 2019 and it is planned to supply natural gas that can produce about 12000 MW

of electricity daily via adequate gas to grid embedded generation planning (Hyde, 2017). With this new development, the prospect of natural gas as a means of providing viable solutions to the Nigerian energy problem has increased, tremendously. It is even more encouraging due to less legal and land right requirement, and the availability of more mature technical know-how, relatively lesser cost of operation, reduced land space requirement and low emission discharge (Sontakke, 2015). In Italy, the practice of gas flaring has reduced, significantly; this is because suitable mechanisms and enabling policies are developed to ensure that all the natural gas produced is used for electricity production at a reasonable price to the gas suppliers (Anon, 2017c).

The federal government, through the Nigerian National Petroleum Company (NNPC) and Nigeria Gas Company (NGC), has already ensured that every region of the country is connected to permanent gas supply facilities (Eboh, 2018; Anon, 2017b). The pipelines extend in hundreds of kilometers from the oil-producing regions to all other parts of the country. Most of these pipelines are underground/buried; hence they are adequately safeguarded against accidental human and natural disasters. The main challenge now is about ensuring adequate security of pipelines facilities against vandalization and theft, which are common actions of perpetrators of socio-political unrests. More investment in natural gas-based IPPs should be encouraged, and a total decentralization of the electricity market should be established. In a fully decentralized market, regional mini-grids can be supported where IPPs can have direct interaction with willing customers, through the adoption of the advanced metering system, at regulated energy prices.

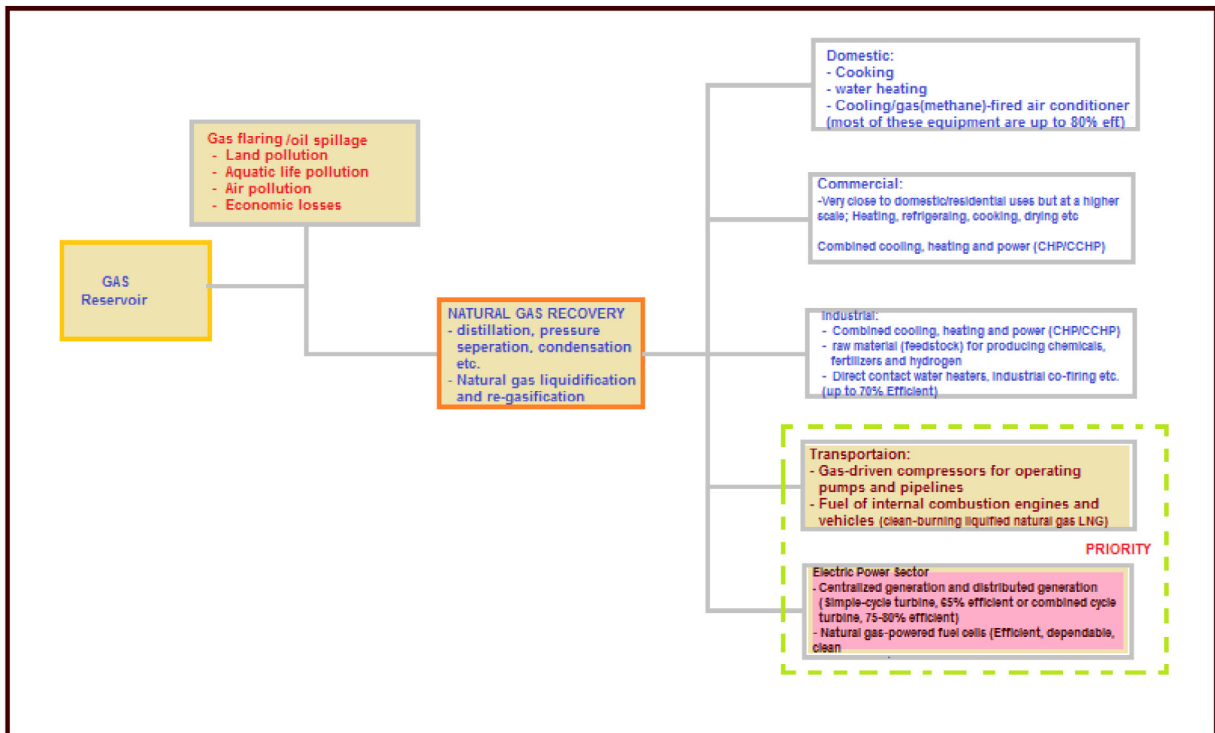


Fig. 8. Natural gas utilization options for Nigerian case.

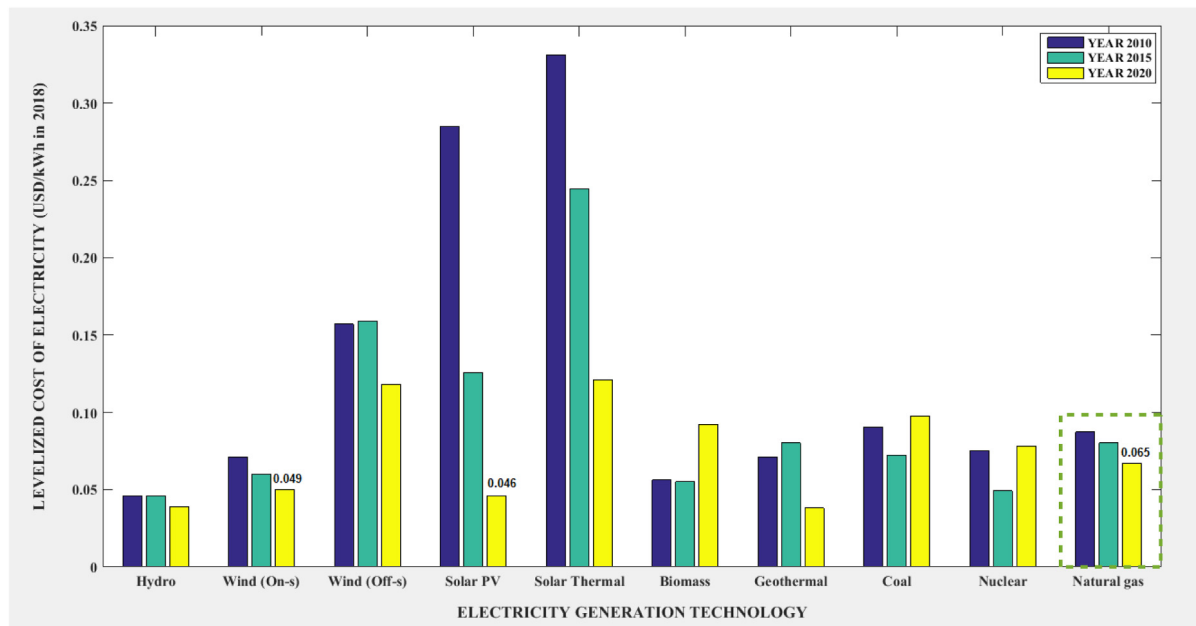


Fig. 9. Levelized cost of electricity for new generation investment (IEA, 2010; WEC, 2016; EIA, 2019).

5. Notable pathways towards achieving sustainable energy transition in Nigeria

The availability of investment capital and external aid is essential to achieving the required energy framework needed to drive the SDGs in sub-Saharan Africa. However, while the amount of required financial aid may not be readily available or may come with expensive/extreme conditions when possible, specific measures can be taken at both the non-governmental and governmental levels towards energy sustainability in Nigeria and other parts of sub-Saharan Africa. Some of the proven approaches are:

5.1. Willing socio-political disposition towards promoting sustainable energy sector

The energy transition of developed nations appears seamless, not only because of their financial strength; but it is more attributed to the enabling policy structure, favorable legislative rulings and legally established competitive yet regulated market environment. Energy democratization and sustainable energy transition across the globe are fundamentally politically motivated (Burke and Stephens, 2018). The last few years have

supported a massive decline in the share of coal in U.S. electricity generation following the environmental de-carbonization and climatic change rules. However, recently, the U.S. pulled out of the agreement terms of the Paris accord after adequately considering the socio-economic and political implications on the U.S. economy, when compared to competing economies such as China, Russia, Japan *etc.*; and at the center of their energy plan is the renewed natural gas utilization policies (Rapier, 2018). It takes a strong political will to make such a stand among conflicting opinions from all over the world. Nigeria and other developing nations can take a clue from this for it takes the willful dispositions of the political elites at the executive, legislative and judiciary arms of government to set sustainable development in motion.

Using the Indian model, achieving a smooth-paced energy transition especially for the remotely located terrain of developing countries requires a socio-political crusading that will ensure a viable and reasonably just structure for both government-owned, privately-owned and community-owned energy systems (Katre and Tozzi, 2019). One way to achieve this is by setting up a profit/benefit-oriented investment environment with favorable policies and legal documentation that will promote environmental sustainability while pursuing energy sustainability. These conditions will easily attract both local and foreign alternative energy sources investors at no outrageous financial and socio-political implications. The domestic consumers will also be encouraged to get involved in any way possible since the existing policies, and the legal framework will protect their national and individual rights and interests.

5.2. Encourage efficient design of utility-scale grid-connected VREs technology

The main problem of the deployment of VREs is intermittency; both wind and solar output are grossly unpredictable, and the level of fluctuations affects the quality and reliability of the supplied power. The energy storage technology can only support the VREs technology at a low scale of about one MW installed capacity. At any capacity above this, most of the tested and trusted storage technology becomes too large and too expensive for comfort. Hence, one adequate approach that has been deployed in developed countries and some developing countries is the large-scale VREs generation, especially solar PV, efficiently conditioned and effectively linked to the existing grid infrastructure. The grid serves as the storage, as well as a buffer for keeping the effects of intermittency minimal. Knowing fully well that the existing grid networks of developing nations are ill-conditioned and susceptible to voltage instability, additional cost for grid enhancement and intermittency effects can be considered while planning for this approach (Solar Trade Association, Aurora Energy Research, 2016). This cost is comparatively lesser compared to the cost of incorporating utility-scale storage facilities. The cost components are externally imposed on all the energy market participants based on the amounts of the variability of the output of VREs and its effects on grid stability and reliability. The essential features of these cost components are illustrated in Fig. 10.

5.3. Increase investment plan for hydroelectric power technology

As indicated in Table 2, only about 17% of the large hydro resources and about 2% of the available small hydro resources have been deployed in Nigeria. Hydropower remains one of the most reliable energy sources in terms of returns on investment, operation, and maintenance, the economy of scales, *etc.* Hence, more investment in hydro generation facilities can be of immense benefit towards achieving both energy and environment

sustainability. Pumped hydro energy storage system (PHESS) can be another way of deploying the sufficiently available hydro resources within the country. In pump hydro energy system, a reversible pump-turbine system pumps water to a reservoir located at a sufficient height from the ground level natural or artificial water dam, when the cost of energy production from either the renewable or non-renewable energy system is low. This stored water can be later deployed to retrieve electricity to the grid, by reversing pump-turbine operation, when the cost of energy production from the actual generating facilities becomes high, or their output becomes insufficient, *i.e.* at peak load demand period (Anon, 2018d). The major challenges for the deployment of both the conventional hydroelectric generation system and the PHESS are the availability of a suitable site and initial cost of construction/investment cost. There are credible sites and high/elevated lands for setting up the PHESS facility, but adequate geographical, hydrological, geological, and topographical surveys and mappings of the suspected regions within the country need to be carried out. The world's largest share of extensive scale energy storage facilities is currently the PHESS due to its low running cost. It now accounts for over 90 percent of storage for massive wind and solar energy deployment and about 530,000 possible PHESS sites, amounting to 22 million GWh energy storage capacity has been identified using the geographical information system (GIS) based mapping infrastructure (AREMI) developed by the Australian Renewable Energy Agency (Anon, 2019a). A preliminary site viability analysis for Nigeria shows several sites for PHESS capacity as low as 2 GWh and as high as 150 GWh as illustrated in Fig. 11. However, other factors such as the geology, hydrology, environmental impact, commercial feasibility and land right-of-way *etc.* needs to be succinctly considered.

5.4. Energy resource management and energy supply conservation

Energy resource management involves putting the available energy resources into best uses. Most times, these available energy bearers are overlooked and allowed to waste and often constitute environmental nuisances. A credible model for energy resource management is the gas-to-grid model that has been discussed extensively in the previous section. The success story of Italy as earlier explained and other developed countries is a model that can be adopted towards achieving the sustainable environment and energy goals. Different aspects of energy resource management such as the deployment of efficient waste-to-energy models for the disposal of agricultural and some non-toxic/organic biological wastes from domestic and industrial wastes are worth considering. The University of Nigeria Nsukka has championed this course through the recently installed 100 kVA refuse-derived fuel (RDF) gasification power plant on their main campus (Anon, 2019b). This action inspires a credible achievement by all standard for a country like Nigeria; more of this type of projects are desired from all the energy research institutes within the country, as the country looks forward to the right pathways to the sustainability of energy and environment.

Energy conservation is concerned with getting the maximum benefits from the available energy production through curtailment of wastage and rational uses of dispatched energy (Askari et al., 2015). Centers of research excellence such as the NCEEC and the NCEE are expected to take up responsibilities for developing strategies for energy conservation and providing adequate public sensitization on the importance, the arts and the acts of energy conservation and management. To sufficiently achieve this in Nigeria and the entire SSA region, cutting edge technologies for advanced energy auditing, monitoring and metering are to be invested upon by the energy industry. By so doing,

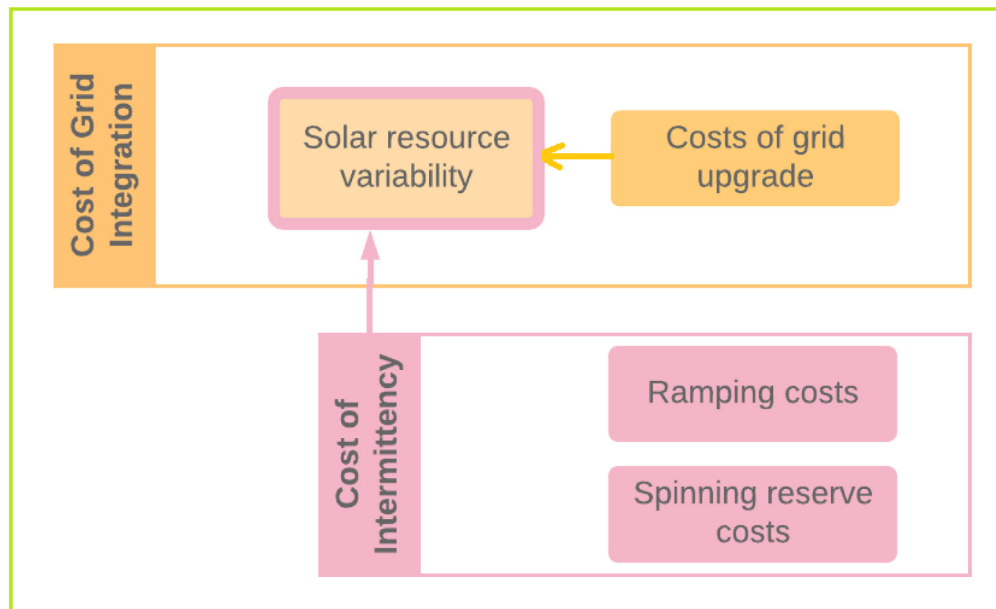


Fig. 10. Additional costs for grid-connected utility-scale VREs (Adewuyi et al., 2019a).

small and medium-scale private energy production through distributed generation (DG) approach, net-zero energy building design and demand-side management (DSM) through consumer demand profile inducement can be deployed, using systematic methods, like in other parts of the world. The proposed regional electricity grid, such as the West African Power Pool (WAPP) can help countries within this region to leverage their collective strength towards accessible, quality and cheap, sustainable energy infrastructure.

6. Profiting from the energy transition experiences of other developing nations

6.1. China energy transition and the role of Demand-Side Management (DSM)

China's path to sustainable economic growth has been extraordinary, yet complex. A few decades ago, the most populated country in the world happened to be in abject economic condition and central to this situation was the problem of the dysfunctional energy sector. However, since the turn of the 1980s, there has been some remarkable achievement in the Chinese energy sector which has tremendously improved the general standard of living in Chinese communities and has specifically lifted millions of people out of the poverty zones (Finamore et al., 2003). The Chinese energy sector reforms are directed majorly towards encouraging safe, efficient, and reliable power supply in short-term, promote a sustainable environment in medium-term and secure the long-term development goals of the power industry; which are to satisfy the present national needs without compromising the security of the future. The current electrification rate for China as reported in the database on countries electricity access in percentage of total population is 100 percent for the year 2016 (THE WORLD BANK, 2019). This remarkable achievement in the energy sector has inspired a tremendous growth of the Chinese economy which currently ranked second globally after the U.S., however with a better GDP growth rate (United Nations, 2018). Hence, China is on the verge of surpassing her specific 2050 target of becoming a medium-developed economy (Finamore et al., 2003) through some well-documented strategies

for sustainable development among which is the Demand-side (load-side) management (DSM).

Several additions were made to the generation facilities to meet the short term goal of the Chinese energy sector reforms most of which are conventional fossil fuel-based such as coal and nuclear. The hydropower, pump hydro storage system, and renewable energy technologies are credible features of this supply (generation) side management. However, the contributions of the fossil-fuel based generation remain remarkably high and unacceptable, especially with the increasing concerns for climate change and greenhouse gases (GHG) mitigation globally. Hence, for achieving the common goal of environmental sustainability and the future goal of a sustainable energy industry that complies with the world standard, the Chinese government made urgent calls for credible efforts to implement demand side management (DSM) and other supporting measures which can promote moderate energy consumption, energy management, and energy conservation. The target of DSM policies towards effective supply-side management is specifically to reduce the energy consumption rate per unit of GDP of a nation (Brophy Haney et al., 2010). Central to achieving this target is the numerous demand response (DR) programs that influence consumers demand pattern to promote energy conservation and efficiency right from the utilization level to the generation level as illustrated in Fig. 12 (Shigenobu et al., 2017; Valdes et al., 2019).

In the face of the new global energy challenges, the energy transition of China has not been easy when compared to other world powers like the U.S., Germany, and Japan. Due to numerous technical and social-economic infrastructural challenges, the successful adoption of demand-side management (DSM) and demand response (DR) programs in China took a while to achieve (Finamore et al., 2003). Some of the initial and current barriers to the effective implementation of DSM in China are; poor power infrastructures which cannot support the technological sophistication required for DSM, unavailable (or grossly insufficient) sustainable mechanism to fund DSM, lack of supportive market structure which promotes right incentives and unbiased gains for both the utilities and the consumer. The Chinese energy transition challenges as mentioned earlier are synonymous to the current challenges of Nigeria and the entire SSA region. To overcome some of these challenges, one of the

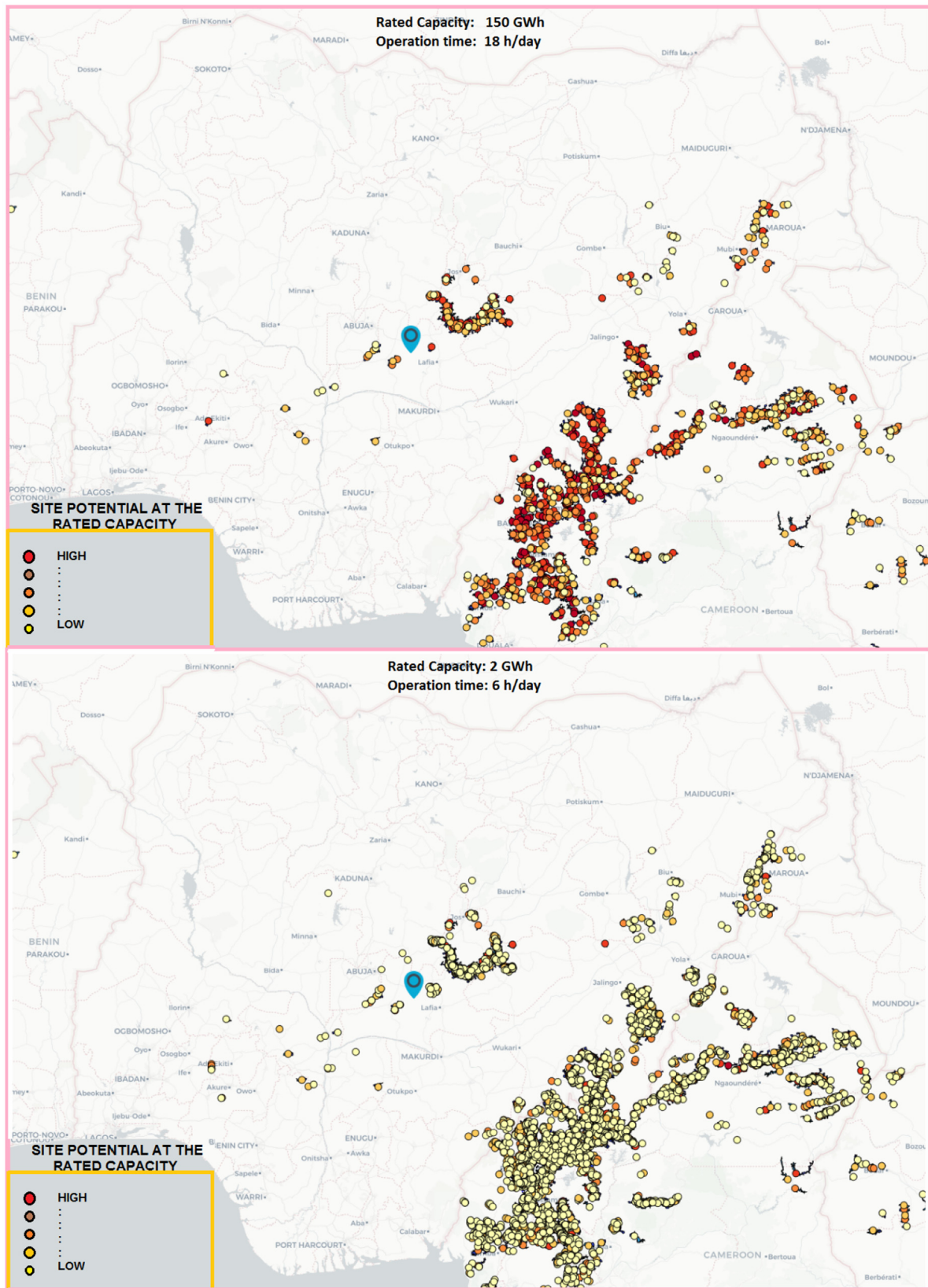


Fig. 11. Potential PHESS sites in Nigeria for different storage capacities.

first step to be taken by China is the electric power industry restructuring. Many developed countries generated a restructuring model that suits their particular situation and what has given

China a remarkable success in her power industry restructuring success is linked, directly, to their ability to learn valuable lessons from both the positive and the negative experiences of other

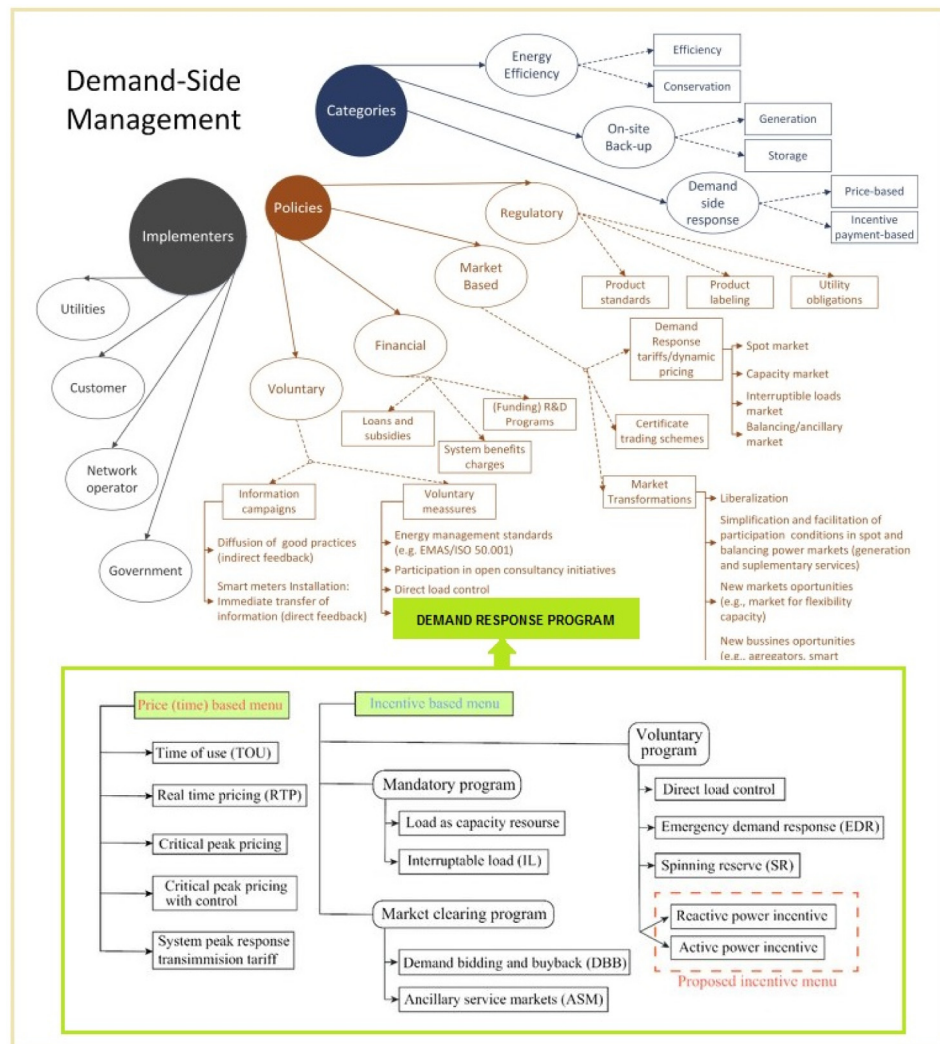


Fig. 12. DSM/DR programs and their features (Shigenobu et al., 2017; Valdes et al., 2019).

front runner countries. With this approach in mind, China was able to develop a DSM model that suits China's socio-economic situation (Victor and Heller, 2007; Finamore et al., 2003). Two essential features of these models that Nigeria and other SSA countries can benefit from are:

- i. The proliferation of VREs and PHESS to limit the inevitable shares of power from coal and nuclear sources. With this approach, reliability and adequacy of the supplied power supply can be guaranteed while the amount of GHG emission is kept under control.
- ii. The development of mutually beneficial energy tariff (rate) which is responsive to the electricity market and other socio-economic dynamics. The main targets of this new energy tariff system are to guarantee a ready market for the produced power in such a way that the utility profits and the consumers are well-served (Finamore et al., 2003). Hence, DSM funding policies that can promote sufficient benefit charges for customers' strict adherence and adequate rate of investment recovery for energy investors based on their performance/quality of service delivery are formulated.

Some of the lessons that Nigeria as well as other developing countries can learn from China's successful DSM models and implementation are:

- i. Well-thought-out DSM plans that are based on the specificity of the energy resource profiles of the concerned nation through efficient hybridization of suitable energy technologies. This step will reduce energy importation and increase local energy productivity.
- ii. Carefully formed national DSM programs can also lead to a rapid increase in local R&D activities which can promote the design of more efficient, economic and environmental-friendly energy technologies.
- iii. Also, the net energy efficiency of the whole nation can be improved through adequate compliance with strategically implemented and regulated DR policies. Some of the successful action policies in China and other countries involves effective energy auditing mechanism by defining the minimum energy efficiency level for appliances, efficient standardization of electrical appliances, financial support to the citizen to purchase energy efficient appliances at subsidized prices, mandatory monitoring of building construction to ensure a bottom-up policy compliance approach *etc.*

6.2. The significance of US-Indian collaboration for sustainable energy development

India provides a good model for effective collaboration for a developing nation like Nigeria to emulate on her path to sustainable development. Indian energy consumption is ranked fourth globally, and the contribution to the world's carbon dioxide emission is ranked third. Hence, Quite a significant number of action plans that revolves around well-coordinated national and international collaboration are pursued, currently, in India. With electricity access rate of 82% of the total population, about 400 million of the people in India are still without electricity (Anon, 2018e); hence Indian quest for energy sustainability is being addressed as a matter of national urgency. Indian green energy capacity is on a tremendous rise due to the set of policies and market environment that has been created by the government; and at the moment, both on-site/distributed generation and large-scale off-grid community-owned generation using VREs and biofuels are encouraged.

The government sector that is in charge of alternative energy integration in India has embarked on ambitious national energy rescue missions which are targeted, mainly, at attracting massive foreign investment and collaboration opportunities which will boost local economy even to the remotest places (Luthra, 2014). The success of these efforts is attributed, significantly, to government-to-government cooperation like the existing US-India collaboration and public-private partnerships such as the community-owned mini-grids that are now taking roots all over the nation. One of the notable features of the U.S.-India collaboration on the issues of energy sustainability is the U.S.-India Energy Cooperation; this led to the design of Partnership to Advance Clean Energy (PACE) which is joint energy submit alternatively host by each of the countries every year since 2009 (Mishra and Babu, 2014). PACE projects are jointly financed by the two countries to facilitates both R&D in the area of alternative energy generations.

Some of the projects are to develop models for affordability, reliability and quality of service delivery. One prominent feature of this bilateral relationship is the assessment of the environment-friendliness of using natural gas technology to build resiliency into the Indian energy market with the plan of increasing the adequacy and reliability. The U.S. has natural gas in abundance, and a mutually beneficial agreement is reached between the two countries to encourage the importation of natural gas from the U.S. to help India energy security. Other areas of PACE R&D focus are energy efficiency in buildings, production of next-generation clean-burning biofuels, support for sustainable policy development, managerial and technical capacity building and financing of innovative pilot projects. If the Nigerian government can show a willing attitude and set credible socio-political actions in motion, this type of mutually profiting bilateral collaboration with other countries can suffice in her quest to meet the UN SDG year 2030 target.

6.3. Government strategic actions for Egypt energy sustainability

The sustainable energy transition model of Egypt remains a front runner in the whole of the African continent. The most populous country in the North African sub-region has proven that extraordinary performances do not necessary involves doing something that is outrightly unheard of before. The Egyptian government has excelled by taking seemingly simple actions with an extra level of sheer determination and accountability. An energy diversification approach was adopted and fully backed by the Egyptian government to promotes more VREs in the nation's energy framework towards reliability and environmental

sustainability (IRENA, 2018). The Integrated Sustainable Energy Strategy (ISES) contains the Egyptian government blueprint towards achieving a diversified and buoyant energy sector come 2035; two main features of ISES are the massive development of the renewable energy markets and strategic rehabilitation of the existing grid infrastructures. The target is that the total VREs contributions should increase from the recent 7% to 20% by 2022 and 42% by 2035. The planned stepwise increment in renewable energy penetration is to be supported by vigorous enhancement of the grid to avoid energy wastage.

True to this target, the Egyptian government embarked on the upgrade of plans and policies to strategically promotes the ISES goals; and remarkable progress has been witnessed within a short period. Recently, Egypt emerged as one of the top twenty countries with virile sustainable energy transition mechanism through the efforts of the government-run New and Renewable Energy Authority (NREA) (Tawfeek, 2017). NREA has ensured an unprecedented investment on clean energy technologies starting from the year 2016 and has also ensured an improved policy framework which gives a better investment environment for both local and foreign energy investors. The deployment of grid-connected solar energy in Egypt is projected to reach a massive 1.8 GW capacity by the middle of the year 2019 through the Benban PV complex and several other solar projects. The government has embraced the feed-in-tariff (FIT) system and the net energy billing system to encourage private rooftop solar PV generation (Bellini, 2019). Much of this generation is expected to be by concentrated solar power (CSP) technologies at the initial stage; with a significant focus on wind generation in the nearest future. Some of the simple, yet crucial, steps that were taken by the Egyptian government towards ensuring an effective achievement of the ISES goals are (IRENA, 2018; salem, 2017):

- i. Uncomplicated land allocation and right-of-way permits
- ii. Environmental impacts, technical Viability and financial feasibility assessments report made available to willing investors and the general public to encourage a vibrant domestic energy industry
- iii. Reduced custom duties on importations for energy projects and governmental guarantees on financial and legal issues
- iv. Supportive reforms on electricity market framework and providing updates based on the changing electricity market dynamics

These simple yet proven strategies can be modified based on the Nigerian situation and adopted by the Nigerian government backed up with unwavering determination and staunch political will.

6.4. Kenya remarkable path to energy and socio-economic sustainability

Just like Egypt, Kenya has also made some bold steps in the quest for sustainable energy development among African countries. Currently, its electricity access rate now stands at above 73% from the 56% reported in 2016 (Njugunah, 2018). For a population of about 49.7 million, Kenya rate of access to electricity is ranked highest in East Africa; and it is judged to be the most remarkable within in SSA (Power Africa, 2015). The reason for this success rate is attributed to the Kenyan government planned, determined and shown committed efforts in attracting investment interests for both the off-grid and grid-connected alternative energy technologies. The national electricity generation installed capacity for Kenya now stands at about 2,700 MW; and this is predominantly from renewable energy technologies, including the seasonally varying hydropower sources (Republic of Kenya, 2018).

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