Renewable Energy: Deployment and the Roles of Energy Storage

S. O. Masebinu, E. T. Akinlabi, E. Muzenda, and A. O. Aboyade

Abstract— **Hydro energy still remains the highest RE contributor to electricity generation globally, nevertheless, trends in solar and wind energy has shown increasing investment in RE. Though a decline in investment was observed between 2012 and 2013, yet investment in RE exceeded that of non-RE in the excess of $80 billion dollar. In 2014, investment increased by 16%. As developed countries get saturated with RE technologies, developing countries are now the focus for investment. Wistfully, path dependency problem, lack of adequate infrastructure and policy framework have been highlighted as the major barrier to RE deployment in developing countries. Also, lack of harmonised government agency for RE implementation, incentives and educational gap are the institutional and social barriers. Energy Storage (ES) is being promoted as the "game changer" with capability of smoothening the variability associated with two RE technologies, wind and solar, with the highest deployment rate. Recent developments are indicative of cost reduction for ES. This paper therefore presents a concise and holistic review of renewable energy (RE) technologies for electricity generation and assess the roles of ES in mitigating intermittency associated with their generation profile.**

Index Terms— ***Energy Storage, Environment, Renewable Energy, and Sustainability***

I. INTRODUCTION

Energy plays a significant role in the economic, environmental and social dimensions of sustainable development. The interdependence of the three dimensions on energy has created a challenge of appropriate energy choice that will facilitate their simultaneous integrated development. Approximately, one-third of the over 7.2 billion people in the world lack access to clean energy while 15% do not have access to electricity [1-4]. There is a positive correlation between electricity access and human development index [5]. Access to electricity is measured by consumption per capita which is currently less than 2 kW/capita for more than 50% of the population in developing countries [2, 3]. Despite the low access in developing countries, energy demand has been increasing at an annual rate of 1.9% and is projected to reach 202,000 TWh by 2030 and electricity demand to reach 30,120 TWh by 2030 [3, 6]. As demand increases, if fossil fuel is used to satisfy demand, greenhouse gas (GHG) emission would amount to 40 Gt by 2030 [6, 7]. To satisfy the unserved population, the focus of global sustainability can only look towards environmentally friendly and low carbon energy resources. The challenge of satisfying the future energy demand of developing countries, especially in the electricity sector, should either expand the sources of current energy resources or allow for efficient use of the limited fossil fuel reserves [8]. According to BP [9], the world coal, natural gas reserves and oil, all fossil fuels which account for about 80% of primary energy, will last 113, 55 and 53 years respectively. However, these resources could be depleted sooner in the 21st century with increasing energy demand. The limiting reserve and negative environmental impact leading to global warming are the two major threats to the continued use of fossil fuels [10, 11]. In an effort to reduce the anthropogenic effects of fossil fuel, provide suitable energy mix and create a sustainable energy supply, different policies, protocols and strategies have been implemented with major emphasis being on increasing the penetration of renewable energy (RE) in satisfying energy demand [12-15]. For instance, Denmark is pursuing a 100% RE agenda for her energy demand, Germany has set an 80% target by 2050, California, USA will have 20% RE sourced energy within her grid by 2017, 15% by 2020 in China while in many other countries, increasing the share of RE is before the legislators [16, 17]. From several case studies, it is indicative that RE sources could contribute a major share of global electricity generation [16]. However, converting and integrating RE sources into existing electricity grid remains a challenge due to their intermittent nature caused by changes in climatic and meteorological conditions [17, 18]. Experiences from countries with higher share of intermittent RE sources within their power grid have indicated clearly the challenges associated with RE integration [16]. Therefore, a multi-dimensional integration approach of increasing the flexibility of existing energy systems and the contribution of RE sources into the energy grid, is needed. Increasing energy system flexibility for RE integration and useful energy extract from RE sources can be achieved

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through strengthening of the power grid for electricity generation, integration of energy storage (ES) systems into the grid, and through time based modification of demand to available energy [16, 19-23].

According to Carvalho, et al. [24], the strength of a decarbonised energy system premises around the integration and advancement in RE, ES, smart grids, energy efficiency, hybrid electric/hydrogen powered vehicles, and green building construction. The integrated optimal functionality of these major future sustainable energy elements, hinges on energy management and ES systems [25]. Energy management provides the framework for optimised system operation for all elements within the grid, thus meeting their objective function. ES system smoothens the stochastic nature of RE especially wind and solar, increase the reliability of micro grids, plays a major role in the development of hybrid vehicles and serves as an energy conservation system in green buildings [26]. Hall and Bain [26] concluded that "*ES is very much the key to unlocking the door of RE*". Towards understanding the role of ES for RE integration, this paper presents a concise review of RE, the recent trends and challenges. Also highlighted, are the benefits of ES towards RE increased deployment rate.

II. RENEWABLE ENERGY

RE are those energy resources with a replenishment rate that exceed utilization due to natural and persistent flow of their energy sources alongside their interaction with the environment [27]. The integration and utilization of RE resources have been the main focus in search of a sustainable energy future, although, alternative energy sources, that are not necessarily renewable but are clean, have been integrated into existing energy systems [1]. The availability of RE resources varies for different locations, therefore, an integrated energy system is preferred as a more robust approach over a single RE based system for satisfying global energy demand [28]. Also, high capital cost and low system reliability are associated with a single based RE sourced technology [28].

Geothermal, gravitational and solar energy are the ultimate sources of all current forms of useful RE [11]. Their cumulative annual energy supply, with solar energy having 3,900,000 EJ, gravitational 94 EJ and geothermal 996 EJ [11], exceed future global energy demand. Other forms of RE resource and their carriers are from the natural, direct or indirect conversion of aforementioned RE sources. Within the scope of this article, only established RE resources that are largely available, harvestable and converted into useful energy for electricity will be discussed. They mainly include: biomass; geothermal; hydro; solar; and wind energy. The availability and suitability of these resources are dependent on the meteorological and geographic conditions [17, 18]. Based on geographical conditions, solar photovoltaic will be suitable for terrains and built-up areas with less shading, costal lines and high wind flow regions for wind energy, biomass energy for forest remote areas, municipal solid waste (MSW) for urban areas, and hydro power will be best suited to water logged hilly regions while the meteorological conditions determine the derivable energy from the locations [28].

A. BIOMASS ENERGY

Biomass are organic materials, excluding those buried in geological formations that has been converted into fossil fuels, derived from living or recently living biological origin of plants, humans, animals and aquatic organisms through the photosynthetic conversion of solar energy [29]. Biomass, thermodynamically could be considered as a thermal engine which naturally receive solar energy, convert it and function as an ES medium in the form of chemical energy [30]. The efficiency of solar energy conversion process by biomass is between 0.1-1.5% [30]. The conversion and utilization processes depend on the state, type of fuel needed and the composition of the substrate, but generally, thermal, biological and mechanical conversion processes are applied [31]. The thermal conversion processes, which are very fast in converting biomass include: combustion; co-firing; gasification; liquefaction; and pyrolysis [31]. Biological processes which are relatively slow include; hydrolysis; fermentation; and anaerobic digestion. The mechanical process involves pressurised extraction [31]. Detailed review of biomass conversion into energy can be found in the literatures [31-37]. The conversion processes produce heat, liquid and gaseous fuels which can be applied to all applications designed for fossil fuel except for nuclear power plant [38]. The energy density for biomass is low, ranges between 15-20 MJ/kg compared to coal 27-32 MJ/kg and crude oil 42-55 MJ/kg [38]. The low energy density impacts on the volume to mass ratio of biomass needed to achieve equivalent energy of other fuels and invariably land associated cost, storage, transportation, and processing cost [38]. For a biomass based energy system to compete economically with a fossil fuel system, efficient conversion technology must be selected [31]. Optimal process conditions, equipment, configuration and decision on the scale of plants is also required [31]. The cost distribution of a standalone biomass electricity generating system is presented in Figure -1. The average reported cost estimate for a standalone biomass electricity generation plant is about 4,226 $/kW with -25% to 50% cost variation while for a co-firing plant, it is about 1,092 $/kW with a -50% to +20% cost variation [39]. From reported installed projects, the levelized cost of electricity (LCOE) for various process routes for electricity generation from biomass ranges on average between 0.034-0.210 $/kWh as shown in *TABLE -1* [40].

TABLE -1 AVERAGE CAPEX, OPEX AND LCOE FOR BIOMASS PROCESS ROUTES FOR ELECTRICITY GENERATION

Process route	CAPEX ($m/MW)	OPEX ($/MW-yr)	Capacity factor (%)	Conversion eff. (%)	LCOE ($/MWh)
Incineration	0.83-5.40	27,657-200,000	50-80	25-35	50-200
Landfill gas	1.43-2.47	90,000-266,667	60-90	25-40	34-95
MSW	2.90-7.70	90,000-200,000	25-80	25-35	80-210
Gasification	3.60-6.40	90,000-200,000	40-80	30-40	50-140

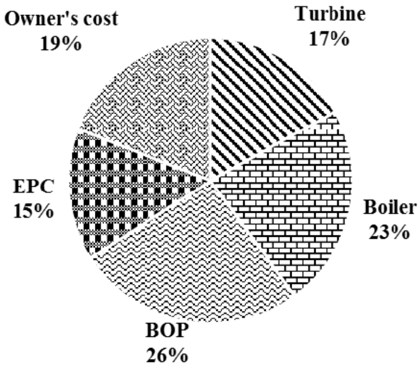

Figure -1 Stand-alone biomass capital cost distribution

B. *Geothermal Energy*

Geothermal energy uses the natural heat generated by friction caused by the sliding action of earth's continental plate and decay of radioactive elements within the earth's interior for electricity generation, district heating or as a source of thermal energy for heat pumps [29, 41]. The heat generated is transferred firstly by conduction through rocks and lastly by convection through geothermal fluids, mostly rain water [42]. Geothermal temperature increases by 25-30 °C per km of depth, hence, increasing the temperature of earth's layers is a function of depth [29, 42]. Due to the temperature difference caused by depth, there is always a continuous flow of heat towards the earth's surface. The fluid that flows out of the earth's crust is a characteristic of the geothermal resource within the earth crust [30]. The fluid serves as a guide to the type and components of the thermal plant to be built. Geothermal resources are generally classified as; dry steam; liquid water; geo-pressured; and hot dry rock [30]. Dry steam is the most desirable because of higher exergy, however, it is limited and most known resources have been used [30]. Geo-pressured and hot dry rock are abundantly available with reported economic viability for electricity generation, though at lower temperature [43]. The working principles of geothermal plant varies, but they all use heat from the earth crust to produce steam, power a turbine and generate electricity [44]. Geothermal plants advantages over other renewable energy sources are; it is a non-intermittent source; unaffected by changes in climatic conditions; a base power with a capacity factor above 90%; less land area between 18-74 km^2/TWh is required; short construction period between 3-5 years as compared to hydro power; and higher thermal efficiency [45]. Despite the advancement and benefits of geothermal energy, it is the least installed RE in the last five years with only 3.2% growth rate [45]. Emission of CO_2, almost 85% in volume and weight of gas emitted, H_2S, NH_3, N_2, H_2 and CH_4, all generally termed non-condensible gases from a geothermal plant, are serious threats to the environment when emitted [42]. High capital cost is associated with the construction of geothermal plants as shown in TABLE -2 [40]. *Figure -2* and Figure -3 show cost component distribution with well drilling taking up more than 25% of the capital cost [39]. With the associated high capital cost, but relatively low operation and maintenance cost, the LCOE for geothermal plant is between 0.02-0.10 $/kWh [42, 45].

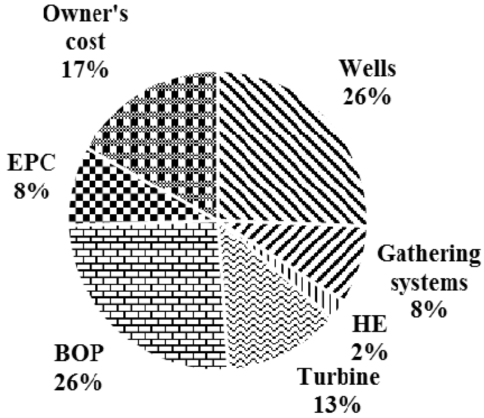

Figure -2 Cost distribution for hydrothermal type of geothermal plant

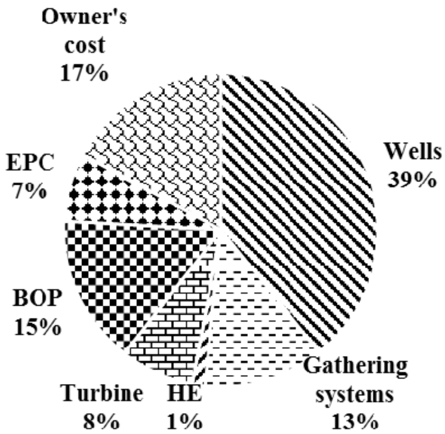

Figure -3 Cost distribution for enhanced type geothermal plant

TABLE -2 AVERAGE CAPEX, OPEX AND LCOE FOR GEOTHERMAL POWER PLANT

Process route	CAPEX ($m/MW)	OPEX ($/MW-yr)	Capacity factor (%)	LCOE ($/MWh)
Hydrothermal	2-6.07	95,687-213,701	85-95	89-276
Enhanced	1.08-6	99,553-261,891	60-95	39-181

C. *Hydro Energy*

Hydro energy is produced by extracting the kinetic energy of a moving water body under gravity to drive a turbine. For electricity to be generated using hydro energy, there must be a water head at some considerable height above the sea level. Hydro energy account for approximately 20% of global energy production, making it the most widely installed RE [46]. A general rule of thumb for hydro energy estimation is a dam with a 1 km diameter, having a depth of 25 m and a 200 m average head would store sufficient water to generate 10,000 MWh of energy [47]. These requirements can be provided by nature, though a major limitation in its wide scale implementation all over the world, or can be artificially provided through the construction of dams but this adds to the capital cost of construction [48]. The average CAPEX, OPEX and LCOE are presented in TABLE -3 [40] while Figure -4 shows cost component distribution for pumped hydro storage [39].

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TABLE -3 AVERAGE CAPEX, OPEX AND LCOE FOR PUMPED HYDRO STORAGE

Scale	CAPEX (million $/MW)	OPEX ($/MW-yr)	Capacity factor (%)	LCOE ($/MWh)
Small hydro <10 MW	1.4-3.68	15,002-85,000	23-80	19-314
Large hydro >10 MW	1.59-4.15	20000-62000	20-75	24-302

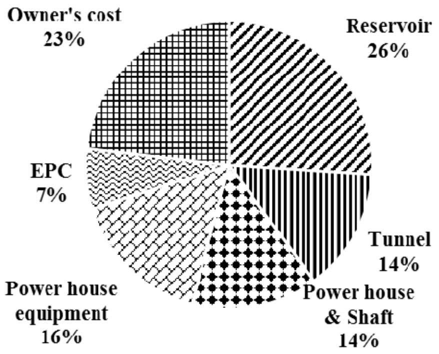

Figure -4 Cost component distribution for pumped hydro storage

D. Solar Energy

The sun is the ultimate source of almost all other forms of energy. It provides the temperature difference that aid the circulation of wind and ocean current globally, facilitate the evaporation and condensation cycle of water that creates water bodies and it's the sole driver of the photosynthesis in biological processes [49]. On a yearly average, the earth receives 120,000 TW of solar energy [50]. It is predicted that if 1% solar irradiance at the earth's surface is converted into storable energy with 10% efficiency, it would provide a resource base of 105 TW that is several times more than year 2050 estimated global energy demand [49]. Whereas, the amount of energy that could be extracted in the same year 2050 from wind, tides, biomass and geothermal would be 2-4 TW, 2-3 TW, 5-7 TW and 3-6 TW respectively [51]. The mean solar irradiance at normal incidence outside the atmosphere is 1,360 W/m^2, however, only about 200 W/m^2 is readily available for collection on earth surface [50]. This solar irradiance can be captured as excited electron-hole in semiconductors and converted by photovoltaic (PV) cells into electricity [50]. Natural capture through photosynthesis, thermal capture and solar synthesis for generation of heat, electricity and fuels are also possible [49]. All energy and fuel produced from the capture and conversion of solar energy are the storage media of the energy which can be reused during low irradiation intensity period [49]. Therefore, an efficient ES technology is required for optimal exploitation of solar irradiation energy. With ES, higher efficiency is achieved within the process, but it's impact on the capital cost as shown in TABLE -4 [40]. The cost component distribution varies and is highly dependent on the technology type, capacity and system efficiency, but generally, *Figure -5*, *Figure -6*, and *Figure -7* present an average estimate cost distribution for solar pv, trough based thermal plant and heliostat solar thermal power plant [39].

TABLE -4 AVERAGE CAPEX, OPEX AND LCOE FOR SOLAR IRRADIATION ENERGY GENERATION ROUTES

Technology	CAPEX (m $/MW)	OPEX ($/MW-yr)	%Capacity factor	LCOE ($/MWh)
PV w/o tracking	1.45-2.66	11,063-60,000	11-21	79-439
PV with tracking	2.37-6.21	40,050-126,450	16-29	90-449
Solar thermal trough w/o storage	3.08-7.67	44,000-63,340	24-28	123-490
Solar thermal trough with storage	6-10.96	61,574-63,700	28-42	156-469
Solar thermal heliostat w/o storage	4.08-6.12	64,714-68,265	21-32	167-399
Solar thermal heliostat with storage	6-8.66	70,403-117,313	42-64	105-317

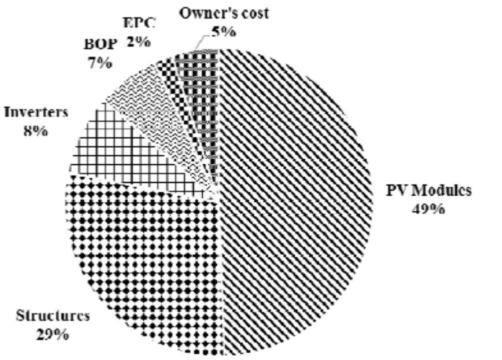

Figure -5 Cost distribution for solar PV power plant

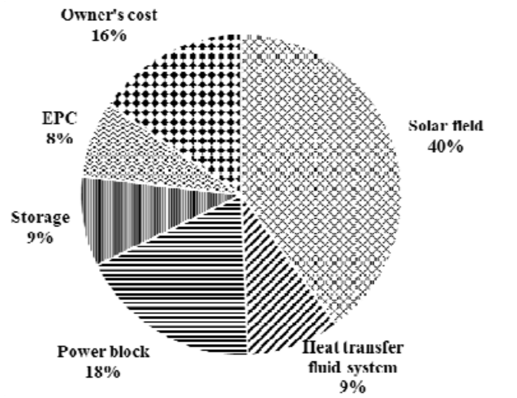

Figure -6 Cost distribution for solar thermal trough power plant

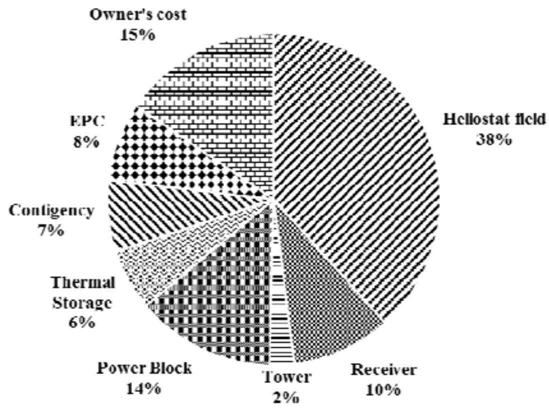

Figure -7 Cost distribution for solar thermal heliostat power plant

A. Wind Energy

Wind is formed by the kinetic movement of the earth about its axis and the heat from the sun that causes temperature rise. The kinetic energy of wind is extracted by well-defined structural vanes of aerodynamic machines called wind turbines to rotate a generator for electricity generation [48, 52]. The wind turbine consists of blades, rotor, gearbox, generator, nacelle, power converter, tower and transformer [53]. The three bladed horizontal axis rotor turbine is the most installed design due to its cost effectiveness and high efficiency [53]. The minimum average wind speed of 6 m/s is required for utility scaled power plants, though energy capture starts at 3 m/s and wind turbines can withstand speeds above 60 m/s [53]. Onshore and offshore sites are possible installation locations for wind turbine with the offshore site closer to the sea, having higher wind speed and electricity potential [53]. The turbine components make up more than 40% of the CAPEX as shown in Figure -8 [39]. The average CAPEX, OPEX and LCOE for onshore and offshore wind turbine installation is as presented in TABLE -5 [40].

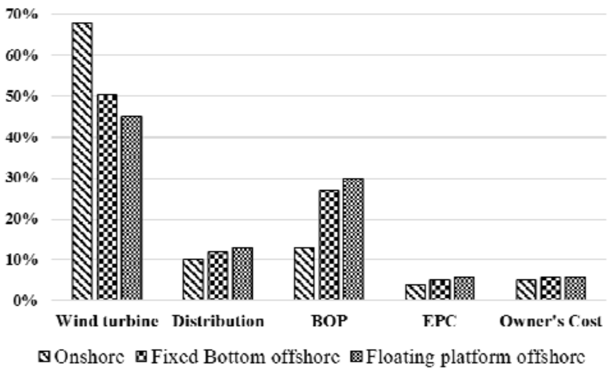

Figure -8 Component cost distribution for wind power plant

TABLE -5 AVERAGE CAPEX, OPEX AND LCOE FOR WIND POWER PLANT

Turbine location	CAPEX (million $/MW)	OPEX ($/MW-yr)	Capacity factor (%)	LCOE ($/MWh)
On-shore	1.08-2.45	10,694-28,750	15-31	47-107
Off-shore	4.29-6.08	100,000-160,000	32-42	147-367

III. Global Trends in Renewable Energy Deployment/Adoption

In 2013, 19.1% of final energy consumption was contributed by RE sources [54]. RE sources, including hydropower, contributed 22.8% to global electricity generation in 2014. Net investment in RE technologies has consistently being increasing [4, 55]. However, between 2012 and 2013, there was a decline in investment which was mainly attributed to uncertainties in supporting policies by major proponents the US and Europe [4, 54, 55]. For instance, the European Union (EU) debt crisis accompanied by tough austerity measures lead to back-cutting of funds for RE [56]. Also the boom of fracking in the US made gas fired turbine cost-effective leading to support for RE being ebbed [56]. Notwithstanding, investment rebounded in 2014 by 16% as shown in Figure -9 which excluded investment in hydropower greater than 50 MW [4, 54, 55]. The decline in RE investment, which exceeded investment in non-RE technologies in excess of $80 billion in 2012, forced a reduction in technology cost [54]. This reflected in about 38% increased installed capacity for Solar PV in 2013 as shown in Figure -10 [40, 54]. Also, technology cost reduction has been attributed to improved manufacturing processes with high production rate, increasing technological efficiency, and technology learning [4, 53]. In 2012, global installed capacity for wind energy reached 246 GW [40]. In Denmark, the penetration level of wind power has reached 24% as of 2010 while in Germany wind power generation will reach 60% by 2020 [17, 57]. Aside wind, various solar PV module technologies increased in system efficiency by a cumulative average of 4.8% between 2003 and 2013 while the unit power cost reduced between 2008 and 2013 by 78% on average to 1.22 $/kW as shown in *Figure -11* [58]. Due to the increasing penetration of RE technologies into the energy mix, accounting for 58.6% of added electricity capacity in 2014, and improved energy efficiency, reported global carbon emission associated with energy consumption remain stable despite the increase in generation capacity and economic growth [4]. The increasing global trend, especially for solar and wind, which accounted for 91.8% of total investment in 2014, is largely due to cost competitiveness of improved RE technologies to conventional energy sources that has not been cross-subsidized by government [4]. Other factors are environmental performance, and improved policy implementation [4]. It is projected that the contribution from RE to global electricity generation will increase from 22.8% to 34% by 2030 [40]. Due to the technology cost reduction trend, World Energy Council [40] has predicted that contribution of solar PV and wind energy will rise from 2% and 5% in 2012 to 16% and 17% by 2030 respectively. In countries like Brazil, India and United Arab Emirate, government has increased contracted capacity due to a low bidding prices for PV power plant at 0.06 $/kWh [4]. In Scotland, wind energy is already cost competitive with fossil fuel generation in high-wind sites due to volatility of fossil fuel prices and advances in wind turbine technology [53]. As the developed countries market get close to saturation, RE penetration with increased investment has continued to shift towards developing countries as shown in Figure -9 [4, 55]. The growth of RE technologies in some developing countries has been hampered due to unfavourable government policies such as subsidies for fossil fuel and uneconomical power purchasing agreements [4, 6, 54]. However, RE cost effectiveness is playing a major role in power generation through mini and micro grids for remote areas in developing countries [4].

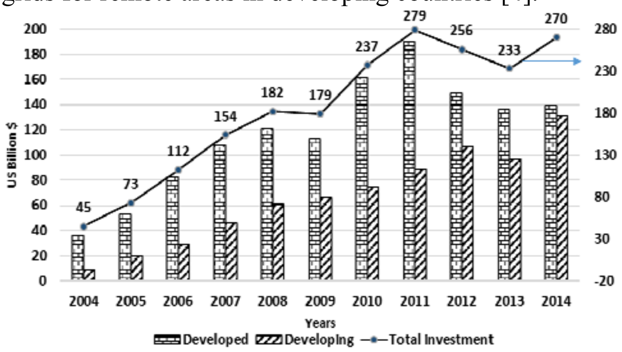

Figure -9 Investment in renewable energy between 2004 and 2014

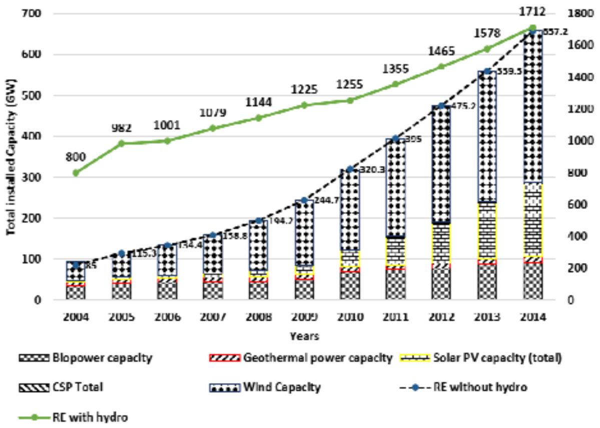

Figure -10 Cumulative electricity installed capacity for renewable energy sources

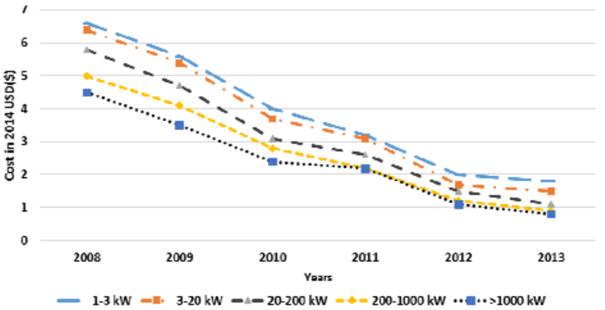

Figure -11 Decline in solar PV module prices between 2008 and 2013

IV. Main Challenges to Renewable Energy Deployment/Adoption

The challenges to the deployment of RE are mainly technical, economical, market, environmental, social and institutional [56, 59]. These challenges are global, however, in developing countries, aside global challenges highlighted, path dependency problem has been identified as the major barrier to RE innovativeness and skills development. The path dependency problem is the reluctance to forego a known technology route in favour of new pathways [60]. Due to this path dependency, research funding and development skills have been geared towards the known technology, creating a major skills gap and willingness to take up new ones [60].

A. Technical Challenges

The technical potentials of RE technologies are well known, but how the potentials for some technologies can be fully realized towards becoming a sizeable integrated part of the grid has been the major challenge [59]. Solar and wind technologies are matured technologies contributing the bulk of non-hydropower RE [4]. However, their resource availability is location dependent and highly intermittent. Aside fully harnessing the potential of RE, other technical challenges are limited grid access and transmission capability, scarce site with good resources, feedstock availability for biomass and construction equipment logistic challenges in developing countries [53]. Also reverse power flow to substation might occur when excess RE is being generated from multiple sources [46]. If no ES is installed to store these excesses, it might lead to damages of power generating facilities.

B. Economic Challenges

Economic challenges are mainly caused by risks and cost factors associated with RE technologies [60]. The risks include market, technology and reputational risks as well as risk of change in legislation while cost factors are the high cost of lending, required market capitalization and cost competitiveness [60]. Most RE technologies have a high LCOE which is mainly due to high capital cost associated with them when compared to conventional technologies [53]. This high capital cost is partly caused by relatively high material cost, use of earth precious metals, high grid connection cost and the cost associated with overcoming technical challenges for optimal performance [53]. Despite the high capital cost though declining with improved system efficiency, RE technologies have become competitive with conventional power plant. In developing countries, RE contractors have been faced with lengthy tendering process [61]. There is also reported cases of difficulty in accessing debt with favourable interest rate and tenor agreement from the financial sector due to the high capital required, risk of uncertainties and low predictability of return on investment [4, 55]. Financial institutions are also cautious of the uncertainties surrounding government future plans for RE investment and subsidies [55].

C. Environmental Challenges

The environmental challenges associated with the deployment of RE technologies are mainly alteration of wildlife natural habitat, migration of animals, competition with staple food, and distortion of landscape serenity [56].

D. Institutional and Market Challenges

For RE technologies to be fully deployed, a well-defined institutional framework is required [59]. The framework defines the roles of every organisation towards achieving government objectives and implementing her policies. The effective implementation of these policies is determined by the political stability of the country [54]. Where policies exist, it has been observed that there are too many government's agencies with duplicating roles causing administrative barriers to policy implementation in developing countries [55, 62]. Lack of skilled manpower, manufacturing capability, appropriate equipment, and local market availability has also been identified as barriers to adoption for RE technologies [53, 61]. In some developing countries, conventional power plant enjoys subsidies which does not account for their negative externalities [63]. Hence, electricity prices are lower than their actual cost, making RE source electricity less competitive [63]. Also, the proponent of conventional technologies influences policy framework of RE so that their technologies are still at an advantage [59]. Aside subsidies, many electricity markets are still controlled by monopolistic entities [64] and does not give room for multiple generation and feed-in to the grid [55]. The major challenge associated with multiple generation and feed-in is at instances when generation exceed demand. At such instances, wholesale prices of electricity becomes low and in some cases to protect the grid, curtailment measures are implemented with shutting down of some power plants [55]. This alters the economic projection of business entity and discourages investment. Risk associated with new technologies, volatility of oil and gas prices and electricity market supply-to-demand ratio are some of the market challenges to adoption of RE technologies [56].

E. Social Challenges

According to van der Gaast, et al. [65], there is a wide gap of knowledge in the potentiality of RE in many developing countries. This gap, according to van der Gaast, et al. [65], is mainly attributed to lack of information, education and pilot project. Lack of information increases the possibility of new technologies being rejected by the locals due to divergent views of RE policies and path dependency problem [62]. In many localities, land is communally owned or considered as an inheritance with a local superior use, than for RE deployment, hence causing friction of interest between the locals and government [62]. Also, the introduction of RE might alter the existing commercial activities that generate high income for the community inhabitants in low income countries without the skills required for the new technology [66]. Lack of social acceptance of RE due to low level of knowledge has hampered the growth, integration, and application of RE technologies [64].

F. Infrastructural Challenges

The development of new RE power generation system, especially in developing countries, requires high investments due to lack of supporting infrastructure [62, 64]. The cost associated with prospecting for acceptable and suitable site with high resource potentials, upgrading and extending grid facilities and permitting issues all add-up to a high investment cost [62].

V. Roles of Energy Storage

ES system has been identified as an inevitable element for the diversification of primary sources of energy [67]. The intermittent nature of RE sources in which the profile of energy generated deviate from the demand profile, can be minimised by implementing ES system [10]. The deviation in demand profile, although follows predictable pattern, is impossible to forecast with precision as the changes could be instantaneous, minute-to-minutes, hourly, diurnal and seasonal [68]. ES systems bridge the link between variable generation capability of RE sources and the highly volatile grid demand profiles [69]. The integration of ES systems into a power network, increase the overall efficiency of RE sources over the network, reduce associated cost and emission caused by the use of primary fuel for baseload and peaking plants, and ensure energy supply security, however, it adds to the degree of complexity of the system [69]. Four major challenges that still pose a threat to the integration of ES system into existing power grid with RE are; cost competitiveness to other energy system, validated reliability and safety of some technologies, environmental concerns and policies, and industry acceptance [67]. While other challenges can be addressed by technology advancement and policy frame work, cost competiveness to other energy systems is still a limitation to the deployment of ES system. Though, a 2016 published report indicated that ES capital cost are gradually reducing, yet high variability of cost data coupled with non-disclosure of major application based economic and technical data are still associated with ES [23, 70, 71]. Current ES systems are based either solely on or a combination of the following principles of storage; chemical, electrical, mechanical and thermal [72]. Identifying the most suitable ES system for all applications is complex, as no single storage system can simultaneously provide least capital and operating cost with high efficiency, as well as extended life time, high power and energy density [73]. Therefore, the right ES system will compromise a combination of technologies to match application, power and energy demand while still being economical.

A. Economic Benefits

The economic benefits associated with integrating ESS into the power grid are; the cost reduction due to bulk energy arbitrage; the cost avoided for constructing new power plants and transmission lines; the revenue increase due to spinning reserve response and load following capability of ES system; and the cost avoided due to transmission congestion charges [74]. Other economic benefits are; reduced demand charges, reduced power reliability and power quality related financial losses and revenue accrued from integrating RE sources [74].

B. Technical Benefits

1) Regulation and Grid Frequency Support:

This service provides support for the grid by reducing the effect of a huge and sudden fluctuation of a load or intermittent RE source within the grid. It provides grid frequency and voltage stability at a pre-defined level by reconciling the momentary imbalance caused by variation between demand and supply [23]. An uncontrolled variation in generation can damage electrical equipment and result to system collapse [16]. ES system with quick response characteristics are most suitable for this support. Such system size is between 10-40 MW, with 15-60 minutes discharge duration and a minimum of 250-10,000 cycles annually [47].

2) Congestion Relief:

ES systems are used to avoid congestion related charges that occur during peak demand when cheap energy cannot be delivered to some loads due to transmission facilities peaking during such period. ES system stores energy on the downstream side of the transmission system with no congestion and would be discharged during peak demand to reduce the need for increasing transmission capacity [47]. The discharge duration cannot be generalised, however, suitable system size ranges between 1-100 MW, with 1-4 hrs target discharge duration and a minimum of 50-100 cycles/year [47].

3) Grid Stability and Voltage Support:

ES system is used to inject or absorb power to improve system performance altered by electrical anomalies, disturbances and for reactance control within the grid [23]. Suitable system ranges between 10 – 100 MW, with 5 seconds to 2 hrs discharge time and a minimum of 20-100 cycles per year [47].

4) Transmission and Distribution Investment Deferral:

ES system can reduce the urgency or defer the need of investing in new transmission and distribution facilities and sub-stations by storing energy until there is less stress on the grid [23]. Suitable system size range for transmission is between 10-100 MW, with 2-8 hrs discharge duration and a minimum of 10-50 cycles per year [47]. While for distribution, it ranges between 500 kW to 10 MW, with 1 –

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4 hrs discharge duration and a minimum of 50–100 cycles per year [47].

5) Energy Management:

ES system assists in storing energy during low electric price regimes and discharge the stored energy when the applicable charges is at peak time of use (TOU), usually with high tariff. This demand side management strategy helps to reschedule energy consumption over a period of time and thus, the end user reduces the overall cost of electricity by shaving consumption, exploiting energy price differential or by matching demand to supply [23]. Suitable system size specification ranges between 1 kW to 1 MW, with 1-6 hrs discharge duration and a minimum of 50-250 cycles annually [47].

6) Power Quality:

ES system can flatten out sudden short-duration surges on waveform caused by variation in voltage, frequency, harmonics, and power factor to improve power quality and protect the customer's sensitive processes and load [75]. Suitable system size specification ranges between 100 kW to 10 MW, with 10 seconds to 15 minutes discharge duration and a minimum of 10-200 cycles annually [47].

7) Power Reliability:

ES system can provide an uninterrupted power supply (UPS) to the support customer load during power disruptions and assist in resynchronization of load with the grid when power is restored [76]. Suitable system size specification is dependent on the energy demand of the load over the time duration of power outages [47].

8) Frequency Support and Spinning Reserve:

Due to the variability of RE especially wind and solar, fluctuation in their generation profile and load alter the grid frequency [10]. ES system minimises the impact of these imbalances by either spinning reserves to match up with demand when generation profile is low or store excess energy when generation exceed demand [76]. The technical specification for this support is dependent on the degree of deviation expected on the grid, but generally an ES system greater than 20 MW with a fast response time will be ideal [47].

9) Transmission Curtailment and Time Shifting Support:

Due to the stochastic nature and remote location of some RE resources coupled with poor transmission facilities, ES systems are used to store excess energy generated until such a period when the transmission lines are least congested for discharge [47]. Where transmission lines are capable of receiving more energy, the stored energy is discharged during high demand, thus reducing the volatility spot prices and the customer exposure risk to these prices [76]. The storage technology for time shifting support should be scalable [10]. In the United Kingdom, a time shifting model implemented between 2008 and 2010 increased revenue by 7% for a 1.2 MW tidal current RE source coupled with a 10 MWh ES capacity [77].

VI. Conclusion

Increasing trends in the adoption of RE have been witnessed in recent years with reduction in unit cost. Developing countries are the new focus for investment as developed countries near RE technology saturation, wistfully, path dependency problem, lack of infrastructure and harmonised government policies are the major barriers to RE deployment. Deploying ES alongside RE is being promoted due to reduction in cost, technological improvement and system efficiency of both RE and ES systems. ES smoothen the variability associated with the two RE technologies, wind and solar, with the highest deployment rate.

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