Journal of Economics and Allied Research Vol. 4, Issue 2 (June 2020) **ISSN: 2536-7447**

ENERGY STORAGE AND MARKET IMPLICATION FOR POWERING AFRICAN COUNTRIES

UDE DAMIAN KALU
Department of Economics, Michael Okpara University
of Agriculture, Umudike,
Email: dk.ude@mouau.edu.ng

ABSTRACT

This study examines energy storage and market implication for powering 54 African countries. The study employed traditional pooled OLS methodology and levelized cost of energy model using secondary data from 1986 to 2018. Aggregating the results on a national level results in a levelized cost of electricity (LCOE) range of 80-200 USD/MWh (on a projected cost basis for the year 2020) in this very decentralized approach. As a continental average, 142 USD/MWh are found, this represents an upper limit for the electricity cost in a fully renewable energy storage. Results also suggests that battery technology has the potential to give countries their own self-sufficient, twenty-four-hour electricity generation systems. That in turn will have a huge impact on the price of energy and the region's economy in a wider context. The specific implications are that energy storage has huge market potential for powering African countries, that access to energy by Africans is critical to the consumption of stored energy and opening up the energy storage market for investment, and that there exists untapped market for energy storage and could be exploited for powering African countries. The study equally found that the advancement of storage technologies, particularly in the context of use with solar, is going to lead to a huge transformation of the way we approach energy in the next few years ahead. The study concludes that there is money to be made from energy storage and the introduction of supportive policies could make the market much bigger and faster.

KEYWORDS: Electricity, Energy, Battery, Storage, Market, Africa
JEL Classification: O33, Q41, Q43, Q47

1. Introduction

Traditionally, African countries have depended on fossil fuel-based plants and unreliable grid infrastructure to generate power. Battery storage may well facilitate renewable energy by evening out the distribution of electricity whilst breaking Africa's dependency on unreliable grid infrastructure through the development of off-grid renewable plants. Small, renewable, off-grid solutions combined with battery storage is arguably the new sustainable alternative to the traditional centralised generation model. While energy storage projects attract financing from developing finance institutes (DFIs), the financing of energy storage projects is still relatively new for commercial banks in Africa. So far, Standard Bank, Africa's largest commercial bank, has only financed power generation based on independent power purchase contracts without on-site storage facilities.

Many people see affordable storage as the missing link between intermittent renewable power, such as solar and wind, and sustained reliability. Utilities are intrigued by the potential for storage to meet other needs such as relieving congestion and smoothing out the variations in power that occur independent of renewable-energy generation. Major industrial companies consider storage a technology that could transform cars, turbines, and consumer electronics (Khoreibi, 2017). Others, however, take a dimmer view, believing that storage will not be economical any time soon. That pessimism cannot be dismissed. The transformative future of energy storage has been just around the corner for some time, and at the moment, storage constitutes a very small drop in a very large energy ocean. Advances in energy storage technology is believed to lead to a huge transformation of the sub-Saharan Africa's energy market in the next decade.

Electricity storage in batteries is a key technology in the world's transition to a sustainable energy system. Battery systems can support a wide range of services needed for the transition, from providing frequency response, reserve capacity, black-start capability and other grid services, to storing power in electric vehicles, upgrading mini-grids and supporting "self-consumption" of rooftop solar power. In the longer-term, batteries could support very high levels of variable renewable electricity, specifically by storing surplus energy and releasing it later, when the sun is not shining or the wind not blowing strongly enough. While pumped-hydro systems still dominate electricity storage (with 96% of installed storage capacity in mid-2017), battery systems for stationary applications have started growing rapidly. Wider deployment and the commercialisation of new battery storage technologies has led to rapid cost reductions, notably for lithium-ion batteries, but also for high-temperature sodium-sulphur ("NAS") and so-called "flow" batteries.

Like solar photovoltaic (PV) panels a decade earlier, battery electricity storage systems offer enormous deployment and cost-reduction potential, according to this study by the International Renewable Energy Agency (IRENA). By 2030, total installed costs could fall between 50% and 60% (and battery cell costs by even more), driven by optimisation of manufacturing facilities, combined with better combinations and reduced use of materials. Battery lifetimes and performance will also keep improving, helping to reduce the cost of services delivered. Lithium-ion battery costs for stationary applications could fall to below USD 200 per kilowatt-hour by 2030 for installed systems. Battery storage in stationary applications looks set to grow from only 2 gigawatts (GW) worldwide in 2017 to around 175 GW, rivalling pumped-hydro storage, projected to reach 235 GW in 2030. In the meantime, lower installed costs, longer lifetimes, increased numbers of cycles and improved performance will further drive down the cost of stored electricity services in Africa.

Battery technology, particularly in the form of lithium ion, is getting the most attention and has progressed the furthest. Lithium-ion technologies accounted for more than 95 percent of new energy-storage deployments in 2018 (Frankel, 2019). They are also widely used in consumer electronics and have shown promise in automotive applications, such as plug-in hybrids and electric vehicles. Prices for lithium-ion batteries have been falling and safety has improved; moreover, they can work both in applications that require a lot of energy for a short period (known as power applications) and those requiring lower amounts of energy for longer periods (energy applications). Collectively, these characteristics make lithium-ion batteries suitable for stationary energy storage across the grid, from large utility-scale installations to transmission-and-distribution infrastructure, as well as to individual commercial, industrial, and residential systems (Frankel, 2019). In most markets, policies and incentives fail to optimize energy-storage deployment. For instance, the output from intermittent renewable-energy sources can change by megawatts per minute, but there are few significant incentives to pair renewable energy with storage to smooth power output.

Another issue is that tariffs are varied and not consistently applied in a way that encourages energy-storage deployment. Thus, customers with similar load profiles are often billed differently; some of these tariffs provide incentive for the adoption of storage to the benefit of the electrical-power system, while others do not. Pairing load profiles with appropriate tariffs and ensuring that tariffs are stable could help build the economic business case for energy storage. Finally, the inability to bring together detailed modeling, customer data, and battery performance (due in part to policy choices and rules limiting data access) makes it difficult to identify and capture existing opportunities.

However, there are other factors to consider. For example, the cost and value of oil is likely to be affected if African countries can create consistent energy from solar and batteries. As a region that is dependent on the revenues of oil - we need to understand the implications of this. The cost of energy is likely to fall with increased use of solar and battery storage. When Enviromena first started building solar installations in 2007 the cost per kWh per plant was around US$0.35. Today we’re closer to US$0.03, which is a huge shift (Powanga, & Giner-Reichl, 2019). Amongst the main markets for energy storage solutions in the mini-grid segment are India, Nigeria, Tanzania, Kenya, Uganda, Mali, Ghana, Indonesia, Bangladesh, the Philippines, and Haiti.

Table 1. Top 10 countries by energy storage capacity 2019

Top 10 countries by energy storage capacity		
Country	**No. of projects***	**Power (KW)**
China	96	33,305,770
Japan	78	28,793,301
US	391	21,656,535
Spain	61	8,029,926
Germany	58	7,165,830
Italy	50	7,132,697
India	18	7,013,260
Switzerland	23	6,437,610
France	23	5,833,075
South Korea	41	4,741,118

The table suggests that the USA has the highest number of projects while Chine has the highest energy storage capacity. However, no African country made it to the top ten in the world in terms of energy storage capacity.

Energy storage technologies are viewed as a potential game-changer for widespread adoption of renewable energy generation throughout Africa. They facilitate the management of renewable power intermittency, demand response services and the dispatchability of stable, clean and sustainable power into the local or national grid system. The reality is that energy storage is going to unlock huge opportunities for more renewable energy investment in Africa at both a utility and distributed scale that will totally disrupt the traditional African power sector model. Africa still faces tremendous energy access challenges (Sokona, Mulugetta, and Gujba, 2012). Access to modern energy services is one of the most severe impediments to development not only in Africa, but also in other developing countries. Whilst the use of battery storage on a utility-sized scale may still be a few years away for Africa, the off-grid sector of the energy storage market has not progressed in recent years even with the support of export credit agencies and development banks. Against this background, this study is poised to ascertain energy storage capacity and developments, and its attendant market implication for powering African countries. The study is structured thus, section one is the introduction of the study which expounded the background and the research problem of the study. Section two is the review of relevant literature of the study while section three developed the methodology and data used in the study. Section four elaborated on the discussion of the estimated results while section five articulated the conclusion and policy recommendation of the study.

2. Literature Review

According to the International Energy Agency (IEA) (Avila, Carvallo, Shaw, and Kammen, 2017), the number of people in the world without access to electricity is around 1.1 billion, significantly down from the 1.7 billion in 2000. In South Africa, where the government has pushed for energy storage efficiency (Van Blommestein and Daim, 2013) a total of 3 GW was saved over ten years through the energy storage efficiency and incentive program, equivalent to the electricity output of five 600 MW generators. In this frame, electrical energy storage may allow a cost-effective exploitation of renewable sources in order to cope with the improvement of the power supply service via local national grids, but mainly it may become a building block of rural electrification through integration within off-grid systems. Mandelli, Brivioa, Leonardi, Colombo, Molinas, Park, & Merlo (2016) focus on electrical energy storage in sub-Saharan Africa providing an overview of the main aspects of this theme. Indeed, the specific features of the power sector in sub-Saharan Africa are analyzed about the framework of application of electrical energy storage. Mandelli, *et al* maintained that the typical technologies implemented in this context and the status of the market as well as of the economic models to support the diffusion of storage together with renewable energy technologies are highlighted. Moreover, an overview of technical aspects such as storage capacity sizing and interface converters for integration with renewables are described. Finally, an experimental application of a hybrid micro-grid in rural Tanzania is presented.

Maatallah, Ghodhbane, & Nasrallah, (2016), Analyzing the assessment viability for hybrid energy system (PV/wind/diesel) with storage in the northernmost city in Africa, Bizerte, Tunisia suggest that the absence of clean electricity in Tunisia means a large number of people are deprived of much needed socioeconomic development. However, wind and solar radiation are two renewable energy resources that are abundantly available in Tunisia. Although, it is not feasible for these two resources separately to meet high electricity demands, hybrid applications can be the best way to get over this weakness.

Yilmez & Dincer (2017) investigate optimal design of hybrid PV-Diesel-Battery systems for isolated lands: A case study for Kilis, Turkey. Yilmez & Dincer (2017) observed that summer houses are widespread in this area, and it is impossible for these buildings to benefit from grid connection. Optimal sizing of hybrid PV-Diesel-Battery systems prove to be very economical as an energy source for these houses. The optimization demonstrated that the lowest investment cost was 12,400 Turkish liras, and renewable energy part of the proposed system was calculated as 79%. In this respect, the system was optimally sized with a PV of 3 kW, a diesel generator of 1 kW, a converter of 2 kW and 6 units of battery. PV panels and diesel generator generate

4248- and 773-kW h/year, respectively, which amounts to 5021 kW h/year. This is a Hybrid PV-Diesel-Battery system. It consists of renewable (PV System) and non-renewable (Diesel Generator) energy sources.

Lin, & Tan (2017) examine sustainable development of China's energy intensive industries: from the aspect of carbon dioxide emissions reduction. The study suggests that the energy intensive industries include six highest energy intensive sub-industries. Because China is still in the process of urbanization and industrialization, it requires the products of energy intensive industries. Lin, & Tan (2017) review the main method of doing decomposition analysis on CO2 emissions, investigate the main factors affecting CO2 emissions in China's energy intensive industries using Kaya identity and Logarithmic Mean Divisia Index (LMDI) method and then adopt cointegration theory to construct the long-term relationship among CO2 emissions and the main factors. The study also estimates the reduction potential of CO2 emissions in China's energy intensive industries in the future. The results show that industrial scale and labor productivity are the main factors increasing CO2 emissions while energy intensity is negative to emissions.

3. METHODOLOGY AND DATA

The study applies traditional pooled methodology and as well build a proprietary energy-storage-dispatch model that considers three kinds of real-world data:

- electricity production and consumption (“load profiles”), at intervals of seconds or minutes for at least a year
- battery characteristics, including price and performance
- electricity prices and tariffs

Using both public and private secondary sources (2018), the study accessed data for more than a thousand different load profiles, dozens of batteries (including lithium ion, lead acid, sodium sulfur, and flow cell), and dozens of electricity tariff and pricing tables.

Energy System Model

The energy system model applied for each local energy system considers ubiquitous resources with high potential: PV, wind energy (onshore) and CSP (Gerlach, Stetter, Schmid, and Breyer, 2011; Trieb, Schillings, Sullivan, Pregger, and Hoyer-klick, 2009). These volatile energy resources are complemented by three energy storage and conversion options. Components and energy flow paths of the model are shown in Figure 3. Besides batteries, the following two additional pathways are considered in this model:

In the first energy conversion-and-storage path, electrical energy is converted to renewable power methane (RPM) via the Power to Gas process, i.e. electrolysis followed by a methanation step. The produced methane is a renewable substitute natural gas (SNG) which can be fed into existing gas grids avoiding the manifold difficulties of hydrogen injection (Müller-Syring, Henel, Mlaker, Sterner and Höchter, 2013; Sterner, 2009). In this way, long-term storage of renewable energy becomes possible, as well as utilization in the heating and mobility sector (natural gas vehicles). However, we focus here on the possibility of reconversion of the renewable gas to electricity. In our model system (Figure 1), there is one direct and one indirect path: The gas can be used in flexible gas power plants, or it can be converted into high-temperature heat and fed into the steam turbine, which originally belongs to the CSP plant.

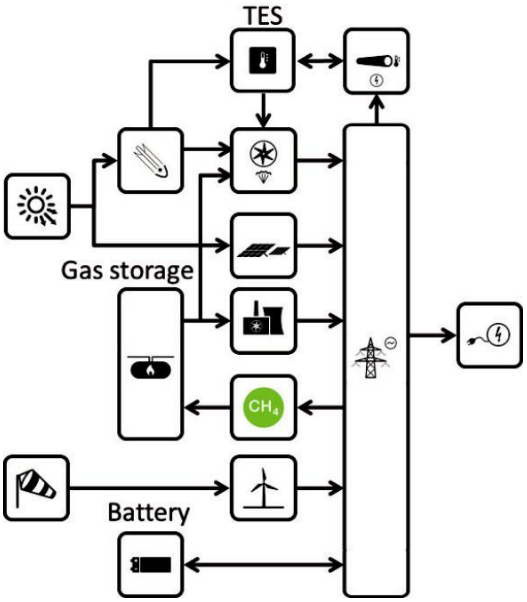

Figure 1. Block diagram of the considered energy system model of a fully renewable electricity supply based on solar and wind energy complemented by three storage options.

The second energy conversion-and-storage path considered here uses excess energy to heat a high-temperature thermal energy storage (TES, e.g. molten salt). The thermal energy comes either from a CSP plant or is generated from electrical energy via a heating rod. In times of high energy demand, the stored thermal energy is converted back to electricity by a steam turbine (ST).

The described energy conversion and storage options are integrated into our energy system model called MRESOM (Multi-Region Energy System Optimization Model) using a linear optimization approach. Analyses of energy systems can be performed with representation of technical interrelationships and economical optimization. It is used to draw decisions on investment and dispatch of power plants and other components of energy systems. The traditional pooled model is thus stated as:

$$\sum_{i=1}^{n} lnEMKT_{it} = \lambda_0 + \lambda_1 \sum_{i=1}^{n} lnESNR_{it} + \lambda_2 \sum_{i=1}^{n} lnESR_{it} + \lambda_3 \sum_{i=1}^{n} lnEPN_{it} + \lambda_4 \sum_{i=1}^{n} lnATE_{it} + \lambda_5 \sum_{i=1}^{n} U_{it} \dots\dots (1)$$

where *i* from 1, ….., *n* represents the 54 African countries, *t* is time from 1986 to 2018 while *U* is the error term.

Description of Data and Variables

EMKT is energy market (proxied by energy demand) (kg of oil equivalent per capita). Energy demand refers to use of primary energy and transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, as well as exports and fuels supplied to ships and aircraft engaged in international transport.

ESNR is energy storage from non-renewable energy sources (oil, gas and coal sources) (% of total). Sources of energy refer to the inputs used to generate energy. Oil refers to crude oil and petroleum products. Gas refers to natural gas but excludes natural gas liquids. Coal refers to all coal and brown coal, both primary (including hard coal and lignite-brown coal) and derived fuels (including patent fuel, coke oven coke, gas coke, coke oven gas, and blast furnace gas). Peat is also included in this category.

ESR is energy storage from renewable energy sources (% of total energy output). Renewable energy storage is the share of energy generated and stored by renewable (Solar energy, Wind energy, Hydro energy, Tidal energy, Geothermal energy, Biomass energy) power plants in total energy generated and stored by all types of plants.

ESPN is energy storage and production from nuclear sources (% of total). Sources of energy refer to the inputs used to generate energy. Nuclear power refers to energy produced by nuclear power plants.

ATE is Access to energy (% of population). Access to energy is the percentage of population with access to energy.

Resource data are based on NASA SSE data 2018 (Surface Meteorology and Solar Energy SSE Release 6.0). the 54 African countries are: Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic CAR), Chad, Comoros, Democratic Republic of the Congo, Republic of the Congo, Cote d'Ivoire, Djibouti, Egypt, Equatorial, Guinea, Eritrea, Eswatini (formerly Swaziland), Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, South Sudan, Sudan, Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe.

Financial and technical parameters

The model determines cost-optimal energy systems on a projected cost basis for 2020. The specific cost estimates for PV and wind power plants are widely used for the year 2020 and accepted in the community. [Capital expenditures (Capex) for gas power plants (OCGT and CCGT) are not assumed to reduce in the coming years.

Parameters for the Power to Gas technology respect the development potential of the technology as well as the fact that in a 100% renewable electricity supply scenario, CO_2 extraction technology (from CO_2 streams or from air) will be required. Specifically, the Capex and efficiency values given for Power to Gas are chosen that such that they effectively include cost and energy expenses required for the CO_2 extraction process. The efficiency given here refers to the lower heating value of methane. Capex for underground natural gas storages is quite low; values in literature range from 0,013 to 0,064 EUR/kWh.

Table 2. Financial assumptions for components of the energy system for the year 2020. Parameters for gas storage, TES and the solar collector field are given per $kW(h)_{th}$. All other parameters are given per kW(h).

Technology	Capex [EUR/kW]	Opex fix [EUR/kW]	Opex var [EUR/kWh]	Lifetime [a]
PV	900	15	0	25
Wind	1000	30	0	25
Power to Gas	940	24	3	25
CCGT	750	15	1	30
OCGT	380	7.6	1	30
Solar collector field	500	10	0	25
Steam turbine	700	14	0	30
Heating rod	20	0.4	0	30
Hot heat burner	100	2	0	20

Storage technology	Capex [EUR/kWh]	Opex fix [EUR/kWh]	Opex var [EUR/kWh]	Lifetime [a]
Battery	250	5	0	10
Gas Storage	0.05	0.001	0	50
TES	28	0.28	0	20

Concerning battery technology, it is assumed that until 2020 lead-acid batteries will be the cheapest electrochemical energy storage option. Afterwards, we assume sodium-sulfur batteries (NaS) to be lower in cost than lead-acid batteries. Assumptions for battery storage base on lead-acid technology with a depth of discharge (DoD) of 80 % (referred to the nominal capacity) and a round-trip efficiency of 80 %. The CSP component in this model consists of a linear concentrating parabolic trough collector, a molten salt thermal energy storage, and a steam turbine power block. In 2010, investment cost of CSP plants with 8 hours thermal storage was at about 6000 $/kW, and it is assumed that this will reduce to 2000 $/kW in 2050.

According to the presented cost development curves, cost CSP plants will decrease to 3600 $/kW in 2020. Cost breakdown for components of CSP plants is based on the study *Desert Power 2050* and further in-depth calculations by the *Dii* for CSP projects in the year 2015.

Table 3. Technical assumptions for components of the energy system for the year 2020

	Efficiency [%]
Battery	80
	10
Gas Storage	0
RPM	50
CCGT	58
OCGT	38
Steam turbine	42
	10
Heating rod	0
Hot heat burner	95

Table 3. Energy-power ratio of considered storage technologies

Energy/Power	[h]
Battery	6
Gas storage	1
Thermal energy storage	8

Further assumptions are weighted average cost of (WACC) of 7 % and an exchange rate capital of
N360 per 1 USD.

Aggregation on a national and global level

The continental simulation yields cost-optimal energy system configurations for each of the simulated 15,388 independent regions in 54 countries. The raw results are normalized, i.e. they provide the required installed system component capacities relative to a total regional electricity demand. To provide absolute numbers, we have chosen the approach to use national data for the total electricity consumption in 2010 for scaling, as well as data for the global population density 2007 on a 1° x 1° grid to provide a scaling of the energy consumption within each country.

Modeling the levelized Cost of Energy

The Levelized Cost of Energy (LCOE) is defined as the total lifetime cost of an investment divided by the cumulated generated energy by this investment. The study adopts the model from (Darling, You, Veselka, & Velosa, 2011). An alternative (but mathematically identical) approach is the definition by means of the net present value (NPV). The LCOE is the (average) internal price at which the energy is to be sold in order to achieve a zero NPV. In order to derive the model for combined power plant, the LCOE of PV generation and storage must be expressed. A fair comparison of different technologies on the basis of LCOE is suggested.

The total lifetime cost is the sum of the cost of PV energy generation and the cost of storage. The energy output of the PP is the sum of directly used energy from PV and the amount that is taken from PV to the storage system and then released to the output of the PP. What can be used directly should be used directly leading to a minimization of the storage system. This principle is an immediate consequence from the LCOE considerations where the effect of 100% utilization of the installed storage capacity on LCOE is clearly outlined. If a storage system is considered it might be uneconomical to dimension it so big to use the total generated energy either directly or via storage system. The model parameter $E_{OUT,PV,Residual}$ is the amount of energy that cannot be stored. It could instead be used for feed into the grid. The usable energy is therefore:

$$E^{*}_{OUTPUPY} = E_{OUTPUTPY} - E_{Residual} \dots\dots\dots\dots\dots\dots\dots\dots.(2)$$

Of this effective energy, only a certain amount will be stored, since it cannot be used directly:

$$E_{INSt} = A.Ex_{OUTPY} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(3)$$

with A the usage factor of PV into storage. The remainder of the energy will be used directly:

$$E_{OUTPYPP} = (1-A).Ex_{oupypp} \dots\dots\dots\dots\dots\dots\dots\dots\dots(4)$$

For a PV & Storage Power Plant (Index PP), we have the following relationship for the levelized cost of energy:

$$LCOEPP = \frac{\sum_{1}^{54} Cpp}{\sum_{1}^{54} E_{OUTPP}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.(5)$$

The total cost of the power plant is the sum of PV generation and storage:

$$\sum_{1}^{54} Cppi = \sum_{1}^{54} Cpvi + \sum_{1}^{54} C_{st\ totali} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (6)$$

The total output of the system is the direct output of PV and the output of the storage system:

$$\sum_{1}^{54} E_{OUTPPi} = \gamma_1 \sum_{1}^{54} E_{OUT,PV,PPi} + \gamma_2 \sum_{1}^{54} E_{OUT,Sti}$$

$$= \gamma_1 \sum_{1}^{54} E_{OUT,PV,PPi} + 5_{St}\ .\gamma_2 \sum_{1}^{54} E_{IN\ sti} + \ \varepsilon_i \dots\dots\dots\dots\dots. (7)$$

In the obvious case of no storage system the formula simply reduces to the LCOE of the PV plant alone.

4. Results and Discussion

The pre-estimation (descriptive statistics) test result is given in Table 4.

Table 4: Summary Statistics, using the observations 1986 - 2018

Variable	Mean	Median	Minimum	Maximum
EMKT	676.67	679.18	653.50	695.91
ESNR	67.959	68.254	63.934	70.891
ESR	21.487	21.308	17.818	26.617
ESPN	3.3671	3.2635	2.4795	4.4526
ATE	34.249	33.279	25.995	47.660
Variable	**Std. Dev.**	**C.V.**	**Skewness**	**Ex. kurtosis**
EMKT	10.814	0.015982	-0.67525	0.028559
ESNR	1.9877	0.029249	-0.37887	-0.52513
ESR	2.5425	0.11833	0.47585	-0.56871
ESPN	0.55800	0.16572	0.29698	-1.0341
ATE	6.0542	0.17677	0.65738	-0.51119
Variable	**5% Perc.**	**95% Perc.**	**IQ range**	**Missing obs.**
EMKT	653.52	694.43	14.229	0
ESNR	63.971	70.855	2.7181	0
ESR	17.865	26.610	4.6699	0
ESPN	2.5197	4.3930	1.0670	0
ATE	26.313	47.061	9.1333	0

Author computation using Gretl 2019a

The result suggests that energy market has the highest mean value while energy storage from nuclear source has the smallest mean value. The mean and the median values appear to be symmetric, which suggests that the mean and median are similar. The minimum and maximum values do not suggest the presence of outliers in the data across variables. As a good rule of thumb for a normal distribution, 99.7% of the values fall within three standard deviations which suggests minimal spread out of the data from the mean. The skewness values suggest that the data are not significantly skewed. However, energy market energy storage from non-renewable sources data are insignificantly skewed to the left while other variables data are right skewed because the "tail" of the distribution points to the right, and because its skewness values are greater than 0. The Kurtosis values indicate that the peak and tails of the distribution do not differ from the normal distribution. However, kurtosis value for energy market has insignificant heavier tails and a sharper peak than the normal distribution while kurtosis for other variables suggests insignificant lighter tails and a flatter peak than the normal distribution. The coefficient of variation (C.V) of the energy market and energy storage from non-renewable sources are more than five times smaller than that of the energy storage from renewable and nuclear sources. In other words, although the energy market has a greater standard deviation, it has much smaller coefficient of variation relative to other variables. The result shows that the interquartile (IQ) range of energy storage from non-renewable and nuclear sources are smaller than the data spread in energy market and access to energy. The summary statistics result suggests that there are no missing values.

Table 5: Energy Storage and Market Implication for Powering African Countries

Dependent variable: l_EMKT

HAC standard errors, bandwidth 2 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
ld_ESNR	2578.90	648.891	3.974	0.0009	***
ld_ESR	818.487	152.806	5.356	<0.0001	***
l_ESPN	115.039	17.5409	6.558	<0.0001	***
l_ATE	152.857	6.50510	23.50	<0.0001	***

Author computation using Gretl 2019a.

The result shows that the coefficient of all the core and control variables are positive and statistically significant. The result suggests that energy storage from non-renewable, renewable and nuclear sources have positive implication for energy market in Africa. The deduced implications therefore are that, (1) Energy storage has huge market potential for powering African countries, (2) Access to energy by Africans is critical to the consumption of stored energy and opening up of the energy storage market for investment, (3) There exist untapped market for energy storage and could be exploited for powering African countries.

Table 6: Influence of the utilization factor of the storage system on total LCOE of the power plant (PV & storage). Ratio of storage A = 0.5, ηSt = 65%.

Table 6. Combined System Model Result

Uitilization of usable storage capacity	100%	75%	50%
LCOESt [€/kWh]	0.339	(+27.7%) 0.433	(+82.9%) 0.620
LCOEPP [€/kWh]	0.255	(+14.5%) 0.292	(+43.1%) 0.365

Source: Author's computation

In the combined system, the effect of under-utilization of the storage system is significantly lower compared to the respective LCOE. This emphasizes the need to consider the aggregated cost of energy when comparing different and maybe mutually exclusive solutions.

The results also show that it is already profitable to provide energy-storage solutions to a subset of commercial customers in each of the four most important applications—demand-charge management, grid-scale renewable power, small-scale solar-plus storage, and frequency regulation.

Using the approach described above, we identify the following capacities as an economic optimum for a global, 100% renewable electricity supply: 7,300 GWp installed PV power, 6,700 GW onshore wind power and 3,900 GW_{el} CSP. In our model, wind power supplies almost half of the generated electricity (see Figure a). PV supplies a third (9,400 TWh) of the generated electricity, whereas CSP generates around 20 % (6,000 TWh).

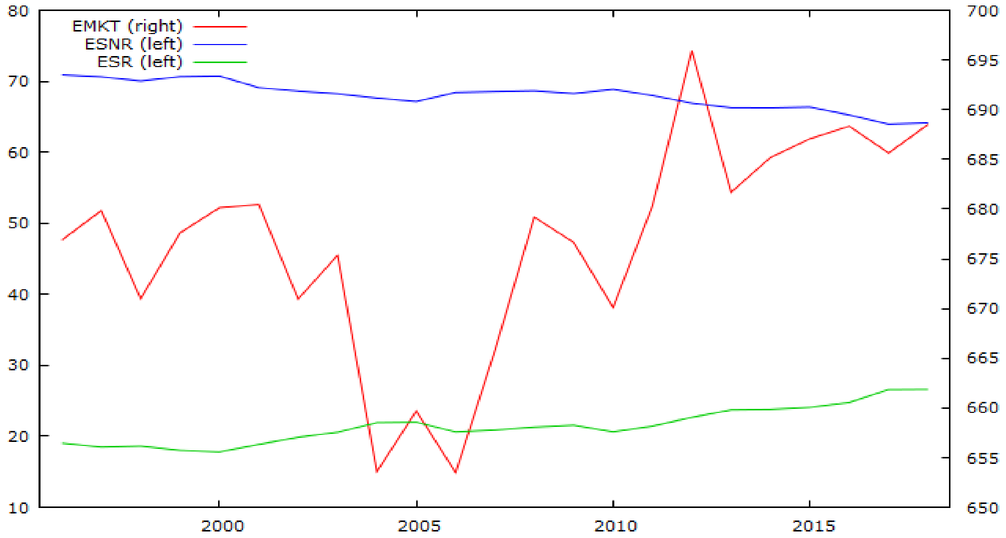

Figure 2: Trend of Energy Market and Energy Storage Variables

The chart suggests that the market for energy storage has fluctuated over time since the 1990s but has shown increasing tendency over the past seven years. Also, energy storage from renewable resources has shown gradual increase from 19.06 in 1996 to 26.62 in 2018. However, there is a marginal decline for energy storage from non-renewable sources from 70.89 in 1996 to 64.12 in 2018.

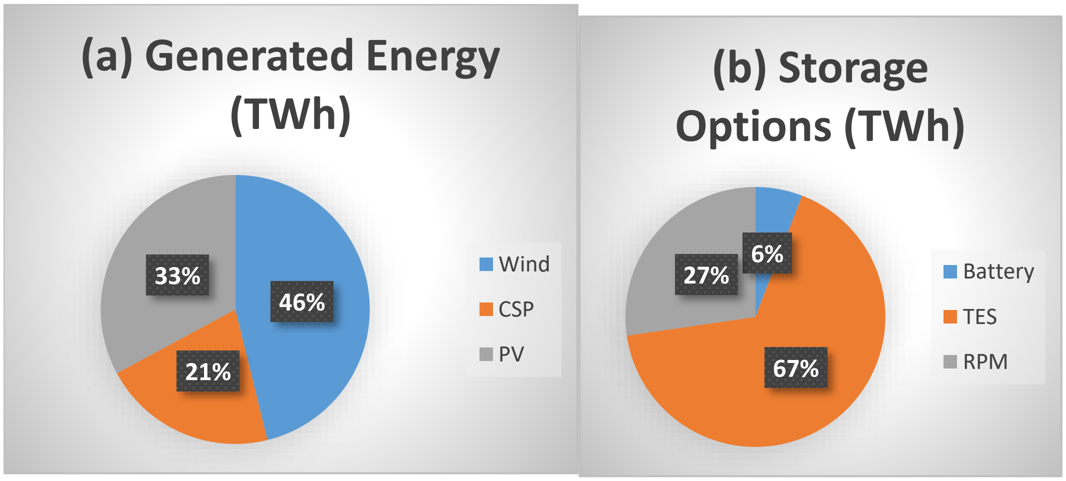

Figure 3. (a) Total annually generated energy and relative shares of the three primary energy sources; (b) Global sum and relative shares of annual energy output of the three considered storage options.

The figures suggest that 65% of electricity demand is covered by immediately consumed electricity supplied by PV, wind power and CSP. Respectively, a share of 35 % is not immediately consumed electricity and is supplied by storages: Batteries supply 420 TWh, gas power plants (OCGT and CCGT) supply 1,960 TWh on the basis of RPM and the TES have the largest global share with an energy output of 4,800 TWh (see Figure 3b).

The study equally found that the advancement of storage technologies, particularly in the context of use with solar, is going to lead to a huge transformation of the way we approach energy in the next few years ahead.

Comparison of different storage technologies

The chosen methodology allows for quick and easy assessment of different storage technologies. It emphasizes the fact that not up-front investment cost but total cost of ownership over the project lifetime are important (Of course, investment cost play a vital role when it comes to financing and risk assessment for investments). An example comparison with all model parameters is given in Table 7.

Table 7: Comparison of LCOE 25 (T=25 years) for different exemplary storage technologies.

Parameter	Redox Flow	Lithium-Ion	Lead-Acid
Project-specific parameters			
Installed storage power (MW)	1.0	1.0	1.0
Investment cost ($)	5.0	2.4	1.2
C-Rate (nominal)	0.25	1	1
Utilization of usable storage capacity	100%	100%	100%
Number of circles per year	365	365	365
External parameters			
Energy price ($/KWh)	0.03	0.03	0.03
PIF Energy price	2%	2%	2%
Loan period	10years	10 years	10years
WACC	3.5%	3.5%	3.5%
External specific parameters			
Residual value after end of lifetime (discounted) of investment cost	15%	0%	0%
Efficiency	70%	80%	65%
Maintenance cost of investment	2%	1%	5%
Degradation storage capacity per year	0.1%	2.0%	3.7%
Calendar lifetime	25	7	3
Usable storage capacity	100%	80%	50%
LCOE of storage ($KWh)	0.338	1.68	3.072

Source: Author's computation

As can be clearly seen, Redox-Flow with by far the highest initial investment cost turns out to be the most economic one when the cumulated energy over the investment period is considered. It outperforms the second-best technology Li-Ion by a factor of 6. However, it should be pointed out, that in reality not just the cumulated energy may be economically relevant, e.g. for power quality purposes. By definition, the LCOE metric disregards any generated revenues from the investment. For that reason, a net present value calculation is suggested to gain better insight into the underlying business case of the planned investment.

5. Conclusion and Policy Recommendation

Energy storage can make money right now. Finding the opportunities requires digging into real-world data. Distributed-energy-resource companies can devise new combinations of solar and storage, tailored to specific uses. While storage could eventually provide more customer value and lower bills, new rate structures will be more complex and policy is unlikely to lock in rates for long periods. Thus, energy storage is a favorite technology for the future—for good reasons. The study suggests that there is money to be made from energy storage even today; the introduction of supportive policies could make the market much bigger, faster. Another implication emanating from the study is that in African markets, energy storage systems offer an opportunity to displace diesel fired power generation with often abundant renewable resources, and to provide reliable electricity supply in markets where centralised grids are not well developed. In this context, the study considers what learnings from more mature power markets may be transferrable to ensure the more successful integration of storage systems in an emerging market context. Specifically, the study recommends the following policy options:

- African countries should invest in energy storage technologies that can store energy from non-renewable, renewable and nuclear sources by creating investment fund as a first line charge from the total revenue of each country.
- Respective African countries should enact a law through their parliaments to subsidize energy storage products. This would enhance affordability and consumption as well as activate the huge market potential of energy storage for powering African countries.
- The African countries governments cannot do it alone. The respective governments should partner with their private sectors to establish public-private partnership in the energy storage business. This will deepen accessibility and opening the untapped market for energy storage and could be exploited for powering African countries.
- The energy storage engineers should be encouraged to engage in the extensive use of the Thermal Energy Storage (TES) - two thirds of electricity supplied by storages is provided by this storage options - leads to high Flh of the steam turbines. The triple use as converter of (i) thermal energy from the solar collector field, (ii) Thermal energy from the high-temperature thermal energy storage, and (iii) of thermal energy generated by using Renewable Power Methane (RPM) in a hot heat burner lowers the cost per unit of energy generated by the Steam Turbines (ST) and improves the economical attractiveness of steam turbines. Even if energy losses on a first look speak against converting electrical energy into thermal energy, the dynamical system approach shows that it is part of the operation of a cost-optimal renewable energy system.

Finally, the study concludes that the decline in battery prices coupled with the global trend towards grids being powered by renewable energy sources would increase the global energy storage capacity to 28 GW in stationary battery storage by 2028 which will trigger market expansion for stored energy. Whilst lithium-ion is set to dominate in the 2020s, other forms of battery and other energy storage technologies are being developed at a rapid pace. In particular, demand is anticipated to grow for storage systems which can exceed 10 hours of storage, or which can meet weekly or seasonal storage requirements.

REFERENCES

Avila, N., Carvallo, J. P., Shaw, B. & Kammen, D. M (2017). The Energy Challenge in Sub-Saharan Africa: A Guide for Advocates and Policy Makers, *Renewable and Sustainable Energy Reviews* 62, 28-51.

Darling, S. B., You, F., Veselka, T., & Velosa, A. (2011). Assumptions and the levelized cost of energy for photovoltaics. *Journal of Energy and Environmental Sciences*. 4(9), 3133-3139.

Frankel, D. & Wagnar, A. (2019). “Sustainability & Resource Productivity practice” McKinsey’s Southern California office. http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/how-we-help-clients Accessed online on 28th March, 2020.

Gerlach, A. K., Stetter, D. J. Schmid, & Breyer, C. (2011). PV and Wind Power - Complementary Technologies. *Proceeding of the 26th European Photovoltaic Solar Energy Conference*. 26, 42-63

Khoreibi, S., (2017). Battery Technology charges ahead. Enviromena. Credit: Environmena http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/battery-technology-charges-ahead Accessed online on 27th April, 2020.

Lin, B. & Tan, R. (2017). Sustainable Development of China's Energy Intensive Industries: From the Aspect of Carbon Dioxide Emissions Reduction. *Renewable and Sustainable Energy Reviews*. 60, 386-394

Maatallah, T., Ghodhbane, N & Nasrallah, S. B (2016). Assessment Viability for Hybrid Energy System (PV/Wind/Diesel) with Storage in the Northernmost City in Africa, Bizerte, Tunisia. *Renewable and Sustainable Energy Reviews*. 59, 1639-1652.

Mandelli, S., Brivioa, C., Leonardi, M., Colombo, E., Molinas, M., Park, E., & Merlo, M. (2016). The Role of Electrical Energy Storage in sub-Saharan Africa. *Journal of Energy Storage*. 8, 287-299.

Müller-Syring, G., Henel, M., Mlaker, H., Sterner, M. & Höchter, T. (2013). Development of Modular Concepts for Generation, Storage and Feeding Hydrogen and Methane into the Natural Gas Network. *DVGW research center, Engler Bunte Institute (DVGW-EBI)* 7(10), 1-350 https://www.dvgw.de/medien/dvgw/forschung/berichte/g1_07_10.pdf

Powanga, L. & Giner-Reichl, I. (2019). China’s Contribution to the African Power Sector: Policy Implications for African Countries. *Journal of Energy*, 70, 1-10

Sokona, Y., Mulugetta,Y., & Gujba, H. (2012). Widening Energy Access in Africa: Towards Energy Transition. *Energy Policy*. 47(1), 3–10.

Sterner, M. (2009). Bioenergy and Renewable Power Methane in Integrated 100% Renewable Energy Systems. *Ecological Economics*, 68(12), 2996-3006

Trieb, F., Schillings, C., Sullivan, M. O., Pregger, T, & Hoyer-klick, C. (2009). Global Potential of Concentrating Solar Power, in Solar PACES.

Van Blommestein K.C & Daim, T. U (2013). Residential Energy Efficient Device Adoption in South Africa. Sustainable Energy Technologies and Assessments, https://works.bepress.com/tugruldaim/20/

Yilmaz, S. & Dincer, F. (2017). Optimal Design of Hybrid PV-Diesel-Battery Systems for Isolated Lands: A case study for Kilis, Turkey. *Renewable and Sustainable Energy Reviews*, 62, 344-352.