Cost and Performance of Grid Scale Energy Storage Options

Moses Jeremiah Barasa Kabeyi

mkabeyi@uonbi.ac.ke

Industrial Engineering Department, Durban University of Technology, Durban South Africa

Oludolapo Akanni.Olanrewaju

oludolapoo@dut.ac.za

Industrial Engineering Department, Durban University of Technology, Durban South Africa

Correspondence to: Moses Jeremiah Barasa Kabeyi: mkabeyi@uonbi.ac.ke

Abstract

Energy storage systems provide an important solution for improving the reliability of electricity networks due to challenges of integrating intermittent electricity from variable sources like wind and solar. Factors considered in the selection of storage batteries are cost and performance since. prices for every kWh injected into the network and battery energy storage system (BESS) costs vary. Energy storage systems play an important role in improving the reliability of electricity networks due to increasing contribution of electricity from intermittent sources like wind and solar. The main considerations in choosing a suitable storage system are cost and performance. Since the price for every kWh supplied to the network and battery energy storage system (BESS) costs are dynamic, consumers interested in a battery may have challenges in choosing between the various batteries available in the market. This study presents a the Levelized cost of storage as a suitable method or approach for selecting the most suitable battery technology for household and industrial consumers. The future power plants are expected to have large proportions of intermittent energy sources like. wind, solar or tidal energy that require scale-up of energy storage to match the supply with hourly, daily, and seasonal electricity demand profiles. Available storage technologies include batteries, pumped hydroelectricity storage, compressed air energy storage and power-to-Gas storage. The energy transition to renewable energy supply calls for increased application of energy storage. Identification of optimal solutions requires a holistic view of the energy system beyond the electricity-only focus. In this study, an integrated cross-sector approach is adopted to identify the most efficient and least-cost storage options for off grid and grid scale application.

Key Words: Electricity price; Battery energy storage system;energy storage;: Lead-carbon batteries; lifecycle cost of energy; Lithium-ion batteries; Levelized cost of storage

1. Introduction

The global increase in use of small-scale and distributed generation, and use of variable renewable have led to high demand for electrical energy storage systems (ESS), which applies different storage device. They include electrochemical storages, super capacitors, gravity batteries etc. The challenge is that we have no universally accepted economic indicator which for use in comparing compare different energy storage systems unlike in power plant planning where "Levelized Cost of Electricity (LCOE)" has been accepted(Melnikov et al., 2018). Combining storage and renewable in a power system improves flexibility, which promotes adoption of renewable energy by ensuring security of the power grid. The future energy systems dominated by renewable energy will require largescale and wide application of energy storage technologies (Xu et al., 2022).

Grid-scale energy storage has an important role to play in the net Zero Emissions target by the year 2050 Scenario by providing services ranging from short-term balancing and operating reserves, provision of ancillary services for grid stability and deferment of capital investment in capacity increase and power distribution system extension, long-term energy storage and grid restoration after blackouts. There are various types of energy storage systems with pumped-storage hydropower being the most widely used storage technology. with total installed capacity of about 160 GW in 2021. Its global capability was about 8 500 GWh in 2020, which accounted for about 90% of total global electricity storage. Batteries storage which is the subject of this study is the are the most scalable type of grid-scale energy storage technology with significant market growth potential. Other storage technologies are compressed air and gravity storage, hydrogen which is an emerging technology with potential for the seasonal storage of renewable energy(IEA, 2022; M. J. B. Kabeyi & O. A. Olanrewaju, 2022a, 2022c).

The grid-scale batteries are projected to account for most of the growth in storage globally with typical applications in sub-hourly, hourly and daily balancing. By the end of 2021, the total installed capacity of grid-scale battery storage was 60% compared with 2020 which implies 6 GW of batter storage capacity was installed in 2021. However, the technology mix of the grid-scale battery technology mix in 2021 remained unchanged when compared to the mix in 2020. Lithium-ion battery storage batteries remained the most widely used batteries and dominated new capacity installation(IEA, 2022).

Levelized cost of storage (LCOS) refers to the ratio between total costs of acquisition and operation costs of a storage system to the cumulated energy generated produced by the storage system or device. Levelized cost of storage (LCOS) is applied in various investigations to assess different storage technologies e.g. pumped-storage hydroelectricity, compressed air energy storage, battery technologies like Lithium-ion, Lead and Vanadium redox flow batteries and power to gas(Cristea et al., 2022). . About 7200 gigawatts (GW) of electricity capacity must be built globally to keep pace with growing electricity demand and to replace retiring power plants by 2014. Future power systems are expected to have large proportions of intermittent power like wind, solar and tidal generation and or inflexible. nuclear, coal, *etc.* There is need to scale up storage scale-up energy storage to match the electricity supply with hourly, daily, and seasonal electricity demand profiles. According to the International Energy Agency, about 310 GW grid grid-connected electricity storage capacity will be needed by the US, Europe, China and India(Smallbone et al., 2017).

The main cause of growing use of energy storage is interest in small-scale and distributed generation, and use of renewable energy sources. There is however no generally accepted economic indicator for comparison of different energy storage systems, unlike in the planning of power plants which mainly use the "Levelized Cost of Electricity (LCOE)" which has now been modified. for application in electrical energy storage systems, this derived indicator is called "Levelized Cost of Storage (LCOS)". However, the LCOS calculation procedure is not yet approved but its popularity has been growing (Melnikov et al., 2019).

Levelized cost (LCOS) quantifies discounted cost per unit of power discharged for a given storage technology and application. Therefore, the Levelized cost of energy is used to account for the technical and economic parameters that affect the lifetime cost of discharging stored electricity. Levelized cost of storage is equivalent to Levelized cost of electricity (LCOE) for generation technologies, but represents an appropriate tool used for comparing the costs of storage technologies.(Schmidt et al., 2019).

1.1. Problem Statement

It is difficult to assess the cost of electricity storage technologies because of the diversity of technologies with different costs and performance characteristics as well as varying storage requirements. Studies on future costs have so far limited investment cost of storage technologies. The result of this is that future role of electricity storage is seen as highly uncertain even with remarkable growth in deployment of storage technologies and applications.(Schmidt et al., 2019).

The capacity of power generation by f renewable energy like wind and solar is variable and intermittent, making it difficult to supply stable power for the system. Curtailment of solar and wind is costly, yet you cannot simply store electricity. This leads to o insufficient renewable energy adoption. The combination of energy storage and renewable energy in power operation has significant advantages in improving the flexibility of a power system, promoting renewable energy adoption, and ensuring the security of the power grid [5]. Many studies have been carried out on the LCOS, but we are yet to have a common definition of LCOS. Some studies neglect parameters like replacement or disposal, cost, while others exclude specific performance parameters, like capacity degradation. Industry reports tend to hide their methodologies while academic studies tend to cover limited number of storage technologies and applications, with all focusing only on current LCOS. There is limited research analyzing the economics of large-scale electrical energy (EES) deployment. Therefore, it is necessary to employ the Levelized cost of storage (LCOS) for evaluation of e domestic EES projects (Xu et al., 2022).

1.2. Rationale of the study

The transition to renewable energy supply requires significant storage capacity for electricity. Optimisation requires a move beyond the electricity-only concentration to have a holistic energy system view for integrating renewable energy. Storage is not the optimum solution for integration of large intermittent and variable renewable energy as more efficient and cheaper options can be found through integration of the power sector and other parts of the energy system through creation of Smart Energy System (M. J. B. Kabeyi & O. Olanrewaju, 2022; M. J. B. Kabeyi & O. A. Olanrewaju, 2022b; Lund et al., 2016).

Uncertainties around the future role of electricity storage can be reduced by increasing transparency of and application of lifetime cost of various storage technologies and their competitiveness in diverse applications(Schmidt et al., 2019). The electricity generation capacity of variable and intermittent renewable energy like wind and solar makes it difficult to provide a stable and reliable power supply for the system. It is difficult to simply store electricity while wind and solar curtailment is costly, leading to insufficient renewable energy adoption. By combining energy storage and renewable energy in power operation significantly improves power system flexibility, increases renewable energy absorption, and provides security of the power grid. With future power systems being dominated by renewable energy, energy storage demand is set to increase significantly (Xu et al., 2022).

To achieve carbon neutrality, the establishment of a "near-zero emission" energy system based primarily on renewable energy is indispensable. Energy storage is the overriding technology that can accelerate energy transition and mitigate the mismatch between electricity supply and demand. Development of energy storage is mediated by the maturity of technology, capacity allocation optimization, system optimization and scheduling of energy storage and energy storage policy. Reduction in energy storage technology cost will shorten the payback period of investment. The Levelized cost of storage (LCOS) is considered as one of the international energy storage cost evaluation indexes(Xu et al., 2022).

Energy storage can be classified into physical energy storage, electrical energy storage (EES), superconducting magnetic energy storage, super capacitors, and hydrogen energy storage used for three main applications i.e. large-capacity energy storage, transmission and distribution support services, and frequency regulation applications. Specific energy storage techniques include pumped storage systems, compressed air systems and chemical batteries, lead-carbon, lithium iron phosphate, and vanadium redox. Although electrical energy storage is developing rapidly, the economics of electrical energy technologies are quite ambiguous, which restricts the development of EES(Xu et al., 2022).

2. Storage Systems

Energy storage involves storing energy by means of equipment or media for release when needed. Energy storage facilitates temporal and spatial transfer electricity and effectively isolates generation and utilization of electricity. This will eliminate the peak valley difference of day and night power consumption, improve resource utilization efficiency, and enable large-scale connection of renewable energy sources to the grid. Energy storage application improves the peak shaving and frequency modulation ability of the power system, reduce the investment in development of peak-shaving power plants reserve capacity, and expansion of power transmission and distribution**(Xu et al., 2022).** EES technology has wider applications in power systems due to their high-energy density, fast response, high specific power, flexible installation, high reliability, long life, etc. The most commonly used EES technologies lead, lithium iron, flow batteries, NaS, and super capacitors.(Xu et al., 2022).

Levelized cost of storage is the total lifetime cost of the investment in an electricity storage technology divided by its total or cumulative delivered electricity delivered. This reflects the internal average price that the electricity is sold for the project's net present value to be zero. The Levelized cost of storage (LCOS) for various technologies and life cycle cost of energy (LCOE) for generation technologies can be compared directly but involve different concepts of providing electricity and leading to differences in cost calculation methods hence their different names **(Schmidt et al., 2019)**

2.1. The International Installed Capacity of Energy Storage and EES

By the end of 2020, about 191.1 GW of energy storage capacity had been put into operation globally with the proportion of EES being about 7.5%, exceeding 10 GW with lithium ion batteries having the largest capacity accounting for about 92% of the total installed capacity of EES(Xu et al., 2022). pumped storage is the most dominant technology used accounting for about 90.3 % of the storage capacity, folowed by EES . By the end of 2020, the cumulative installed capacity of EES had reached 14.2 GW. The lithium iron battery accounts for 92% of EES , folowed by NaS battery at 3.6%, lead battery which accounts for about 3.5%, flow battery 0.7%, supercaacitor 0.1% and others 0.2%.

The cumulative installed capacity and growth rate of the global EES in 2014–2020(Xu et al., 2022) are shown in 1.

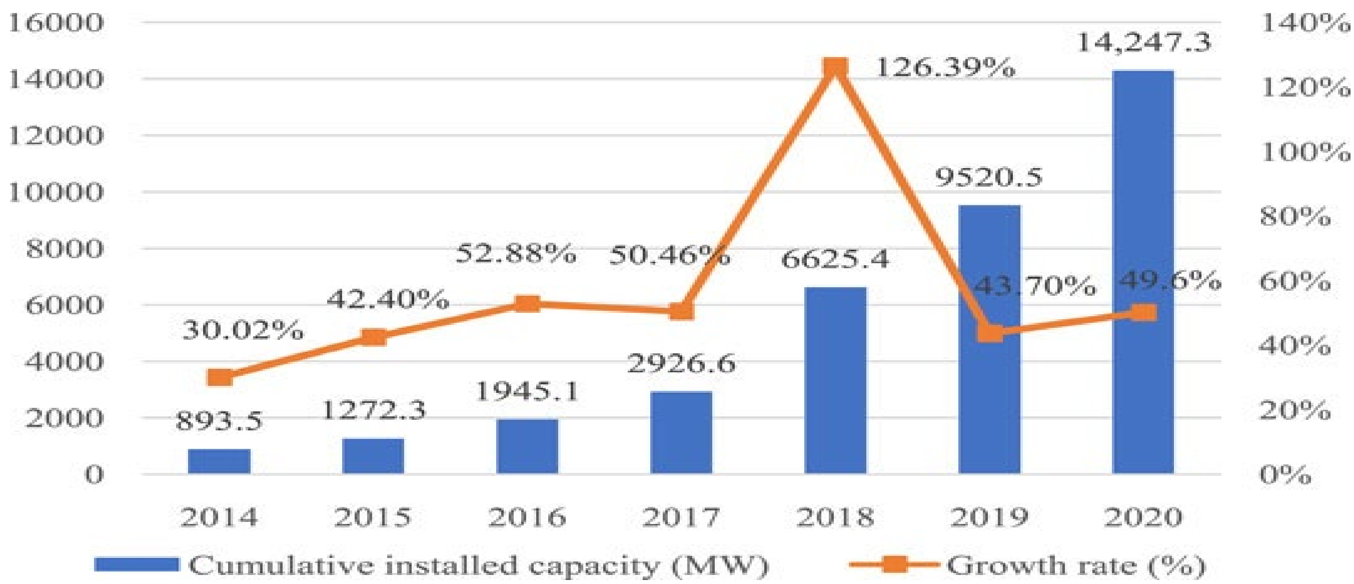

Figure 1: cumulative storage capacity of EES

From figure 1, it is shown that the cumulative storage capacity of EES grew from 893.5 GW in 2014 to 14.247.3 kW in 2020. The highest growth in capacity was realised between the year 2017 and 2018 at 126.39% and the least growth was realised between 2024 asnd 2015 at 30.02%.

3. Battery Energy Storage (BESS)

BESS have wide scale applicxations in power generation, transmission, and distribution of power to consumers using different types of batteries. These types batteries include lead-acid, lithium-ion, redox flow, NaS, and nickel-cadmium battery(Choudhury, 2022; Faisal et al., 2018). There are many types of commercially available batteries globally e.g. Lithium-ion (Li-ion), absorbed glass mat valve-regulated lead-acid (AGM-VRLA), gel valve-regulated lead-acid (Gel-VRLA), Lead-carbon (LCB), and Aqueous Ion Hybrid (AIHB) batteries(Cristea et al., 2022; Faisal et al., 2018).

3.1. AGM-VRLA batteries

3.1.1. Lead –acid (LA) cells

The Lead-acid (LA) cells widely used BESS technologies in applications like solar traffic lights, telecommunications, automotive, uninterruptible power supplies (UPS), energy storage devices and many others. There are theree distinct desgns of the leadacide batteries having different structural and functional characteristics. The flooded or vented design ihas a large amount of liquid electrolyte (sulfuric acid) in which the electrodes are immersed and needs periodic watering to limit electrolyte depletion. The other two are sealed and valve-regulated (VLRA) lead-acid batteries, that contain minimal amount of electrolyte, and need no watering (Cristea et al., 2022).

The main advantage of the VRLA batteries is their quick charge capabilities, high power density, and low maintenance requirements. Their basic components are the positive and negative plates, an electrolyte, and a separator used to immobilize the electrolyte. Separators are absorptive glass mat (AGM) or silica particles, which react with sulfuric acid to form a gel. The separators are made of glass microfibers obtained based on a paper-making process and wicked the sulfuric acid between the plates . This separator, makes the AGM battery spill-proof and can making their shipping easy. The AGM batteries have a high discharge rate with low internal resistance and provide electrical reliability due to its low maintenance requirements. These batteries have between 500 and 2500 life cycles at a depth of discharge (DoD) of 30–50 % and efficiency of 80–90 %, and are widely used for household and industrial consumers(Cristea et al., 2022)..

3.1.2. Gel-VRLA Batteries (GEL-Batteries)

A gel battery has gelled electrolyte whose quality has a significant impact on its battery characteristics. Fumed and colloidal silica are the most widely used gelling agents with the first one being more reliable under deep-discharge conditions, but with shortcomingslike an increased internal resistance and high production costs. The colloidal silica gels are simple to prepare and use lower material cost, but has higher impurities content of impurities like iron leading to high water water consumption, and increased production costs(Cristea et al., 2022). The Gel-VRLA are superior to the AGM technology, in terms of higher reliability as a result of high deep-discharge performance, long service life of over 12 year, small self-discharge rate, good charge stability. The Gel-VRLA can reach 4500 cycles at 40 % DoD with and efficiency of 90 % to 99 %(Cristea et al., 2022).

3.2. Lead-Carbon Batteries (Lcbs)

The Lead-carbon batteries (LCBs) are suitable replacement for conventional lead-acid technologies because oftheir longer cycle life under deep charge/discharge partial-state-of-charge operation conditions. Carbon and electrolyte additives can be used to o lower the hydrogen reaction rate in the batteries thus increasing lifecycle, and enhanced the reversibility of deep cell discharge. These batteries have between 500 and 2500 life cycles at 50–100 % DoD, at charge/discharge efficiency of 90–99 %(Cristea et al., 2022).

3.3. Lithium-Ion Batteries (Li-Ion)

The Lithium-ion batteries (Li-ion)technically present the most BESS for residential consumers commercial consumers because of the high flexibility in power and scalability. The anodes and cathodes are composed of different materials; with lithium iron phosphate and lithium nickel cobalt aluminum oxide being most used materials. Their advantage over the lead-acid are their higher power and energy density, higher charge/discharge efficiency of 90–99%, longer lifetime of 7 and 20 year and over 6000 complete cycles based on operating conditions. However, the main disadvantage is tthat connecting them in parallel/series has risks concerning safety and balancing in operation due to high temperature, overload, short-circuits, which can esily lead to explosion and battery burns. These riskd are minimised by use of electronic circuits for each battery cell. High operating temperature and deep discharge can also limit the overal r life cycle of the litium –ion batteries(Cristea et al., 2022).

The dominance of lithium-ion technology results from good parameters, like high round-trip efficiency, sufficient cycle life, and lower investment cost due to a high experience rate coupled with moderate levels of installed capacity for stationary systems which explains the continuing dominance of 1st-generation (crystalline silicon) solar cells eve with significant investments in alternative solar cell technologies initially expected to be significantly cheaper(Emblemsvåg, 2020). Like the crystalline silicon solar cells, the lithium ion range of technologies offers the possibility of chemistry or design improvements to ensure cost reductions for the technology group(Schmidt et al., 2019). High experience rate for stationary lithium-ion systems is the technology's modularity that enables knowledge spillover from other markets, for example lithium-ion batteries for electric vehicle applications. However, the lithium–ion batteries for transport, portable, and stationary applications may be inching closer to the performance limits than others as a result of significant recent research and deployment focus on lithium-ion thus offering an avenue for alternative technologies to become more competitive (Schmidt et al., 2019)

3.4. Aqueous Ion Hybrid Batteries (Aihbs)

The AIHBs are attractive due to high safety performances and ionic conductivity amoiung all rechargeable batteries and are suitable for medium and large-scale applications. The AIHB technology employs similar electrodes to those used in Li-ion batteries. The lectrolyte is based on an aqueous solution which reduces their environmental impact compared to the Li-ion batteries. The aqueous ion hybrid batteries (AIHBs) are however still under research and development stage though some commercially available solutions are available. The life of the AIHBs BESS is about nine years which is approximately 3,000 life cycles at a 70 % DoD and a charge/discharge efficiency of about 90 %(Cristea et al., 2022).

3.5.Bess Input Data

Battery energy storage systems have different performance parameters and indicators , based on type type of battery technology, the manufactuirer manufacturer, the operating environment and conditions i.e. temperature, maximum current, voltage, and power and maintenance needs. The analysis assumes that for 24-hours period, the battery is fully charged and discharged at the various design like recommend DoD specified in the technical/commercial datasheets by the distributor, calendar life (n) and number of cycles considered per year i.e. (3 6 5).Table 1 shows the performance indicators for various grid scale storage batteriews.

Table 1. Input parameters for the analyzed BESS technologies.

		AGM-VRLA	**Gel-VRLA**	**LCB**	**Li-ion**	**AIHB**
1	Norminal volatge	6–12	2–12	6-12	12–600	48
2	Rated capacity [Ah]	22–460	17–3170	70–300	8.33–500	50
3	Rated energy [kWh]	0.264–3.48	0.204–14.4	0.84–3.264	0.3–25.6	2.4
3	Battery efficiency [%]	80–90 %	80–95 %	90–99 %	90–99 %	90%
4	DoD [%]	30–50 %	30–60 %	50–100 %	50–100 %	70
5	Cycles at DoD	400–2500	550–4500	500–2500	2000–7000	3000
6	Cycles/year	365				-
7	Calendar life (*n*)	2-7	2-13	2-7	6-20	9

From table 1, it is noted that Li-ionm LCB and AIHB batteries have the highest efficeincies, AIHB and Li-iom have highest average nominal voltage . Overal, the Li-ion has superior performance characteristics compared to others while AGM-VRLA (absorbed glass mat valve-regulated lead-acid.

3.6. Comparison Of Levelised Coast Of Storage (LCOS)

The LCOS analysis determines the total cost for one kWh stored by each type of the analyzed BESS. It includes the capital expenditure (CAPEX), operation, maintenance (OM) and charging (C) costs over the entire lifetime (n) of the storage system divided by total energy generated by the storage system (W_{out}) in the entire lifetime. Annual costs and energy output are then discounted considering a discount rate i e.g. 8.5%.(Cristea et al., 2022).The other cost parameters for consideration are annual operation and maintennace costs . which vary with storage technology. Values may be comuted as percentages of CAPEX i.e 0.5 % for lead-acid/carbon technologies and 0.25 % for Li-ion and AIHB batteries (Cristea et al., 2022). Charging costs per year (C) is price of electricity used for battery charging hence not injected into the grid. This reperesents the money a prosumer would receive if he decided to store the surplus for later insstead of supplying to the grid and for demnistartetiion in this study for 2021 is 40.67 € for each

MWh suppplied to the grid.(Cristea et al., 2022) CAPEX, OM and C costs, are established on the basis of market analysis. The analysis gives a wide range of values for each cost factor analysed in the study. This implies that the same battery or system may have may have different costs, based on the manufacturer and distributor(Cristea et al., 2022).

Identification of a representative value for each technolgy requires the use of an interquatile interquartile range (IQR). to remove outliers for each cost factor. The IQR determines values between the first and third quartiles, spread out around the data' median and indicates the middle (50 %) of the serioes. The median is determined based on first and third quqrtiles with the difference between the quartiles defines the IQR. The average IQR is used to represent each cost factor's representative value. The range values, IQR and *Avg* for the primary cost parameters used to determine LCOS values are presented in table 2

Table 2. Main cost parameters of BESS technologies

			AGM-VRLA	Gel-VRLA	LCB	Li-ion	AIHB
1	C_{BESS} [€/kWh]	Range	77.55–248.78	55.95–516.55	143.34–219.81	233.35–2397.68	
		IQR	119.04–172.58	110.87–191.01	156.22–192.55	373.56–769.37	
		Average	146.59	142.03	180.01	568.89	470.40
	VAT [€/kWh]	Range	14.73–47.27	10.63–98.14	27.23–41.76	44.34–455.56	89.38
		IQR	22.62–32.79	21.06–36.29	29.68–36.58	70.98–146.18	
		Average	27.85	26.99	34.20	108.09	89.38
	DS [€/kWh]	Range	9.23–29.61	6.66–61.47	17.06–26.16	27.77–285.32	
		IQR	14.17–20.54	13.19–22.73	18.59–22.91	44.45–91.55	
		Average	17.44	16.90	21.42	67.70	55.98
	S_{BESS} [€/kWh	Range	30.45–97.70	21.97–202.85	56.29–86.32	91.64–941.57	
		IQR	46.75–67.77	43.54–75.01	61.35–75.61	146.70–302.13	
		Average	57.56	55.77	70.69	223.40	184.73
	OM [€/year]	Range	0.28–4.57	0.42–14.30	0.84–3.51	1.33–33.32	3.69
		IQR	1.08–2.10	1.09–2.20	1.48–2.63	3.17–12.98	
		Average	1.55	1.59			

From table 2, it is noted that amoung grid scale storage bateries analysed, Li-ion bateries have highest cost averages while the Gel-VRLA has lowest average cost averages.

3.7. LCOS Method Results And Discussion

Two values of LCOS were determined for the abtteries. First, LCOS does not incude subsidies while the second includes subsidies. The second LCOS i.e (LCOS2) includes subsidies provided. The average values obtained are summarised in table 3.

Table 3. LCOS for the examined BESSs technologies

			AGM-VRLA	Gel-VRLA	LCB	**Li-ion**	AIHB
	$LCOS_1$ [c€/kWh]	Range	27.75–109.29	20.41–132.3	28.87–54.33	18.68–157.62	50.76
		IQR	41.79–80.39	36.28–65.98	31.6–42.95	25.96–76.57	
		AVR	54.58	48.13	39.04	45.6	
	$LCOS_2$ [c€/kWh]	Range	22.23–79.76	17.01–95.6	22.78–39.49	14.5–112.9	37.64
		IQR	32.42–59.12	28.45–49.01	24.57–32.53	19.7–55.54	
		AVR	41.18	36.91	29.39	33.63	

. Table 3 shows the LCOS1 and rLCOS2. Based on average values, the lowest values for LCOS1 and LCOS2 are fro the LCB battery technology technology at 39.04 to 29.39c€/kWh. They have high DoD of 50–100 %, conversion efficiency higher than 90 % and low battery cost of 180.01 €/kWh), hence more electricity at low battery cost.

The Li-ion battery with 45.6 and 33.63c€/kWh offer the second best LCOS other some studies have shown higher values of between 61.1c€/kWh and 83c€/kWh. Clearly the battery prices are on a decreasing trend mainly due to incentives and taxes. In the third and fifth place of the LCOS ranking is the Gel- and AGM-VRLA batteries The LCOS values for the two lead-acid batteries are lower generally 58.68c€/kWh to 98c€/kWhalthough in some values, 17 and 25c€/kWh were established

The fourth place lies the AIHB battery with between 50.76 and 37.64c€/kWh. . It has high LCOS values, but prefereed by buyers due to its low environmental impact, and thus are considered to be eco-friendly alternative of Li-ion batteries. Although the LCB technology has a shorter life of 2–7 years compared to the Li-ion battery, it has a lower CAPEX of about 238 €/kWh, hene lower LCOS. The Li-ion batteries have longest period of exploitation. The LCOS values maybe close to Gel-VRLA battery, but the difference in life is about 7 years with the AGM-VRLA battery having shorter life and high LCOS values, which makes then inefficient(Cristea et al., 2022)..

3.8. Thermal Storage

There are many forms of thermal storage e.g. chilled water tank, and ice storage whose operation fit in the operation possible energy source and supply profile e.g. a chiller linked to solar only starts operation if the PV power is available at a specific supply level and cuts off when, PV power supply drops below the threshold or its demand capacity(Luerssen et al., 2019). Decentralized energy storage systems can a used as cold thermal energy storage, if used for cooling applications. Cold thermal energy storage can be applied for demand side management, to reduce peak-loads, in combination with PV(Emblemsvåg, 2021). Hot water storage can be integrated with heat pumps and optimised. Thermal energy storages, applying chilled water or ice as storage medium, can be used in cooling systems to take advantage of lower night tariffs or to avoid chiller electricity consumption peaks (peak electricity rates) in district cooling systems as well as larger office buildings Storage systems can also be used for maximisation of photovoltaic (PV) energy self-consumption(Luerssen et al., 2019).

A Pumped Heat Energy Storage system stores electricity in the form of thermal energy by applying a proprietary reversible heat pump (engine) which compresses and expands the gas. The system uses two thermal storage tanks for storage of heat at the temperature of the hot and cold gas. In a typical study, it was demonstrated using the Levelized Cost of Storage method that the cost of electricity storage is between 2.7 and 5.0 €ct/kW h, based on assumptions made. Comparison of the LCOS with other storage technologies of size 100 MW and 400 MW h showed that Pumped Heat Energy Storage is cost-competitive with Compressed Air Energy Storage systems as well as Pumped Hydroelectricity Storage with the additional advantage of full flexibility for location(Smallbone et al., 2017).

4. Environmental Impact of Energy Storage

The environmental impact of energy storage technologies depends on the specific technology used technology. Large plants such as pumped storage hydropower stations require major civil engineering structures that can cause , significant local disruptions especially during construction., while small storage systems like flywheels or super-capacitors have less physical impact. Some battery systems use toxic metals or other exotic ingredients, hence immediate environmental impacts should be balanced against other benefits offered by the storage system. Storage helps reduce e carbon emissions and make electricity more sustainable by enabling more uptake of non-dispatchable renewable energy source. Storage also enhances grid stability and grid reliability which are vital for some modern technologies(Breeze, 2018).

Compressed air energy storage (CAES) has proved to be suitable for large-scale grid applications. Life cycle assessment (LCA) is widely used to evaluate the environmental sustainability of products and services including energy storage systems (Rahman et al., 2022). The environmental impacts of different storage systems are based compared based on their life cycle. The impacts of storage can be assessed using Impact 2002+, EcoPoints 97, as well cumulative energy demand methods. Assessment indicators used are carcinogens, noncarcinogens, respiratory inorganics, ionizing radiation, ozone layer depletion, aquatic ecotoxicity, land occupation, mineral extraction, nonrenewable energy, terrestrial ecotoxicity, respiratory organics, and global warming. The impacts can also be assessed for the end-point categories of human health, climate change, ecosystem quality, and resources. Overall metal emissions like mercury, zinc, cadmium, lead, copper, and greenhouse gas emissions like CO_2, NOx, SO2, and ammonia are also assessed. Studies show significant environmental impact due to NiMH batteries compared to Li-ion batteries in terms of amount of toxic chemical elements in NiMH batteries (Mahmud & Tasmin, 2022).

5. Results and Discussion

Energy storage technologies have the capacity to improve the utilization of renewable energy grid power applications. (Faisal et al., 2018).. There are many energy storage methods like flywheel, compressed air, battery, fuel cell, supercapacitor, super magnetic, redox flow, lithium ion, and the hybrid ESS, like battery/supercapacitor, battery/SMES, and battery/F in grid service. Among the **two** challenges facing energy storage are development of appropriate materials, storage capacity limitations, short life cycle, low and low efficiency(Choudhury, 2022; Faisal et al., 2018).

The cumulative installed capacity of lithium-ion batteries is highest of the chemical storage batteries accounting for about 88.8% of electrical energy storage (EES) in China for the year 2020. Lead-carbon batteries have highest safety due lack of combustibles during operation and are increasingly used for large-scale EES technology. The initial cost of vanadium redox flow is high, the cost will reduce as development of technology and industry progresses. The batteries have a very flexible scale design. The electrolyte capacity and concentration influence energy storage capacity, thus increasing volume of the electrolyte increases energy storage capacity. This makes the vanadium redox flow the most promising large-scale electrical energy storage (EES) technology in the future.(Xu et al., 2022). The LCOS for the thermal energy storages are usually lower than that of the battery, at 23–47 USD ct/kWh(Luerssen et al., 2019).

Energy storage is essential for implement the large-scale integration of renewable energy for the current and future transition to a 100% renewable energy supply. An electricity-only focus – as in a smart grid approach – leads to options primarily focused on electricity storage technologies in combination with flexible electricity demands and transmission lines to neighbouring countries.

Electricity storage is approximately 100 times more expensive than thermal storage and much more expensive than storage for gases and liquids. It is therefore advisable to apply thermal and fuel storage since it is cheaper and more efficient solution to utilise thermal and fuel storage technologies for integration of fluctuating renewable energy, such as wind and solar power, thane rely on electricity storage which however requires strong integration across different energy sectors. The cross-sector smart energy systems approach leads to better and much cheaper options in terms of thermal, gas and liquid fuel storage combined in a cross-sector energy conversion technology. Use of heat pumps, in each building in rural areas or in district heating system in the urban areas, can efficiently connect the electricity sector to thermal storage, while electric vehicles and electro-fuels can interconnect the electricity sector and storage in the transport sector. The use of more efficient and cheaper options eliminates the need for other options in the electricity sector required solely for the integration of renewable energy. Large electricity storage capacity is not economically viable within any of the steps between now and a future 100% renewable energy supply.

Large-scale integration of fluctuating renewable electricity sources, and electricity storage should be avoided to encourage other storage types to provide optional system balancing and flexibility at lower costs. Direct electricity storage can be put to other applications but should not be prioritized if its objective is to supply electricity to the grid. Storage may not be the optimum solution to integrate large fluctuating renewable energy, since due to availability of more efficient and cheaper options for integration of electricity with other parts of the energy system and creation of a Smart Energy System. However, storage remains important for large scale integration of variable renewable to the electric power systems.

For Chinese case, studies established for application scenario of energy storage peak shaving, due to the abundant lead resources and mature lead-carbon battery recycling system, the initial cost of lead-carbon batteries is much lower than others while the LCOS of lead-carbon is about 0.84 CNY/kWh. The LCOS of lithium iron phosphate batteries is about 0.94 CNY/kWh mainly because of long life cycle but high end-of-life cost. As a result of high recycling value and high investment cost, the vanadium redox flow technology is still evolving but has LCOS of 1.21 CNY/kWh, which is the highest of the three common types of batteries.

A possible pathway to increase the business case for electricity storage is through multiple services using the same device which brings multiple revenue streams also called "benefit-stacking". The nominal power capacity is based on the largest service i.e., sequential stacking or the sum of all service provided at the same time i.e., parallel stacking. The discharge duration reflects the sum of durations required by all services for sufficient energy capacity when all services are needed in parallel or directly one after another. The full equivalent cycles also reflect the respective sum for all services provided by the system. Average electricity price could be the sum of prices captured during charging for individual services weighed by the full equivalent cycles attributed to them(Schmidt et al., 2019).

6. Conclusion

Energy storage systems provide an important solution for improving the reliability of electricity networks due to challenges of integrating intermittent electricity from variable sources like wind and solar. Factors considered in the selection of storage batteries are cost and performance since. prices for every kWh injected into the network and battery energy storage system (BESS) costs vary. Energy storage systems play an important role in improving the reliability of electricity networks due to increasing contribution of electricity from intermittent sources like wind and solar.

Levelized cost of storage (LCOS) refers to the cost of kWh or MWh electricity discharged by a storage device when accounting for the entire costs incurred, and energy generated throughout the lifetime of the storage device. Energy storage is a high-quality flexible resource, with an important regulatory role in a high increasing the uptake of variable and intermittent renewable energy resources. The various elements of Levelized cost of storage are the Capex, Opex, charging cost, tax cost, replacement cost, and end-of-life cost. From the cost breakdown, it is indicated that the proportion of *Capex* and charging cost is the largest, while the proportion of tax cost and Opex is the smallest. Batteries with a short life cycle and many replacements have the highest cost. Levelized cost of storage varies with different application scenarios e.g., for transmission and distribution applications LCOS is the lowest when lithium iron phosphate batteries ae used because the batteries only need one replacement thus take advantage long life.

Therefore, improving round-trip efficiency and storage duration, reducing the unit initial investment cost, and giving full play to the advantages of different technology types when laying out EES can be used to reduce costs.

The use of LCOS is dependent on economic storage characteristics and, unlike the traditional Levelized cost of energy (LCOE) which also depends on the temporal characteristics of the electricity price profile. Hence an analysis the whole power system will provide more information than a single Levelized cost measure to compare different storage technologies in the electricity market.

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Authors Biographies

Moses Jeremiah Barasa Kabeyi is currently a doctoral researcher in the Department of Industrial Engineering at Durban University of Technology. He earned his B.Eng. degree in Production Engineering and MSC in Mechanical and Production Engineering (Energy) from Moi University, in Kenya, MA in Project planning and Management from University of Nairobi, in Kenya and Diplomas in Project management, Business management and NGO management respectively from The Kenya Institute of Management. He has worked in various factories including sugar manufacturing at Nzoia Sugar Company Ltd, pulp and paper at Pan African Paper Mills EA Ltd, and power generation at the Kenya Electricity Generating Company (KenGen) in Kenya, in an industrial career of 16 years before moving into teaching. He has taught in various universities in Kenya including University of Nairobi, Technical University of Mombasa, and Egerton University and currently on study leave. His research interests are power generation, fuels and combustion, internal combustion engines and project management and sustainability. He is registered with the Engineers Board of Kenya (EBK) and Institution of Engineers of Kenya (IEK) and has published several journal papers.

Oludolapo Akanni Olanrewaju is currently a Senior Lecturer and Head of Department of Industrial Engineering, Durban University of Technology, South Africa. He earned his BSc in Electrical Electronics Engineering and MSc in Industrial Engineering from the University of Ibadan, Nigeria and his Doctorate in Industrial Engineering from the Tshwane University of Technology, South Africa. He has published journal and conference papers. His research interests are not limited to energy/greenhouse gas analysis/management, life cycle assessment, application of artificial intelligence techniques and 3D Modelling. He is an associate member of the Southern African Institute of Industrial Engineering (SAIIE) and NRF rated researcher in South Africa.