Chapter

Energy Storage Efficiency

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Abstract

Renewable energy sources with their growing importance represent the key element in the whole transformation process worldwide as well as in the national/global restructuring of the energy system. It is important for a sufficient energy system is to find a solution and key element to complete energy supply, that is, energy storage. Reasons and background, which make the energy storage so crucial, imply that exact, enduring development of energy storage is an indispensable part of the full energy supply. There are some necessary components for further development and implementation of renewable energy sources, and these components involve not only a flexible generation system but also network expansion, demand-side integration, and storage. As the energy storage is a much needed component that can facilitate a low carbon energy system, energy storage technologies find their applications in two major areas, and these are electricity network energy storage and transport/mobility. Interest toward energy storage has also grown due to technical and innovative progress in the field of energy storage technologies. Additionally, energy storage can be considered from different perspectives, which always give corresponding benefits, emphasizing the importance and attractiveness of energy storage.

Keywords: energy storage system, renewable energy, energy supply, storage technologies, energy storage efficiency

1. Introduction

A strong deployment of flexibility solutions for energy storage is necessary to provide the system with the capacity to adapt the dynamics of the load from the frequency response to interannual flexibility. The main candidate for such solutions to offer flexibility networks, response to demand, and dispatchable and flexible energy production is energy storage.

There are five major subsystems in energy power systems, namely, generation, transmission, substations, distribution, and final consumers, where energy storage can help balance client demand as well as the generation itself.

Energy storage is a making a lot of possibilities for technology for various applications, such as power top shaving, renewable energy utilization, boosted structure energy systems, and advanced transporting within multiple areas. Important elements regarding application of energy storage necessary to explain in the introduction are:

- Peak charge or discharge rate of storage—as the maximum power or rate of energy transition to or from storage,

- Peak storage – the largest possible size or capacity available for storing energy. We can simply calculate and get more information about this peak storage capacity if we take into account two factors - namely the discharge speed and the number of peak storage hours that the device where the energy is stored, can actually provide for us,

- Energy density—the sum of energy that can be contained in each mass of a substance or system [1].

In the process of productive use of energy storage, a balance needs to be struck between implementing frameworks that facilitate cost monitoring and establishing a secure climate for investment in the field.

Energy storage is also one of the leading forces in the implementation of renewable energies and plays a key role in sustaining a strong and efficient modern electricity grid, with minimizing the power volatility, increasing the reliability of the electrical grid, and allowing the storage and delivery of electricity produced by intermittent renewable energy sources.

In terms of how to ensure transparency and predictability for market participants, we have learned that adaptation policies that incorporate cost-tracking capabilities of technology are the perfect way to do this.

To reduce costs, which is one of the most contentious topics relating to storage, one of the most successful approaches was to tightly track costs as the share of the use of renewables and energy mix in general expanded.

If renewable energy prices continue to fall and grid parity is reached in various countries, a new period of policies will be required to ensure further growth of renewables in the energy mix.

2. Importance of energy storage

Energy storage is important for developing electricity, since storage technology allows us to 'reserve' electricity, which is of tremendous advantage not only in terms of technical growth but also in economic terms. As energy storage is being used more often than ever before, diversification and protection of supply have improved, which means that the energy market will be balanced. Another energy storage aspect is the use of green energy sources. Ancillary networks for grid convergence are probable options for the advantage of clean energy sources. Asset utilization is supported as well as voltage control and device stability due to the likelihood of a long-term reserve, which is not necessarily feasible for any form of storage technology [2].

The second application is transport and mobility, but this form of application is not as large as for the usage of electricity, but even energy storage in this area provides the possibility of minimizing fuel consumption by providing a kinetic force against a gasoline-fueled internal combustion engine. A particular interest can be defined by the lengths of the charge/discharge, which will be deemed to be the most relevant features that have contributed to a great deal of concern on the end-user side.

Energy storage in transport and mobility has benefits on a broader scale, as increasing system reliability and reducing greenhouse gas emissions and technology related to this form of storage are flywheels or supercapacitors [2].

Prioritizing the use of energy from the on-site renewable energy source over the utility grid (based on fossil fuel) also aims to minimize the consumption of fossil fuels and, as a result, to advance the priorities of the clean environment [3]. In 2015, the European Commission released two Communications: "*Providing a New Deal for Energy Consumers*" and *"On a New Energy Market Layout*" [4]. Their message was that there are three columns of future customer energy plan, which include:

a. Consumer empowerment,

b. Clever houses, work environment,

c. Information monitoring and security.

The importance of this was clearly emphasized from the beginning: minimizing energy expenses with self-generation and consumption [4] as well as increasing the customer's role via intermediation and cumulative engagement systems [5].

To fulfill the environmental and energy policy goals of the European Union, the energy market will have to experience systemic improvements in the coming decades, where electricity will play a key role in the transition phase and increase its share of final energy use.

3. Application of energy storage technologies

Energy storage offers a variety of useful services and cost benefits to electrical systems, and companies are adopting storage technology for a variety of reasons. Large-scale energy storage also allows today's electrical systems to operate more efficiently. This efficiency gain means lower costs, less pollution, and more stable power.

Traditional energy sources such as coal and natural gas power plants must be cycled on and off in response to changing demand and rarely operate at peak efficiency. Not only does this make energy more expensive but it also creates more pollution than is necessary to meet our energy needs. In addition, due to long start-up times, these large-scale power generation facilities cannot keep up with real-time demand spikes, which can lead to blackouts.

It is possible to use the technology for a variety of applications, ranging from offering ancillary services to grid operators to reducing end-user costs behind the meter. There are a diversity of uses for pumped hydropower, flywheels, and thermal storage systems; however, battery energy storage systems have seen the most use across a wide range of applications.

- Energy arbitrage

Using energy arbitrage, prices can be offset in markets characterized by significant variations in locational marginal prices (LMPs) over time. Low LMP levels are used to purchase and store wholesale electricity for resell when high LMP levels are reached.

- Black start

In the event of a network-wide power outage, the black start tool is used to restore power. Since it has to work without being connected to an energy source, it can cause many problems. Energy storage systems are ideal for black start applications because they can operate in standby mode and restart other grid systems on their own.

Hardware-in-loop (HIL) simulations, optimization algorithms, and other intelligent methods and techniques are essential and appropriate for advanced energy management technologies to boost storage life and operability. The HIL energy storage testing enables the optimum calculation of battery capacity and energy density along with the algorithm management tuning. In general, HIL gives insight into the optimum storage configuration. HIL simulations are also used as part of the validation process of either machine models running in real time or laboratory testing of components outside their traditional system [6].

The operation of an energy storage device may pose a problem of optimization where the cost function is defined by a financial metric, a grid gain metric, or a combination of the two. Restrictions are placed on the model and on the features of the energy storage system. There are many optimization methods that are mostly applicable to decision issues, which are mathematical programming, stochastic programming, dynamic programming, and optimal control. Predictive strategies are a model-free monitoring technique that uses weather forecasts without model or historical evidence. Control of temperature settings is also suggested as their control at the component level is simple to be applied by traditional controllers. In the sense of the choice of parameters, it can be defined as: weather forecast only and/or weather forecast and building characteristics. If we regard the weather forecast only, the controller calculated the setting of the wall temperature as a function of the cloud forecast and the actual electrical price situation relative to the optimum price. Compared to unpredictable performance, thermal comfort was vastly improved, and the price and energy savings were recorded at 41% and 30%, respectively. Thus, this form of predictive control could provide good results in the case of an active storage device [7].

4. Key attributes of energy storage

- Reducing imbalances between energy demand and production.
- Managing the amount of power required to supply customer when it is needed.
- Improving power efficiency and secure supply of electricity to customers.
- Enhancing the stability and reliability of transmission and delivery systems.
- Increasing the use of current facilities, deferring or removing expensive upgrades.
- Strengthening availability and improved market demand of distributed generation sources.
- Improving efficiency of green energy generation.
- Cost savings by capacity deferral and transmission of payment [8].

4.1 Advantages and disadvantages of energy storage

Without storage, the production and use of electricity must still be balanced. And since generation and consumption are physically different, transport capability is also a limiting factor. Owing to these limitations, the value of energy on wholesale markets will change rapidly and considerably over time, often even adversely. Electricity spot market rates reflect this abrupt shift in value [9].

Various storage devices are found in energy systems. They can be cataloged as: chemical or electrochemical, mechanical, electromagnetic, or thermal storage. Generally, the energy storage plant consists of a storage medium, a power conversion device, and a balance of plant [10]. Obviously, these forms of energy storage have many promising features, but on the other hand, certain important elements are still lacking.

Electricity storage systems have major beneficial energy, economic, and environmental impacts:

a. Reduction of backup power plants by satisfying fluctuations and peaks in demand,

b. Mitigation of electricity-loss costs by bridging the difference during power outages and by easing short-term volatility,

c. Support for green energy by smoothing out the uncertainty of renewable energy sources and allowing electricity to be dispatched as needed,

d. Steadily upgrading production and costs.

Despite the apparent benefits for the use of storage systems, it is evident that more measures are needed to address the major obstacles. The key one is the initial capital cost of storage per kW of all storage technology. It should be remembered that the cost of using Pumped Heat Electrical Storage (PHES) and Compressed air energy storage (CAES) systems is comparatively low. Battery technology is less efficient than PHES technology but can be found to be comparatively cost-effective.

While there have been significant technological improvements in energy storage systems, in many countries, it is still not cost-competitive for electricity consumers (whether at a residential, commercial, or utility scale) to store their energy. It means that when a consumer demands electricity, supply across the transmission and distribution networks must be carried out in real-time. One of the biggest disadvantages of energy storage is the fact that energy storage usually uses electricity and stores it but afterward distributes it back to the grid, which is called "round-trip" as a proportion of energy put in to energy returned, measured in %. This is inefficient, because the energy lost in the process of this round trip could be stored better, and no wastage of energy would be possible in this cycle. It depends on the use of storage technology; the higher the round-effectiveness, the lesser will be the amount of energy lost [11]. The last disadvantage is certainly the necessity of a significant amount of additional energy, which represents a reserve used for energy storage [12]. Reserve or in other words "back-up" can have two types, i.e. capacity and operational backup. The optimum proportion of variable renewable energy (VRE) sources in the composition of energy sources depends on different factors [13]. Backup power, network flexibility, transmission-system quality and capacity [14], as well as load efficiency characteristics [15] and real local weather models will determine the amount and variety of

VREs required to backup and that can be safely fed into the system. By adding storage space to the energy grid, it is possible to gain greater resilience of VRE by supplying contingency ability for peak load shaving or valley loading [16]. There is considerable variation in national markets because of the different endowments of indigenous fossil fuels and renewable energy potential, levels of technological development, and environmental and energy security risks. As a result, the relative importance of each of the above characteristics defining electricity as a 'mixed good' varies between countries [17].

5. Types of energy sources

5.1 Hydroelectric (hydropower) energy

Hydroelectricity (hydropower) is generated by the gravitational flow of water through the turbine attached to a generator. Most of the hydropower is created from water stored in a reservoir with a wide dam. The largest hydropower plant in China is currently in operation with 22.5 gigawatt (GW). The rising portion of hydroelectricity is created by water flowing down the river straight through the turbine or by water flowing via the pipes and the turbine near the spur of the river before returning to the river, and this form of hydroelectricity is called run-of-the-river hydropower. Advantage of it is that vast areas of land are not submerged behind a dam, but on the other hand, a smaller volume is valuable for storage [18].

Environmental impact relies in some cases on eliminating the likelihood of carbonic acid gas release during power generation. It has been found that areas with hydropower potential that value more highly to utilize the sources of power that depend on fossil fuels emit up to four times more the quantity of greenhouse emission than necessary [19]. This suggests that hydropower production does indeed have the power to cut back greenhouse emissions.

Increased opportunities for hydropower would also result from changes in how electricity markets are run. Sub-hourly scheduling tries to encourage greater participation and compensation for flexibility. Hydropower may be compensated for forward market scheduling. Independent System Operators (ISOs) arranging hydropower resources across several hours or days would also enable hydropower optimization in the context of other resources. This "fixed-schedule" method might boost plant earnings by 63–77%. Why? Because the existing market structure advantages fossil fuel producers with time-independent output. They may burn fuel to create power at any time of day or night. Pumped hydropower or energy-limited hydropower does not have this benefit and must instead guess the lowest cost time to "refuel" and the greatest price time to sell.

5.2 Wind energy

Wind turbines convert the mechanical energy of the wind right into electricity [20]. Wind speed is normally measured at a height of 10 m. The suspensions in the elevation will adjust the wind speed at just a few hundred meters. Hills or mountains have a major impact on wind direction. The technical device, such as the wind turbine, should draw as much input out of the wind as possible with the use of wind power. Wind turbines slow down the wind by transferring energy from wind to electricity. However, the pre-and post-wind turbine mass flow remains steady [21].

The maximum power in the wind extracted from the wind turbine is 59% and with connecting the principle of preserving mass and momentum through a theoretical disk that extracts energy from the air result is called Betz's law [18].

Wind turbines are often found in the coastal region of mountain passes, ridges, and offshore. Onshore wind farms typically consist of some thousands of midsize 1–8 MW generators to power portions of communities. Offshore wind farms typically consist of several to a lot of medium- to large-sized 3–15 megawatt (MW) turbines; for example, one of the 12 W generators specifically built for overseas use has an elevation of about 150 m above the sea level, which means that the rotor capacity is 220 m, which is the height of the Eiffel Tower and can provide electrical energy for approximately 16,000 homes.

Collecting and storing energy from wind turbines is possible using battery storage with electrical batteries, which is a very common type of storage for wind and solar energy. Other solutions could be compressed air storage and hydrogen fuel cells to store energy surplus [22].

To get a perfect score of 100% on the efficiency table, the wind turbine must capture the full kinetic energy of the wind. Using all of the kinetic energy, however, will result in zero velocity or no wind on the other side of the turbine. At the same time, we must keep in mind that these wind turbines are intended to operate at a specific speed that maximizes production. If the wind turbine is designed to produce the most energy at a speed of 20 mph, the highest amount of energy produced will be at that speed, while the amount will be less at lower speeds. For comparison, traditional power plants have a theoretical maximum output or load factor of roughly 50% on average. Although the same is true for wind power, the fact that it is an environmentally benign and renewable source of energy gives it the necessary push. The entire concept that promotes wind power as the best future power source is based on the idea of maximizing output while keeping expenses to a minimum. When the initial cost of infrastructure development and payback time are considered, it is safe to say that wind power is cost-effective in the long run.

5.3 Solar PV

Solar power may be concentrated, better known as concentrated solar power (CSP), through mirrors or reflective lenses that focus sunlight onto a collector containing a fluid to heat the fluid to an extreme temperature; then, the heated fluid flows from the collector to an engine, where a little of it is converted to electricity, and a few kinds of CSP allow the warmth to be stored for several hours. One kind of collector is termed "*long parabolic trough mirror reflectors,* "and therefore, the second type is "*central tower receiver* "with a field of mirrors surrounding it. Within the central power, the focused light heats a circulating storage fluid known as concentrated solar power (CSP). CSP is a dispatchable form of solar power, whereas PV is not to be dispatched. PV only works while the sun is shining. CSP can be dispatched on demand, much like flipping on a solar switch. So, CSP is not competing with PV [23]. During days without sun, a storage plant additionally produces electricity but only for few hours, so basically without storage, the CSP ability to store is around 25%. With storage availability, the capability element raises to around 65%. CSP is great for helping to satisfy the power need and power requirements, and importantly, CSP collectors can ramp their power manufacturing up and down quicker than coal or nuclear plants [24].

Photovoltaic systems demand more maintenance than other forms of energy generation. Solar systems has a tendency to become the greatest source of power generation by boosting the efficiency of solar cells, which is now around 43%, although manufacturing these cells has not yet been accomplished. A battery will never drain below 50%, preventing the cells from deteriorating and thereby increasing the battery's life expectancy. It is evident that a battery with double the amperage must be utilized instead of a battery with the same power as required. All of these elements influence solar system efficiency; therefore, by boosting solar system efficiency, power system stability may be enhanced. As a result, we might claim that this strategy is still one of the most expensive.

5.4 Bioenergy

Bioenergy (from conventional Greek bios, life) is extracted from organic materials such as wood, agricultural products, or organic waste and is originated from a recently produced organic material, known as biomass, as an anti-fossilized biomass fuel. It is also used in electricity, heating, cooling, and transport. It can be used in liquid forms, including biofuels; in gaseous forms, like biogas; or in solid forms. Bioenergy is the oldest form of energy used by humans, but it is also at the forefront of Europe's new attempts to step away from fossil fuels and decarbonize our economy. As a result of European climate and energy policies, the use of bioenergy is increasing exponentially [25]. European policies consider all bioenergy to be renewable energy and the foremost important measure from the EU within the fight against temperature change, so much hope currently lies on the performance of bioenergy. The sustainable use of biomass for heating/cooling and the generation of electricity will result in a variety of energy, economic, employment, and environmental benefits. Biomass can be processed at times of low demand and can be used to provide energy as required. Depending on the type of conversion facility, biomass will also play a role in managing the growing share of intermittent renewable energy from wind and solar energy in the electricity system. The possibility to store biomass enables the production of heat to satisfy seasonal demand. In addition, biomass enables the production of high-temperature heat that cannot easily be provided by other low-carbon sources [26]. In 2011, 95% of bioenergy was consumed as heat, 4.7% as transport fuel, and 72,700 kWh as electricity [27]. As far as bioenergy storage is concerned, the sufficient way to store biomass is to accommodate seasonal production and to ensure daily supply to the biomass utilization facility [28]. Wet storage systems may be used for higher yield intended for wet use, such as in brewing and anaerobic digestion systems, with tight monitoring of storage times to prevent unnecessary depletion of feedstock. Storage structures usually used for dry agricultural residues should be secured against spontaneous combustion and excessive decomposition, and the actual storage moisture depends on the type of storage used [28].

The effectiveness of various biomass-to-energy conversion processes varies greatly. For example, producing electricity from pure biomass is only about 30–35% effective; however, producing heat from the same material is frequently more than 85% efficient. In general, utilizing bioenergy for heat and electricity is a far more efficient approach of decreasing greenhouse gas emissions than using bioenergy for transportation fuel. Organic waste and agricultural or forestry residues are more resource-efficient than many other types of feedstock because they do not place additional strain on land and water resources and offer significant greenhouse gas savings.

5.5 Ocean energy

Oceans cover about 70% of earth's surface area, making them the globe's biggest solar batteries. The installed capacity of ocean energy in 2019 was 530 MW [29]. Sunlight warms the surface area of water by a lot compared to the deep ocean water, and also this temperature-level difference develops thermal power. Simply, a tiny low part of the heat trapped within the ocean might power the planet [30]. Underwater compressed air energy storage (UWCAES) and underwater pumped hydro storage (UWPHS) are the second type of ocean energy storage available at the moment [31]. Air is contained in foldable bags on the seafloor in the UWCAES system. This underwater storage system has a great advantage over its ground equivalent. In standard CAES, air is contained in a tank of a set capacity, while the compressed air releases the pressure within the pipe, which reduces the flow to the turbine. UWCAES systems operate well at depths of 400–700 meters below sea level; this water depth provides the pressure required for most turbine compressors where compressed air energy storage is usually used. Seawater is used as a working solvent instead of air in the UWPHS system. This system uses solid steel or concrete spheres. To 'release' as an energy storage unit, the mechanism allows high-pressure seawater to penetrate the sphere through an opening by means of a turbine attached to the generator. Such energy storage systems are best used in peak-saving grid applications. Round-trip efficiencies for UWCAES and UWPHS are in the range of 70–85%. Concerns on how to create the most efficient energy storage of seawater are still on the way and raise the most important question-how to install them and how to do it cost-effectively [31]?

5.6 Geothermal energy

Geothermal energy is derived from hot water or steam that, in both cases, emanates from hot rocks or soil and exists below the earth's surface. Some of the high-temperature rocks are discovered around volcanic activities as well as low-temperature rocks and soil that we can find everywhere, including in the ice field [18]. Geothermal energy is used to supply heat directly or at high temperature it is able to supply electricity. Lower temperature (0C–120C) is employed to warm buildings, and hot-temperature warmth (120C–400C) is normally used to generate electrical power. For electricity production, there are three types of geothermal plants: flash steam, dry steam, and binary geothermal plant [18]. Energy storage for geothermal energy works by technology that transfers heat energy from underground water to electricity, and after that, extra energy is stored into the underground water. Geothermal storage also has disadvantages such as fluctuation in the binary geothermal plant, mostly used in the US as a heating agent, that can cause more damage than we imagined. If it is used for other purposes, environmental impact is pretty huge, especially when geothermal fluid is not stored and recycled in a pipe, which can then absorb toxic compounds such as arsenic, boron, and fluoride. These poisonous compounds may be taken to the surface and leak as the water evaporates [32].

In the framework of the effectiveness of geothermal energy, we are mainly talking about the fact that geothermal systems can provide any combination of forced-air heating, radiant in-floor heating, domestic hot water, and air conditioning all from the same unit.

The heating efficiency of a geothermal heat pump is assessed by the coefficient of performance (COP), while the cooling efficiency is reflected by the energy efficiency ratio (EER). These metrics relate the number of units of heat given or withdrawn to the number of units of power consumed to complete the task. Ground source heat pumps generally provide 4 units of heat energy for every unit of electricity consumed.

So, we are talking about 400% effectiveness. In comparison, the most efficient conventional systems on the market today are just 98% efficient (**Figures 1** and **2**).

6. Energy storage technologies

Energy storage technology is often classified on the basis of its use in large- or small-scale applications. Flywheels, pumped energy storage, and compressed air storage are among the forms of storage typically used in large scales. Battery systems are expected to have a significant impact on the small-scale installation of clean energy resources in commercial and residential buildings [35]. Some technologies provide short-term energy storage; others can endure for much longer. In short-term response energy storage devices as a short-term duration applications whose big advantage is quick discharging, we identify flywheels or supercapacitors. Moreover, their application prevents the collapse of power systems, and use of short-term response energy system is more practical in terms of renewable energy like wind [36]. Use of long-term energy storage devices is expected to be functional even more in the upcoming years, and these devices are compressed air technology, batteries, or pumping hydro storage. Energy storage contains technologies such as flywheels or flow batteries that are part of a so-called “distributed” storage, and technologies such as PHES or CAES are very important in “bulk” storage [37]. **Figure 3** shows these technologies divided into categories:

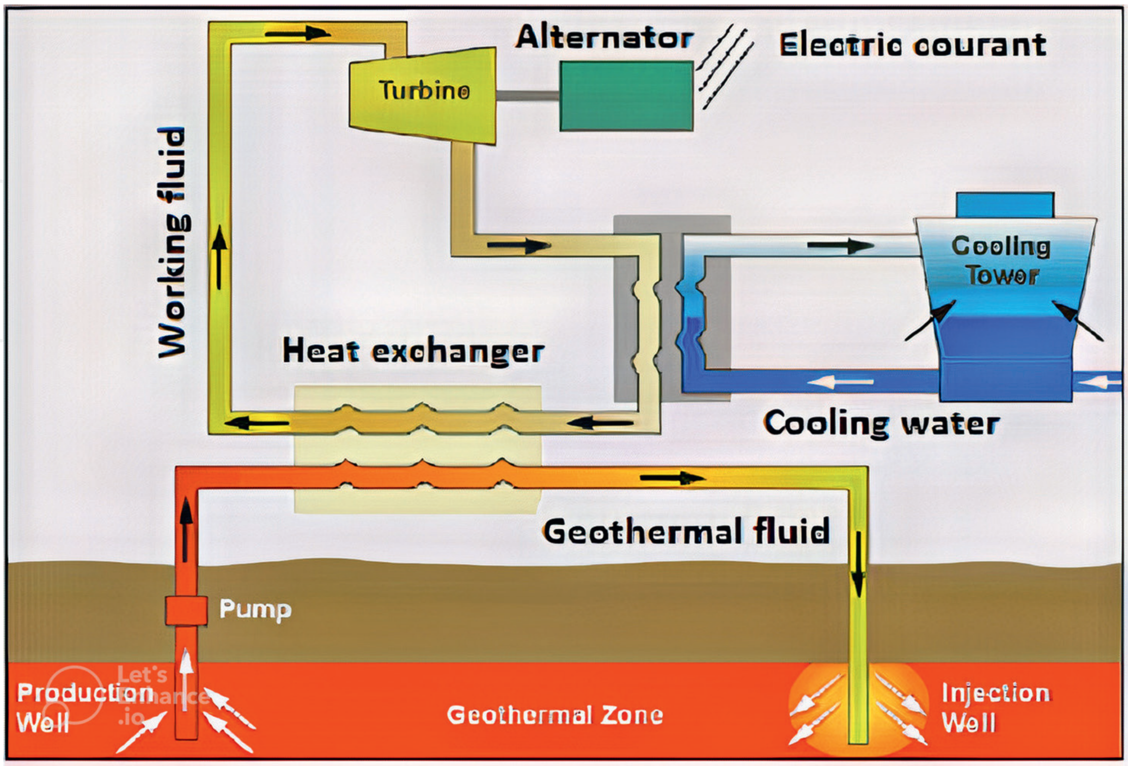

Figure 1.
Schematic of a typical binary cycle geothermal power plant [33].

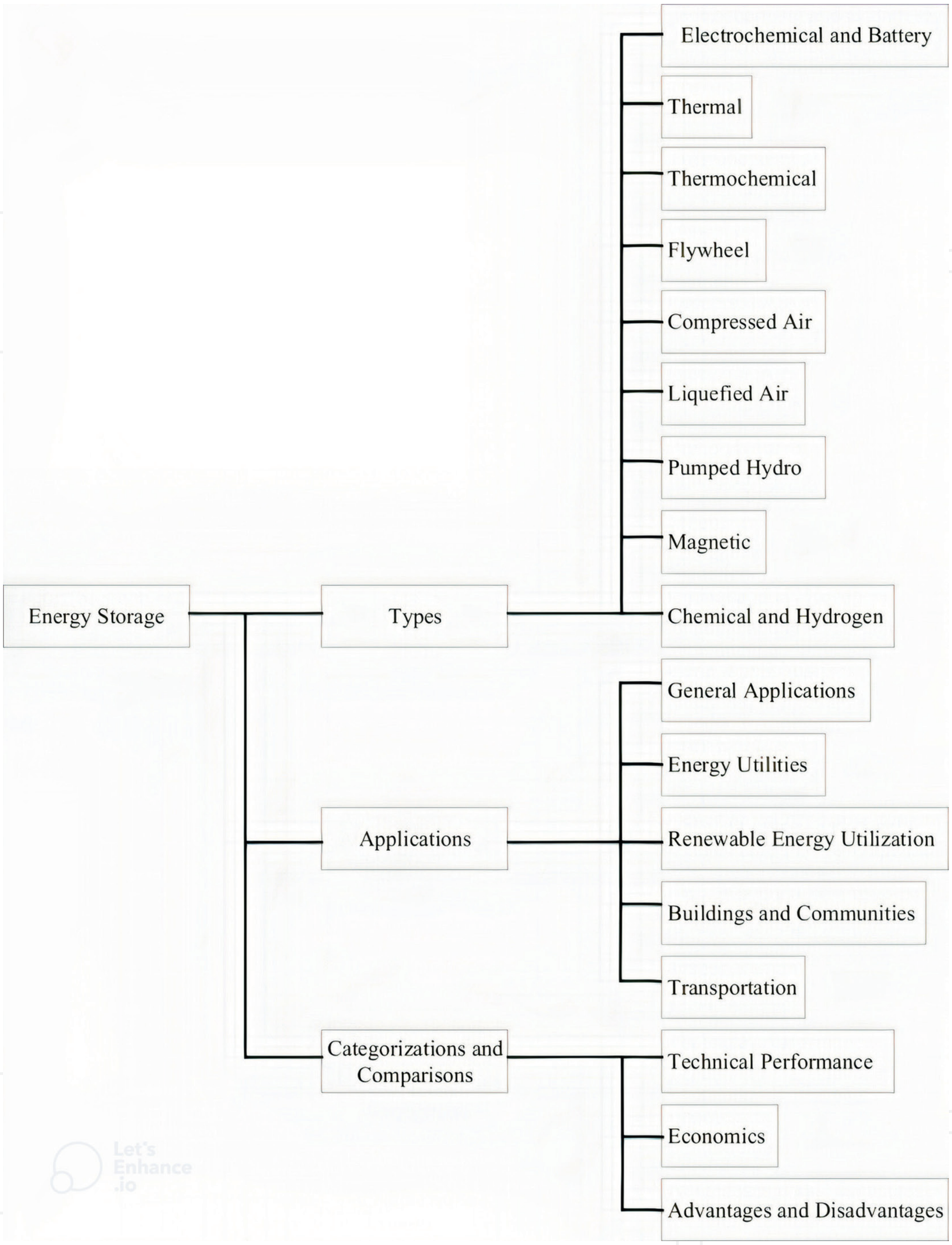

Figure 2.
Storage types and applications [34].

6.1 Battery energy storage system (BESS)

A battery is an electrochemical cell that transforms chemical energy right into electricity. While the battery is filled, the direct current is transformed into chemical energy; when the chemical energy is discharged, it is converted back into the flow of electrons in a direct current form [36]. Batteries are the most common storage devices for electricity. However, the term battery consists of a variety of technologies applying various operating concepts and materials. It is necessary to differentiate between two essential principles of battery: electrochemical and redox flow [36].

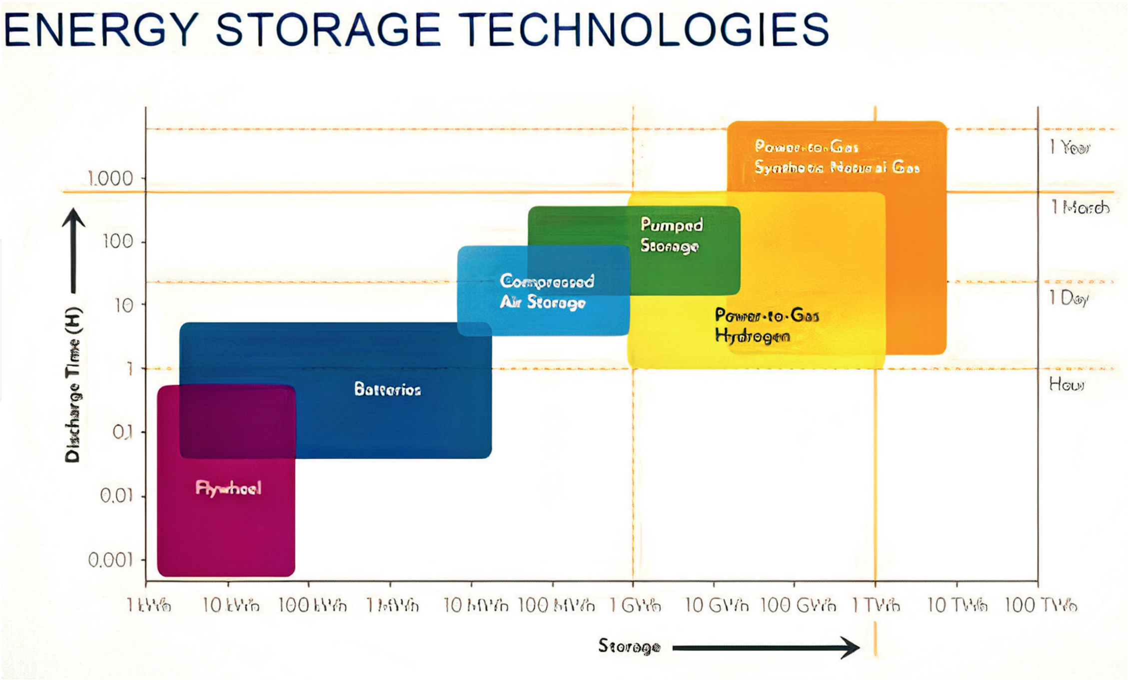

Figure 3.
Energy storage types and their discharge time [38].

Battery-storage growths have mainly focused on transportation systems as well as smaller systems for portable power or periodic backup power, although system dimension and volume are less crucial for grid storage than portable or transport applications [39]. Future utility applications of batteries could be focused on providing peak distribution capability deferral as well as top shaving at the substation along with reliability improvement [40]. Study into battery storage at the grid range is concentrated on longevity for multitudes of charge/discharge cycles and life time, high round-trip-efficiency, capability to react rapidly to adjustments in lots or input, and practical capital costs [41]. Utility packages of batteries in future might be targeted on supplying distribution ability deferral and peak shaving on the substation in addition to reliability enhancement [40]. Batteries are regularly compared to supercapacitors for various energy applications, and it is predicted that exploiting their features (i.e., frequent electricity storage functionality without sacrificing their cycle) by means of integration should help cope with future electric-storage demanding situations. For big-scale electrical storage (e.g., strength from renewable strength sources), the use of flow batteries seems to be the most appropriate option, even though charges and development continue to be a challenge [42]. Attributes of battery storage system are:

Rated power capacity—the overall viable rapid discharge functionality (in kilowatts [kW] or megawatts [MW]) of the BESS, or the maximum rate of discharge that the BESS can obtain, starting from a completely charged position [43].

- Storage capacity—the overall volume of energy stored (in kilowatt-hours [kWh] or megawatt-hours [MWh]).

- Storage length—the amount of time for storage to discharge to its energy capacity earlier than the exhaustion of its energy capacity.

Cycle lifestyle/lifetime—the period of time or cycles that a battery storage unit can deliver daily charging and unloading earlier than loss or full-size deterioration. Self-discharge occurs while the accumulated charge (or energy) of the battery is depleted by internal chemical reactions or when it is not discharged to do work for the grid or the consumer. Self-discharge, calculated as a percentage of the rate misplaced for a given period of time, decreases the amount of energy needed for discharge and is a significant criterion that is not to be ignored in batteries designed for longer-lasting programs [43].

BESSs account for around 5% of worldwide energy storage capacity, far less than pumped-storage hydropower. According to Fortune Business Insights, the global battery energy storage market is estimated to reach €19.74 billion by 2027, growing at a 20.4% compound annual growth rate (CAGR). Given its availability, efficiency, and recent developments in electrochemical storage technology, a BESS is expected to be a leader in energy storage in the next years. Alternatively, on the other hand, it can compete with battery power storage systems, gaining the upper hand in some situations.

6.2 Pumped hydroelectric storage (PHES)

Pumped hydroelectric energy storage (PHES) is the most established storage innovation in the world today. The International Energy Agency (IEA) estimates that PHES installments make an increase in capacity of 26 GW, and energy storage capability of PHES will overtake battery storage globally by 2050. The current storage volume of PHES plants is measured at 9000 GWh, although the battery capacity is just 7 GWh [44]. By 2023, electricity production from PHES has expanded by one quarter to 146 TWh; however, the estimated operating hours of the PHES were considerably unpredictable, and the spectrum of capacity factors was broad due to the uncertainty of market conditions. Storage consist of a reservoir, specifically upper and lower [18], Besides the power stored behind hydropower dams, 97% of all energy stored for electrical usage is currently in the form of pumped hydropower storage [18]. Where current surplus energy or costs are low at the moment, water is pumped through pipelines from the pumping station in the lower reservoir to the upper reservoir, as seen in **Figure 4**. At the same time, as pumped hydro storage is introduced into the grid or the capability of the water reservoirs is more advantageous, the hydropower facility can provide most of the load necessities, obviating the need to build huge top-load fuel mills [46].

Pumped storage hydropower (PSH) systems account for more than 94% of the global energy storage capacity. Water-spinning turbine, as water flows down from a higher tank to a lower reservoir, generates electricity in PSH. This energy storage system (ESS) may provide large storage capacity at a low cost, fulfilling the needs of bigger electrical networks. The difficulty with pumped hydro storage systems is that they take years to create and need significant investments.

6.3 Flywheels

Flywheel energy storage systems use a rapidly rotating flywheel to help convert mechanical energy to electrical energy and back to electrical energy. This system consists of four main parts as follows:

Solid cylinders, bearings, motor/generators, and vacuum-tight housings. To generate kinetic energy, the motor draws energy from the electrical grid to rotate a

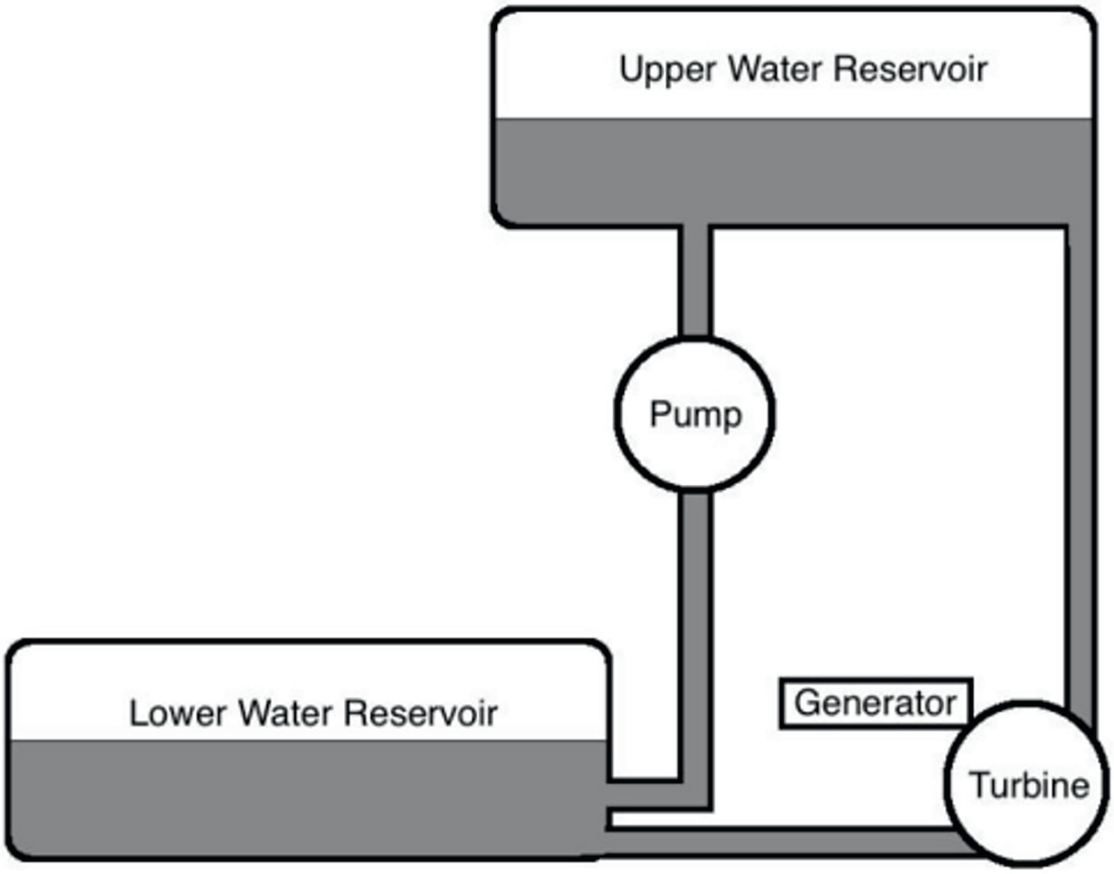

Figure 4.
Pumped hydro storage [45].

cylinder or disc at speeds up to 60,000 rpm. Flywheels are considered "dynamic" energy storage systems because they must be accelerated by an external force before they can store energy. A flywheel is a rotating wheel or disk, mostly made from steel or carbon fiber, that turns around an axis and is usually used in short-term energy storage devices for motion applications such as powertrain engines and road cars. In these applications, the flywheel soothes the power load during deceleration by dynamic braking operation and provides a lift during acceleration [47]. A flywheel generates power as a rotational kinetic energy and later converts the power into electrical energy. The flywheel is an electric motor, a holding system for energy, and a generator at the same time. As excess power is available, the power and electric motor spins the flywheel roughly at a high speed. For the energy applied to the flywheel, a small amount is used to hold the flywheel rotated; the remainder is storage energy [18]. Flywheels are suitable for storing surplus electricity from intermittent solar and wind power on the electrical grid; on the other hand, flywheels cannot conserve an immense amount of power due to the fact that they have a high loss rate, so the generated electrical energy can be consumed very rapidly and has a high loss rate.

Because of these losses, the cost per kWh of energy stored is high, and power-specific costs are relatively low [48].

Simply put, the advantages and disadvantages of flywheels can be summarized as systems notable for their longevity (up to decades), easy maintenance, and fast response time. But they can only operate for a short period of time (**Figure 5**).

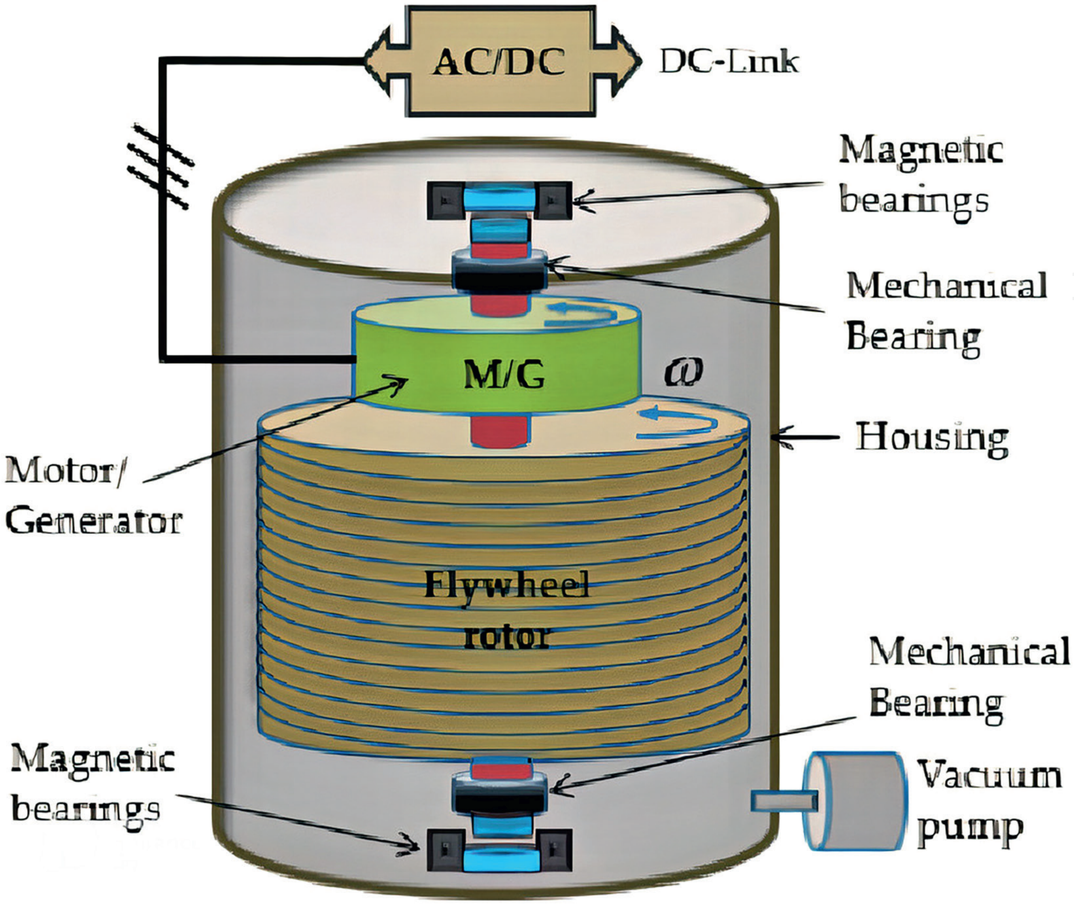

Figure 5.
Flywheel energy storage [49].

6.4 Compressed air energy storage (CAES)

The method to gather periodic renewable power is fixed by utilizing compressed air power storage space. This manner of storage opens up possibilities to keep power for a long-time period and then to resupply that electricity to the grid. Excess recurring electricity is made use of to compress air. Using this form of storage ensures that intermittent renewable energy may be stored for a long period of time, in contrast to flywheels or supercapacitors. The place of CAES is mainly underground, and globally, there are just a few buildings, just one in Europe-Germany and two in the U.S. CAES is normally attached to a power-producing system, such as a wind turbine, and when energy is required, compressed air is expanded and transferred back to a power-extending engine. For better perception, **Figure 6** contains how the CAES system looks exactly.

CAES systems are widely employed in the manufacturing and mining industries. However, adopting this technology in some applications, particularly residential solutions, and their installation itself might be difficult and expensive.

7. Economic aspects of energy storage

Market integration means the process of step-by-step harmonizing of the rules of the various power markets, culminating in the harmonization of all cross-border

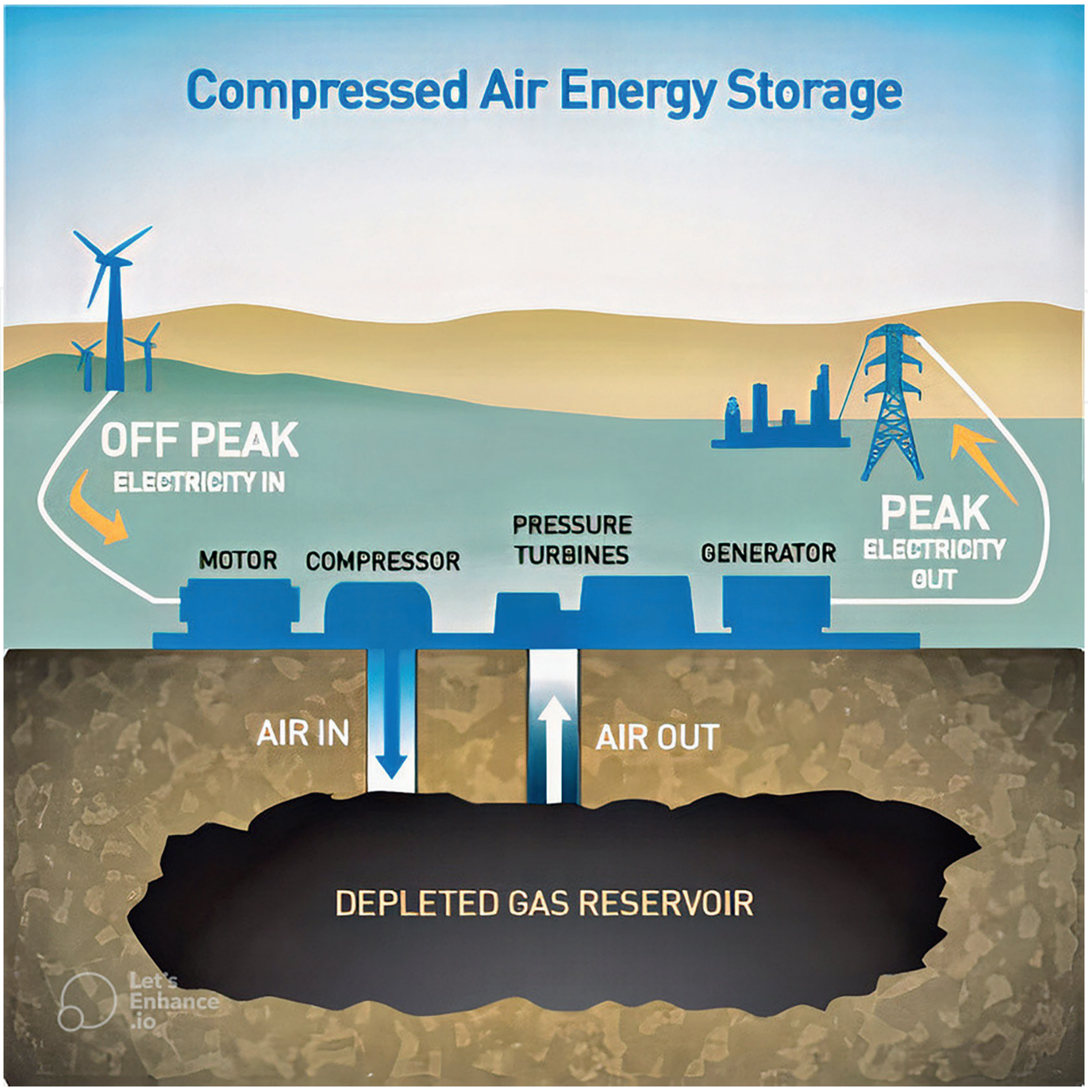

Figure 6.
CAES [50].

market rules that allows electricity to respond to price signals and flow freely across borders (as do goods and services in the internal market).

As several aspects of the evolving modern energy economy, the greatest results come from the cooperation of bringing components mentioned above together in an actively and carefully built system that consists of: dispersed renewable energy generation, scalable baseload infrastructure, smart grid, demand response, and rapid energy storage response [51]. Markets integrate into regional markets for cross border trade of electricity and its continuously increasing.

A reinforced, interconnected European network requires coupled markets, versatile production, increased backup and storage capability, demand response measures, clear worth signals, responsiveness of support, and cost-effectiveness to balance the fluctuation of energy sources across Europe [52]. These are the aspects that help to improve the functioning of the electricity system and financial market [53].

7.1 Energy storage systems costs

The cost of large-scale mechanical storage devices is influenced by location. Pumped hydro systems need locations that can accommodate both a storage reservoir and a sufficient elevation variation to produce potential energy. Compressed air energy storage (CAES), like pumped hydro systems, has been constrained by the availability of natural resources to supply low-cost air storage [54]. Calculation of related costs and operating prices for energy storage devices is a problem because of not only a wide variety of innovations but also a multitude of external factors.

In contrast to pumped hydro and compressed air systems, where the storage medium is virtually free, finding low-cost heat-retaining materials is crucial for thermal storage systems. Although heat may be stored directly as steam, molten salts are the most popular choice since they can reach greater temperatures [55].

Although most studies employ such a meter, there is no globally accepted standard or method for calculating the costs of energy storage, due to the fact that different metrics emphasize different aspects of storage cost and operation.

One way to make apple-to-apple comparisons between storage technologies is through the use of the Leveled Cost of Energy (in this case, the Leveled Cost of Storage or "LCoS"), where the technology per kWh is calculated as a function of the total project life cost divided by the expected lifetime power output. The cost of electricity in this calculation includes any capital expenses associated with electricity generation for direct consumption (ccap, gen), capital expenses for electricity generation that goes to storage (ccap, gen2stor), capital expenses for storage technologies (ccap,stor), fuel (pfuel), or purchased electricity (pelec) costs (accounting for generator-efficiency losses, gen, and round-trip-efficiency losses of storage charge and discharge, RTE), and to compute LCOE, costs may be discounted (using discount rate r) to find the net present value, which is then divided by the discounted quantity of energy provided during the system lifespan (**Figures** 7 and **8**).

Whatever calculation is chosen, one important point to make when calculating the LCOE or LCOS is that the cost is also affected by the demand for electricity or stored energy. Although a storage system may be technically capable of cycling continuously for 24 hours a day, demand is determined by use patterns. This implies that even if a system is built to provide longer-duration storage, actual cycling behavior might mean that the charging and discharging cycles are frequently just a fraction of the installed capacity, limiting the power produced by the system and raising the levelized cost [54]. For example, where a compressed air energy storage (CAES) system may have a higher initial capital cost than a Li-ion battery system, the CAES system's lifetime power output is far higher than the Li-ion battery system (which normally lasts only 10 years), which reduces the LCoS [57].

However, the LCoS formula does not adequately represent other crucial points, including spatial limitations (vital for CAES and pumped hydro systems), safety issues about battery explosions, and technological features that are best suited for various applications. Seems that we are still in the process of creating or implementing a

$$LCOS = \frac{\Sigma(Capital_t + O\&M_t + Fuel_t) \cdot (1 + r)^{-t}}{\Sigma MWh_t \cdot (1 + r)^{-t}}$$

Figure 7.
LCoS calculation [56].

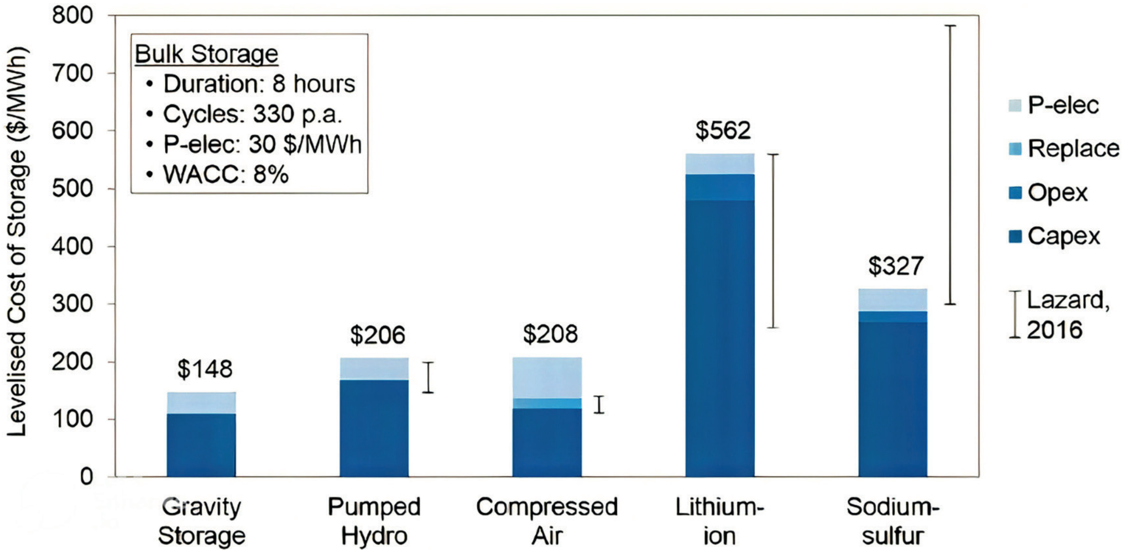

Figure 8.
LCos calculation based on different storage types [57].

formula for calculating energy storage efficiency that would take into account all the abovementioned parameters.

Other costs to consider are:

- Construction and commissioning

C&C expenses, also known as engineering, procurement, and construction (EPC) costs, include site design costs, equipment purchase/transportation costs, and labor/parts for installation [58]. Cost reductions for C&C are not likely to be as significant since these expenses are more mature than those that are more directly related to each technology. The cost of grid integration is primarily determined by the system footprint and weight (with discrete steps in costs), the degree of factory assembly versus on-site assembly (the total cost may be the same regardless of where the assembly occurs), and the architecture (open racks vs. containerized systems) [59]. The literature consensus C&C expenses were raised by 15% for the technology with the lowest energy density indicated as the highest liters per watt-hour (L/Wh). This figure was multiplied by the normalized volume per watt-hour multiplied by 0.33 to obtain a lithium-ion C&C cost of €100/kWh, which is somewhat higher than the €80/kWh reported by McLaren et al. [60]. While improvements have been achieved in recent years, the anticipated C&C cost of €100/kWh is on the low end of current forecasts, with minimal room for future cost reduction owing to “learning.”

- Operations and maintenance

Expenses that are necessary to maintain the functionality of the storage system during the period of its economic lifespan are linked to the demand for energy. According to the available literature, fixed O&M costs for all battery chemistries range between 6 and €20 per kW-year, with the majority falling between €6 and €14 per kW-year [58]. While lithium-ion batteries may have higher costs for safety and battery management systems (BMSs), the larger size of other battery technologies can result in higher O&M costs, and their relatively safe operational characteristics contribute to lower O&M costs.

7.2 Financial instruments and support

A number of public or private funding instruments are currently in operation in European countries to promote renewable energy and energy storage itself. The choice of instruments depends on the point at which technology or projects are created. The bulk of funding instruments come into three primary categories:

- Energy market tools (feed-in tariffs, premium, green bonds, tenders, fiscal incentives);
- Equity funding mechanisms (venture capital, equity, R&D grants, capital/project grants, contingent grants);
- Debt financing mechanisms (mezzanine debt, senior debt, guarantees).

The criterion used to test the funding systems, the financial instruments, and the support are as follows:

Efficiency-applies, on the one hand, to extra generation costs and, on the other, to regulation costs. Although the additional generation costs reflect the welfare effects in general, the policy costs additionally consider the distributional effects or the issue of which stakeholder pays for the additional costs.

Effectiveness- analyzes the effect of funding systems on the business diffusion of clean energy technology.

Certainty for investors-the degree to which policy instruments are capable of minimizing the uncertainties of energy and renewable energy ventures, which could be of a fiscal, technical, or political type.

Long-term competitiveness.

Market compatibility (only applicable to help schemes, not applicable) [61].

7.3 Financial benefits of energy storage

Energy management is a critical issue for businesses seeking to maintain and reduce operational costs. Energy storage systems give businesses the control over distributed energy resources, allowing them to save money on demand charges, provide critical continuous power to protect against grid variability, and better integrate renewable energy sources to foster more sustainable and financially sound business practices. Every planning and execution approach should be connected to the real-time control and organizational functionality of the ESS in conjunction with Distributed Energy Resources (DER) in order to achieve a rapid integration process [62].

The bulk of C&I-scale(commercial and industrial) facilities must pay demand charges based on peak power use. This expense often accounts for 30–70% of the total energy expenditures on a commercial electric bill. Energy arbitrage can result in significant cost savings by discharging energy during peak usage and cost periods, reducing load during those peak periods, and resulting in lower demand charges.

Load shifting is a critical component of this method for lowering energy expenses. BESS (described in Chapter 5 (5.1)) and related software assess consumption patterns and storage to efficiently identify the ideal time to charge and discharge stored energy, moving peak loads to off-peak hours.

Finally, BESS may be utilized to "smooth out" grid fluctuations, effectively becoming the major source of site power and relegating the grid to a secondary energy source. This allows the site to not only disregard grid power outages (and the possible expenses associated with them), which are limited only by the site's storage capacity, but also maintain a constant power factor and eliminate any grid oscillations that may compromise sensitive equipment.

Moreover, the energy storage could be used to adjust the amount of electricity produced from renewable energy sources. Energy is retained when demand and energy prices are low so that it can be used when.

a. demand and energy prices are high and

b. output from intermittent renewable energy production is low [62].

- Cost avoid or revenue gain of ancillary services: it is well-recognized that energy storage can provide many forms of ancillary services. In short, they are what could be considered support facilities that are used to keep the municipal grid running. Two of the more common ones are: the spinning reserve and the accompanying load [63].

- Cost saving or revenue improvement by bulk energy arbitration: Arbitration includes the procurement of low-cost power available during low-demand storage times so that low-priced energy can be used or sold at a later time when the price of electricity is high.

At present, in many parts of Europe, energy storage projects have to pay for both extracting electricity from the grid and pumping power into it, and this legacy policy has long been seen as both a major obstacle to making an economic argument for energy storage and one that could be overcome reasonably quickly. The Committee of Members of the European Parliament (MEPs) has recently pointed out that this is one of a number of 'shortcomings' in network codes across Europe. Further changes will be made to the European Energy Taxation Directive in 2023 to 'ensure a harmonized taxation on all storage and hydrogen production.' In the meantime, the EU also responded to the fact that the share of energy costs charged as tax is much higher than energy consumption itself [64], i.e. one of the appropriate and important steps and solutions should be to tax reduction.

8. Environmental impacts and future promising technologies for renewable storage

Key environmental impacts include: lifetime energy efficiency, lifecycle greenhouse gas emissions, supply chain criticality, material intensity, recyclability, and environmental health and social impacts as and safety and human rights. Energy efficiency of the life cycle is important since high performance sustained over a long planned lifetime minimizes the criteria for technological uptake and the related impacts. Supply chain criticality recognizes not only the geological availability of essential commodities but also the possible supply chain vulnerabilities and threats associated with fiscal, technical, social, or geopolitical influences. Owing to the high usage of nonrenewable materials in main energy storage systems, content intensity is an important parameter. Battery storage systems typically have a higher material density relative to other technologies.

The recyclability of battery storage technologies has the capacity to minimize high material intensity by recycle, reuse, or remanufacturing. Poor recyclability highlights the need to implement innovative approaches to infrastructure and technologies [65].

Environmental health is significant as an adverse effect on habitats or human health. The supply chain will negate the benefits of moving into a green energy system. Since batteries are material-intensive technologies, they have the most important impacts. The effect varies depending on the location of extraction, manufacturing, and end-of-life due to variations in technologies, production pathways, and local environmental and social norms. The most important mining impacts in China include pollution and water and soil emissions from lead, graphite, and phosphate mining, both of which have severe health impacts. There are important human rights impacts associated with the resource market for lithium-ion batteries, in particular lithium and cobalt. Cobalt mining is mostly undertaken by artisanal and small-scale miners who work in precarious environments in handheld mines without adequate protective equipment and widespread child labor.

8.1 Storage and future

Targets aimed at zero emissions are more difficult and costly than net-zero goals, which utilize negative emissions technology to achieve a 100% reduction. Pursuing a zero, rather than net-zero, aim for the energy system may result in high power costs, making the achievement of economy-wide net-zero emissions by 2050 more difficult.

Storage can help poor countries lower their power costs while also delivering local and global environmental advantages. Lower storage costs enhance both the savings in electricity and the environmental advantages.

For example, E-mobility as one of the possible solutions for energy storage in coming years seems realistic. E-mobility is expanding, and now we are seeing hybrid vehicles, e-bikes, scooters, and kick bikes on the streets. They will shortly be followed by more fuel cell vehicles running on hydrogen. The use of all these vehicles will be expanded beyond their planned use as means of transport to also provide energy storage: they will charge when renewable energy is available in the system and feed back into the micro-grid battery as required. Such vehicle-to-grid and vehicle-to-building systems will become more prevalent as regulatory barriers are eliminated. With compact storage with more secure solid-state batteries and hydrogen bottles, our phones will never run out of batteries again [66]. Emerging battery storage systems would reduce energy storage costs and boost new opportunities in the energy market. In the coming decades, we are anticipating new types of batteries, such as solid-state batteries, to increase the efficiency of airplanes, vehicles, or medical devices. The other alternatives are sulfur-based chemistries, as their continued development would ensure the appropriate use of renewable-grid installations or magnesium batteries, which may meet their maximum capacity and be ready for commercialization within the next 5 years [67].

We can utilize energy more efficiently and reduce carbon emissions by storing it. Energy storage capacity would need to expand from 140 GW in 2014 to 450 GW in 2050 to keep global warming below 2°. Currently, just 3–4% of the power generated by utilities worldwide is stored.

Conclusion? We still have a long and difficult road ahead of us.

9. Conclusion

Arising from government policies to minimize greenhouse gas emissions and improve economic feasibility combined with storage, clean energy sources and more advanced storage systems in comparison of 20 years ago will inevitably increase dramatically over the next decades. To find out how this 'Grid of the Future' will look and work is a global problem that every nation will have to face in its own way. This continues to be a main theme of future studies, as developed and emerging countries face a wide variety of problems in terms of energy and power systems. While the prospects for decarbonizing the energy market are facing significant challenges in terms of technical breakthroughs, stationary energy storage has already achieved a competitive edge, partially due to cost declines in the production of batteries. The increase of incorporation of storage would lead to closer relations between supply and demand in the transition to a decarbonized energy environment. As a consequence, the value of the device would not depend on the volume and size of the hardware used, as is the case for current storage modes (hydro- or fossil fuel-based). Storage should also be known as an additional type of investment in grids (copper grid lines), an aspect of demand for service responsiveness, and a stabilizing factor for power grids. The energy storage market is increasingly shifting from an equipment-based industry to a service-based industry where various device players (generators, grid managers, aggregators, and final customers) will be given access to storage-related facilities. This summary of energy storage shows the future role of emerging services in the transition of energy systems. However, regulation and implementation of new market rules across MS in the EU are essential. In conclusion, despite all the above market problems, incomplete regulations, and the lack of legislation, the most important human factor is the ability to cooperate that EU member states must understand and ensure the functioning of the renewables market and their subsequent storage.

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Conflict of interest

"The author declares no conflict of interest."

Notes/thanks/other declarations

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References

[1] Carnegie R, Gotham D, Nderitu D. Preckel Utility Scale Energy Storage Systems Benefits, Applications, and Technologies. State Utility Forecasting Group. Indiana, United States: Purdue University, Energy center, Indiana Utility regulatory commission; 2013

[2] Irina S. Renewable Energy Storage Possibilities. Saarbrucken, Germany: AV Akademikerverlag; 2013

[3] Mishra S. Efficient Power Flow Management and Peak Shaving in a Microgrid-PV System. Tulsa, USA: Transmission Planning Engineer, American Electric Power

[4] European Commision. Communication from the Commission to the European Parliament 339 and 340. Brussels, Belgium: European Commission, European Union; 2015

[5] IRENA, Adapting Renewable Energy Policies to Dynamic Market Conditions. In 2014

[6] Cleary T, Ballew B. Electrical energy storage hardware-in-the-loop simulation of a hybrid electric diesel and electric only locomotive. In: 2015 Joint Rail Conference. San Jose, California, United States: American Society of Mechanical Engineers; 2015

[7] Thieblemont H, Haghighat F, Ooka R, Moreau A. Predictive control strategies based on weather forecast in buildings with energy storage system: A review of the state-of-the art. Energy and Buildings. 2017;**153**:485-500. DOI: 10.1016/j.enbuild.2017.08.010

[8] Energy storage. Energy.Gov. Available from: https://www.energy.gov/oe/energy-storage

[9] Swinkels V. Bottlenecks for Energy Storage in Europe – And how to Address Them. SQ Consult based in Netherlands, written with cooperation of Fraunhofer ISI in Karlsruhe, Germany and Universitat de Catalunya in Barcelona, Spain. Available from: https://www.sqconsult.com/en/news/bottlenecks-for-energy-storage-in-europe-and-how-to-address-them

[10] Ould Amrouche S, Rekioua D, Rekioua T, Bacha S. Overview of energy storage in renewable energy systems. International Journal of Hydrogen Energy. 2016;**41**(45):20914-20927. DOI: 10.1016/j.ijhydene.2016.06.243

[11] Round trip efficiency. Energymag. Cameron Thouati, Energy storage blog, www.energymat.net, Hartland Wisconsin. 2014. Available from: https://Energynet/round-trip-efficiency/

[12] Esteban M, Zhang Q, Utama A. Estimation of the energy storage requirement of a future 100% renewable energy system in Japan. Energy Policy. 2012;**47**:22-31. DOI: 10.1016/j.enpol.2012.03.078

[13] Delucchi MA, Jacobson MZ. Meeting the world's energy needs entirely with wind, water, and solar power. The Bulletin of the Atomic Scientists. 2013;**69**(4):30-40. DOI: 10.1177/0096340213494115

[14] Czisch G, Giebel G. Realisable scenarios for a future electricity supply based 100% on renewable energies. In: Energy Solutions for Sustainable Development. Denmark: Risø National Laboratory; 2007

[15] Widen J. Correlations between large-scale solar and wind power in a future

scenario for Sweden. IEEE Transactions on Sustainable Energy. 2011;**2**(2):177-184. DOI: 10.1109/tste.2010.2101620

[16] Zsiborács H, Baranyai NH, Vincze A, Zentkó L, Birkner Z, Máté K, et al. Intermittent renewable energy sources: The role of energy storage in the European power system of 2040. Electronics (Basel). 2019;**8**(7):729. DOI: 10.3390/electronics8070729

[17] Hall PJ, Bain EJ. Energy-storage technologies and electricity generation. Energy Policy. 2008;**36**(12):4352-4355. DOI: 10.1016/j.enpol.2008.09.037

[18] Jacobson MZ. 100% Clean, Renewable Energy and Storage for Everything. Cambridge, England: Cambridge University Press; 2020

[19] Severnini E. The unintended impact of ecosystem preservation on greenhouse gas emissions: Evidence from environmental constraints on hydropower development in the United States. PLoS One. 2019;**14**(1):e0210483. DOI: 10.1371/journal.pone.0210483

[20] American Geosciences Institute. What are the advantages and disadvantages of offshore wind farms?. Alexandria, Virginia: American Geosciences Institute. Online article. 2016;**1**:1-1. Available from: http://www.americangeosciences.org/critical-issues/faq/what-are-advantages-and-disadvantages-offshore-wind-farms

[21] Quaschning V. Understanding Renewable Energy Systems. London, England: Earthscan; 2004

[22] Arnold B. Collecting and storing energy from wind turbines [Online]. 2014;**1**:2-7. Available from: https://www.azocleantech.com/article.aspx?ArticleID=488

[23] Kraemer S. CSP doesn't compete with PV - It competes with gas. SolarPACES. 2017;**1**:1-1. Available from: https://www.solarpaces.org/csp-competes-with-natural-gas-not-pv/

[24] Concentrating Solar Power. Stanford.edu. Available from: http://large.stanford.edu/courses/2013/ph240/rajavi1/

[25] Eubioenergy.com. Available from: https://www.eubioenergy.com/whatisbioenergy/

[26] European Commision. Commission Staff Working Document State of Play on the Sustainability of Solid and Gaseous Biomass Used for Electricity, Heating and Cooling in the EU. Brussels, Belgium: European Commission, European Union; 2014

[27] Available from: http://chrome-extension://gphandlahdpffmccakmbngmbjnjiiahp or https://usewoodfuel.co.uk/wp-content/uploads/2020/01/aebiom_european_bioenergy_outlook_2013.pdf

[28] Zafar S. Biomass Storage Methods. Salman Zafar: Blogging Hub; 2021. Available from: https://www.cleantechloops.com/strorage-biomass/

[29] Ocean energy. Irena.org. . Available from: https://www.irena.org/ocean. [Accessed: November 30, 2022]

[30] Wikimedia.org. Available from: https://upload.wikimedia.org/wikipedia/commons/c/c7/High_School_Earth_Science_14-26.pdf

[31] Ocean Energy Storage. The Liquid Grid. 2017. Available from: http://www.theliquidgrid.com/marine-clean-technology/marine-energy-storage. [Accessed: November 30, 2022]

[32] White DE. Geothermal energy. Bulletin of Volcanology. 1966;**29**(1):481-483. Available from: https://www.

nationalgeographic.org/encyclopedia/geothermal-energy/. [Accessed: November 30, 2022]

[33] Ouali S, Hazmoune M, Bouzidi K. Low temperature geothermal energy for rural development. Antalya, Turkey: Researchgate.net. 07-10 October 2015:1-8. Available from: https://www.researchgate.net/publication/283499353. [Accessed: 3 Feb, 2023]

[34] Journal of Energy Storage editors. Science Direct-review of Energy Storage Types. Vol. 272020

[35] Hemmati R. Technical and economic analysis of home energy management system incorporating small-scale wind turbine and battery energy storage system. Journal of Cleaner Production. 2017;**159**:106-118. DOI: 10.1016/j.jclepro.2017.04.174

[36] Faias S, Santos P, Sousa J, Castro R. An overview on short and long-term response energy storage devices for power systems applications. Renewable Energy and Power Quality Journal. 2008;**1**(06):442-447. DOI: 10.24084/repqj06.327

[37] Elgqvist E. Energy Storage Economics. U.S.A: National renewable energy laboratory; 2017

[38] Energy Storage – HiSoUR – Hi so you are [Internet, Hisour.com.]. Available from: https://www.hisour.com/energy-storage-42824/

[39] Battery Storage to Drive the Power System Transition. Europa.eu. Available from: https://ec.europa.eu/energy/sites/ener/files/report

[40] Joint Legislative Commission on Energy Policy. Deq.nc.gov. Available from: https://deq.nc.gov/media/17484/download

[41] Mohamad F, Teh J, Lai C-M, Chen L-R. Development of energy storage systems for power network reliability: A review. Energies. 2018;**11**(9):2278. DOI: 10.3390/en11092278

[42] European Comission directorate. The Future Role and Challenges of Energy Storage. Available from: http://chrome-extension://gphandlahdpffmccakmbngmbjnjiiahp or http://www.fze.uni-saarland.de/AKE_Archiv/AKE2014H/Vortraege/AKE2014H_04BemtgenEU2014_EnergyStorageStrategyPaper_36p.pdf

[43] Grid Integration toolkit, Grid- Scale Battery Storage. Nrel.gov. Available from: https://www.nrel.gov/docs/fy19osti/74426.pdf

[44] 2018 hydropower status report. Hydropower.org. Available from: https://www.hydropower.org/publications/2018-hydropower-status-report. [Accessed: November 30, 2022]

[45] Blonbou R, Monjoly S, Bernar J-L. Dynamic Energy Storage Management for Dependable Renewable Electricity Generation. London, UK: Energy Storage - Technologies and Applications. InTech; 2013

[46] Benitez LE, Benitez PC, van Kooten GC. The economics of wind power with energy storage. Energy Economics. 2008;**30**(4):1973-1989. Available from: https://econpapers.repec.org/article/eeeeneeco/v_3a30_3ay_3a2008_3ai_3a4_3ap_3a1973-1989.htm. [Accessed: November 30, 2022]

[47] The renewable electron economy part VII: Stationary energy Storageâ⇆¦Key to the renewable grid. Futurelab. 2007. Available from: https://www.futurelab.net/blog/2007/10/renewable-electron-economy-part-vii-stationary-energy-storage%C3%A2%C2%80%C2%A6key-

renewable-grid. [Accessed: November 30, 2022]

[48] Luo X, Wang J, Dooner M, Clarke J. Overview of current development in electrical energy storage technologies and the application potential in power system operation. Applied Energy. 2015;**137**:511-536. DOI: 10.1016/j.apenergy.2014.09.081

[49] Analysis of Standby Losses and Charging Cycles in Flywheel Energy Storage Systems Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Structure-and-components-of-flywheel-energy-storage-system-FESS_fig1_343930266 [Accessed: December 1, 2022]

[50] Compressed Air Energy Storage (CAES). Pge.com.. Available from: https://www.pge.com/en_US/about-pge/environment/what-we-are-doing/compressed-air-energy-storage/compressed-air-energy-storage.page

[51] Siegel RP. The pros and cons of energy storage systems. Triple Pundit: People, Planet, Profit. Abgerufen am 04. 2017 von. 2017;**1**:1-1. Available from: http://www.triplepundit.com/special/energy-options-pros-and-cons/energy-storage-systems-pros-cons/

[52] Of the european parliament and of the council of 5. On the Internal Market for Electricity (Recast) (Text with EEA Relevance). Official Journal of the European Union; 2019

[53] Commission staff working document, European Commission Guidance for the Design of Renewables Support Schemes

[54] Hittinger E, Ciez R. Modeling Costs and Benefits of Energy Storage Systems. TA – Annual Review of Environment and Resources. Princeton, New Jersey. 2020;**45**(1):445-469. Available from: https://www.annualreviews.org/doi/abs/10.1146/annurev-environ-012320-082101

[55] Liu M, Tay N, Bell S, Belusko M, Jacob R. Review on Concentrating Solar Power Plants and New Developments in High Temperature Thermal. 2016

[56] Available from: Resource-innovations.com or https://www.resource-innovations.com/resources/lcos-key-metric-cost-energy-storage. [Accessed: November 30, 2022]

[57] Lazard. Lazard's levelized cost of storage analysis—version 7.0. Available from: https://www.lazard.com/media/451882/lazards-levelized-cost-of-storage-version-70-vf.pdf

[58] Energy storage publications. DNV. Available from: https://www.dnv.com/power-renewables/energy-storage/energy-storage-publications.html?. [Accessed: November 30, 2022]

[59] Mongird K, Viswanathan V, Balducci P, Alam J, Fotedar V, Koritarov V, et al. An evaluation of energy storage cost and performance characteristics. Energies. 2020;**13**(13):3307. DOI: 10.3390/en13133307

[60] McLaren J, Gagnon P, Anderson K, Elgqvist E, Fu R, Remo T. Battery Energy Storage Market: Commercial Scale, Lithium-ion Projects in the U.S. United States. 2016:4-13. Available from: https://www.osti.gov/servlets/purl/1337480

[61] Financing Renewable Energy in the European Energy Market. 2011

[62] Ibrahim H, Adrian I. Techno-Economic Analysis of Different Energy Storage Technologies. Energy Storage - Technologies and Applications, January. InTech. 2013:8-10. DOI: 10.5772/52220.2

[63] Mohd A, Ortjohann E, Schmelter A, Hamsic N, Morton D. Challenges in integrating distributed energy storage systems into future smart grid. In: 2008 IEEE International Symposium on Industrial Electronics. Cambridge, United Kingdom: IEEE; 2008

[64] European association for storage of energy. The Way Forward for EnergyStorage Grid Fees. General Overview and Best Practices Across Member States. Brussels, Belgium: Lidia Tamelini, European Association for storage of energy. 2022. Available from: http://chrome-extension://gphandlahdpffmccakmbngmbjnjiiahp or https://ease-storage.eu/wp-content/uploads/2022/07/2022.07.07_The-Way-Forward-for-Energy-Storage-Grid-Fees_EASE.pdf

[65] Florin N, Dominish E. Report Prepared by the Institute of Sustainable Futures for the Australian Council of Learned Academies. 2017

[66] Sweco Group, Maria Xylia, Julia Svyrydonova, Sara Eriksson, Aleksander Korytowski. Urban Energy Report beyond the tipping point: Future energy storage. Urban Insight 2019;**1**:38-44. Available from: https://www.swecourbaninsight.com/urban-energy/beyond-the-tipping-point-future-energy%20storage/ [Accessed: November 30, 2022]

[67] Energy focus, magazine from the energy industries council, Towards the Ion Age. 2019