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Review

Renewable Energy and Energy Storage Systems

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Abstract: The use of fossil fuels has contributed to climate change and global warming, which has led to a growing need for renewable and ecologically friendly alternatives to these. It is accepted that renewable energy sources are the ideal option to substitute fossil fuels in the near future. Significant progress has been made to produce renewable energy sources with acceptable prices at a commercial scale, such as solar, wind, and biomass energies. This success has been due to technological advances that can use renewable energy sources effectively at lower prices. More work is needed to maximize the capacity of renewable energy sources with a focus on their dispatchability, where the function of storage is considered crucial. Furthermore, hybrid renewable energy systems are needed with good energy management to balance the various renewable energy sources' production/consumption/storage. This work covers the progress done in the main renewable energy sources at a commercial scale, including solar, wind, biomass, and hybrid renewable energy sources. Moreover, energy management between the various renewable energy sources and storage systems is discussed. Finally, this work discusses the recent progress in green hydrogen production and fuel cells that could pave the way for commercial usage of renewable energy in a wide range of applications.

Keywords: large scale renewable energies; solar energy; wind energy; biomass energy; hybrid renewable energy; energy management; green hydrogen; energy storage systems; fuel cells

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1. Introduction

Population expansion and technological advancements have led to an exponential increase in fossil fuel usage, which is limited in resources and has significant environmental consequences reflected in global warming and climate change [1–3]. Therefore, researchers worldwide are searching for different methods to reduce or eliminate fossil fuel usage. Fossil fuels usage, and consequently its contribution to climate change, can be effectively reduced through the implementation of three distinct strategies: (a) enhancing the efficiency of conventional power conversion devices/systems through waste heat recovery [4–6]; (b) developing efficient energy conversion devices that are friendly to the environment, such as fuel cells [7–9]; and finally, (c) a shift toward renewable energies that comes from nature and have minimal negative effects on the environment [10–12]. In general, using renewable energy is the most attractive method as it could significantly decrease the usage of or even eliminate the reliance on fossil fuels. In the last decade, there has been rapid growth in the production and usage of renewable energies. Some of them are applied for generating power at a mega-scale, such as the case of solar energy [13,14], wind energy [15–17], biomass energy [18,19], and ocean energy [20,21]. Table 1 shows some of the large-scale projects implemented worldwide.

Table 1. Examples of the largest renewable energy projects of different technologies around the world.

Power Plant Name	Technology	Country	Year	Installed Capacity (MW)	Reference
Three Gorges Dam	Hydroelectric Power	China	2003	22,500	[22]
Itaipu Dam	Hydroelectric Power	Brazil and Paraguay	1984	14,000	[23]
Bhadla Solar Park	Photovoltaics	India	2018	2245	[24]
Longyangxia Dam Solar Park	Photovoltaics & Hydroelectric Power	China	2015	2130	[25]
Huanghe Hydropower Hainan Solar Park	Photovoltaics	China	2020	2200	[26]
Gansu Wind Farm	On-Shore Wind Farm	China	2009	7965	[27,28]
Alta Wind Energy Center	On-Shore Wind Farm	United States	2010	1550	[28]
Muppandal wind farm	On-Shore Wind Farm	India	-	1500	[28]
Ironbridge power plant	Biomass Power Plant	United Kingdom	2012	740	[29]
Alholmens Kraft Power Plant	Biomass Power Plant	Finland	2002	240	[30,31]
Polaniec biomass power plant	Biomass Power Plant	Poland	2012	220	[32]
Ouarzazate Solar Power Station	Parabolic trough and solar power tower (CSP)	Morocco	2016	580	[33]
Ivanpah Solar Power Facility	solar power tower (CSP)	United States	2014	377	[34]
Mojave Solar Project	Parabolic trough (CSP)	United States	2014	280	[35]

While the various renewable energy sources have promising features, they are mostly intermittent and thus, need to be integrated with other renewable energy resources and/or proper energy storage systems [36,37]. The need for flexible high-capacity energy storage in the power system will grow as renewable energy consumption rises over 80% [38]. Flexibility in power systems refers to its ability to ensure a supply-demand balance, maintaining continuity in unpredictable scenarios [39]. Weather variations contribute to the intermittent nature of electricity generation from some types of renewable sources, such as solar and wind energies. Calm days can lower the power-generating capacity of wind turbines by 100%, while on cloudy days, the capacity of solar power plants can be reduced by up to 70%. This is closely tied to fluctuations in power output from traditional power plant generators and variability in load demand. With the rising integration of unpredictable renewable energy sources into the power grid, this challenge has grown in importance and complexity [40]. Therefore, developing various renewable energies requires developing energy management systems that optimize the overall performance of the energy system using modern techniques, such as artificial intelligence, and adequately managing the hybrid renewable energy/energy storage systems to reduce the effects of the intermittent nature of renewable energy sources. This work covers the following points: (1) the recent progress in commercial renewable energy sources focusing on solar energy, wind energy and biomass energy; (2) the progress in hybrid renewable energy resources/energy storage systems; (3) the development of various energy management systems to optimize performance; and (4) emerging topics that are effectively used for the deployment of renewable energy sources at commercial scales, such as green hydrogen and fuel cells.

2. Solar Energy

Solar energy is one of the renewable energy sources that is available worldwide. Solar energy, whether solar thermal [41] or solar PV [42], has already been applied in various applications, such as residential [43], desalination [44], transportation [45], drying [46], irrigation [47], etc. In this regard, several works have been done to cover part of these developments and applications. Concentrated Solar Power (CSP) technologies are one of the promising technologies for generating both heat and electricity. Globally, significant investments have been made in the development of these technologies. Since 2005, various commercial systems have been installed. However, we lack the necessary experience to develop CSP into a dependable, low-cost power source. Line focus, which focuses solar energy along a collector's focal length (parabolic trough collectors and linear Fresnel reflectors), and point focus, which focuses the energy of the sun on a point (solar thermal towers and parabolic dishes), are the two types of solar collectors used [48], as shown in Figure 1.

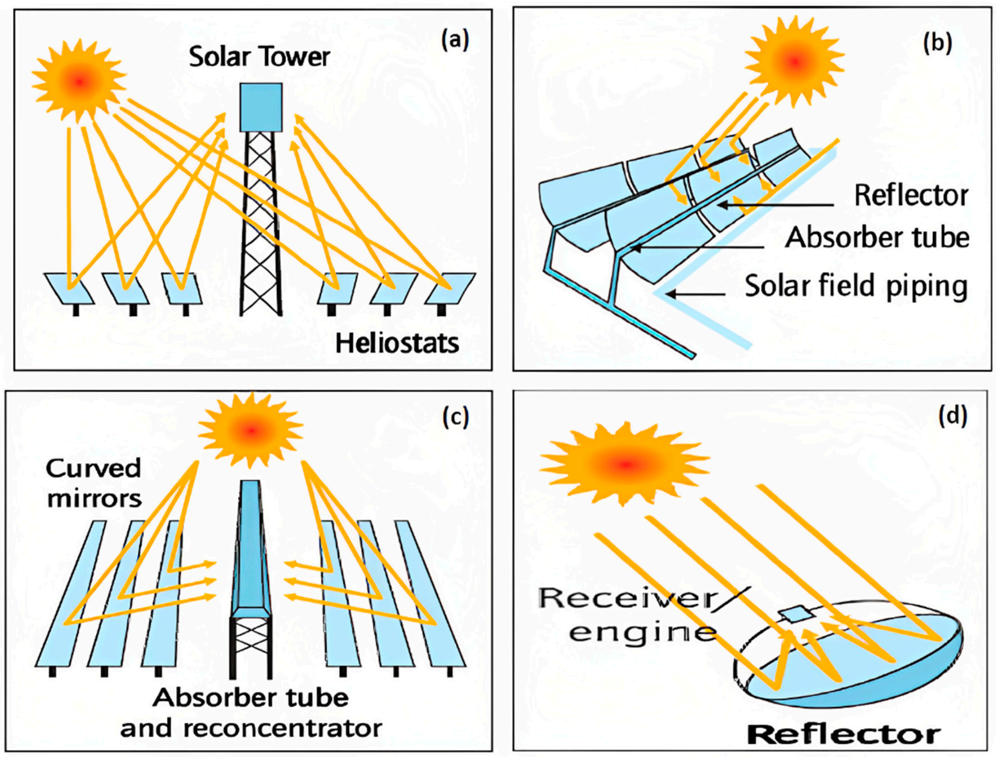

Figure 1. Recent available CSP technologies: (**a**) solar thermal tower, (**b**) parabolic trough collectors, (**c**) linear fresnel reflectors, (**d**) parabolic dish [49]. (Source: International Energy Agency, Technology Roadmap-Concentrating Solar Power).

Several research and studies on large scale CSP have been conducted. Ahmadi et al. [50] carried out a cost estimation for CSP power installations. When compared to photovoltaic (PV) projects, the initial investment cost of CSP power plants was greater. However, the financial benefits of CSP plants outperformed those of photovoltaic power plants. Desideri et al. [51] examined the environmental impacts of various technologies. The environmental effects of constructing, commissioning, operating, and decommissioning PV and CSP installations were also investigated. The PV system assembly had a greater environmental impact than CSP installations. This encourages one to learn more about the current CSP circumstances and its ongoing advantages. Gamarra et al. [52] assessed the sustainability effects of possible CSP project deployments, taking into account various CSP systems and situations involving component provenance. The findings demonstrated that central receivers had greater positive financial impacts, both in terms of value added and increased employment, and less negative environmental implications in terms of carbon emissions and water consumption. Hansen and Mathiesen [53] presented a unique technique for assessing the potential of large scale solar thermal technology in Europe. The use of renewable energies, notably solar thermal energy, to meet European-defined objectives was evaluated. Countries were chosen based on many factors, including significant heat savings, district heating network growth, and high-renewable power and heating sectors. Lambrecht [54] highlighted previous research and future methods to improve the pairing of heat transfer fluids containing material used in CSP plants, with an emphasis on the most promising HTF (heat transfer fluid): molten chloride salts. In fact, their cheap cost and operational temperature range make them desirable candidates for upcoming CSP plants, which may be further improved by strategically adding nanoparticles. Montenon and Meligy [55] analyzed the performance of a linear Fresnel collector using a number of different modeling approaches and compared their results. Both with and without the use of the PID controller, the authors examined and contrasted the ISO9806 model, the CARNOT model, and a model they suggested called RealTrackEff. The results revealed that the RealTrackEff model delivered the most accurate forecasts of the actual output temperatures, with an accuracy of 1.0 degrees Celsius compared to 2.9 degrees Celsius for the CARNOT model, and 6.3 degrees Celsius for the ISO9806 model. The suggested model was the most accurate system representation and was appropriate for fine-tuning the controller's settings.

Solar photovoltaics is a technology that converts solar energy directly into electricity, and extensive research is being conducted to improve its efficiency. Bifacial photovoltaics (BPVs) are gaining popularity as potentially useful solutions with the potential to increase the energy output by utilizing the rear side to absorb light, decreasing costs, as shown in Figure 2.

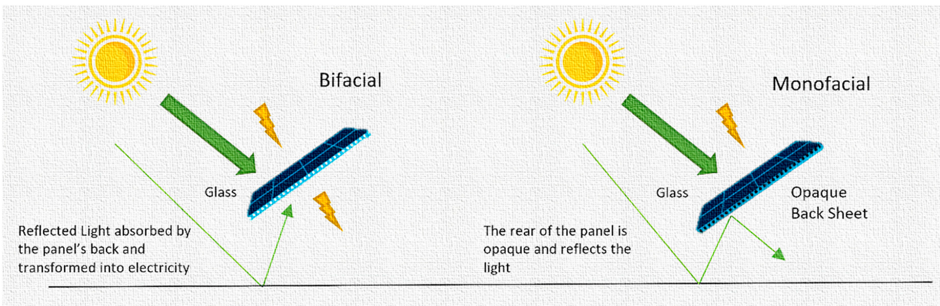

Figure 2. Bifacial vs. mono-facial solar panels.

To realize the full potential of BPV technology, a thorough understanding of the system's physical characteristics is required. With this aim, Leonardi et al. [56] used experimental measurements to create a physical model of the BPV. The authors then examined and statistically modeled the outcomes of three days of testing performed under clear sky conditions on two Si HJT-based (silicon heterojunction) PV mini-modules. In the case of bifacial operation, the experimental measurements indicated that a greater short-circuit current was mainly responsible for enhancing the energy output. This was also found to be the case when looking at the model results of the study. The model faithfully reflected the experimental findings of module temperature, Voc, Isc, MPP (also known as maximum power point), and energy yield in the mono-facial and bifacial operations. As a direct consequence, the model was used to determine yearly energy yields in addition to analyzing the impact of changing the power temperature coefficient.

One of the primary benefits of renewable energies, such as solar energy, is that it can be used in arid areas with no grid connections. For this reason, Vance et al. [57] developed a novel sizing methodology for transactive microgrids' centralized energy sharing (CES) and interconnected energy sharing (IES) operating strategies. Several variables were explored to evaluate their influence on the overall cost. The centralized strategy consistently resulted in a seven to ten percent reduction in overall costs compared to the isolated strategy. Compared to the isolated standard, the interconnected technique continuously saved more money. The total number of connected systems had little effect. Theoretically, increasing the total number of systems would result in greater energy-sharing benefits. The four analyzed climatic zones (cold, "hot-dry/mixed dry," "mixed humid," and "cold, but with decreased sun irradiation”) revealed a wide range of costs, with “hot-dry/mixed dry” being the cheapest and “cold, but with decreased sun irradiation” being the most expensive. The results of a cost sensitivity analysis revealed that the unit cost of solar energy significantly impacts the overall cost. The cost was inversely proportional to the required reliability of the power supply, as measured in outage hours. Anani and Ibrahim [58] presented a comprehensive mathematical analysis and comparison of the performance of commonly reported analytical methods for parameter extraction of a PV module’s single-diode model under standard test conditions (STC). Using numerical and iterative methods, the values of reference parameters were extracted and compared with the parameters extracted using the various models. Several large-scale solar thermal or PV projects have been implemented worldwide, as can be seen in Table 2.

Table 2. Largest Solar Energy Projects Around the Globe.

Power Plant Name	Technology	Country	Year	Installed Capacity (MW)	Ref.
Bhadla Solar Park	Photovoltaics	India	2018	2245	[24]
Huanghe Hydropower Hainan Solar Park	Photovoltaics	China	2020	2200	[26]
Benban Solar Park	Photovoltaics	Egypt	2019	1600	[59]
Noor Abu Dhabi	Photovoltaics	United Arab Emirates	2019	1200	[60]
Noor Energy 1	Parabolic Trough	United Arab Emirates	2022(Under Construciton)	700	[61]
Ouarzazate Solar Power Station	Parabolic trough and solar power tower (CSP)	Morocco	2016	580	[33]

The Bhadla project, a single solar industrial park, was put into operation in 2017 in India, the first country to implement an ultra-mega power plant, also known as a UMPP. The Ministry of New and Renewable Energy (MNRE) had originally set a goal for forty industrial solar parks with a combined capacity of 20 GW, but that objective was then increased to 40 GW, planned to be achieved by 2022. Starting in 2020, the Bhadla Solar Park holds the title as the world’s biggest solar park. About one and a half billion dollars-worth of total capital was invested in the project [24].

In 2011, China owned the Huanghe Hydropower Golmud Solar Park, which was the globe’s biggest photovoltaic solar facility at the time. The photovoltaic capacity of this installation was 200 MW. A new record was set in 2018 with the Tengger Desert Solar Park with its 1.5 GW solar capacity. Both of these accomplishments were made in China. The 2.2 GW Huanghe Hydropower Hainan Solar Park, which China now owns, is the world’s second-largest solar project in terms of capacity. It was planned that by 2020, solar energy would account for just a small portion of China’s total energy consumption, accounting for approximately 3.5% of the country’s total energy capacity [26].

The Ouarzazate Solar Power plant has been recognized as a worldwide landmark project in the solar sector since it became the world’s largest concentrated solar power station. It consists of four different power plants with different technologies (power tower and parabolic trough). The Moroccan government’s dedication to ensuring energy security and reducing its excessive dependency on the energy supplies of other countries has resulted in the development of several extremely innovative solar projects. The Ouarzazate Solar Power plant is a three-phase project that will provide a total of 580 MW and is located in the desert lands of Draa-Tafilalet, near Ouarzazate. The current heated molten salt technology that the 2500 hectares project benefits from stores up to 8 h of solar reserves, which are useful during the project’s nighttime hours of operation. In addition to giving clean energy to over one million households, this initiative is now in the process of expanding into subsequent stages to eventually supply clean energy to European nations [33].

3. Wind Energy

By converting the wind's kinetic energy, wind energy may either be transformed directly into mechanical power or indirectly into electrical energy. The wind turbine is an essential part of any wind energy system since it is the component responsible for converting the potential energy of the wind into a form of mechanical power that can then be used in various contexts. At the beginning of the 20th century, construction began on the first wind turbine designed to generate electrical power. Despite the fact that wind turbine technology has been steadily advancing, enormous advances have been particularly achieved in wind turbine design [62]. Modern technical advancements and refinements of a turbine and its components have resulted in considerable improvements in produced power production and efficiency. Furthermore, advancements in particular generators, as well as the usage of power electronic devices, have enabled gearless turbine designs [63]. The main components of a wind turbine are its tower, blades, and the nacelle, which houses the generator, gears, and control system. Similar to how an airplane wing provides lift for a plane, the wind propels the blades into motion. The generator inside the nacelle receives energy from the turbine through the driving shaft. After the generator has converted the kinetic energy that is being produced into electrical energy, the transformer will deliver that energy to the grid. As can be seen in Figure 3, the two primary classifications of present wind turbines are known as horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). The HAWTs dominate the majority of the wind sector since they are more efficient and produce more electricity than VAWTs. Since VAWTs are situated close to the ground and are consequently less exposed to the wind, reducing power production, they are inherently unreliable [64]. In addition, VAWTs are substantially more expensive since they need more material and a larger size to provide the same amount of output as HAWTs [65].

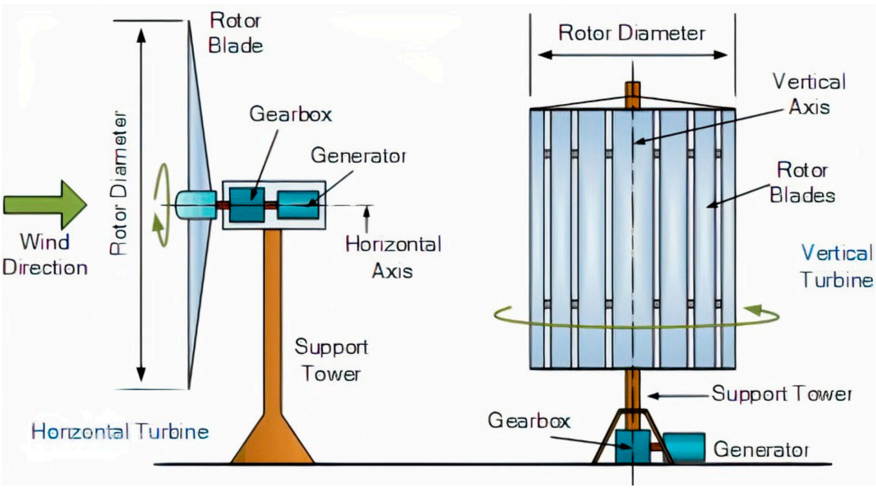

Figure 3. Wind turbine types: VAWT and HAWT [66]. (Open Access).

The working principle of wind turbines is simple: the shaft to which the generator is connected revolves because the wind causes the blades to rotate. The gearbox increases the turbine shaft's rotational speed from 30 to 60 rpm to 1200 and 1500 rpm in the generator shaft, which joins the slowly revolving turbine shaft to the quickly spinning generator shaft—causing the magnet that houses the generator to spin copper coils. This magnet causes the electrons in the wire to excite, producing electricity. The amount of power generated depends on the quantity of copper coils and the rate at which the shaft rotates in the magnetic field [67]. Another emerging and new technological design is bladeless wind turbines (Vortex), which aim to address problems with rotational wind turbines, including logistics, aesthetics, maintenance, amortization, noise, and influence on birds and the environment.

In contrast to HAWT and VAWT, which work by rotation, vortex bladeless is a vortex-induced vibration resonant wind generator. The originality of the vortex comes from its unique design and method of oscillating energy [68]. As seen in Figure 4, a vortex is a cylindrical, vertical, and slender device. It is made up of two basic components: a fixed base that is connected to an anchor and a flexible mast that, by acting as a cantilever, interacts with moving fluid in a more unrestricted manner when the oscillating motion is taking place. Since it does not have gears or other moving parts that come into touch with one another, it does not need lubricants or oils as rotary machines do.

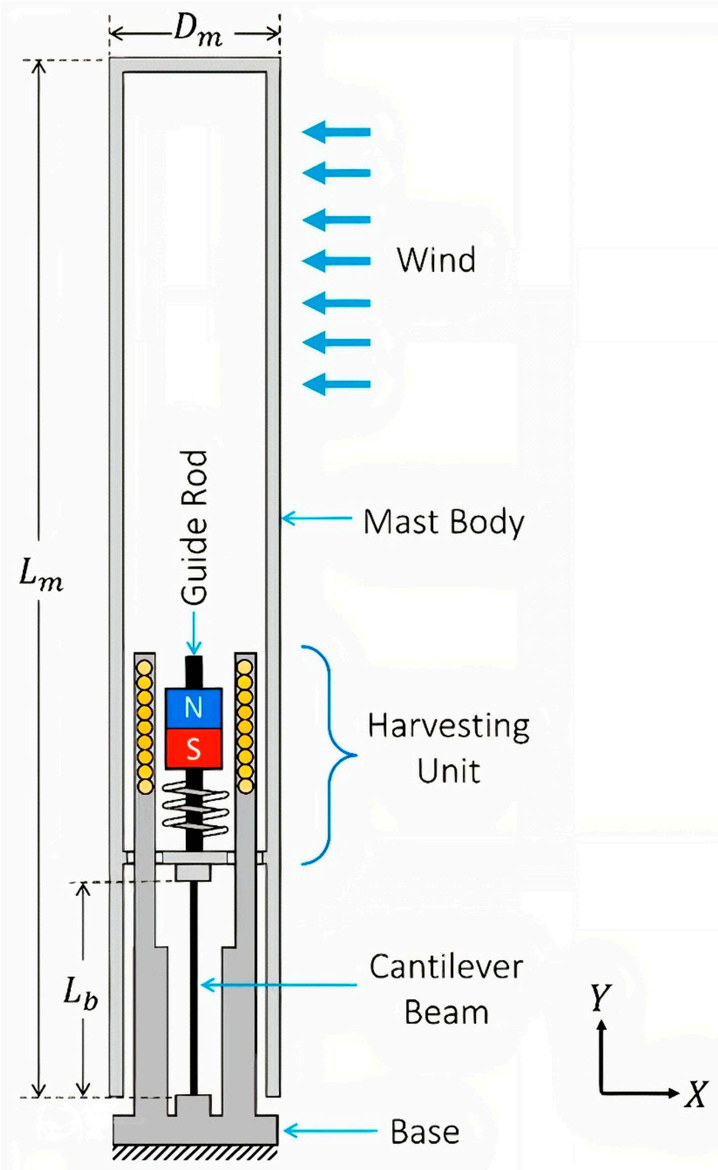

Figure 4. Schematic drawing of a bladeless wind turbine [69]. (Open Access).

Through modeling of fluid-solid interactions (FSI), Manshadi et al. [70] studied the improvement of the output electrical power of a vortex bladeless turbine, yielding a complete dataset for forecasting method and optimal design. As a result, the long short-term memory (LSTM) approach was presented to estimate the power of the vortex bladeless turbine from the gathered data due to its time-series prediction accuracy [71]. The design and study of a bladeless vortex turbine were carried out by Francis et al. [71], who also tried to maximize the amount of deflection that a bladeless turbine might produce. A 3D model was constructed with the help of the design program Solid Works, and analyzed using the ANSYS software to verify the findings. Thakre et al. [72] provided a mathematical analysis of a bladeless hybrid system, a solar panel, and a comparison analysis of a bladeless hybrid system with an existing solar wind hybrid model. In addition, they presented the results of a comparative study of the voltage, current, and power produced by both hybrid systems. The bladeless hybrid system was developed, and MATLAB Simulink was used to verify all the results.

Several large-scale wind projects based on two technologies, i.e., on-shore and off-shore, implemented worldwide are shown in Table 3.

Table 3. Largest wind energy projects around the globe.

Power Plant Name	Technology	Country	Year	Installed Capacity (MW)	Reference
Gansu Wind Farm	On-Shore Wind Farm	China	2009	7965	[27,28]
Alta Wind Energy Center	On-Shore Wind Farm	United States	2010	1550	[28]
Muppandal wind farm	On-Shore Wind Farm	India	1986	1500	[28]
Hornsea Project Two	Off-Shore Wind Farm	United Kingdom	2022	1800	[73]
Hornsea Project one	Off -Shore Wind Farm	United Kingdom	2019	1200	[73]

The Jiuquan Wind Power Base, also known as the Gansu Wind Farm Project, is a group of huge wind farms currently being constructed on the western side of the Gansu province in China. The Gansu Wind Farm Project is located in a desert area adjacent to the city of Jiuquan at two distinct places in Guazhou County, as well as close to Yumen City, in the northwest province of Gansu (which has an availability of wind power). These sites are part of Guazhou. The complex only uses 7.965 MW of its installed capacity, while it has a projected capacity of 20 GW and is now running at less than 40% capacity utilization of its existing 8 GW [27].

The Alta Wind Energy Center in California has been crowned the wind farm with total turbines of 1320 MW, and there are plans to extend it to 3000 MW in the future. At the end of 2012, it had 440 wind turbines as part of its infrastructure. In the United States, 815 wind farms have been placed into service, with a total power capacity of 60 GW. This is sufficient to power 15 million residences in the United States. Wind power has overtaken solar as the leading source of newly installed capacity in the United States. The United States has reclaimed its position as the world's leading wind power market. China's wind power capacity has hit 75 GW, making it the nation with the highest installed capacity globally [74].

The Hornsea Project Two wind farm, which will become one of the largest offshore wind projects, received approval from the British government in August 2016, allowing it to continue with its construction. It can generate 1.8 GW of electricity when fully operational. This project is an expansion of the 1.2 GW Hornsea Project (offshore wind farm), which was already cleared for construction. The Hornsea Project comprises 300 wind turbines made by Dong Energy, is now under development and will produce enough energy to power 1.6 million households. The project's location will be around 90 kilometers (55 miles) east of Yorkshire's coast in England [73].

4. Biomass

Biomass is one of the most available energy forms that is effectively used in several applications starting from conventional burning [75–77] and ending with direct usage in fuel cells to generate electricity [78–80]. Although fuel combustion is a conventional method, it is not the best choice to get the value energy contained in the various biomass resources. Converting biomass into biofuel, such as biodiesel [81–83] and biochar [84,85], are promising methods that consequently could be applied in various applications. Figure 5 shows the resources of biomass energy. From this point of view, Han et al. [86] studied the effect of the acid pretreatment of corn straw on the biochar yield using a hydrothermal treatment. The results revealed that the acid pretreatment effectively improved the quality of biomass solid fuel while simultaneously enhancing the hydrothermal carbonization (HTC) process. Despite the high value of solid biochar compared to raw biomass, as discussed by Han et al. [86], the production of biodiesel has several advantages, including ease of transportation, higher heating values, and flexible application, i.e., a wide range of applications such as for diesel engines [87–89]. In light of the rising demand for coffee worldwide, coffee grounds have recently been brought up as a potential candidate for a new biomass resource [90,91]. Choi et al. [92] applied the Lagrangian multiphase model to simulate the rapid pyrolysis of coffee grounds in a reactor with an inclined slide. The yields of volatile compounds generated at various reactor temperatures were compared to the experimental data. The volatile yield climbed gradually with rising reactor temperature in the simulation, which did not incorporate a secondary gas-phase reaction, but started to decline at higher temperatures in the experiment. Since the procedure included subsequent tar-cracking processes, the volatile species were successfully degraded into light gas species. The modeling predicted that at a temperature of 554 degrees Celsius in the reactor, the maximum volatile output was 59 percent, which matched the actual results. Although the simulation had a higher volatile yield than the experiment, the decreasing trend of volatile production at high temperatures could be correctly predicted by including secondary tar-cracking processes.

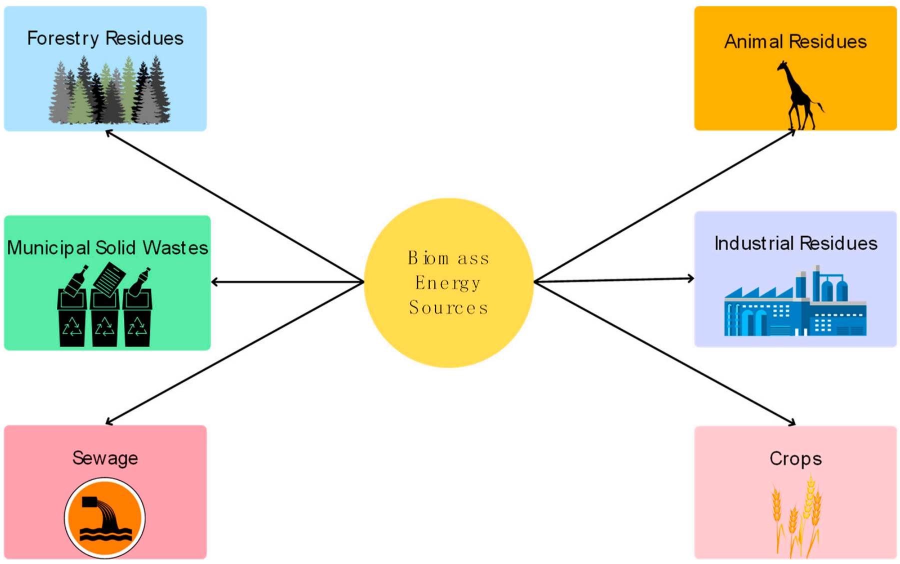

Figure 5. Biomass energy sources.

The bio-oil produced from fast pyrolysis has a high viscosity, making its use more difficult. For this reason, Choi et al. [93] developed a pilot-scale burner with a capacity of 35 kW and equipped it with an air-blast atomizing nozzle. In order to improve the fuel spray ignition and maintain a more stable flame, a downward fuel injection system was developed. There was a volumetric ratio of nine to one between biocrude oil and ethanol. The combustion stability was improved by adding a swirl flow to the air used in the combustion process. An increase in the swirl motion in the combustion air resulted in improved flame stability and a decrease in gaseous emissions. The high porosity of the biochar that is produced from biomass makes it an excellent candidate for use in applications other than combustion. For example, it can be used as a bio-adsorbent for hazardous compounds that are found in wastewater. This is despite the fact that biomass is primarily viewed as a renewable energy source, such as biochar and biodiesel. For example, corn straw was converted into hydrochar adsorbent and tested towards the adsorption capability of Cd^{2+}. At a temperature of 140 °C for 2 h, the straw was heated until it became 77.56 percent hydrochar. The prepared hydrochar had a Cd^{2+} adsorption capacity of 5.84 mg/g [94].

Individual facilities have remained relatively small compared to coal or nuclear-generating plants due to the dispersed nature of biomass fuels and the limiting economies of scale associated with plants of this sort. For instance, the Polaniec power plant in Poland has a capacity of 205 MW and is fueled by biomass, comprised of both wood and agricultural waste products. The Ironbridge power facility in the United Kingdom had a capacity of 740 MW, making it one of the largest biomass power plants in the world; however, it was decommissioned in 2015 in accordance with EU regulation after reaching the upper limit total lifetime operating hours that were allowed. In 2012, the plant's fuel source was changed from coal to wood [95]. In Jakobstad/Pietarsaari, Finland (at the time), Alholmens Kraft Ltd. had developed the world's largest biomass-fired power plant, which had begun commercial operation in October of 2001. This environmentally friendly and economically feasible power plant can generate 240 MW of electricity. This facility is intended to operate on either 100% coal or 100% biomass (which includes wood, wood waste, and peat) and any mix of the two. It generates electricity for the pulp and lumber mill's internal use and for export to the Nordpool grid. Additionally, it can export low-quality heat for use in the Pietarsaari district heating system [96].

5. Hybrid Renewable Energy Sources

Although renewable energy sources are sustainable and have zero or minimal adverse effects on the surrounding environment, the vast majority, such as wind and solar power, only produce energy intermittently. Therefore, renewable energy sources have to be integrated with energy storage systems. Sometimes there are several different renewable energy sources integrated with one or more other energy storage systems, as shown in Figure 6. The main purpose of these integrations is to guarantee a continuous energy supply all day at the lowest cost [97–99]. Many researchers have studied the combination of different renewable energy systems to provide carbon-free, higher energy production, and cheap energy sources [100].

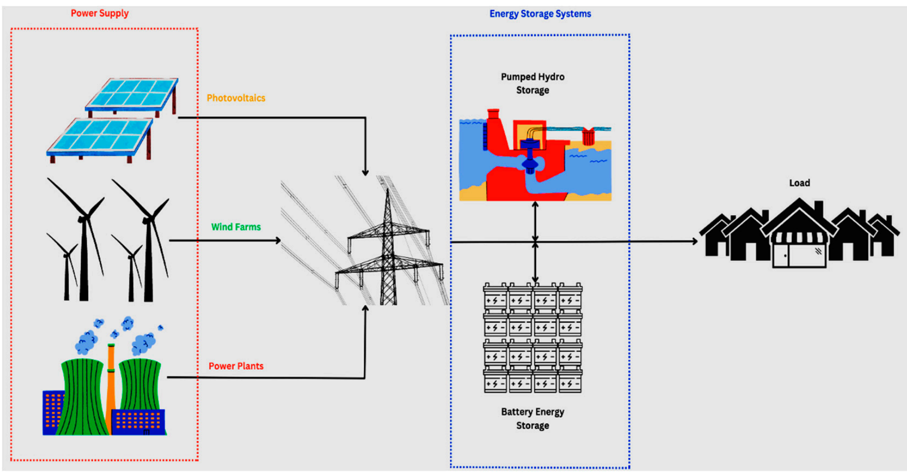

Figure 6. Schematic of hybrid wind/PV/thermal power plants integrated with different energy storage systems.

Using a computational design strategy, Kim et al. [101] determined the dimensions of a hybrid power system that included national electric, solar, and fuel cells, and then determined the ratio values of the system. Between 0.46 to 0.54 was the ideal ratio of the amount of energy generated by fuel cells to that generated by solar cells. In addition, the authors provided a revised version of the uDEAS method, which stands for "univariate dynamic encoding algorithm for searches," as a new optimization strategy. Bauer et al. [102] investigated the idea of merging biological power-to-methane conversion to help and maintain the energy transition of power, heat, and gas. To improve the energy system, the Calliope tool was employed.

Gajewski and Piekowski [103] examined cutting-edge hybrid renewable energy systems (HRES) via analysis and simulation. The HRES consisted of a generator for the wind turbine called a permanent magnet synchronous generator (PMSG), a system of solar panels, and a system for storing energy in batteries. Research on the multi-converter DC-coupled design of the HRES was carried out. Under a wide range of varied operational situations for renewable energy sources, the system guaranteed that the loads would receive the correct amount of power flow at all times. The PMSG control method with machine-side converter was based on rotor field-oriented control. Additionally, it contained the tip speed ratio (TSR) algorithm which is used in the maximum power point tracking (MPPT) algorithm. The method known as direct power control (DPC) was put into practice to control the grid-side converter. The DPC ensured that the voltage value of the DC connection was appropriately maintained to the reference value and could alter the necessary power flows between the grid and the system. The PV system's operation control was implemented using the MPPT algorithm, which is founded on the perturbation and observation (P&O) approach. Using this method, the researchers could determine the level of solar irradiation and the temperature of the surrounding environment that would result in the greatest amount of power being produced by photovoltaic cells. The defined energy management procedures made it possible for the wind and solar energy systems to operate as intended in various environmental circumstances, all while keeping the load side's power supply demand at the required level. The converter system, which used battery energy storage, was incorporated into the design and was connected to the common DC connection. This was done to facilitate communication between the two systems. Even in conditions where wind speeds or solar irradiation values were low, the renewable hybrid system could nevertheless reliably provide the load with the necessary amount of power. The battery system stored any extra power produced by the wind turbine or solar panel system in the event it created more energy than necessary. When the battery was used up to its maximum capacity, any remaining power was sent back into the grid that supplied alternating current electricity. The simulation results showed that the wind turbine control system, consisting of PV panels, a battery energy system, and a directly driven PMSG, was of very high quality.

To lower electricity costs, residential properties must have home energy management (HEM) systems. Energy consumption and expenses might be decreased by combining renewable energy sources (RES) with battery energy storage systems (BESSs) and central battery storage systems (CBSSs). Rashid et al. [104] established a cost-effective HEM scheme within the context of a microgrid to encourage the decrease of energy demand while also considering energy storage and the incorporation of renewable sources. The user preferences and the length of time they need the appliance to operate may affect the runtime preferences and lengths of operation of typical household appliances. These preferences and durations of operation can vary. The HEM model allows residential consumers to modify their total energy consumption profile, lowering the expenses connected with it and giving them access to real-time pricing. By merging RES, BESSs, and CBSSs in a shared power environment, the HEM model is able to reduce energy use and save money. Papadopoulou et al. [105] compared a hybrid system comprised of photovoltaics (PV) and offshore wind energy, as well as two distinct storage options. In this regard, the aforementioned technologies were compared using two complimentary metrics: the levelized cost of energy and the net present value. The hybrid system was more energy-cost-efficient.

Noor Energy 1 will be responsible for putting into action the 700MW CSP + 250MW PV Project found in the fourth and final phase of the Mohammed bin Rashid Solar Park. By its completion, this project will have created the largest single-site concentrated solar power plant in the world. Additionally, the levelized cost of power has set a new global record at $7.3 cents per kilowatt-hour, making it competitive with electricity generated from fossil fuels without subsidies for reliable solar energy that can be dispatched at all hours of the night. The technique combines the tallest solar tower in the world (at 260 m tall and

100 MW) with parabolic trough concentrated solar power technologies (totaling 600 MW and split into 200 MW for each unit) to harness solar energy and bifacial photovoltaics (250 MW), which convert sunlight from both sides of a solar panel. This project helps Dubai reach its Renewable Strategy goal of using 25% renewable energy by 2030. Moreover, it will prevent the release of 2.4 million tons of carbon dioxide (CO_2) into the atmosphere [61].

Zebra et al. [106] focuses on the application of HRESs for off-grid electrification in developing-country rural populations that lack access to inexpensive, dependable, and sustainable sources of energy. The research examines HRESs as a means of overcoming renewables' fluctuating nature and compares the levelized cost of electricity (LCOE) of several mini-grids. Diesel is the most costly technology when compared to solar photovoltaic and hybrid solar photovoltaic/diesel. The research also highlights elements that impact the effective integration of HRESs, including as government support and community organization, which are critical for the systems' long-term viability. Furthermore, the paper tackles hurdles to mini-grid adoption, such as a lack of supporting policies and expensive capital costs, but emphasizes that government incentives may assist minimize these costs. The findings of this research are especially noteworthy for underdeveloped nations, because power provision through HRESs is often faster and less expensive than grid expansion. According to the report, more research on appropriate local design and ownership models might assist speed and decrease the costs of sustainable power provision in distant places.

CleanMax has begun offering a service called wind-solar hybrid (WSH) to businesses and factories that have significant power demands. The WSH projects in India combine solar and wind energy to take advantage of their synergistic effects on electricity output. Under a build-own-operate or energy sale paradigm, CleanMax has implemented this WSH solution for one of the organizations with the most significant data center operations. A 13.5 MW WSH power plant with a solar hybridization rate of less than 52% will provide the client with around 90% of their required energy (wind capacity 13.5 MW and solar capacity 10.5 MW). It is expected that the wind-solar hybrid plant will generate around 57 million units of energy annually, resulting in an annual decrease of about 46,740 tons of CO_2 emissions. While the wind turbine capacity has been installed and commissioned, the solar panel capacity is still being added and is expected to be commissioned within the next few of months. The 13.5 MW WSH plant is part of a larger 150 MW WSH project being built by CleanMax [107].

6. Renewable Energy Statistics

Since 2012, millions of renewable energy capacities have been installed around the world, demonstrating significant technological progress in developing, installing, and operating new renewable projects. According to a recent assessment by the International Renewable Energy Agency (IRENA), by 2022, 3068 GW of installed capacity will have been made. Of this installed capacity, 1.8% were installed in Africa, 21.1% in Europe, 14.94% in North America, 8% in South America, and 47.4% in Asia, making the latter continent the one that has made the most contribution to replacing conventional energy sources. Table 4 shows statistics about the installed capacities by 2021 and power production in 2020 of solar, wind, bioenergy and hydropower for the five continents. Table 5 shows the installed capacities and electricity production for the most contributing countries.

Table 4. Renewable energy installed capacities and electricity production in the world [108].

Continent	Solar Energy		Wind Energy		Bioenergy		Hydropower	
	Capacity (MW)	Energy (GWh)	Capacity (MW)	Energy (GWh)	Capacity (MW)	Energy (GWh)	Capacity (MW)	Energy (GWh)
Asia	485,948	447,985	385,393	555,824	56,969	211,827	594,267	1,927,807
Africa	11,393	17,037	7334	10,557	1785	3203	37,677	141,437
Europe	187,360	167,605	220,760	488,412	41,712	206,760	224,393	608,207
North America	105,881	137,703	154,733	397,157	16,956	72,683	198,026	722,078
South America	19,649	22,126	29,754	79,601	18,484	71,882	178,033	672,569
Oceania	23,242	21,548	9827	22,760	1104	4285	14,498	41,314
Total in the World	854,795	843,855	823,484	1,588,586	143,195	583,775	1,360,502	4,476,230

Table 5. Renewable energy installed capacities and electricity production in the most contributed countries [108].

Continent	Solar Energy		Wind Energy		Bioenergy		Hydropower	
	Capacity (MW)	Energy (GWh)	Capacity (MW)	Energy (GWh)	Capacity (MW)	Energy (GWh)	Capacity (MW)	Energy (GWh)
United States	95,209	119,329	132,738	341,818	13,574	60,269	101,894	308,213
China	306,973	261,659	328,973	467,037	29,753	98,978	390,920	1,355,210
India	49,684	54,666	40,067	63,522	10,592	21,987	51,565	164,678
Canada	3630	4846	14,304	35,638	2416	10,094	82,740	386,617
Germany	58,728	48,641	63,865	132,102	10,439	50,858	10,739	24,876
Japan	74,191	79,087	4467	8970	4592	27,995	50,019	87,548

7. Energy Management

As aforementioned, the majority of RES are intermittent, such as solar, wind, and wave energies. Therefore, managing a hybrid energy system composed of one or more renewable energy sources and one or more energy storage systems is frequently used to obtain a sustainable energy source with the lowest energy cost. Energy may be stored through a variety of techniques. These techniques are frequently categorized according to the period that the energy will be stored. The most prevalent methods for categorizing energy storage systems are based on the kind of energy storage used and the time it takes for the system to discharge its stored energy. Based on how long it takes for the stored energy to be discharged, techniques of energy storage may be categorized as either short-term (seconds or minutes), medium-term (minutes or hours), or long-term (hours to days). The type of converted energy has a significant impact on how energy storage techniques are categorized. These can be categorized into five major categories: mechanical, electrochemical, thermal, electrical, and chemical energy storage. These technologies store energy until it is needed [109]. Various energy systems are available such as supercapacitors [110,111], batteries [112,113], flywheel [114,115], compressed air [116,117], thermal energy storage [118,119], pumped hydro [120], and others. Table 6 shows a comparison between the different storage systems, and Table 7 shows the largest energy storage systems installed around the globe.

Pumped hydroelectric storage uses electricity produced during off-peak hours to raise water from a lower tank to a higher tank, dam, or reservoir, where it may be stored as potential energy. To make use of the higher reservoir as a storage space for surplus electrical power, a pump is installed within the conduit that connects the lower and higher pools. This pump moves water from the lower reservoir into the higher reservoir. The amount of energy retained there is determined by the amount of water stored, as well as the difference in level between the two pools of water. If there is a shortage in the grid or in the production of the local sources of energy, the water that is held in the upper reservoir may be released, which will cause turbines and generators to produce electrical energy. This will help make up for the shortage. The energy required to drive these pumps and turbines may be sourced from local energy sources, consumed, or delivered into the grid, all of which are viable options [121].

The utilization of the potential energy that is stored during the pressurization of a compressible fluid is the central focus of the design process that goes into creating compressed-air energy storage devices. The execution of the tasks required to run installations based on this concept is not too complicated. When there is less demand for power, fluid is forced into a smaller, more impermeable reservoir, where it is subjected to sustained high pressure over an extended period. During periods of very heavy demand, the available electrical supply will be bolstered. In this scenario, the fluid is released from its high-pressure storage and is fed into a rotating energy extraction mechanism known as an air turbine. This mechanism converts the kinetic energy of the fluid into rotating mechanical energy in a wheel connected to an electrical generator, which is then fed back into the grid [122]. Large-scale compressed air energy storage methods, such as pumped hydro storage, reap the benefits of having both cavernous and impermeable subterranean reservoirs simultaneously. Natural salt mines and oil and gas fields that have been drained of their resources would be the best possibilities for meeting such a substantial need for storage space; nevertheless, it is unfortunate that these resources are not commonly available.

A battery storage system is an advanced technological solution that enables electricity to be stored until it is needed. Rechargeable batteries, particularly lithium-ion battery storage systems, have several advantages, including greater renewable energy output, economic savings, and sustainability, owing to reduced consumption. Energy battery storage systems typically have a lifetime of five to 15 years. Supercapacitors are electrochemical energy storage devices that employ the same fundamental equations as control capacitors. However, supercapacitors frequently utilize porous carbon or electrodes with more significant surface areas and thinner dielectrics to collect huge numbers of charge carriers. Numerous benefits are provided by this type of system, such as extraordinarily high capacitance characteristics, on the order of thousands of farads, increased cycle life, low internal resistance, quick charging and discharging, extraordinary reversibility, excellent low-temperature performance, no destructive material, lower cost per cycle, and high cycle efficiency (up to 95%) [123].

In the power industry, only one of the three distinct types of thermal energy storage devices is now available at a commercial scale. The alternatives involve a level of complexity and expense that are not comparable to sensible heat storage. Both thermal-chemical storage systems and latent energy storage are considered to be rather costly and mostly experimental technology. In the field of power production, the method of storing thermal energy is commonly referred to as sensible heat storage. In a sensible heat thermal energy storage system, energy is stored by either heating or cooling a solid or liquid storage medium, such as molten salt, sand, water, or rocks. Other examples of storage mediums include; Sensible heat storage is common in concentrated solar power (CSP) plants. These plants make use of thermal energy storage so that they may continue producing electricity long after the sun has set. Molten salts are the material of choice in most CSP systems that use thermal energy storage because of their ability to withstand extremely high temperatures. Although it is very seldomly used in the field of power production, latent heat storage has shown to be potentially useful in a range of contemporary technologies. A change in the state of the medium used to store heat, such as from solid to liquid, is necessary for the process of latent heat storage. The term "phase change material" (PCMs) may also be used to refer to latent heat storage mediums. The term "thermo-chemical storage," or TCS, refers to a method of energy storage that makes use of chemical processes. Compared to PCMs, the energy density of TCS systems is much more attractive [124].

Power-wise, the Three Gorges Dam far surpasses any other hydroelectric dam. The dam came into use in 2013, so it is still quite new. It can hold 22,500 MW of capacity. The dam is found in the Xilingxia Gorge, one of the three gorges situated in the Hubei province of China along the Yangtze River. It is claimed by NASA to be one of the few man-made structures on Earth visible to the human eye when viewing the world from space. A combined annual output of 84.7 billion kWh is anticipated from the 26 power-producing units, each with a generating capacity of 700 MW. The Three Gorges dam is one of the longest dams in the world at 2.3 kilometers long. Its undertaking required the participation of about 40,000 employees and was carried out over 17 years. Approximately 28 million cubic meters of concrete were used in the construction project, making it a massive structure. To prevent flooding, gates for a spillway were constructed along the concrete pillars. Water may be discharged via these gates and travel more than 100 m downstream. The dam is 2309 m in length and has a height of 185 m. The predicted 85 TW/h of energy from the dam project is nearly one-tenth of China's current demand. The project was estimated to cost $22.5 billion [22].

Florida Power & Light's (FPL) decision to replace the Manatee Energy Storage Center's gas-fired generation with solar energy/battery storage was motivated by the utility's plan to eliminate more than one million tons of CO_2 emissions from its portfolio, and to generate savings of one hundred million dollars for its customers. Within the scope of this strategy is the installation of 30 million solar panels by the year 2030 after completing some less extensive battery installations around the state. The FPL concluded that the relatively low prices of battery technology might be utilized to both replace the Manatee plant and provide consumers with clean energy. An energy storage facility with a capacity of 409 MW will take the place of the Manatee plant, which is scheduled for retirement. The information provided by FPL indicates that this will be the largest battery system installed in the world. The energy storage facility will stretch over an area of 40 acres in size and have the capacity to distribute 900 MWh of power. While still in operation, the two outdated gas-fired peaker facilities will be replaced by the Manatee Energy Storage, which will then be fueled by the FPL solar facility and will store the energy. The solar plus storage system provides an added benefit to customers in the form of cost savings (approximately $100 million in savings to ratepayers), a reduction in emissions (one million tons of CO_2), an improvement in service reliability, an increase in the integration of clean energy, and the creation of new jobs (approximately 70 new jobs during construction) [125]. Companies that manufacture batteries are engaged in a race to develop ever-more-capable utility-scale battery systems. The Moss Landing Energy Storage Facility, owned and operated by Vistra Energy, began operations in 2021 with a 400 MW/1600 MWh capacity. The battery at this site was the largest ever constructed. In January of 2022, Vistra announced that the Moss Landing Energy Storage Facility would gain an expansion that will increase its capacity to 750 MW/3000 GWh by the end of the year 2023 [126].

Compared with all of these energy storage systems, a grid is the largest energy storage that can accept huge amounts of energy. Grid protection is becoming more difficult as more renewable energy sources are incorporated and converted to usable forms by power electronic inverters. Inverter-based resources have failure responses that differ from conventional generators due to improved inverter control algorithms. This distinction has the potential to have a significant impact on how the power grid is protected. Ekic et al. [127] explored the dynamics of solar inverters by utilizing a real-time digital simulator (RTDS). The researchers focused their attention on the negative-sequence quantities that occurred during the restoration phase after a grid disruption. The authors conducted research on the dynamics of solar inverters by using RTDS-based electromagnetic transient simulations with detailed inverter models that take into account switching dynamics, as well as inverter blocking and deblocking modes. They placed a particular emphasis on the negative-sequence current that occurred during the time when the grid was being restored. In addition to this, they investigated the ways in which these dynamics influenced various protection mechanisms. Solar inverters, after they have been cleared of any obstructions, have been shown to be capable of operating as negative-sequence sources, which reintroduce energy into the power grid over the period of time necessary for the grid to recover from the impacts of a grid disruption. The amplitude of the current flowing in the negative sequence may be influenced by a wide range of operational parameters, such as the number of inverters that are now being put to use, the power of the grid, and the kinds of grid failures that are occurring. These negative-sequence responses have the ability to reduce the performance of protection measures that are based on negative-sequence components and to end up causing relay maloperations in the power grid during the restoration period. Additionally, these negative-sequence responses have the potential to cause a power outage. For this reason, the protection provided by the grid will become less trustworthy and secure.

Table 6. Energy Storage Systems Comparison.

Technology	Power Rating (MW)	Cycle Efficiency (%)	Lifetime (Years)	LCOE ($/kWh)
Compressed Air	110–1000	42–54	20–40	2–120
Pumped Hydro Storage	30–5000	70–87	40–60	5–100
Thermal Energy Storage	0.1–300	30–60	20–30	3–60
Lead Acid Batteries	0–40	63–90	5–15	50–400
Li-ion Batteries	0–100	75–97	14–16	600–3800
Flywheels	0.25–20	90–95	15–20	1000–14,000
Supercapacitors	0–0.3	84–97	10–30	300–2000
Fuel Cells	<58.5	20–66	~20	2–15
Super magnetic Conducting Energy Storage	0.1–10	95–98	20–30	500–72,000

Table 7. Largest energy storage systems projects around the globe.

Power Plant Name	Technology	Country	Year	Installed Capacity (MW)	Reference
Three Gorges Dam	Hydroelectric Power	China	2003	22,500	[22]
Itaipu Dam	Hydroelectric Power	Brazil and Paraguay	1984	14,000	[23]
Ouarzazate Solar Power Station	Thermal Storage (Molten Satl)	Morocco	2018	Total of 7325 MW_t NOOR I (1200) MW_t NOOR II (3500) MW_t NOOR III (2625) MW_t	[128]
Manatee Energy Storage Center	Batteries	United States	2021	409	[125]
Moss Landing Vistra Battery	Lithium-Ion Batteries	United States	2020	400	[126]

Connecting a large number of decentralized sources to the grid that operates at medium and low voltage presents a number of challenges. Pijarski and Kacejk [129] brought to light the potentially disastrous effects on voltage that might result from the connection of a large number of dispersed sources to a grid that operates at medium voltage. Due to the fact that they are situated at various points along medium voltage (MV) lines and have the potential to reach their maximum generation during off-peak hours, the voltage that they produce may fluctuate over a wide range. The fact that the voltages can occasionally reach values that are outside of the acceptable range is unfavorable for customers. With the help of specialized management and control systems that are self-sufficient, it is possible to get rid of the negative voltage phenomena that come from RES. Managing excessively large voltage changes is possible not only through the conventional control of the ratio of high voltage to medium voltage (HV/MV) transformers, but also through the control of power consumption of flexible loads and the simultaneous use of the possibilities offered by RES in the context of reactive power generation or consumption. Both of these methods are complementary to the traditional HV/MV transformer ratio control. It has been established that including electrolyzer installations into MV networks has a good influence, not only on the optimal voltage values from the point of view of the quality indicator that is being used, but also on minimizing the amount of power that is lost in the network. The method of optimum voltage control is one that has the potential to be carried out effectively if certain requirements are met. One of these factors is that the real network must be precisely mapped before the optimization process can begin. In order to develop a calculating model, it is necessary to make an assessment of the current condition of the MV networks. The measurements of current and voltage that are carried out are what allow for the creation of this estimate in the first place. Due to the radial topology of the network, which consists of just a few numbers of nodes, the complexity of the computations required to solve this issue is significantly decreased when compared to multi-node closed HV networks. It would seem that the application of the suggested voltage control system is feasible in practice due to the relatively small scale of the computational task, and as a result, the short length of time required to obtain outcomes. This allows for the process of optimal control to be carried out in real-time, which is advantageous.

Utilizing distributed generating systems (DGSs) is one of the most significant advances facilitating the energy transition. The DGSs provide for more user agency over energy use and production, but are more complex to set up and maintain. The optimization models that are being applied under uncertainty in DGSs is summarized by Alonso-Travesset et al. [130]. The authors analyzed more than 170 articles that optimized DGSs while considering uncertainty. The authors showed that adding elements, such as grid testbed validation, a battery aging model, taking into account demand response or controlled loads, correlating unknown parameters, and decentralization, all added to the complexity of the models. All of these improvements, along with others under development, will allow optimization models to be used in practice. It is expected that the number of DGS-focused research initiatives will grow, making a significant contribution to the energy transition and paving the way toward a totally green society free of carbon emissions.

Transportation is one of the major pollution sources that must be electrified in order to reduce global warming. Commercially, electric vehicles (EVs), including hybrids, are currently in use. A hybrid electric vehicle (HEV)'s energy management strategy (EMS) and control algorithm have a direct influence on energy efficiency, control effect, and system dependability. The difficulty is in designing an efficient EMS and a suitable control algorithm for a particular configuration of a HEV engine in order to achieve a number of different developmental objectives, while simultaneously preserving vehicle performance [131]. The EMSs and control algorithms of HEVs were compared by Xue et al. [131] in terms of features, applicability, real-time capabilities, and the technological advancement that has occurred over time. Various control systems each have their own set of limitations when it comes to the difficulties associated with the management of energy that comes along with HEVs. Existing EMSs only take fuel economy into account, and there have only been a handful of in-depth studies done on economy, emissions, battery life, and driving style. Deciding the maximum power point at which any device is operated is important to increase efficiency and decrease the cost. Thermoelectric generators (TEG) are effectively used to harvest power from different resources, including the waste heat generated in various processes. Deciding the MPP of the thermoelectric generators will also improve the efficiency; therefore, Kanagaraj et al. [132] introduced an innovative MPPT method that is based on VFOFLC, which stands for "variable fractional order fuzzy logic controller." This method is intended to extract the most amount of energy that can be obtained from the TEG. The fractional factor was included into the MPPT approach that was presented so that the length of time required to track up to the peak level in the P-V curve could be reduced, and the steady-state output could be maintained at a level that was centered around the MPP. The findings of the research indicated that the MPPT technique based on VFOFLC was able to modify the duty cycle of the DC–DC boost converter in an appropriate manner by employing the variable fractional factor. This was demonstrated by the fact that the technique made use of the variable fractional factor.

8. Fuel Cells and Green Hydrogen

Fuel cells have shown encouraging results in a variety of applications, including transportation, i.e., fuel cell vehicles [133–135], off-grid applications [136], portable devices [137], stationary [138,139], etc. Figure 7 presents an illustration of the primary components that make up fuel cells.

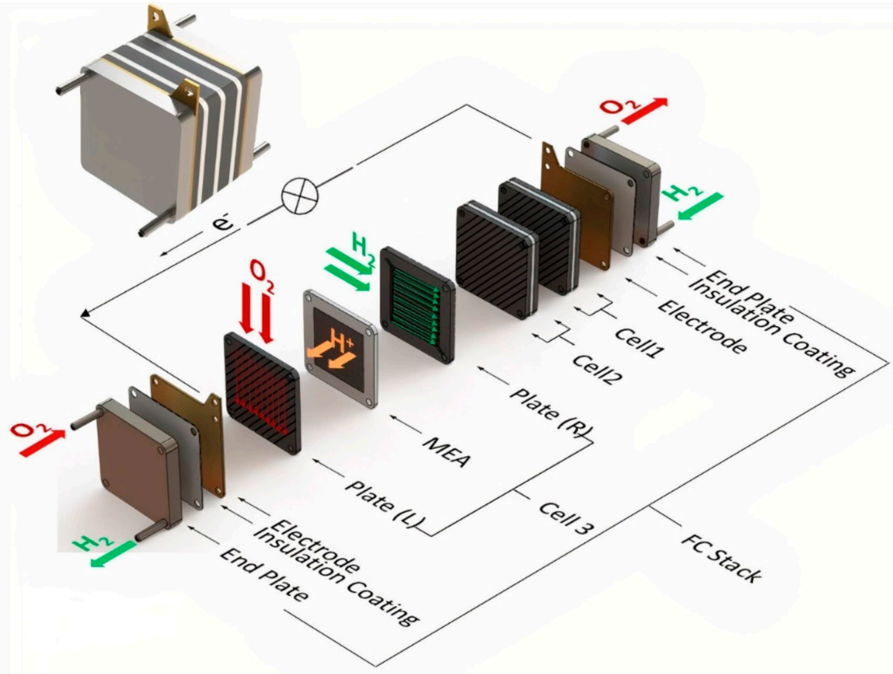

Figure 7. Fuel cells stack and components schematic [140]. (With permission, license number: 5430310482582).

Proton exchange membrane fuel cells (PEMFCs) are the most prevalent kind of fuel cells that can function in a variety of applications, even when the temperature is rather low [141,142]. Due to the importance of this type of fuel cells, proton exchange membrane fuel cells, including their materials and methods of manufacture, were summed up by Olabi et al. [143]. The authors showed that a considerable amount of focus was spent on the newly created materials that were utilized for PEMFC, as well as the features of these materials. In spite of the progress that has been achieved with PEMFCs, there are still challenges that need to be handled before these devices can be deemed inexpensive and extensively utilized. These concerns include the cost of these devices as well as their durability. Two of the difficulties that the FC must overcome are its low power density and its poor mechanical durability. When it comes to the components that make up the membrane, the Nafion membrane delivers the highest level of performance. The search for new materials that are capable of entirely replacing Nafion and platinum is the primary focus of efforts being put forth right now by those who are making those attempts. When it comes to end plates, the most major challenge is the deflection, which is particularly troublesome for stacks that include a big number of cells. This is because the deflection causes the end plates to bend out of shape. This problem may be solved by using a material with a high tensile strength, yet still relatively lightweight.

Renewable energy is widely recognized as one of the most potentially fruitful approaches to achieving sustainable development goals related to reducing greenhouse gas emissions. Today, we are confronted with the challenge of further expanding the infrastructure for renewable energy, which calls for the development of dependable energy storages, carriers that are kind to the environment, such as hydrogen, and highly competitive international markets.

The most significant trends in the expansion of renewable energy, as well as the chances for further scaling up this expansion via the use of green hydrogen solutions and the participation of resource-based nations in energy transition processes, were analyzed by Kopteva et al. [144] These included three potential strategic scenarios for the development of the energy industry: (1) the diffusion of renewable energy sources into the current energy system via the development of power accumulators; (2) the prerequisites for the development of green hydrogen; and (3) other related areas. The authors also analyzed a pilot project's technical and economic feasibility to produce green hydrogen in the Magadan area (Russia). The authors concluded that most businesses' projections regarding the hydrogen demand level in international markets are optimistic. At the moment, the majority of hydrogen is produced through a process known as steam methane reforming. This process results in significant emissions of carbon dioxide, which in turn exacerbate the greenhouse effect. This concern for the environment gives impetus to the process of methane cracking, which is one of the most promising alternatives to the production of hydrogen and has the potential to produce zero CO_2 or carbon monoxide (CO) emissions. The cracking of methane has been the subject of extensive research, utilizing both metallic and carbonaceous catalysts. Researchers have recently concentrated their efforts on pyrolyzing methane in molten metals and salts to avoid the problems of reactor coking and rapid catalyst deactivation. A further advantage that is anticipated to arise is an improvement in heat transfer due to the high heat capacity of molten media. The energy used in the endothermic process can help lessen adverse environmental impacts in addition to the reaction that takes place and produces solid carbon and hydrogen. For pyrolysis in molten medium, concentrated solar energy has not been substantially investigated. The majority of studies have relied on electrical heating or the burning of fossil fuels as nonrenewable sources. However, it has the potential to be a viable and innovative route to further enhance the sustainability of hydrogen generation obtained from methane cracking. Msheik et al. [145] provided a summary of the research conducted on the generation of hydrogen by catalytic and molten media pyrolysis. The authors showed that the use of solid metals and carbonaceous catalysts for catalyzed methane cracking highlighted several noteworthy problems. These issues were principally concerned with the deactivation of the catalysts and the accompanying regeneration procedures. As a consequence, there was a limitation in the overall efficiency of the process, and it was unable to maintain the environmentally friendly qualities of methane cracking. The utilization of solar energy could be a feasible alternative for building a sustainable pyrolysis process to overcome the limits imposed by the catalyst. The high operating temperatures that may be obtained via the concentration of solar energy have made it feasible to do away with the need to use catalysts in the process of thermal methane pyrolysis. In addition, there is no production of CO or CO_2 emissions, and the heat that is necessary for this endothermic process is obtained only from the concentrated energy that is provided by the sun.

9. Others

Wave energy is a clean and sustainable type of energy that may be harvested in coastal areas. When undertaking analytical, numerical, and experimental investigations, such as those involving wave farms and extremely large floating structures, it is standard practice to use the assumption that the wave field is uniform over its whole. When it comes to the interactions between the floating components, the direction, amplitude, and phase of the waves acting on each element are all important factors to consider. Consequently, it is probably unreasonable to anticipate that the waves would be consistent in the near-shore locations where these systems will be situated. Rodrigues [146] shows that interaction theory can deal with inhomogeneous wave conditions. When the amount of energy produced by renewable sources is more than the amount of energy used, a variety of energy storage technologies may be utilized to store the excess energy. According to Nemś [147], the shape of the components that make up the thermal energy storage system affects how heat is transferred through those materials. In order for scientists to make a significant contribution to the development of renewable energy, it is essential for them to perform an in-depth analysis of the structure that is behind the distribution of academic research subjects that are related to renewable energy, and the areas that are most likely to attract new interest in the near future. Using research articles from 2010 to 2019, Park and Kim [148] statistically investigated the temporal variations in renewable energy themes using sophisticated probabilistic topic modeling. They also examined the qualities of the themes from the standpoint of future signals. As a result, much emphasis is made on optimally incorporating renewable energy sources into the electricity system.

10. Conclusions

The use of fossil fuels has contributed to a rise in climate change and global warming, raising the need for energy sources that are both sustainable and kind to the environment. It would seem that the most viable alternatives to fossil fuels will soon be those derived from renewable energy sources. Since the turn of the twenty-first century, there has been a significant increase in the focus placed on studying renewable energy systems. Among the various renewable energy sources, significant research has been focused on commercially available solar and wind energy. The most current innovations and achievements in the fields of solar, wind, biomass energy, and energy storage systems have been highlighted in this review. It has been described that hybrid renewable energy sources, including energy storage systems, are necessary to reduce the negative effect of renewable energy sources' intermittent nature. Furthermore, proper energy management is essential to balance energy production/consumption/storage from various renewable energy sources, as well as the case of connecting renewable energy to the grid. Large-scale energy storage systems integrated with various renewable energy sources were also discussed. There is a rapid deployment of renewable energy at a large scale worldwide, and this transition from fossil fuel increases with the technical advances in renewable energy and energy storage technologies.

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