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Review

Solar Energy: Applications, Trends Analysis, Bibliometric Analysis and Research Contribution to Sustainable Development Goals (SDGs)

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Abstract: Over the past decade, energy demand has witnessed a drastic increase, mainly due to huge development in the industry sector and growing populations. This has led to the global utilization of renewable energy resources and technologies to meet this high demand, as fossil fuels are bound to end and are causing harm to the environment. Solar PV (photovoltaic) systems are a renewable energy technology that allows the utilization of solar energy directly from the sun to meet electricity demands. Solar PV has the potential to create a reliable, clean and stable energy systems for the future. This paper discusses the different types and generations of solar PV technologies available, as well as several important applications of solar PV systems, which are "Large-Scale Solar PV", "Residential Solar PV", "Green Hydrogen", "Water Desalination" and "Transportation". This paper also provides research on the number of solar papers and their applications that relate to the Sustainable Development Goals (SDGs) in the years between 2011 and 2021. A total of 126,513 papers were analyzed. The results show that 72% of these papers are within SDG 7: Affordable and Clean Energy. This shows that there is a lack of research in solar energy regarding the SDGs, especially SDG 1: No Poverty, SDG 4: Quality Education, SDG 5: Gender Equality, SDG 9: Industry, Innovation and Infrastructure, SDG 10: Reduced Inequality and SDG 16: Peace, Justice and Strong Institutions. More research is needed in these fields to create a sustainable world with solar PV technologies.

Keywords: Sustainable Development Goals (SDGs); bibliometric analysis; solar energy; large-scale solar PV power plants; residential applications of solar PV; green hydrogen; water desalination

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1. Introduction

The sun is a huge sphere of gases emitting light and energy towards our planet, and this energy received from the sun is a form of radiation best known as electromagnetic radiation [1]. It can be measured in the wavelength range of a measuring device, and it is called solar irradiance. The units used to measure this solar irradiance are W/m^2 in the SI system of measuring units [2] and are the radiant energy emitted into the surrounding environment integrated over a specified time. Figure 1 shows the average of this irradiance around the planet. Sun irradiation, solar exposure, solar insolation or insolation and several other terms are all used for this combined solar irradiance.

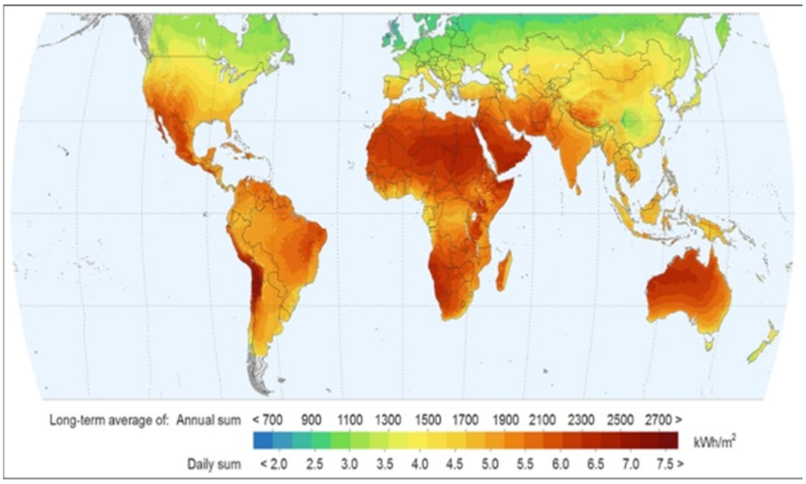


Figure 1. Long-term average irradiance around planet earth (from www.smartenergyconsulting.com, accessed on 13 July 2022).

Solar energy is the term for the energy collected from solar irradiance, and this energy can be in the form of heat (thermal energy), a chemical change or process or even pure electrical energy (electricity) [3,4]. The overall amount of solar energy that strikes the earth is much greater than all its current and future energy demands, so this highly distributed source could meet all of our energy demands if it is properly utilized. Solar energy, in contrast to common sources of energy such as coal, petroleum and natural gas, has become one of the most prominent and environmentally safe energy sources recently, which indicates that it will last millions if not billions of years. The sun is not just a tremendously strong energy source; its light is by far the most abundant source of energy received by the earth. However, its intensity at the surface is quite modest, which is mostly due to the distance between the earth and the sun, causing a vast radial dispersion of radiation along the way. The earth's atmosphere and clouds absorb or scatter more than half of the incoming sunlight [5], resulting in a small extra loss. More than half of the sunlight received from the sun is called visible light, with the remaining consisting of infrared, ultraviolet and other kinds of electromagnetic radiation. The amount of raw energy received from the sun is more than enough to cover all the planet's energy demands thousands of times over [6], so this is why solar energy possesses an incurable potential that needs to be explored thoroughly. Unfortunately, however, despite the fact that solar energy is a free and available almost everywhere on the planet, the high cost of collecting this energy and then converting it and storing it restricts its use in many regions all around the globe. Solar radiation can be turned into thermal energy (heat) or electrical energy, with the former being more straightforward [7], as the heat emitted from the sun is used directly for heating purposes for a long time. However, solar heat (thermal energy) can be used in so many different applications and ways in our current time, as the technology for solar collectors and dryers has improved drastically, as can be seen from the literature [4,8–11].

Renewable energy has proven its ability to supply considerable amounts of energy for all sorts of different locations. Solar, wind and hydroelectric energy supply and consumption should be favored, especially given greater knowledge of the detrimental environmental implications of oil and gas production. The need for renewable energy is expanding all around the world [12], as renewable energy adoption is crucial for the power industry all around the globe, enabling us to finally achieve sustainable energy development in our regions. Solar energy plays a major role in this development, as it can even challenge other renewable energy sources. Table 1 below shows a comparison between solar energy and other renewables [13].

Table 1. Advantages and disadvantages of some renewable energy resources.

Energy	Advantages	Disadvantages
Biomass	• Very versatile in terms of fuel used • Reduces waste • Carbon-neutral	• Presence of impurities • Requires a lot of space • Can cause deforestation
Geothermal energy	• Has huge potential • Effective for heating/cooling purposes • Eco-friendly	• Very restricted in terms of location • High cost
Hydro-energy	• Low emissions • Can generate power during day or night • Safe	• Can have potential consequences on some sea habitats • Expensive
Solar energy	• The most sustainable source, as the sun will last for a long time • Completely clean • No noise generated • Simple • Low-maintenance	• Not available during the night • Highly dependent on the weather • Storage issues • High initial cost
Wind energy	• Cost-effective • Clean energy • Provides jobs	• Can pose a threat to some kinds of wildlife • Very noisy • Wind is not available all the time • High initial cost

This paper aims to provide knowledge about the different applications of solar PV systems and about how they assist with the accomplishment of the Sustainable Development Goals (SDGs). A bibliometric study is also conducted to understand the publication trends of "solar" and its discussed applications, namely "Large Scale Solar PV", "Residential Solar PV", "Green Hydrogen", "Water Desalination" and "Transportation" within the SDGs, while shedding light on what the SDGs lack/require in research in the fields of solar energy and determining the most frequent keywords in each of these fields.

2. Solar PV: The State of the Art

2.1. Fundamentals of Solar PV

Solar photovoltaic (PV) cells directly take sunlight and convert it into electrical energy [14,15], and this phenomenon is known as the PV effect. The science behind these solar PV cells is quite simple; a semiconductor such as silicon is used alongside metal or another semiconductor [16]. As sunlight strikes the junction between them, electrons obtain enough energy to be activated and freed from the semiconductor, thus moving to the other side in one direction, resulting in a small electric voltage in the cell. A single PV cell produces a small amount of power of usually around 2 W [17]. Small solar PV cells are commonly used in small/low-power devices, such as calculators, watches and flashlights. However, these cells can be combined and connected to create a single module commonly known as a solar PV panel. Solar PV panels can be used individually or connected together (in series or parallel) to form an array of panels that produces much larger amounts of electricity [18].

A solar PV system comprises several components, and the PV panel/array is only one of them. Figure 2 shows some other various components that are used, such as a battery in the case of off-grid PV systems used to store the produced energy, alongside a charge controller to regulate and control the charge and to protect the battery. An inverter is also used convert the DC (direct current) produced by the solar panels into the AC (alternating current), which is used in all houses.

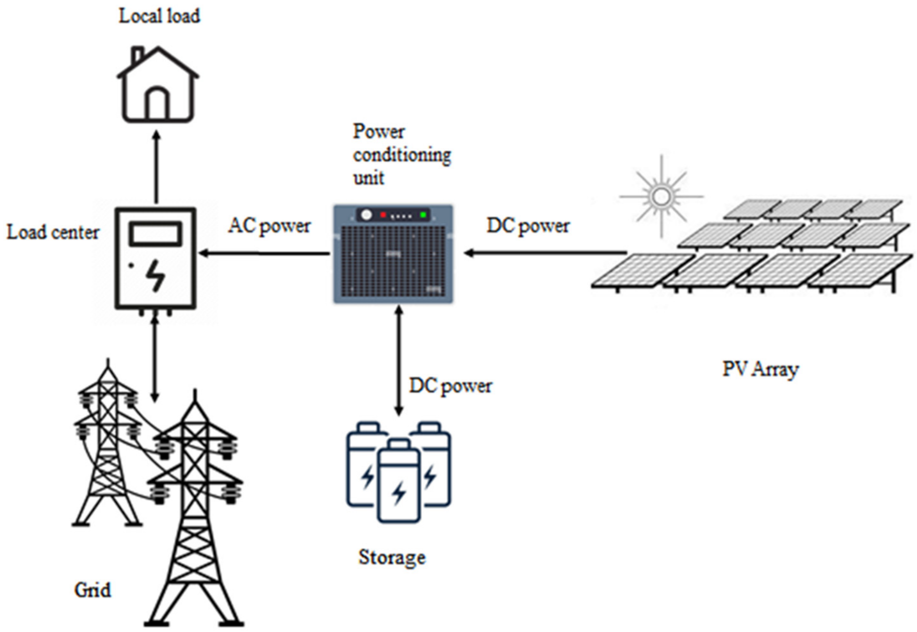


Figure 2. Schematic of an on-grid solar system.

Commonly used solar PV panels have an energy efficiency percentage ranging between 16% and 22%, which is quite low, forcing the use of a higher number of panels/cells to produce enough power output to support the grid [19]. Much research is being conducted to increase the output efficiency of solar PV cells, and their technology has advanced in the past few years, which, in return, is very promising.

2.2. Different Generations of Solar PV

Solar PV technology can be categorized into three main sets [20], which are commonly known as the first, second and third generations of solar PV, determined by their technologies and market entry time. It is very important to understand and distinguish between different types of solar PV cells when choosing one over the other, as this can be influenced by numerous factors such as the cost of the cells, efficiency, materials and even geographical location. Table 2 presents a summary of the different types and generations of solar PV technology [21–32].

2.2.1. The First Generation of Solar PV Technology

The vast majority of today's solar PV cells use silicon as a semiconducting material [33], mainly monocrystalline silicon or polycrystalline silicon. These cells are known for their high efficiency rates and long lifespan, making them a very valuable option for residential and commercial use.

Monocrystalline Silicon Solar Cells

The most common types of solar cells and the oldest of them are monocrystalline silicon solar cells. These cells comprise a single pure silicon crystal. Because of their purity, these cells are characterized by a high efficiency rate (usually above 20%), but their purity is also the reason why they are one of the most expensive cells [34]. However, huge improvements in solar PV technologies over the past years, as well as the drop in raw silicon prices and the rise of newer PV cells, have caused their prices to drop significantly. It is also worth mentioning that silicon-based PV cells are more sensitive to higher temperatures, which can lead to a drop in their overall efficiency.

Polycrystalline Silicon Solar Cells

These cells are produced with a faster method compared with the previous one. By melting raw silicon together [35], PV cells that are made using this way are cheaper in comparison to mono-silicon cells, but they are also a little less efficient and have a shorter lifespan, which are important factors to be considered.

2.2.2. The Second Generation of Solar PV Technology

The second generation of solar PV cells refers to what is known as thin film solar cells [36]. They are typically made from very thin layers (only a few micrometers thick) of polycrystalline semiconducting material. These solar cells are cheap and very easy to construct because less of the material is used for their production. They are also characterized by their outstanding flexibility and light weight, which make them optimal for portable needs. Thin-film solar cells are also very common in buildings and small PV systems.

Amorphous Silicon Solar Cells

Amorphous silicon solar cells are one of the main thin film cells that are commonly used today; these cells are found in very small devices, such as calculators. Usually made with a one-micrometer thickness [37], these very thin cells are very flexible and great for curved surface usage, and they also function very well in low light. However, their disadvantage is their low efficiency rate of around only 7%.

Cadmium Telluride Solar Cells

Cadmium telluride solar cells have gained huge popularity in PV technology, as they can be produced expeditiously with very low prices. In addition to that, these cells have good light absorption and minimal energy losses, making them a great option overall, but the shortcoming of this technology is that cadmium is a known toxic material, which has made many people concerned regarding the use of this type of solar PV panel [16].

Copper Indium Gallium Diselenide Solar Cells

Copper indium gallium diselenide solar cells are another type of thin film solar cells [38] in use. The technology behind such cells is quite complex, and their materials are hard to work with, making it very difficult to withstand the competition against silicon-based PV cells. Copper indium gallium diselenide solar PV cells have higher costs compared with amorphous silicon and cadmium telluride cells.

2.2.3. The Third Generation of Solar PV Technology

Solar PV technology has advanced tremendously since its first generation appeared, and it is still advancing every day as new research and experiments are conducted in this field all around the globe, leading to a new generation of solar PV cells that is still mostly under research and development. This makes them unavailable for commercial use [33]. There are many different types and technologies of what can be classified as a third-generation solar PV cell. One example is an organic PV (OPV) cell, in which an organic semiconductor is used as the light absorbent layer, and the organic semiconductor is usually either a very small molecular or a polymer. Another type of third-generation PV cell is called a concentrated PV (CPV) cell. They work like any conventional PV cell, but they consist of multiple junctions and can reach a very high efficiency level of up to 40% [39]. In addition to that, CPV cells can withstand high temperatures and can still be three times more efficient than traditional solar PV systems. To reach such high efficacy rates, CPV systems are integrated with lenses, tracking devices and cooling systems, which lead to large capital costs in most cases. CPV cells are already available on a large scale, with a capacity of 27 kW in Malaysia [40], 480 kW in USA [41] and 75 kW in Japan [42], as well as in several sites around the world.

Table 2. Comparison of different generations of solar PV cells.

Generation	Type	Efficiency	Advantages	Disadvantages
First Generation	Monocrystalline silicon	Up to 24% [43]	• High efficiency • Long lifetime	• High cost
	Polycrystalline silicon	13–20% [43]	• Lower cost	• Lower efficiency
Second Generation	Amorphous silicon	5–10% [14]	• Lower cost • Flexible • Ease of production	• Shorter lifetime • Lower efficiency
	Cadmium Telluride	18–22% [44]	• Lower cost • High absorption	• Toxic
	Copper Indium Gallium Diselenide	15–22% [45]	• Higher heat resistance	• Higher cost
Third Generation	Organic PV	Up to 17% [46]	• Lightweight • Eco-friendly	• Lower efficiency • Shorter lifetime
	Concentrated PV	40% [47]	• Very high efficiency • Can withstand high temperatures	• Very high cost • Must be integrated with solar tracking systems and cooling devices to reach high efficiency

3. Applications of Solar PV Technology

The pursuit of a green and sustainable energy source has quickly become one of the world's greatest challenges, especially in this modern era. This has mainly occurred as a result of the abrupt debilitation of conventional energy resources, such as oil and fossil fuels, as well as global environmental climate changes, such as global warming and the ever-increasing demand for power and energy. Among various sustainable and renewable energy technologies, solar PV cells are the most common and mature green energy systems [48] used to counter the world's growing need for energy. Like any other energy technology, solar PV cells are not perfect and face many challenges when integrated. However, with their fast advancement in technology, solar PV cells have managed to be used in various applications in our modern time, with some systems producing as little as a few watts (W) and others producing megawatts (MW) of power every day.

3.1. Large-Scale Solar PV Power Plants

Solar PV technology has gained wide popularity in the last few years in large-scale power generation, making it a key factor in the power sector around the globe. Solar PV power plants (also known as solar farms) function very similarly to how a small domestic PV system does; however, solar PV power plants are usually connected to the power grid and are known as grid-connected centralized PV plants [49,50]. These power plants feed a large bulk of energy to the associated grid through the centralized generation of energy. A PV energy generation system is usually considered a power plant when its total power output is no less than 1 MW. However, some power plants are rated with a power generation output of dozens of MW to several hundred MW [51]. Such systems are designed and regulated with varying complexity regarding their environmental surroundings and geographical location in order to obtain the highest possible performance, all while maintaining a desirable balance between the performance and the cost of the system. For instance, in 2022, the United Arab Emirates had solar PV power plants of a total capacity of 950 MW [52].

3.1.1. Components of Solar PV Power Plants

PV power plants consist of several components, as shown in Figure 3, such as the cells, mounting, connections (both mechanical and electrical) and many others [53]. The appropriate selection of these components plays a major role in the design of the system, and the most important components are shown below.

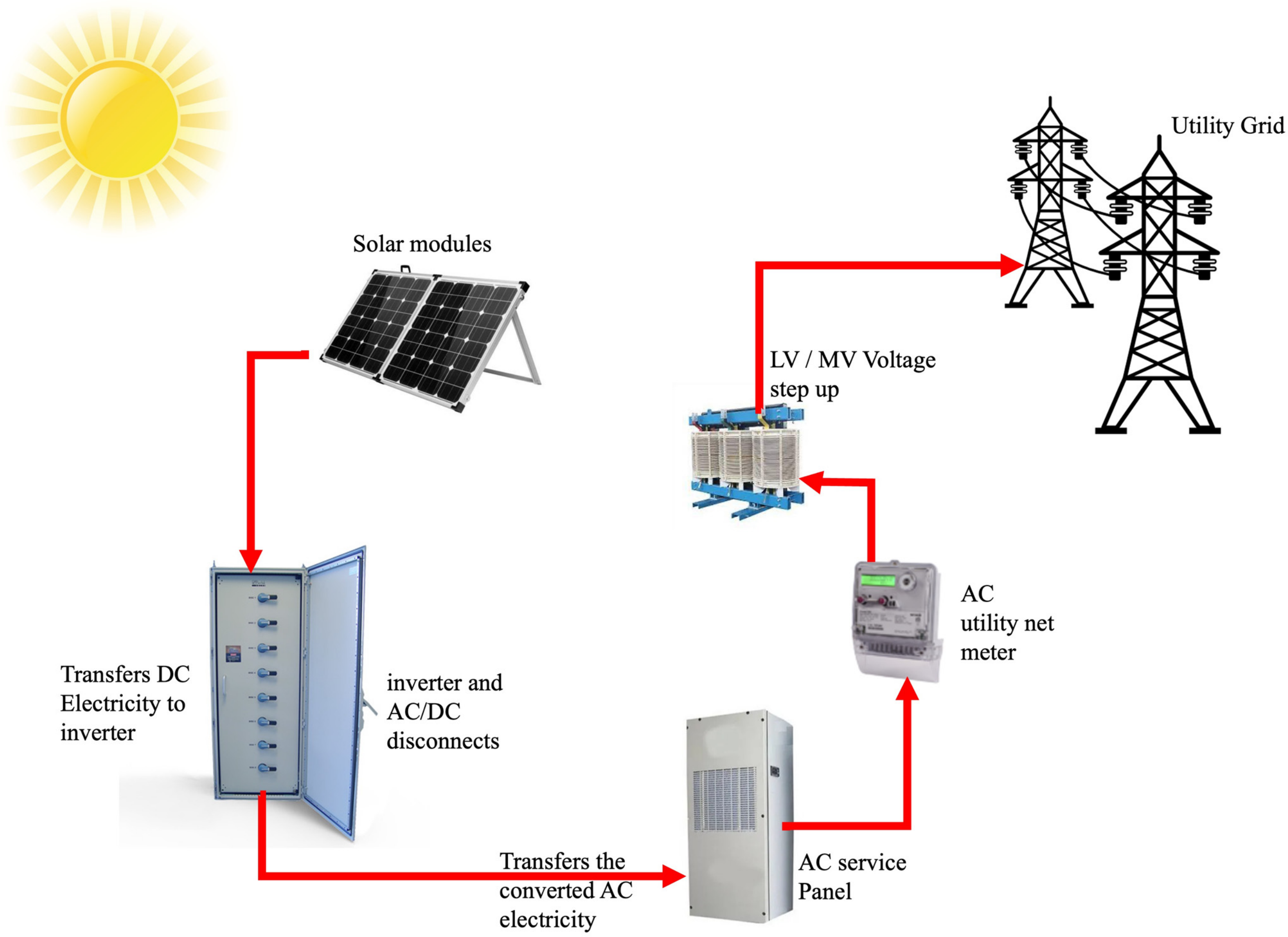


Figure 3. Main components of a solar power plant.

PV Modules

Solar PV power plants comprise a large number of PV cells that are connected together, thus making PV modules which, in return, are also connected together, making PV strings that are able to generate the desired power output. Solar PV modules are the core of a PV plant, and their sole function is to take the solar irradiance coming directly from the sun and convert it into electrical energy through this process, known as the PV effect. The generated electrical output is in the form of DC current. Solar PV modules have the highest cost of components in a PV power plant [54], which is usually due to the large number of modules that are used.

The site of the PV power plant plays a major role in determining what kind of solar PV module to use, and there are many important factors [55] to consider here regarding the surrounding environment. The three most important environmental factors are: (1) the temperature, (2) distance to shore and (3) dust and snow.

Mounting and Tracking

In a PV power plant, a mounting structure is required for the panels to keep them attached and supported in a secure manner while keeping them facing the correct direction for maximum power generation. These structures can be either a fixed system or a tracking system. In a fixed mounting system, the solar PV panels are oriented in a fixed direction, with a fixed tilt angle all the time. It is crucial to choose the correct angle and direction in order to obtain the maximum power output possible from the total solar irradiance on the solar panels. Unlike fixed mounting systems, tracking systems allow the panels to follow the sun as it moves during the day, and solar tracking systems are essentially the only parts that move in a solar PV power plant. Tracking systems help solar PV panels generate more energy than fixed systems due to them following the direction of direct sunlight, and trackers can help PV power plants generate up to 37% more energy output than systems without trackers [56].

Inverters

An inverter is used to convert DC electricity coming from the solar panels into AC electricity to feed into the grid. Inverters are classified into two main types: central inverters and string inverters [57]. For central inverters, a whole block (multiple strings) of solar panels is connected to a single central inverter, thus converting a huge amount of power, whereas string inverters use a separate inverter for each string of panels.

Transformers

These devices are critical, and they are required in PV power plants. As the output voltage coming from the inverters is usually lower than that of the AC grid, this is where transformers are used to increase the voltage to match the required voltage of the grid so that, when the plant is connected to the distribution grid, electricity can be directly pumped into it. When the plant is connected to a transmission network, the grid transformer is necessary to increase the voltage even more.

Grid Interface

The power is transferred into the grid network from this point. The power plant's substation also includes necessary grid interface switch-gear, such as circuit breakers and disconnects that are used to shut down the system in cases of faults, as well as generation and supply metering equipment for the PV power plant's safety and isolation.

3.2. Residential Applications for Solar PV Systems

Solar PV systems are not limited to utility-scale power generation; solar PV systems have gained usage in many households all across the world, proving that solar power is an effective source of energy. Solar PV modules have grown in popularity in recent years due to the numerous advantages and opportunities they provide [19]. A rooftop solar PV system, as shown in Figure 4, refers to a household or building that has solar PV panels installed and mounted on its roof for electrical energy generation purposes. Rooftop-mounted solar PV systems are very modest in terms of size and output compared to utility-scale solar PV power plants with capacities in the MW range. Residential rooftop solar PV systems normally have a capacity of 5–20 kW [58], whereas commercial rooftop PV systems can easily reach 100 KW to 1 MW depending on the size of the building [59], the available space and the number of installed solar modules. Larger industrial-scale PV systems ranging from 1 to 10 MW [60] can be installed on big rooftops, such as large factory roofs, etc. Although rooftop solar PV systems can vary in terms of design and used components, all of these systems require a base set of components, which are PV solar panels used to convert sunlight into electricity, mounts, clamps used to fix and install the modules on a set of racks, inverters for DC/AC conversion and batteries for storage (if required), cables and other possible accessories.

There are two main ways for households to adopt solar PV into them, either by using a grid-connected PV system or a stand-alone PV system [61]. Grid-connected systems heavily depend on a nearby power grid to remain connected to a power source at all times. This means that, if the building requires more power than the solar panels have produced, if a problem occurs in the PV system that prevents it from generating electricity, or even if power is used during the night when there is no sunlight, the grid can provide the necessary power. Grid-connected PV systems are also great for areas that usually have cloudy and dusty weather situations. However, if a residential solar panel system manages to produce more electricity in a day than that which the household uses, the excess energy can then be transferred to the nearby power grid, which provides support to it and relieves the load of the grid during peak hours, creating a solid network of energy between residential areas and their associated grid. This is why grid-connected solar power systems account for the majority of rooftop PV installations, with so many governments and utility companies adopting this method. Additionally, they provide attractive Net Metering and Feed-in Tariff programs that can help consumers [62] offset their power expenses. Grid-connected solar PV systems have many advantages, but what makes them unique is the fact that they are less complicated to install. They do not require a battery for storage, as the extra energy goes directly to the grid, making these systems provide the benefit of maximizing the usage of generated energy due to the absence of storage losses. However, stand-alone PV systems have no direct connection to the power grid. As shown in Figure 5, these systems are built to take the electricity generated by the solar panels and store it inside batteries, and the stored electricity from these batteries is used to power all the gadgets connected to it. Stand-alone systems are usually utilized in places where there is no access to the grid [63], but that is not the only case, as many people today use these systems in conjunction with the grid. The advantage of these systems lies in their ability to use them in the nighttime when solar panels do not generate any power. However, stand-alone PV systems are often more expensive than grid-connected PV systems due to the high cost of batteries [64,65]. Until now, the most popular kind of batteries for residential PV has been lead–acid batteries, which are a form of electro-chemical storage [66]. They has solely been employed in off-grid solar applications because of their exorbitant pricing, but with power rates rising in many areas around the globe and battery prices falling, viable battery storage solutions for grid-connected homes are developing.

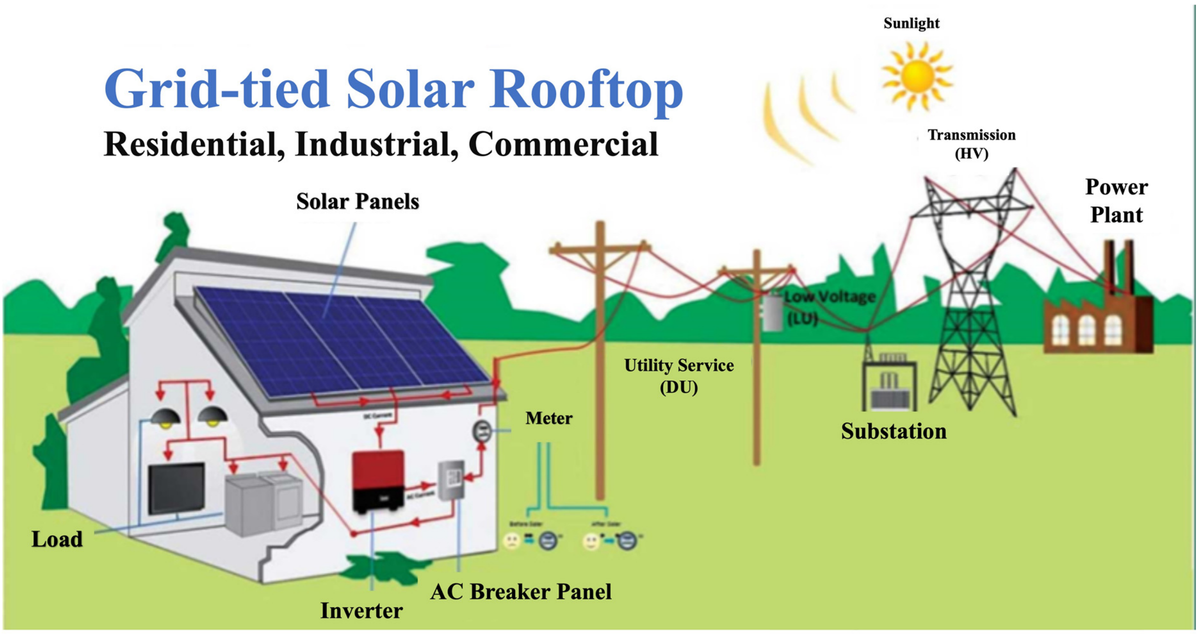


Figure 4. Grid-connected solar rooftop system (from www.solarideatspl.com, accessed on 13 July 2022).

From the standpoint of global climate change mitigation and sustainable energy supply, this breakthrough is critical. Residential battery storage systems with solar PV and smart inverter technologies can modify this paradigm, allowing users to not only adjust when they use power but also to lower the amount of electricity they need from the utility grid or to even completely unplug from it.

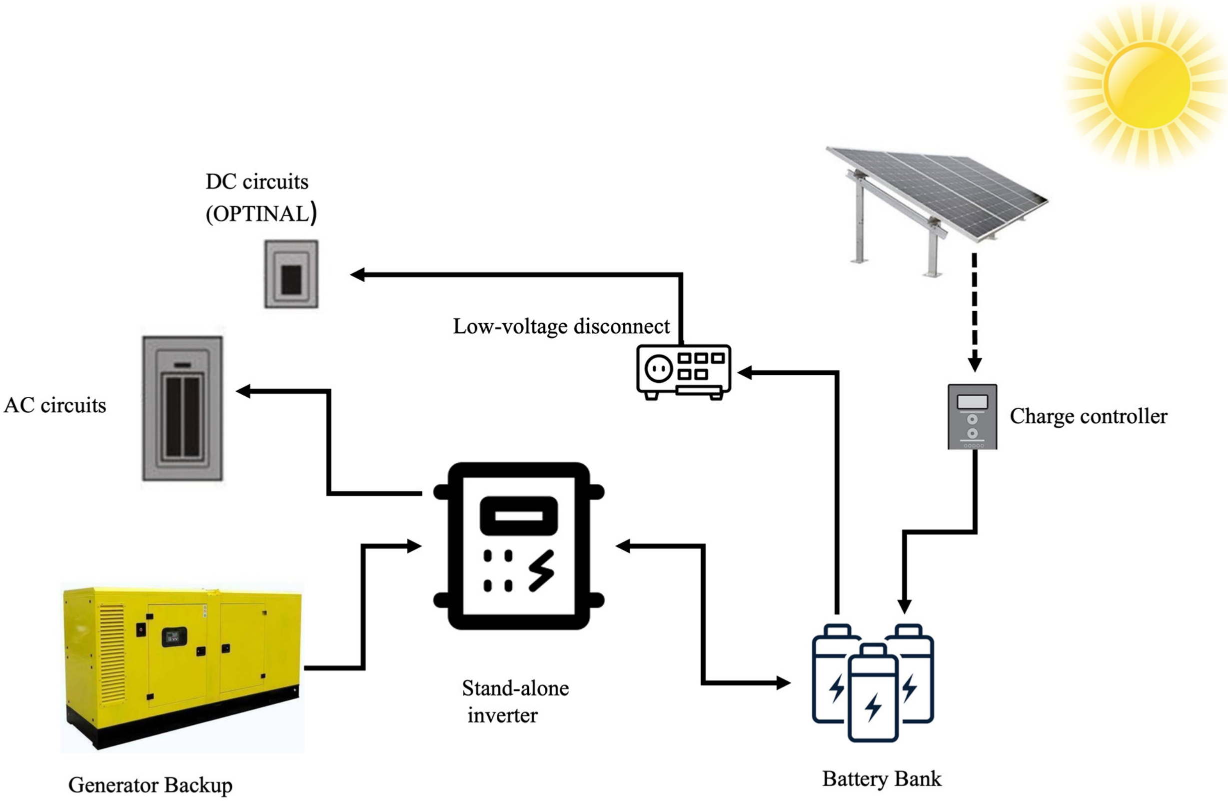


Figure 5. Rooftop stand-alone PV system with batteries.

3.2.1. PV-Powered "Heating, Ventilation and Air Conditioning" (HVAC) Units

In hot and humid areas, such as the Middle East, air conditioning systems are critical for ensuring thermal comfort in all interior spaces. Air conditioning, which includes cooling and de-humidification, especially during summertime [67], has experienced a significant rise in power demand due to the widespread usage of air conditioning equipment, which has eventually led to high stress levels on the grid, especially during peak hours. As a result of the high match between the diurnal cooling load and the availability of solar irradiance, using solar PV systems for domestic air conditioning is a very appealing application, as it has the power to supply the chosen indoor area with the needed cooling capacity. Solar PV cooling systems can employ electricity generated by PV cells from residential PV systems to power a traditional vapor compression air conditioning system. Despite PV systems being simple, their applications have been hampered for years by the high cost of solar PV modules alongside the rest of the accompanying air conditioning equipment. However, with the rapid decrease in the cost of solar PV modules and the rapid increase in energy usage for cooling/heating purposes in recent years, more attention has been drawn to these technologies. There are many advantages of a PV-powered air conditioner, and the most important of them can be seen in its very simple structure, operational stability and rapid reaction to load variations during the day. PV-powered air conditioners also have the ability to offer warmth in the winter under certain climate conditions [68,69], because, in many cases, traditional residential air conditioners can act as heat pumps. Because both the heating/cooling demand and the electricity generated from a PV system vary during the day and are not always the same, whenever the PV system generates extra power, it can be stored in the battery of a stand-alone residential PV system or can even be transferred to the grid with a grid-connected residential PV system [68,70]. Air conditioning energy usage is now at a larger proportion of the total building energy consumption in hot climate countries. In the UAE, it is estimated that the cooling energy used in buildings and homes exceeds 50%, as shown in Figure 6. This is why PV-powered air conditioning systems installed on a large scale might be a useful way to relieve the load on the electric grid during peak hours, saving not just energy but also a huge sum of money over time.

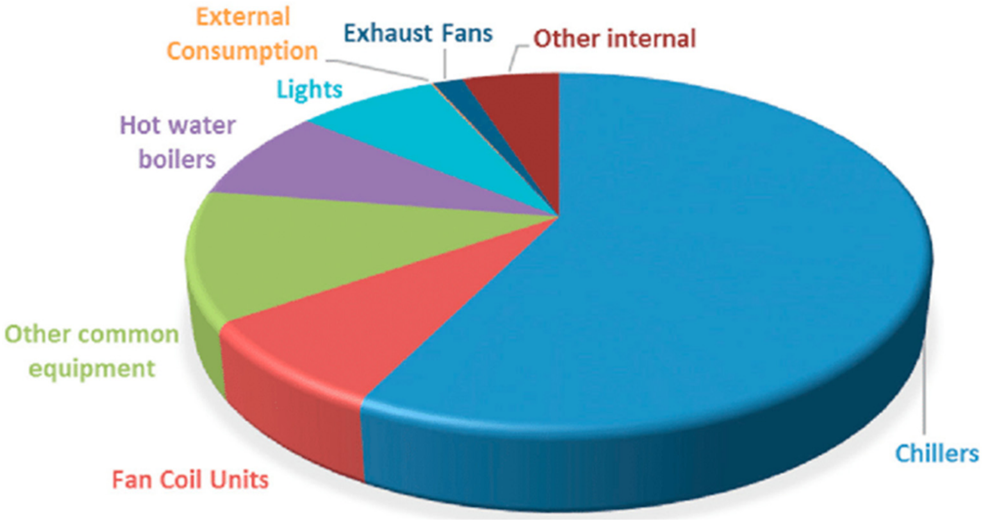


Figure 6. Energy consumption of residential equipment in the UAE [71], open access.

PV-powered air conditioners have three main types based on what kind of electricity they use to function [72,73], which are DC solar air conditioners, AC solar air conditioners and hybrid solar air conditioners. DC solar air conditioners work using direct current (DC), and these air conditioners can be either connected directly to solar PV panels or connected to a battery system charged by PV panels. These air conditioners run completely off the grid, as they cannot function with an alternating current (AC) supply. DC solar air conditioners are quite simple and easy to use; however, if they are used during the nighttime, it should be ensured that there is enough battery storage capacity. In contrast, AC solar air conditioners (shown in Figure 7) use alternating current (AC) as the driving power and require the presence of an inverter. These air conditioners are the most common of the three. AC solar air conditioners may or may not use a battery, but their main advantage is that they can be connected to the grid and run on it either partially or fully. As the name implies, hybrid solar air conditioners function using DC and AC supply, as they are connected to both the solar system and the grid unit at the same time, making them an overall solution that works with any system available, switching from DC to AC or the opposite with total ease. Although these air conditioners work with inverters, they are not necessary components.

3.2.2. PV-Powered Water Pumps

Water is essential for human survival because it is required not only for drinking purposes but also for everyday domestic use and even large-scale applications such as irrigation and hydro-power generation. This is why water plays an important part in any country's growth, and even though fresh water is plentiful, it is not always readily available in certain places. Research indicates that, by 2025, around three billion people will not have access to potable water [74] around the globe. This will raise the need for a pump to take water from deep below earth's surface, where it is needed. Water pumps have been used for decades. However, they are commonly diesel-powered pumps, but due to the unfortunate increase in the price of fuel in the global marketplace, toxic pollutants from its combustion, the cost of maintenance and its limited lifespan, an alternative is highly needed. Different renewable energy sources can be utilized for water pumping, but solar is gaining a lot of popularity because it is accessible almost everywhere on the planet, even in distant locations, reducing reliance on the grid and diesel for pump drives [75]. The concept is very simple. Solar energy is clean and abundant, and solar PV panels turn sunlight directly into usable electrical energy, which is, in return, used to power the water pump directly or via an inverter. Solar-powered water pumps have various benefits over traditional pumping systems [76], such as the fact that gasoline and diesel engines require expensive fuel for long periods of time and pollute the air and noise in clean residential areas, and solar water pumps are ecologically benign and do not require extra fuel to operate, making them cost-effective, environmentally friendly and dependable, with less maintenance and a longer life span.

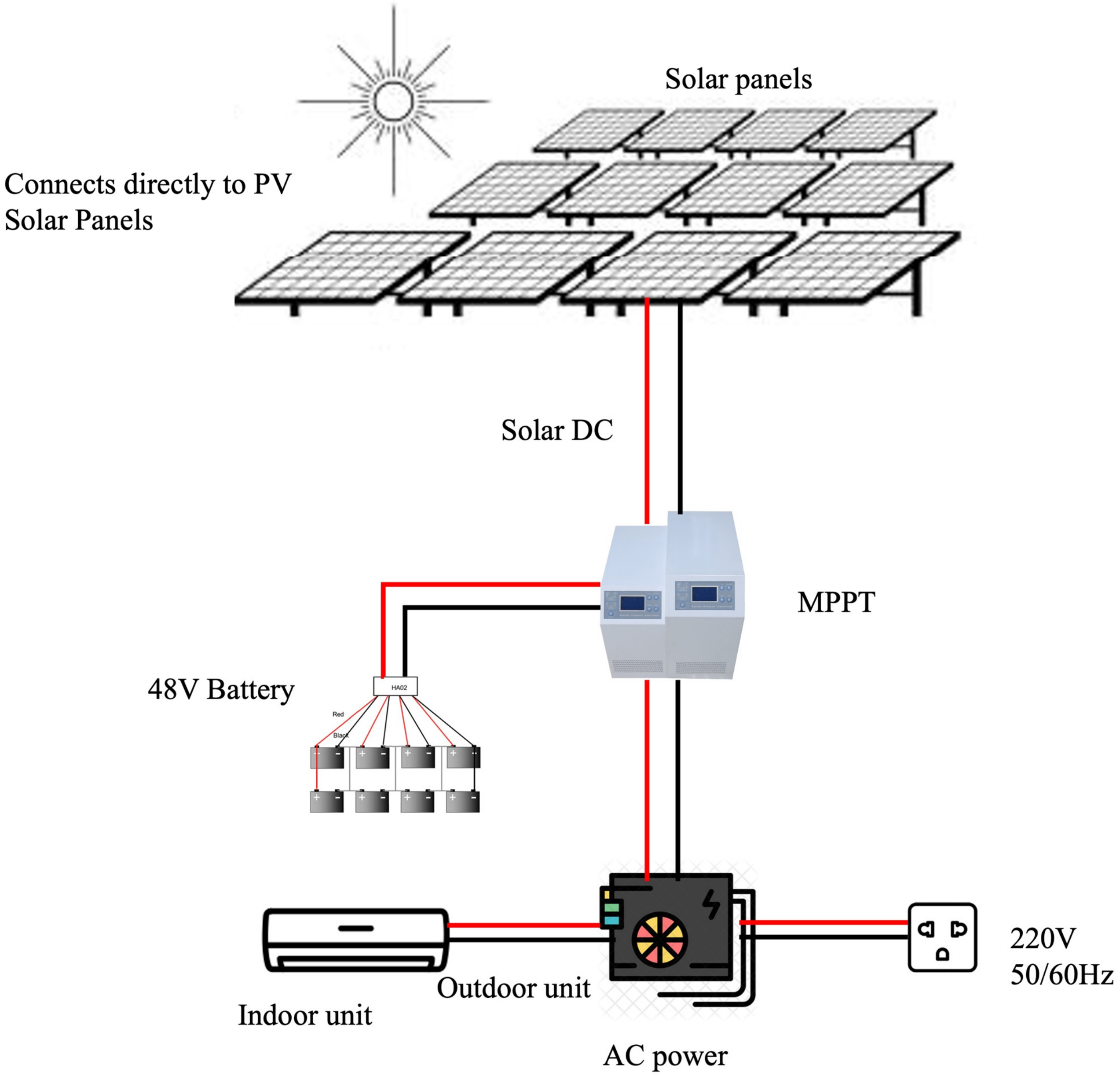


Figure 7. Schematic of solar-powered air conditioner.

Solar water pumps can be developed or designed in a variety of ways, but the majority of these systems function with the same common method, which is to employ PV panels to power water pumps. The system consists of a solar PV system integrated with a power conditioning unit, a hydraulic water pump and a storage tank, as shown in Figure 8. PV panels are sometimes installed with a tracking system for increased efficiency, but it is not a necessity. In addition, because the produced energy is predominantly DC and the pump is mostly AC, an inverter must be utilized in order to convert the output energy to AC before it can power the water pump. The water pump can be submerged in the water or positioned at ground level, depending on what type of solar water pump is used [77]. The water pump delivers the water upward from a water reservoir to a storage tank high above, the reason for which is to allow the storage tank to use gravity to naturally pump water back down whenever needed at no extra cost. The head of the pump is used for the height difference between the tank and the water reservoir level, which is a crucial consideration when choosing a pump to deliver water from the reservoir to the tank.

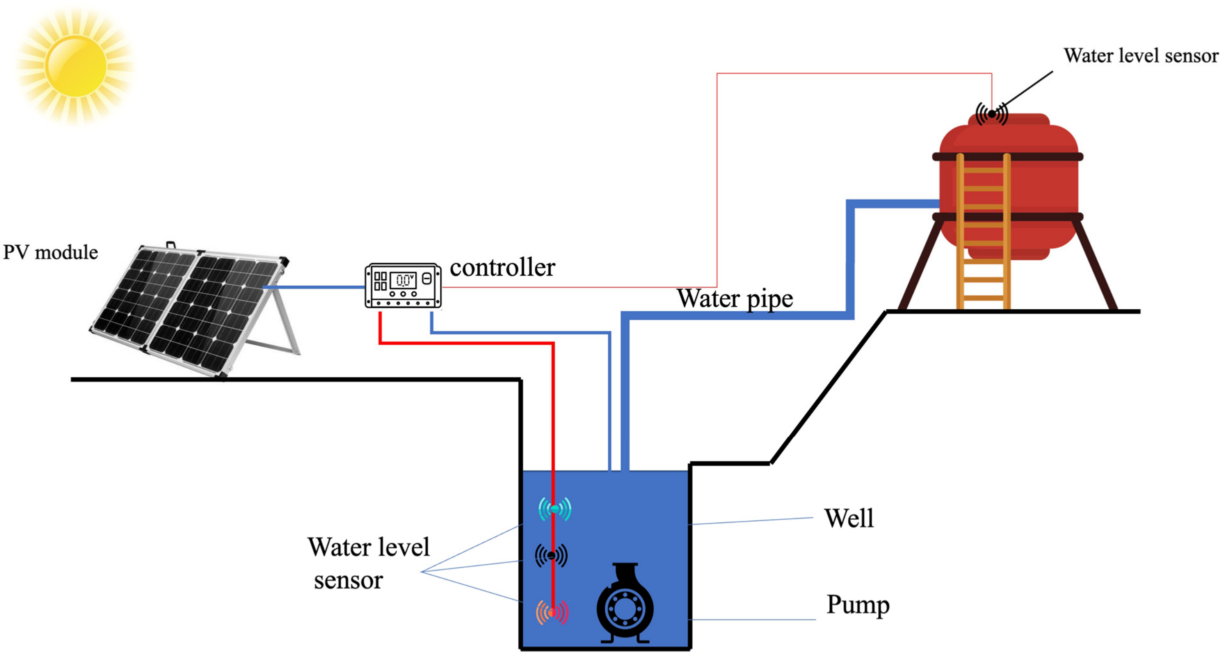


Figure 8. Schematic of a solar-powered water pump.

3.3. Green Hydrogen

Energy storage technologies are undoubtedly a critical and important component of modern-day energy sources, particularly those of which are considered renewable, such as wind and solar. The reason is that renewable energy sources do, in fact, require a storage system to ensure a reliable power supply due to their intermittent nature [78]. Storage systems enable a solution for the maximum demand problem, and from an energy standpoint, energy storage technologies can take numerous shapes and forms. Figure 9 shows the different ways that energy can be stored. Anything that allows for the storage of energy, such as batteries, can be employed as an energy storage system in practice. However, not all storage systems are devices, as green hydrogen is considered a great way to gather and store energy in a safe and clean manner [79].

Hydrogen fuel is a long-term clean energy carrier that can play an important part in today's global energy situation, as it is highly capable of reducing the CO_2 footprints [80] of the transportation and manufacturing industries. Hydrogen fuel is rarely found in its natural condition (H_2) on our planet, and traces of it can be found in our atmosphere, the majority of which is combined with oxygen to form water. Thus, H_2 must be manufactured artificially by humans. Today, hydrogen is primarily derived from hydrocarbons, which, in return, emit a significant quantity of CO_2 into the environment [78]. However, other methods are available, such as water electrolysis. Water electrolysis is a typical method for producing pure hydrogen, in which electricity splits water into its two counterparts, hydrogen and oxygen, in a safe controlled process. Figure 10 shows a simple illustration of water electrolysis. Hydrogen, like gasoline, is an extremely combustible type of fuel; however, unlike gasoline, which spreads horizontally, hydrogen flames soar upward due to its buoyancy, as it is far lighter than the air around it.

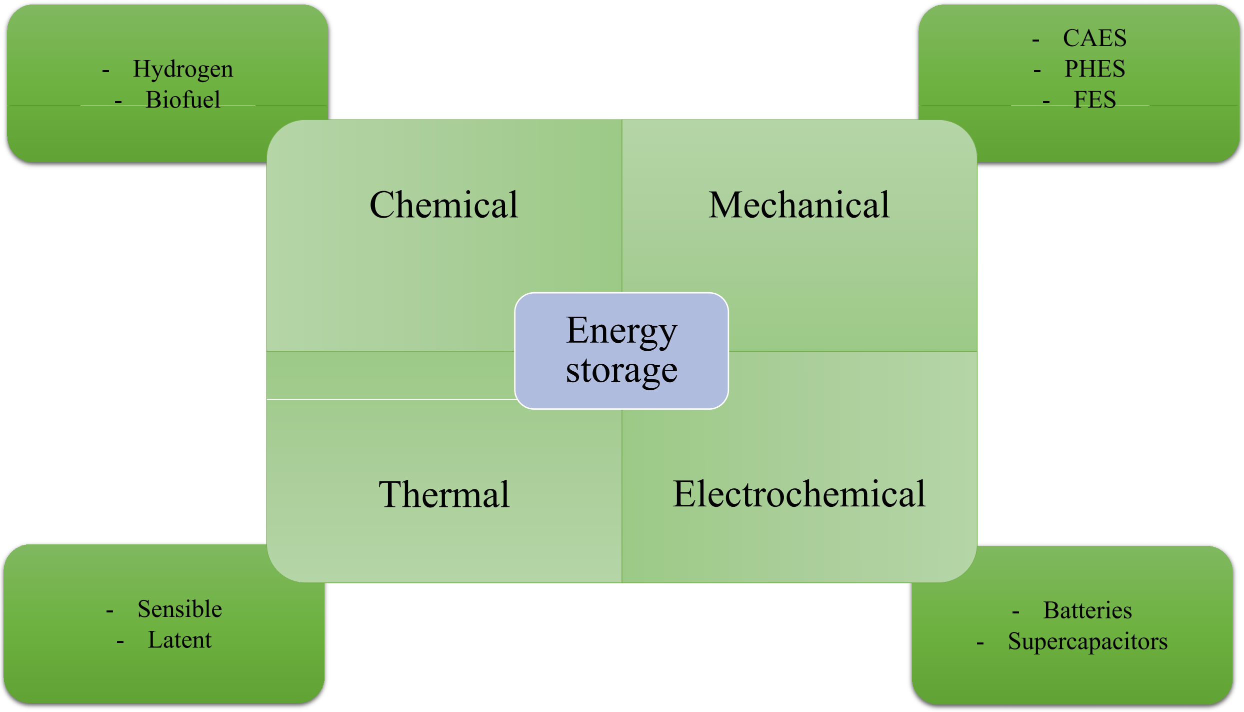


Figure 9. Types of energy storage routes.

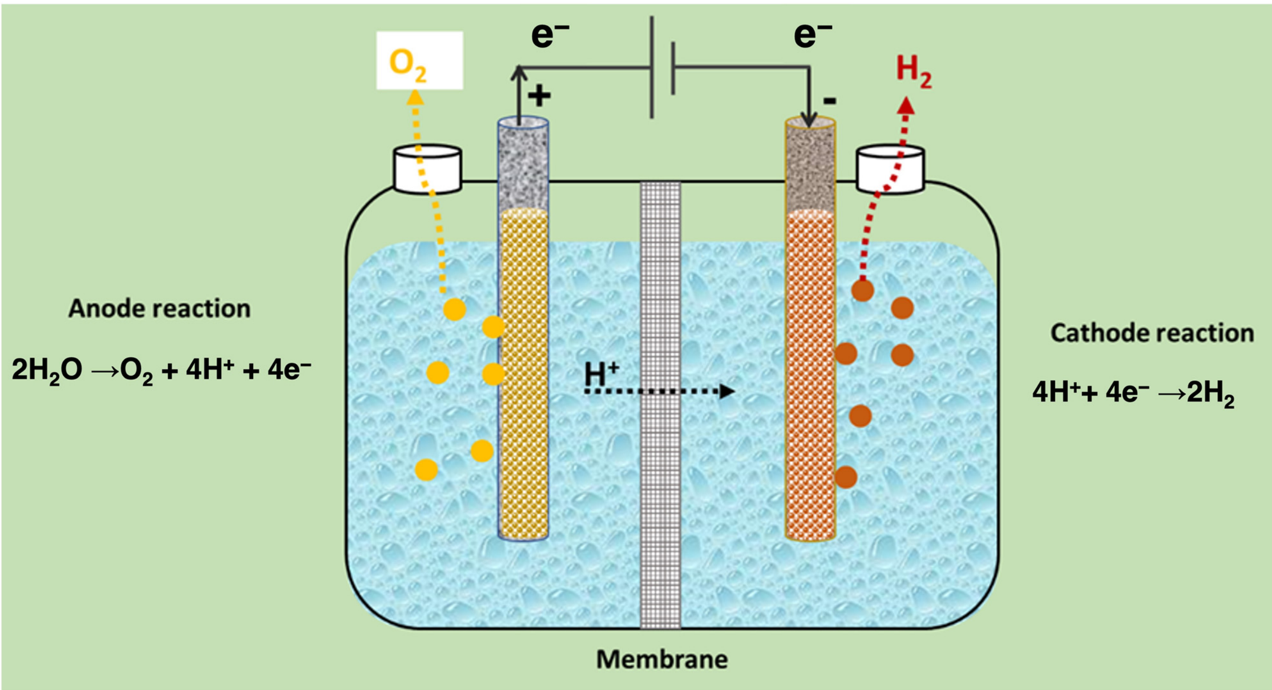


Figure 10. Simple water electrolysis.

Hydrogen can be classified into three main types depending on how it is extracted. The first and most common type of hydrogen is known as gray hydrogen [81], which is considered the least renewable kind of hydrogen because it is obtained from natural gas and is manufactured using fossil fuels. The process is conducted via reforming natural gas, which is a method of altering the molecular structure of hydrocarbons through a catalytic chemical reaction. Methane, which is a major constituent in natural gas, is then mixed with steam at a very high temperature to create hydrogen and carbon dioxide. Gray hydrogen is quite cheap, and it is widely utilized in the chemical sector to create fertilizers and refine oils. However, its shortcoming is the huge amount of CO_2 produced from this process, which is ten times more than the amount of H_2 produced, thus giving it the name gray hydrogen. The second type of hydrogen available is known as blue hydrogen [82], which is produced using the exact method used for producing gray hydrogen, with the difference being how the carbon that is generated as a result is handled. CO_2 produced here is not released to the atmosphere, but it is captured instead and stored in a process called "Carbon Capture and Storage", or CCS for short [83]. Blue hydrogen is now gaining more traction as a viable alternative because it emits less CO_2 than gray hydrogen, making it more environmentally friendly. However, it does not completely reduce carbon emissions into the environment, as it just stores it, making it not free of cost and causing several challenges for blue hydrogen. The third and final type of hydrogen is called green hydrogen [84]. This type of hydrogen is truly a step closer to achieving true sustainability, as it is produced in a completely different manner compared to the previous types of hydrogen. Green hydrogen is produced using water electrolysis, which is a process we discussed earlier, where electrical energy is applied to water in order to separate hydrogen and oxygen molecules from each other. The electricity for this procedure comes from renewable sources [85,86] rather than fossil fuels; thus, the name "green hydrogen" was chosen for it. This method is unique, as it produces a complete loop of sustainable energy with no hazardous gases produced at any step in the manufacturing process, making it the ultimate aim in the hydrogen fuel sector. Several variables are responsible in determining the wholesale cost of green hydrogen, such as, but not limited to, the total expense of the electrical power that is produced from renewable and sustainable energy sources to initiate the electrolysis process. Additionally, the cost of the electrolysis itself, in which hydrogen is produced from water, should be addressed, as it is a critical factor as well.

In 2021, water electrolysis was found to provide only about 4% of the much-needed hydrogen, with the remaining 96% coming primarily from non-renewable sources [87], such as fossil fuels, leaving behind the enormous potential to replace fossil fuels if technological limitations can be overcome. By building a strong connection between energy consumption and production capacity in both decentralized and centralized systems, hydrogen can improve the overall low-carbon energy system reliability. However, even though all the environmental and economic securities of hydrogen fuel in end-use applications seem very promising, the implementation of hydrogen manufacturing techniques, generation and distribution networks, and sales services is difficult, especially with the high costs of electricity. This is why investigations into using solar energy as a prime source for generating required energy are critical to address these challenges for an industrialized system in manufacturing solar green hydrogen.

Figure 11 shows how a solar–electrolyzer system is connected. PV cells and an electrolyzer are linked together in a series of connections, thus resulting in the same operational current and voltage for both of these devices [88]. As result, the current and voltage during this process's operation are determined by the crossing point between them. In PV–electrolysis wired systems, the PV junction is commonly electrically connected to the catalysts of the system. The strength of these systems is not only how they run as a standalone system but also how they can be integrated into residential solar PV systems with total ease, as whenever a residential solar PV rooftop system produces more power than its required residential demand, the excess can then be fed into a water electrolysis cell to produce green hydrogen. Usually, batteries are used in off-grid solar systems to store excess energy for later use, but, as is known, the limited lifespan and poor storage capacity of traditional batteries render them unsuitable in long-term sustainable energy storage, which is why renewable energy storage in the form of hydrogen is much more dependable and efficient than standard battery storage.

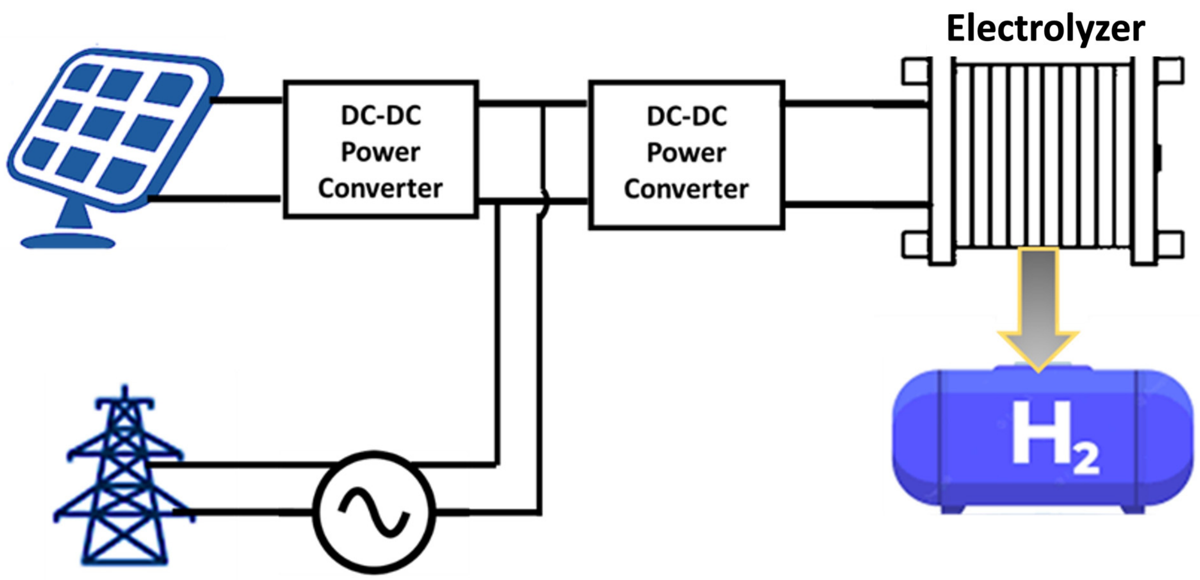


Figure 11. Schematic of solar–electrolyzer system with a storage tank [89], open access.

Producing hydrogen from the excess electricity of residential buildings and homes and utilizing it as an energy storage bank to create electrical energy when the sun is not present is very cost-effective due to lower fuel cell pricing. Solar-produced green hydrogen may be used in a variety of applications on both industrial and residential levels, as well as transportation, making PV green hydrogen an extraordinary idea. Subsequently, solar PV systems can play a critical role in the globe's forthcoming energy sector. This is attributed to solar-to-hydrogen being a way of creating green energy growth, and hydrogen is a long-term energy vessel that can replace non-renewable energy sources while lowering CO_2 emissions, hence mitigating global climate change. Hydrogen generation using ubiquitous renewable solar energy and plentiful water is an eco-conscious answer to the world's growing energy needs and requirements that also provides needed long-term energy stability.

3.4. Water Desalination

Water desalination is a process in which salt is eliminated from salty water to produce potable water [90]. Water desalination provides a great number of advantages, including the capacity to easily utilize any available water resource, such as seawater. It also provides the ability to secure the collected water in dry and coastal locations using techniques that can handle a variety of operating circumstances. However, water desalination comes with several drawbacks as well, such as the required energy for the process, as water desalination requires a lot of energy. There is also the threat of released salts and fuels from the process, as they can impact the associated environment and the living creatures within it. In addition, as is obvious, the system requires a high cost.

One category of water desalination technologies is called membrane separation. This technology was once restricted to municipal water treatment [91] in the past, but as the technology developed over time and new membrane types were created, its applications further expanded to include not only the water industry but also other high-return industries, such as beverage purification processes and chemical processes regarding enzymes and separation. In order to create potable water, this method employs a reasonably permeable membrane to transport either water or salt between two separated zones with various concentrations. The idea of combining solar PV with water desalination systems is a very luxurious one, especially in locations where there is an abundance of both solar irradiance and salt water. There are three main processes that allow the integration of solar PV as a source of power in water desalination systems; these processes are known as reverse osmosis (RO), electrodialysis reversal and membrane distillation [92].

RO is a water filtration method that focuses on separating all the ions, salts and other undesirable particles from saline water in order to produce drinking water [93]. This method is known for using a semi-permeable membrane for the separation. RO is similar to normal osmosis, in which there are two liquids separated by a membrane and the less concentrated liquid tends to go through the membrane to the liquid with the highest concentration in order to eventually become even. However, in RO, pumps are used to apply pressure to counteract osmotic pressure, which, in return, results in forcing all the water to cross the membrane, leaving behind all the salts and solid particles on the other side [94–96]. RO has proven that it can remove not only salts but also a wide range of dissolved materials as well as biological species such as bacteria from water, making RO a method utilized in both global industrial operations as well as potable water production. RO is quite different from filtration, as in filtration, the membrane in use has pores in with a size of 0.01 μm and is dependent on the size of the particles in general. RO uses a membrane of 0.001 μm and depends largely on the pressure applied to the side of the membrane [97,98].

Electrodialysis reversal desalination (EDR) is also a membrane desalination process like RO [99]. However, it differs quite a lot regarding how the salts are separated from the water, as in this process, an electrical current is used to separate all kinds of salt ions from the water through the membrane. This system's main components consist of a desalination unit, a selective membrane, a pump and a power source unit. The electrodes in the desalination unit are submerged in the saltwater solution, which then produces a current that moves the ions through the membrane separating them from the water. The process is then reversed in a periodic manner every set amount of time by altering the polarity of the electrodes, allowing higher amounts of water to be recovered. The electrodes can be made from different kinds of metals, such as niobium and titanium, and are usually coated with platinum coatings, and the membranes of such systems usually last for 5–7 years [100]. Electrodialysis reversal desalination has some advantages over RO, such as a high water recovery rate, which is mainly due to the reverse in polarity as well as the fact that the water can be treated without any chemicals. However, these systems have the disadvantage of the desalination process always being kept under a certain current density limit in order to keep the total efficiency of the system high and prevent the ionization of water.

Finally, there is membrane distillation (MD), which is a hydrophobic membrane-based thermally driven water desalination technique [101]. In this process, a vapor pressure difference is created between the two faces of the membrane pores, which, in turn, drives this desalination process and allows the volatile solution components to transfer their mass and heat. Membrane desalination's simplicity, along with the fact that it can utilize waste heat or even other renewable energy sources, such as solar and geothermal energy, makes it a promising water desalination technique that can be used in conjunction with other processes in hybrid or integrated systems. The vapor pressure differential created by a temperature difference across the membrane provides the driving power for the membrane desalination process. Membrane desalination can be kept at a significantly lower temperature of around 30–60 °C compared to conventional thermal distillation methods because the driving force is not purely thermal [102]. In addition, due to surface tension in the process, the hydrophobic property of the membrane prevents water molecules from entering. Water vapor, on the other hand, produces a pressure differential and passes through the membrane pore system before condensing on the opposite cold side of the membrane. Although membrane desalination systems use heat, solar PV modules can be used as a power source for these systems, as shown in Figure 12, by providing electricity to power up the heaters in the MD system.

3.5. Transportation

The transportation sector presently accounts for roughly 20% of worldwide CO_2 emissions, which come from fuel combustion and internal combustion engines in most of today's road vehicles [103]. Unfortunately, road transportation emissions are continuing to rise as time passes, which is why electric vehicles (EVs) are becoming a more appealing option for reducing CO_2 and other hazardous air pollutants in this industry [104]. An electric vehicle is one that is propelled by one or more electric motors, meaning that EVs can run directly on electricity. Electric vehicles can be powered by a collector system that uses electricity from outside the vehicle, or they can be self-powered with a battery. Figure 13 shows that electric vehicles are not only pure electricity machines, as hybrid EVs exist [105], which can run on both electricity and conventional fossil fuels exactly like internal combustion engine vehicles. EVs are not limited to small cars only, as road and rail vehicles, underwater watercrafts, electric airplanes and spacecrafts are all examples of electric vehicles. There are already more than five million EVs on the road, nearly 67% of which are pure battery EVs. EVs also have better efficiency than conventional cars and can be converted to using low-carbon electricity for fuel. In 2018, EVs accounted for approximately 2.5% of the new vehicle market and are expected to reach 15% by 2030 [106].

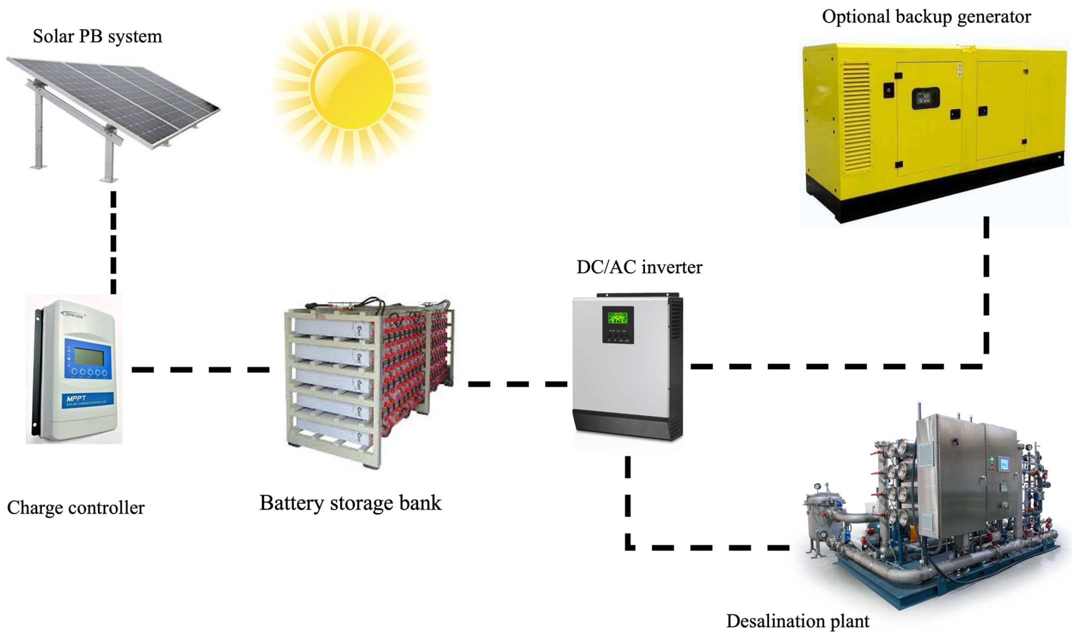


Figure 12. Schematic of solar water desalination system.

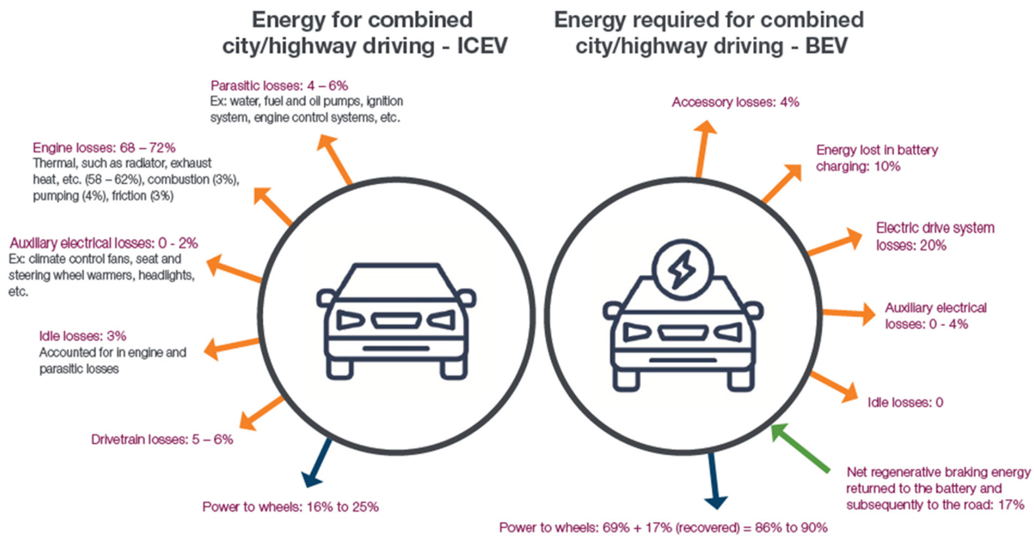


Figure 13. Energy of internal combustion engine vehicles (ICEV) and battery electric vehicles (BEV) [107], open access.

In most cases, the local grid provides the power needed to charge an electric vehicle, but the reason why EVs are becoming very popular and attractive is because they can run on renewable energy sources, especially solar energy, as it is free fuel for the car to use. The adoption of specialized solar PV charging stations, as shown in Figure 14, is highly capable of reducing CO_2 emissions from road vehicles greatly, as they limit the use of fossil fuels at the bare minimum. Solar-powered EVs are also more than capable of cutting emissions, as they enable a decrease in local grid overloading [108], especially in peak hours, and enhanced grid flexibility, which are further advantages of the synergy between solar PV and EV technologies. The constantly lowering battery prices that are driving EV adoption also allow for the addition of batteries to store collected solar energy during the day for later charging in PV-powered charging stations. This is a great feature, as it also helps in boosting the grid's resilience to the inherent intermittent nature of solar energy in general. PV cells can also be directly incorporated into the electric car's body so that they can also be used to charge EVs, which are known as PV-integrated EVs [109]. However, given the diverse orientations of main vehicle surfaces and the vehicle's ever-changing exposure to the sun during the day, owing to factors such as location at different times of the day and frequent shade, estimating the potential usefulness of PV systems in boosting EV range is extremely challenging, which is why they are not implemented as much. Solar PV EVs can be helpful in powering up secondary systems and extra functions in vehicles, such as lighting systems or even possibly passenger cooling systems within the car.

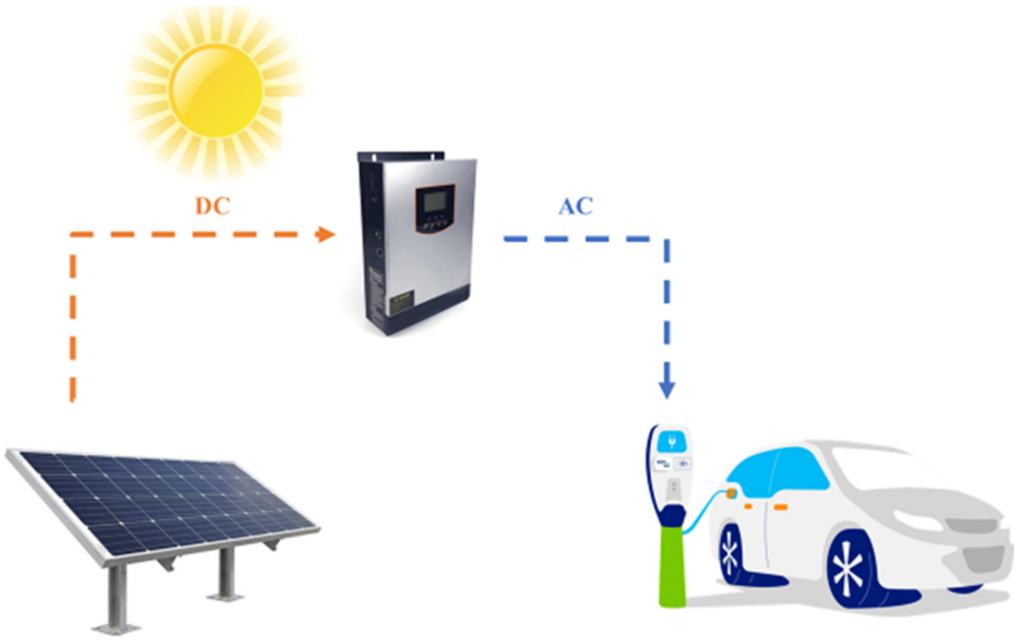


Figure 14. Schematic of a solar charger for EVs.

From the aforementioned applications, it is clear that the applications of solar energy play a significant role in deciding proper solar technology. However, it is also important to mention that the that the selection of sustainable solar energy technology varies from one place to another according to meteorological parameters; therefore, they must be considered before selecting the proper solar technology for a specific application.

4. Methodology

The first step for conducting this analysis was to consolidate our search to a database. The SCOPUS database was thus chosen. For the search parameters, we searched the required topic, such as "solar", which was our first part of this analysis. Then, some restrictions were added to the search, such as the date range, the language and the type of paper. After obtaining the results, this search was combined with each of the United

Nations (UNs) Sustainable Development Goals (SDGs) one at a time. The process was then repeated for all five applications discussed in this study. All the data were transferred to Microsoft Excel, where they were analyzed and cleaned, removing things such as repeated words, etc. These data were then finally ready for the bibliometric analysis and data presentation. Figure 15a,b show a simplified version of the process.

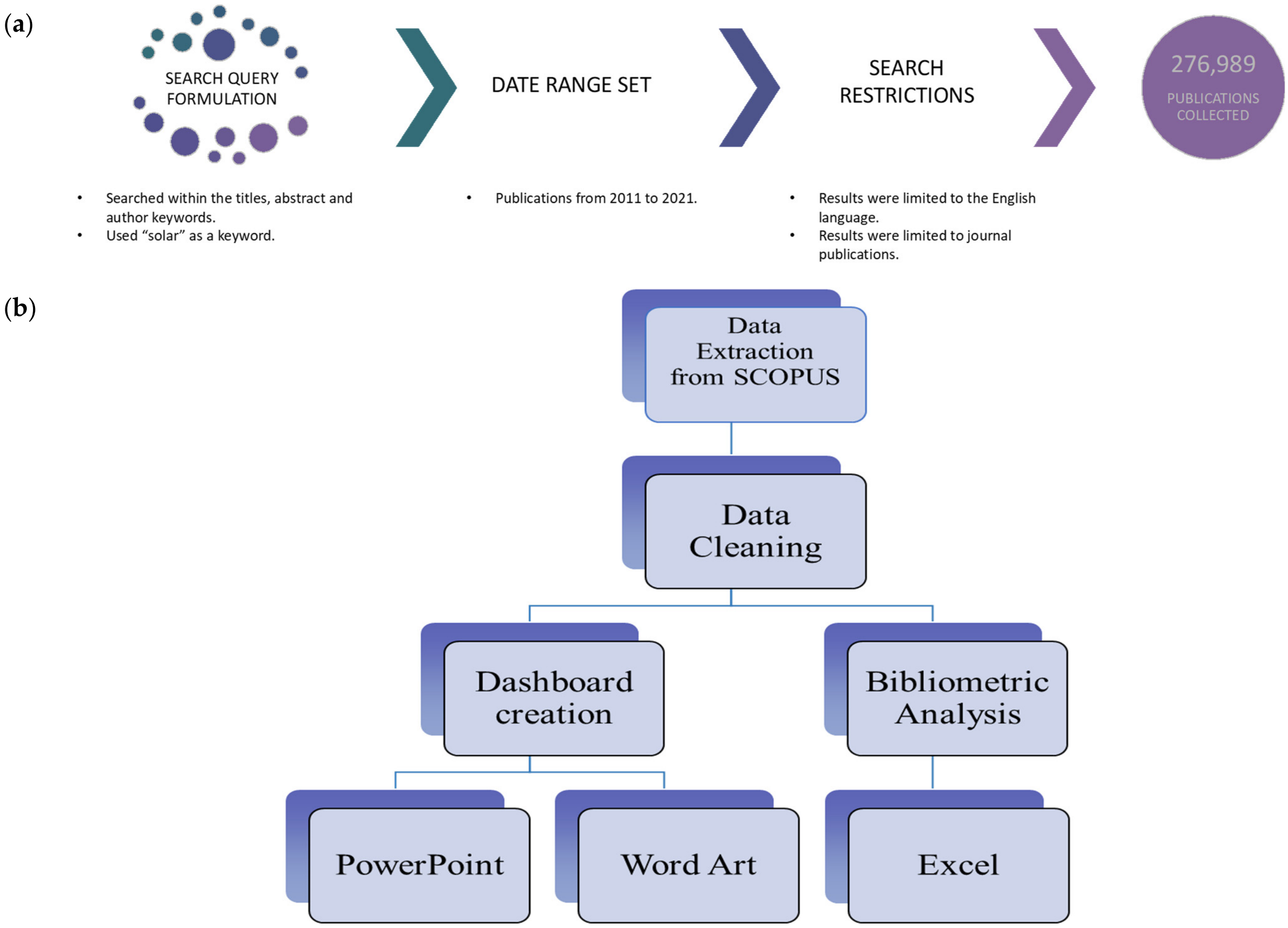


Figure 15. Data extraction process of "solar" from SCOPUS (**a**) and analysis of data process (**b**).

5. Results and Discussions

This section describes the bibliometric analysis of the solar photovoltaic systems in relation to the SDGs. For investigating and evaluating vast amounts of scientific data, a bibliometric analysis is a well-liked and great technique, as it allows exploring the subtleties and points of interest of a particular field's developed history in depth over a period of time while highlighting different important aspects. The aim was to utilize bibliometric techniques regarding solar energy and its applications discussed in this study in combination with the SDGs [52], as shown in Figure 16, in order to shed light on the research gap related to the contribution of solar energy to the SDGs.

The SCOPUS online database was used to collect all the scientific papers published regarding "solar" from 2011 to 2021, and the total number of documents extracted from the database was 276,989. These data were then imported to Microsoft Excel for statistical analysis purposes and data cleaning. Afterwards, the SDGs were implemented one by one alongside "solar" in the SCOPUS database search, eventually resulting in a total of 126,513 documents, which was less than half of the papers discussing solar in the selected years. The same procedure was also conducted for the five applications of solar discussed in this paper, which are as follows: large-scale solar PV power plants, residential applications of solar PV, green hydrogen, water desalination and transportation. Figure 17 shows an overview of the distribution of solar papers by the type of SDG, and from this chart, it can be clearly seen that SDG 7 (affordable and clean energy) was, by far, the most dominant in solar research, with 91,708 documents in total, rounding up to over 72% of the total documents, followed by SDG 13 (Climate action) with 11.46%. The contribution of solar research in the other SDGs was weak. This was also true for the other five applications, and SDG 7-related papers had the highest percentage in each of them. It can also be noticed that SDG 4 (quality education) was the lowest in solar research with merely 32 documents, which was only 0.03% of the total documents. The most interesting finding was that, in general, most published papers focused on technical perspectives of solar and on the environmental pillar of sustainable development. The other pillars of sustainable development (social and economic) were less analyzed in the literature.

Figure 16. Sustainable Development Goals (SDGs) (from www.sdgs.un.org, accessed on 13 July 2022).

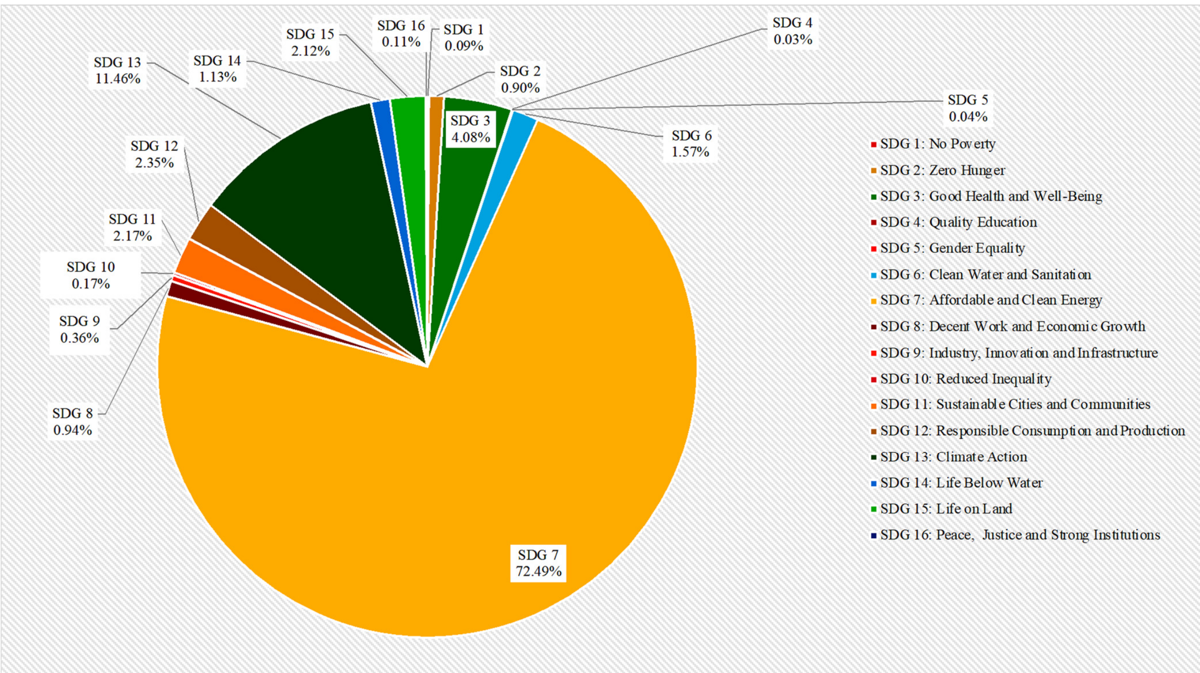


Figure 17. Solar papers regarding SDGs between 2011 and 2021.

Figure 18 compares the research papers based on the related SDGs for each year. It can be noticed that the number of the research papers increased from year to year, indicating that the SDGs received more attention regarding solar applications from year to year. In 2011, only 5179 documents were released, whereas in 2021, that number increased by almost four times to reach 20,392 documents. However, it is clear that some SDGs lacked enough research in solar energy; for example, SDG 4 and SDG 5 had only two documents released each in the year 2011, whereas in 2021, they had four and five documents released, respectively.

Application 3, green hydrogen, had the lowest contribution among the other applications, with only 201 documents published. Furthermore, there were no papers published regarding SDGs 1, 3, 4, 5, 8, 10 and 16. This could be related to the fact that the study of green hydrogen is quite new. In all applications, SDG 7 (Affordable and Clean Energy) was clearly dominant in the number of documents published.

In application 4 (water desalination), SDG 6 (Clean Water and Sanitation) was the second highest, with 89 documents published out of 723. For application 5 (transportation), SDG 11 (Sustainable Cities and Communities) was the second highest, with 73 documents out of 1898. From these obtained data, it can be easily seen that, in the field of solar energy, the majority of SDG research was concentrated heavily within SDG 7 (Affordable and Clean Energy), as it is directly related to the energy sector. The data lacked enough research in the vast majority of the remaining SDGs, especially SDGs 1, 4, 5, 9, 10 and 16.

These results indicate that solar energy, in general, needs more research in terms of SDGs. In reality, solar energy does not only contribute to the SDGs by providing clean and cheap energy, but it also affects all the other SDGs. Climate change has been a global issue for a long time, causing extreme damage to countless environments on the planet mainly due to the high usage of fossil fuels. By utilizing and investing in solar energy, it is possible to achieve low emission societies with healthy land, water and air quality, thus accomplishing SDGs 13, 14 and 15. Through solar energy adoption, not only can it reduce emissions and carbon footprints, but it can also lead to significant economic development. One way of achieving this economic development is through the creation of new employment. Solar energy also offers potential for additional economic activity, which is another benefit. These actions are crucial for promoting growth from the ground up. As new business models appear, entrepreneurs can invest in them, laying the groundwork for the generation of power. Supply problems can also call for a much more centralized structure.

During the COVID-19 pandemic [110,111], the importance of the internet in gaining access to education was demonstrated. During that year, SDG 4—quality education—suffered, mostly in areas without access to power and the internet. Schools may also have not had access to electricity. Without it, learning materials and learning time are reduced. However, the provision of the required electricity can keep students at school for a longer period of time as a result of solar panels in schools. These locations can now have computers and internet connections installed so that kids can study more. Additionally, access to basic necessities such as food, water and health care is now made feasible as a result of solar energy. Farmers rely on solar-powered irrigation systems in the contemporary world to help them produce more food. When there is a surplus, food security improves, hunger declines and thus SDG 2 is addressed. Solar energy also helps to accomplish the SDGs in the area of health care. The sun is a clean energy source that does not contaminate the atmosphere. Because of this, most nations that use this technology have clean air and inhabitants who are not prone to illness or bad health because of pollution. Modernizing and enhancing the efficiency of healthcare facilities is another application for solar energy. In addition to keeping the lights on and life-saving equipment running, solar-powered health care can also chill vaccines and perform many other life-saving tasks. More and more establishments must install solar panels in order to fulfill SDG 3. They offer affordable and dependable electricity. Health institutions can reduce their power costs and save money that can be put back into the building. Additionally, SDG 5 strives to empower all women and girls in order to achieve gender equality. When there is access to power, children in developing countries, especially girls, can pursue an education. Energy also encourages women to pursue their own businesses. The presence of solar energy in the neighborhood helps to level the playing field for women and girls. This is how solar energy can lay the basic groundwork for achieving all SDGs, proving how important it is for our future.

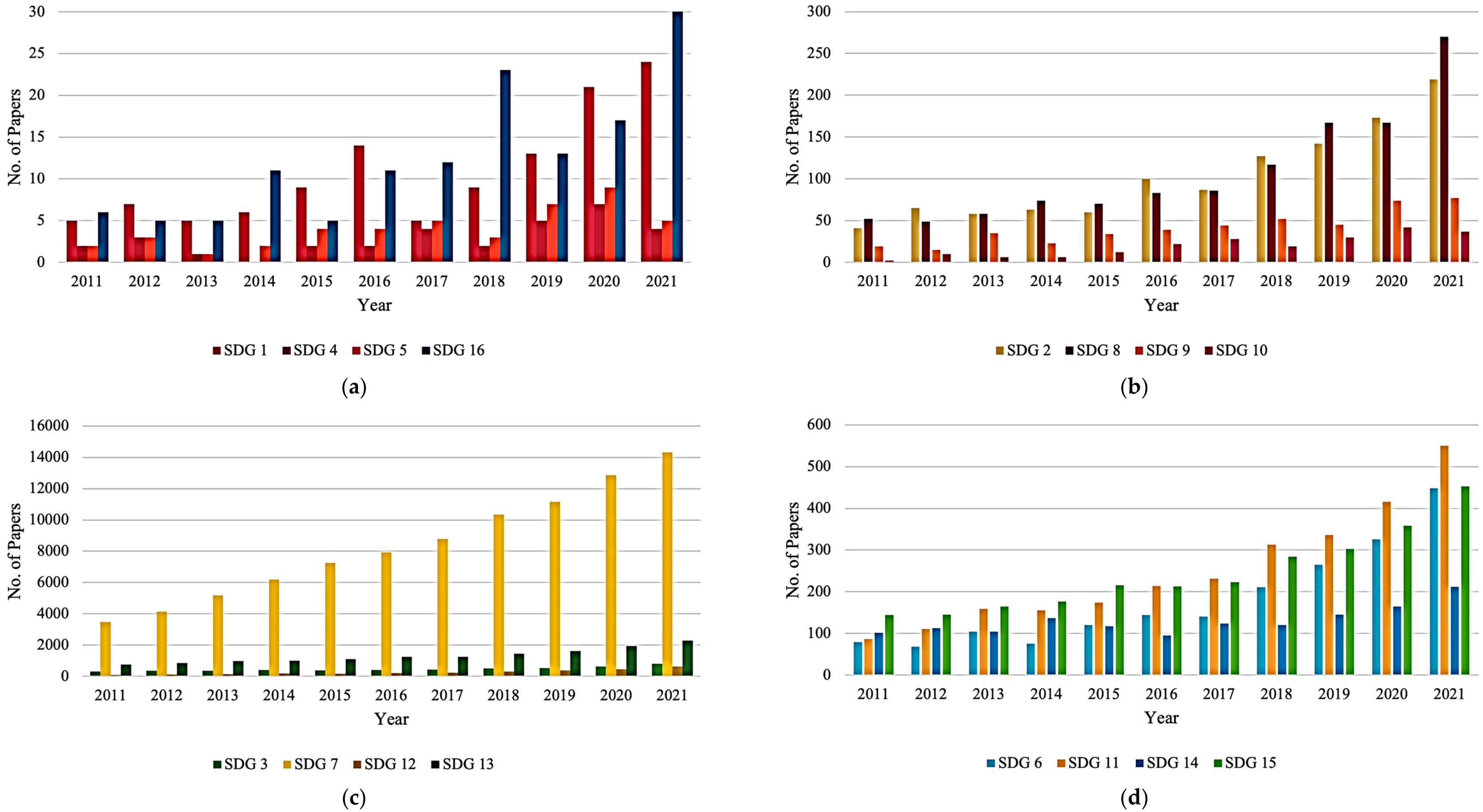


Figure 18. Solar SDG-related research papers by year: (**a**) SDG1, SDG 4, SDG 5 and SDG 16; (**b**) SDG2, SDG 8, SDG9 and SDG 10; (**c**) SDG3, SDG 7, SDG 12 and SDG 13; (**d**) SDG6, SDG 11, SDG 14 and SDG 15. A similar analysis, i.e., investigating the number of research papers related to SDGs, was conducted for the main five applications of solar (i.e., “Large-Scale Solar PV”, “Residential Solar PV”, “Green Hydrogen”, “Water De-salination” and “Transportation”). For application 1, which is large-scale solar PV power plants with a capacity of more than 1 MW, the total number of documents including SDGs was 4451 and was the highest among the five applications, and like the rest, SDG 7 had the highest percentage of documents with 84%. The second was SDG 13 with 6% of the total documents, and SDG 4 came last with zero documents.

Figure 19 shows how solar energy relates to the three pillars of sustainable development, indicating why more research and the implementation of solar energy plans in all sectors are required for a secure, sustainable and reliable future.

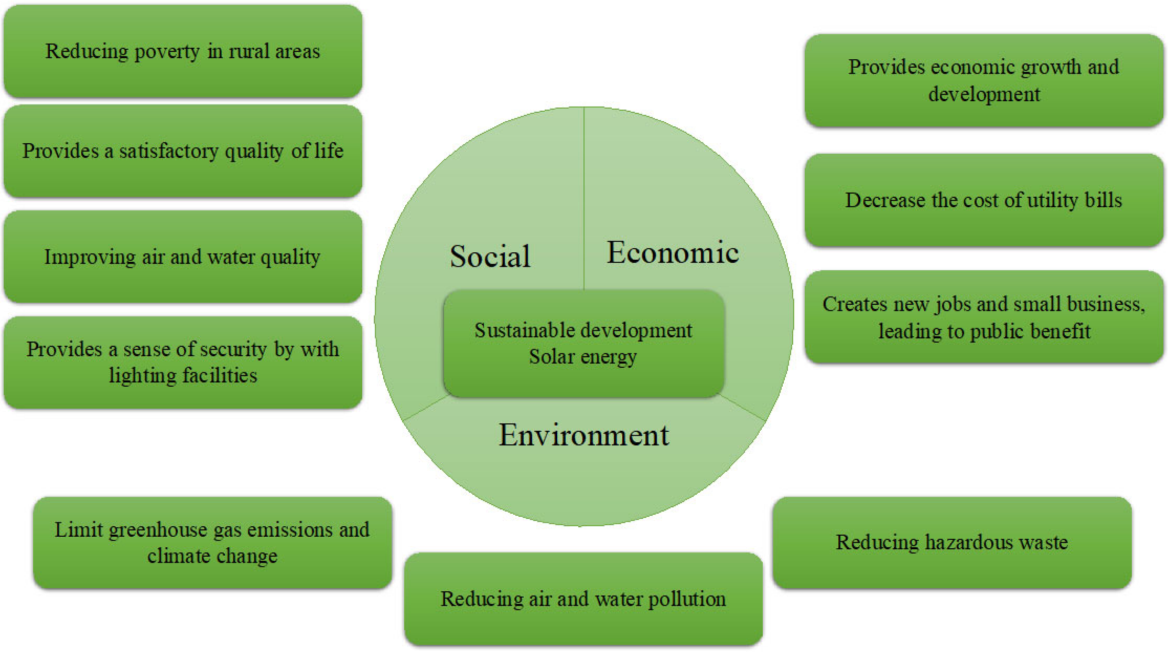
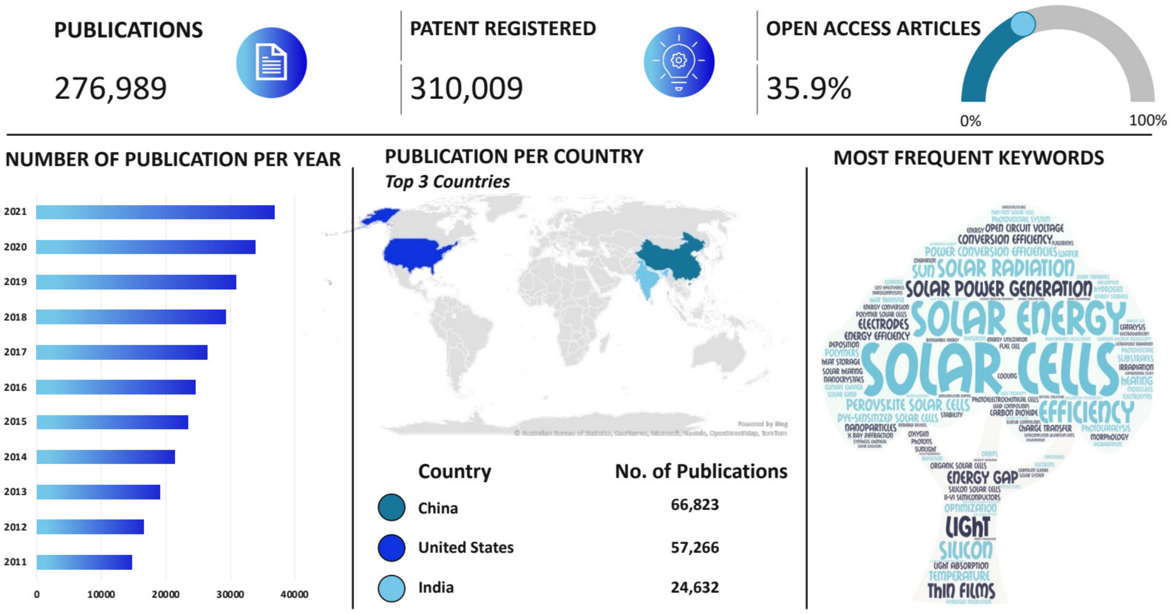
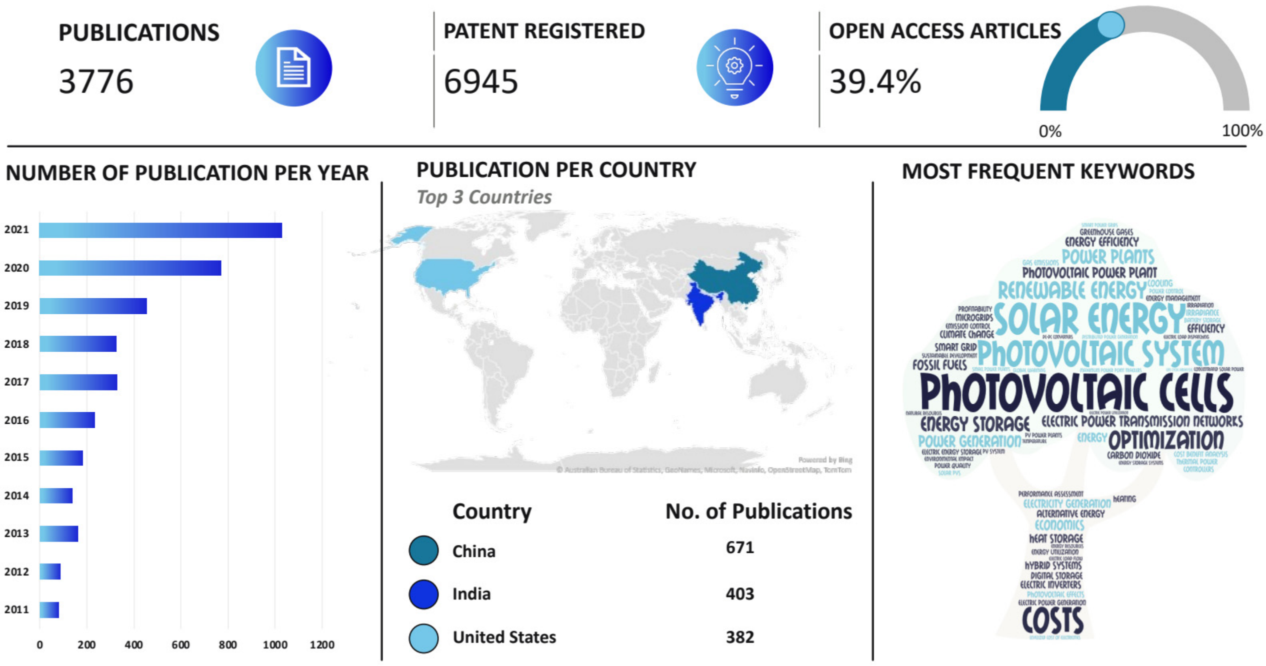


Figure 19. Solar energy and the three pillars of sustainable development.

Moreover, from the data collected and the bibliometric analysis, the keywords from all papers and documents were also extracted. This allowed us to find and explore the points of interest in each of the various analysis fields. This analysis focused on the results of SDG 7 only in each application, because it was the SDG with the greatest number of documents. In the solar analysis, the highest occurring keyword was "Solar Power Generation" with 23,169 documents, and the lowest was "Photocatalytic Activity" with 1166 documents. For applications 1 (Power Plants) and 2 (Residential), the highest occurring keyword was "Photovoltaic Cells" with 1633 and 563 documents, respectively, and the lowest was "Solar Heating" with 59 documents for application 1 and "Hydrogen" with 23 documents for application 2. For application 3, (Green Hydrogen) the highest was "Hydrogen Production" with 141 documents, and the lowest was "current" with only 3 documents. For applications 4 and 5 (Water Desalination and Transportation) the highest occurring keywords were "Desalination" and "Electric Vehicles" with 475 and 625 documents, respectively, and the lowest were "Water Conservation" and "Electric Load Management" with 11 and 27 documents, respectively. The obtained results for the keywords are logical and make sense, especially the highest occurring keywords in each analysis, as they are directly connected to the topic itself. Figure 20a–f shows the dashboards made for solar and the five applications that are discussed in this paper using the data collected above. These dashboards offer a synopsis of the most significant findings and results obtained throughout the analysis that was carried out. The results that are presented in these dashboards include the total number of publications, the number of patents that were discovered, the percentage of open-access articles, the number of publications that were discovered each year, the top three countries in terms of the number of publications that were discovered and, finally, a word cloud that was generated from all of the keywords that were extracted from the data. In Figure 20a, it can be seen from the data presented that there was a huge number of patents registered (310,009) in the field of solar energy between 2011 and 2021. According to what is shown in the graph, in the next few years, there will likely be an increase in the number of publications that are related to solar energy. China is the country that is responsible for the publication of the most papers, with a total of 66,823. The USA came in second place with 57,266 published papers, and India came in third place with 24,632 published papers. The vast disparity in the number of publications between the leading two countries (China and USA) and India suggests that China and the USA will most likely continue to be the leading two countries in terms of research in solar energy.

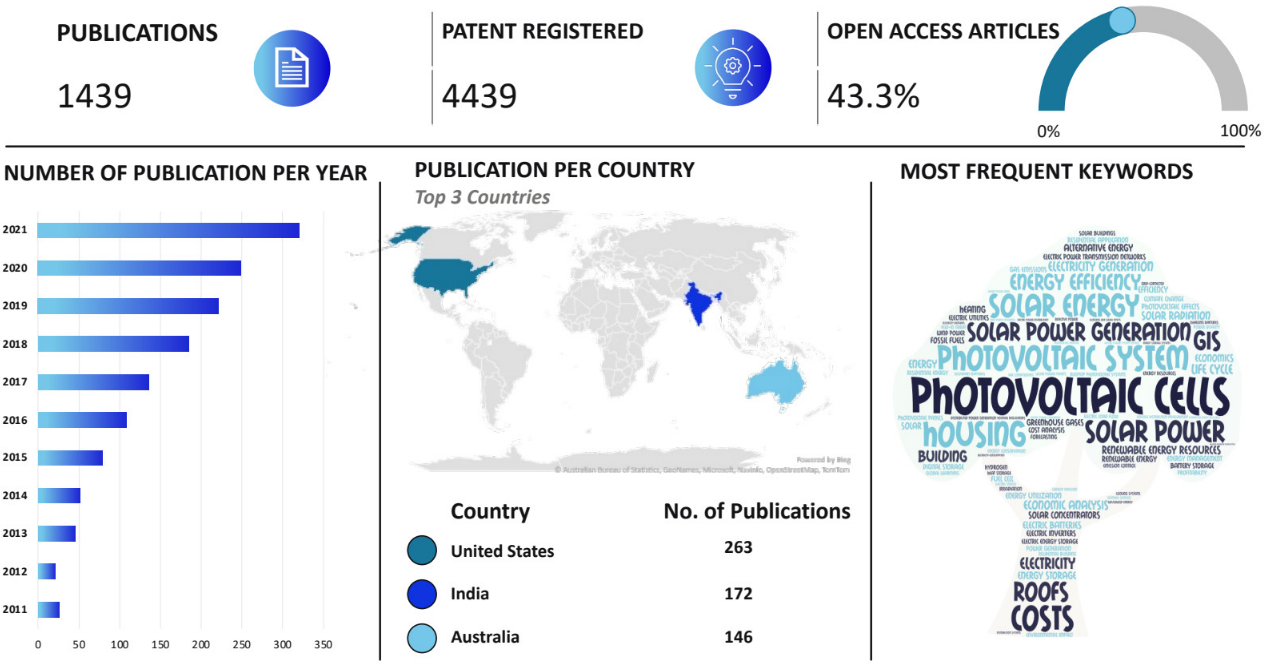


(a)



(b)

Figure 20. *Cont.*



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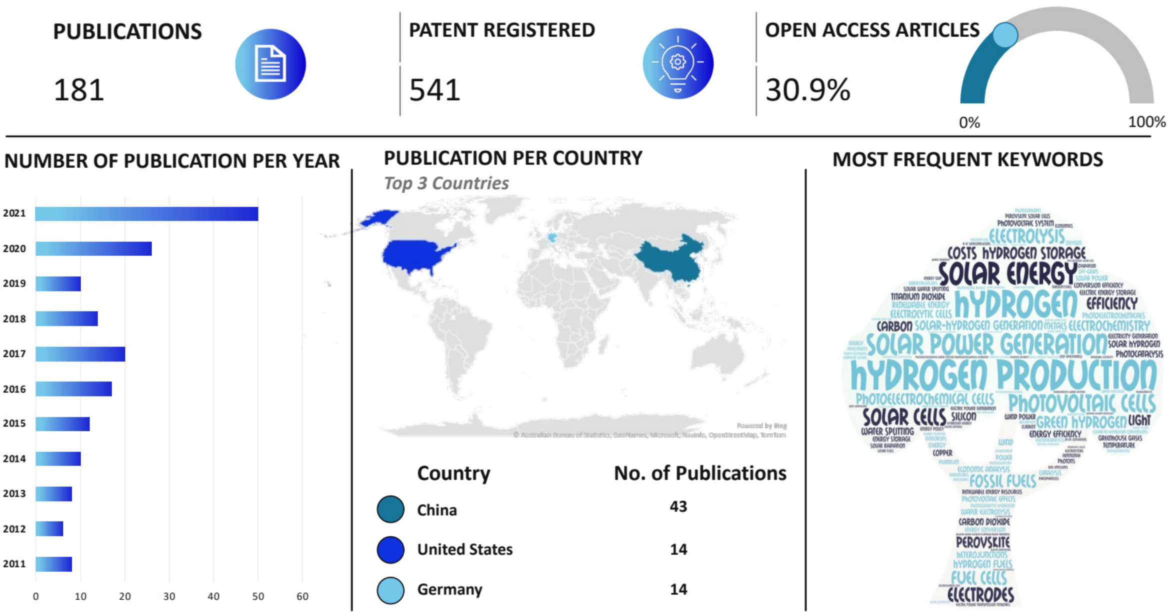

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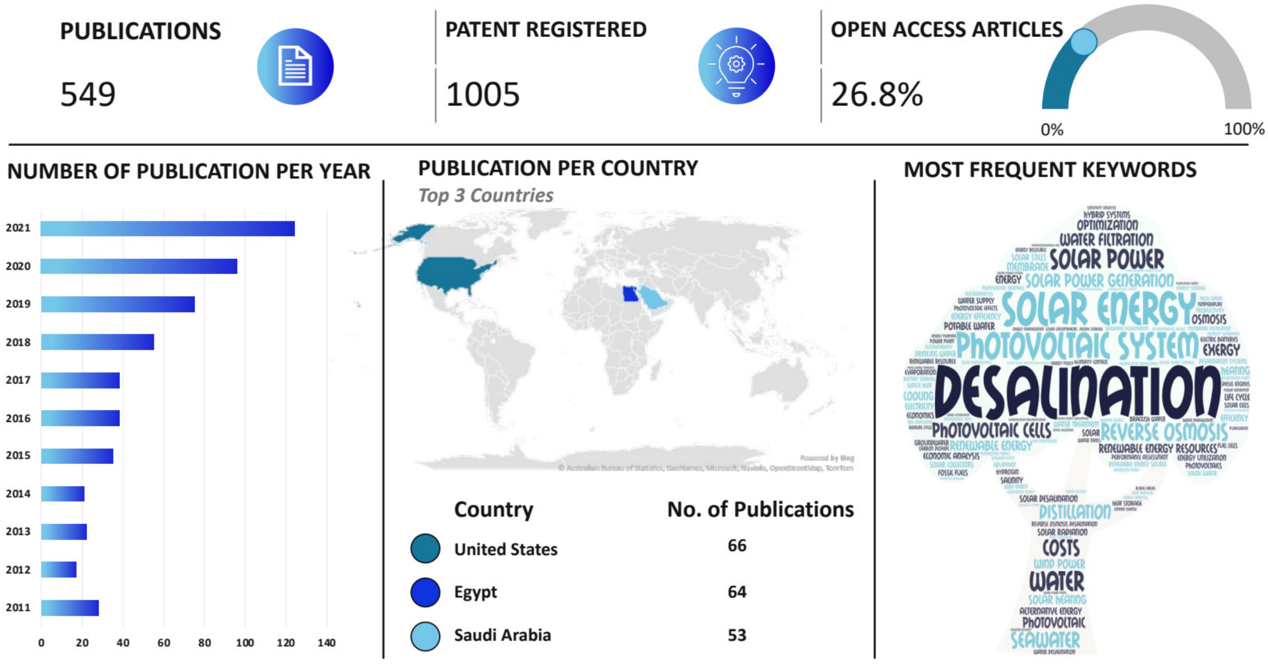
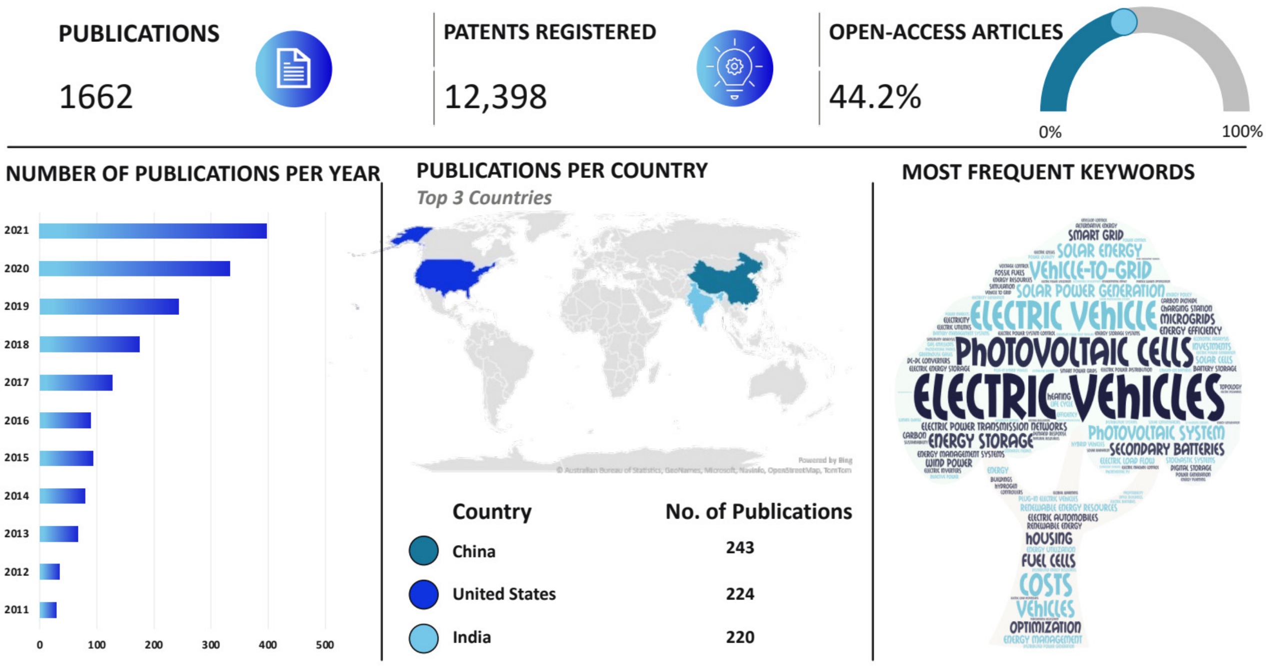
Figure 20. *Cont.*



(e)



(f)

Figure 20. (**a**) Dashboard for solar; (**b**) Dashboard for large-scale solar power generation; (**c**) Dashboard for residential solar; (**d**) Dashboard for green hydrogen; (**e**) Dashboard for water desalination; (**f**) Dashboard for transportation.

As can be seen in the word cloud that was generated, the term "solar cells" appears most frequently in these results. The findings that are presented in Figure 20b are associated with the first application discussed in this paper, which is solar power generation on a large scale. It was observed that, in the years 2020 and 2021, there was a noticeable increase in the number of publications. This was quite a reasonable result given that the world witnessed an increase in the number of solar power plants in the most recent years. With a total of 671, 403, and 382 published papers, China, India and the USA, respectively, were the top three countries in terms of the number of publications. In Figure 20c, it can be seen that the third dashboard focuses on residential PV, and it is important to note that the number of studies conducted on this subject is also growing. The USA, India and Australia are found to be the top three countries in this category, with a total of 263, 172, and 146, respectively. According to these findings, a greater number of people in the USA are considering the possibility of installing PV solar panels on the roofs of their homes and other buildings. This work includes a dashboard for green hydrogen, which can be found in Figure 20d. The data make it very clear that China was the leading country regarding research on the production of green hydrogen from solar PV, with 43 published papers, and the USA and Germany came in second place with only 14 publications each. This is a clear indication of China's dominance in this area. Although 43 publications may appear to be a very low number when compared with other results when viewed in isolation, this may be due to the fact that green hydrogen is still a relatively new topic that has only recently gained popularity. Figure 20e shows the dashboard for the solar water desalination system. As depicted in the figure, the total number of papers published each year has been steadily growing, particularly in the recent years. The USA, Egypt and Saudi Arabia were the top three countries represented here, each with a total of 53 publications, 66 publications and 64 publications, respectively. The fact that two of the top three countries were located in the MENA region (i.e., the Middle East and North Africa) demonstrates that the concept of desalinating water by utilizing solar energy has the potential to gain an enormous amount of popularity in the MENA region in the following years. The last dashboard in this paper, as shown in Figure 20f, is related to transportation (which concerns solar PV and electric vehicles (EVs)). The dashboard analysis shows that the total number of publications was found to be 1662 published papers, with 12,398 patents registered. Out of the 1662 publications, 44.2% were open-access articles, which accounted for 734 papers, allowing people from all around the world to reach these papers free of charge. It can be seen from the chart that, from 2011 to 2015, the number of published papers slightly increased with each passing year; however, in 2016, the number of publications slightly dropped for an unknown reason. Then, from 2017 and onwards, the number of publications went back to increasing, especially in the last few years. This result is in accordance with the strategic plan for switching from fossil-fuel-based transportation to electric transportation. People are switching to electric vehicles from normal combustion engine cars, and several countries are promoting the use of electric vehicles and hybrid vehicles that run on both electricity and combustion in order to minimize the environmental impacts of combustion engine vehicles. The top three countries in the number of published papers for this topic were found to be China in first place with 243 published papers, then the USA with 224 published papers and finally India in third place with 220 published papers. As can be seen, the numbers are quite close to each other, and this can indicate that these three countries could be, in the future, the leading countries in terms of research regarding solar PV and electric vehicles. Some of the most recurring keywords were found to be "electric vehicles", "photovoltaic cells", "vehicle to grid" and "secondary batteries". Even though the six dashboards below do not cover all the results and findings in this paper, they still present a summary for the readers of some of the most important results that were found during this bibliometric analysis for solar and the five chosen applications.

6. Conclusions and Recommendations

Solar energy is one of the most prominent renewable energy sources. Solar energy holds great potential for solving many global issues, such as climate change, securing fresh water and securing a green energy source. This work discusses the state of the art of solar photovoltaics systems, including their fundamentals, different generations of the solar PV and large-scale applications of solar PV systems, such as residential applications, green hydrogen production, water desalination and transportation. Then, a bibliometric analysis is described regarding solar PV systems in relation to the United Nations (UNs) Sustainable Development Goals (SDGs). A total of 276,989 documents available on the SCOPUS database were analyzed, and the main conclusions of this study can be summarized as follows:

- Solar PV systems applied on a commercial scale in power plants with a power capacity of more than 1 MW and can reach the Giga scale.
- Solar PV power desalination systems are available worldwide on a commercials scale, and their potential is increasing over time. Significant progress has been realized in the application of solar PV in the production of green hydrogen and green buildings as well as electric vehicles in the transportation sector.
- The bibliometric study demonstrates that there has been a notable increase in the amount of research conducted on solar energy over the past decade.
- The majority of solar research is concentrated within SDG 7, which is directly related to clean energy, while lacking in many other SDGs, such as SDG 6: Clean Water and Sanitation, SDG 1: No Poverty, SDG 4: Quality Education, SDG 5: Gender Equality, SDG 9: Industry, Innovation and Infrastructure, SDG 10: Reduced Inequality and SDG 16: Peace, Justice and Strong Institutions.
- China, India and the USA were the primary contributors of published research, and the rest of the world contributed a significantly lower number of publications.
- This study proves that more research is needed in the solar energy sector regarding the SDGs, as solar energy impacts not only SDG 7 but all other SDGs, whether directly or indirectly. Such studies are crucial for securing a sustainable future for current and future generations.
- Within the five chooses application of solar energy, a ranking of publications was as follows: (1) large-scale solar power generation, (2) transportation, (3) residential applications, (4) water desalination and (5) green hydrogen production.
- The vast majority of the research was focused mainly on the technical aspects of solar energy, whereas other important aspects received significantly less attention.
- There is a significant lack of research in relation to SDG 1: No Poverty, SDG 4: Quality Education, SDG 5: Gender Equality and SDG 16: Peace, Justice and Strong Institutions.
- The results of the bibliometric indicate that there was a total of 276,989 published studies, in addition to 310,009 patents that were registered.
- Overall, there was a good percentage of research published in open-access journals, which shows good financial support from different stakeholders.
- The keywords ”electric vehicles”, “photovoltaic cells”, “vehicle to grid” and ”secondary batteries” were found to be among the most frequently used keywords.

Based on the funding of this research, a key policy priority should therefore be to explore the impact of the solar energy on all the SDGs, especially SDG 1: No Poverty, SDG 4: Quality Education, SDG 5: Gender Equality and SDG 16: Peace, Justice and Strong Institutions. Moreover, there is a need for more research in the rest of the world, other than China, India and the USA, to better understand the solar impact on SDG achievements. Furthermore, policymakers should focus on understating the social and economic aspect of solar energy, such as the total number of jobs created by solar projects, the impact on gross domestic product (GDP) and gender inequality in solar projects. In addition, policymakers should allocate a larger amount of their funds to new areas of solar energy applications, such as green hydrogen and electric vehicles. Another implication of our study is that policymakers should ensure that there is alignment between funded research and the priority SDGs and SDG targets within the country. Finally, policymakers are recommended to push toward increasing the percentage of open-access research.

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