Proceedings of the 2nd International Conference on Functional Materials and Civil Engineering
DOI: 10.54254/2755-2721/98/20241116

Introduction to Solar Technology and its Environmental Importance

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Abstract. In the past few decades, scientists have been seeking more environmentally friendly sources of energy due to the increasingly serious issue of global warming. As a result, photovoltaic technologies as emerged as one of the most prominent sustainable energy technologies due to their significance in controlling future carbon emissions. In this paper, the operational process of photovoltaic systems and the reason why silicon remains the most important element in building solar cells will be equally explored. Furthermore, the environmental importance of solar technologies will also be discussed, including its ability to save carbon footprints compared to traditional energy sources.

Keywords: photovoltaic system, solar cells, photovoltaic effect, silicon, global warming.

1. Introduction

In recent decades, global warming has risen as a serious topic of environmental concern. As a result, various countries began making efforts toward decreasing greenhouse gas emissions to control the increase in global temperature. The climate change Conference was held in 2021, when 197 nations agreed to reduce their reliance on fossil fuel and coal energies to improve the climate and to limit the increase in global temperature to 1.5 degrees [1]. Under such an international call for environmental protection and controlling global warming is when solar power comes into play due to its minimal release of greenhouse gases and pollution of air.

Solar panel technology was initially invented by Edmond Becquerel in 1839 [2], discovering the photovoltaic effect, a process that generates current in photovoltaic cells when they are exposed to sunlight, when determining that the exposure to light could generate electricity when two metal plates were placed together. A few years later, Charles Frits in 1883 produced the first solar cells, a device that converts light energy into electrical energy using the photovoltaic effect, using selenium, which was discovered to be photoconductive [2]. Then, silicon was determined to be more a more suitable material to be used when producing solar cells. The development of silicon solar cells in 1954 by Gerald Pearson, Calvin Fuller, and Daryl Chapin marked one of the most important breakthroughs in photovoltaic technologies [2], as this was the first time in history when solar technology could generate electricity for a long period of time (several hours). From then on, silicon remained as the primary material utilized in photovoltaic systems.

After the discovery of solar systems in the 19th century, scientists have been making continuous efforts to increase its efficiency on electricity generation. after Gerald Pearson and other scientists'

DOI: 10.54254/2755-2721/98/20241116

discoveries in 1954, silicon had risen as one of most effective materials for the construction of photovoltaic systems. Although there are other more efficient materials in construction of semiconductors, silicon marked its surpassed all its competitors due to its cost efficiency, marking it as the most commonly used material in solar panels. There are also benefits of silicon as well, like its non-toxic character and stability, helping it to become the most popular material in solar industries so far, which will be addressed later in the article.

In this paper, we will address the detailed functioning process of photovoltaic systems, specific steps of how current is generated when solar cells come into contact with sunlight. We will also discuss several of the most important types of silicon and its character that determines its popularity as the main material used in the construction of solar technologies. The environmental impacts and why solar energies remain as one of the energy sources with the greatest future potential will also be addressed.

2. Introduction of PV systems and the photovoltaic effect

The sun emits a huge amount of solar radiation each day onto earth, and this form of solar energy could be obtained by a device system known as the photovoltaic system. Firstly, the basic components of photovoltaic systems would be introduced. The modern photovoltaic system is a system consisted of solar panels, inverters, and other electric hardwares that converts light energy from the sun into electric energy. Among them, solar panels are of utmost importance—they are the structures in charge of capturing sunlight for electricity generation. Solar panels have several components. First of all, photovoltaic cells is the most essential structure inside, a core device that allows for energy conversion to take place and turning light into DC current. Then, solar panels have a front glass sheet at its surface to protect PV cells from damages from severe weather or clashes against other structures. Solar panels also contain several types of wires. They have MC4 connectors which connects solar panels together, forming a large system of interconnected panels. Bus wires are in charge of linking internal PV cells in each solar panels. Finally, there are standard wires which connects panels to inverters and eventually allow for transfer of electricity generated by PV cells to individual electric appliances.

When electricity is generated by PV cells in solar panels, it is in the form of DC electricity. Then, the DC electricity from solar panels flow through inverters, the devices that convert DC current into AC current so that electricity from the current can be used by electric appliances. There are several types of inverters. For example, the string inverters serve to form a string of solar panels, like resistors in series combination in a circuit. There are also micro inverters, inverters that are attached on each solar panel, which, unlike string inverters, converts electricity individually from each panel [3].

There are other components in the photovoltaic system as well, like breakers, disconnects [4], and most importantly, electric appliances that would be using electricity generated by the solar panels. Circuit breakers, as the name suggests, serve as switches and stop current from flowing through the PV system when there are risks of overcurrent that could overheat and damage the system [4]. Electric meters are devices that measures the amount of energy that enters and leaves the PV system, allowing owners to trace the amount of energy consumed by the PV system and monitor its performance [4]. Last but not least, electricity is transferred to electric appliances in the form of AC current for electric appliances. Nowadays, there are many areas that often incorporates PV systems for electricity generation for different kinds of devices, and the domestic sphere in individual households is one of the major areas using photovoltaic systems for electricity consumption. Some of the major household appliances that can run on solar power includes washing machines, air conditioners, and refrigerators. Many people begin using solar panels for domestic electricity usage due to several benefits like their cost efficiency in the long term and environment benefits, as PV systems emits nearly zero greenhouse gases.

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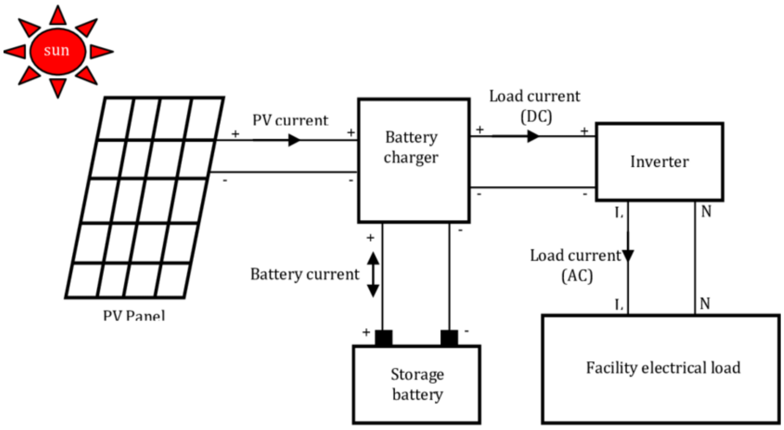

Figure 1. Demonstration of a basic PV system composition [5]

Now, the functioning process of solar systems would be introduced. In solar panels, electricity is generated through a process named the photovoltaic effect, which is the process of current generation as sunlight strikes onto solar cells. During daytime, sunlight composed of tiny particles called photons would strike solar panels—more specifically, the solar cells, devices made of semiconductor materials (commonly silicon) inside panels. Solar cells are p-n junctions constructed of three layers, the p region, the depletion region, and the n region. The p region is positive with an extra number of holes, which are positive charges that are exactly opposition from electrons, abundant in the area. The n region is negative with an extra number of electrons in the area. The depletion region is neural with equal number of electrons and holes in the region. Because the n type semiconductor is overall negative, there are holes to the side of the n region in the depletion zone to balance off the negative charges, which is the exact opposite in the side next to the p type semiconductor—there is an extra number of electrons to balance off the holes. When photons hit onto solar cells during daytime, electrons in the depletion region will absorb the light energy and jump into the conduction band from the valance band because of the extra amount of energy given, and one electron and hole would be released, free to move around. The electron would be attracted to the holes, which are positive, to the side of the depletion zone next to the n region. On the other hand, the hole would be attracted to the negative charges in the depletion region next to the p type semiconductor. Over time, there would be a potential difference generated across the p and n region, causing current generation which could be used to power electric devices connected to the photovoltaic system [6]. Overall, this is what happens in the photovoltaic effect in photovoltaic systems.

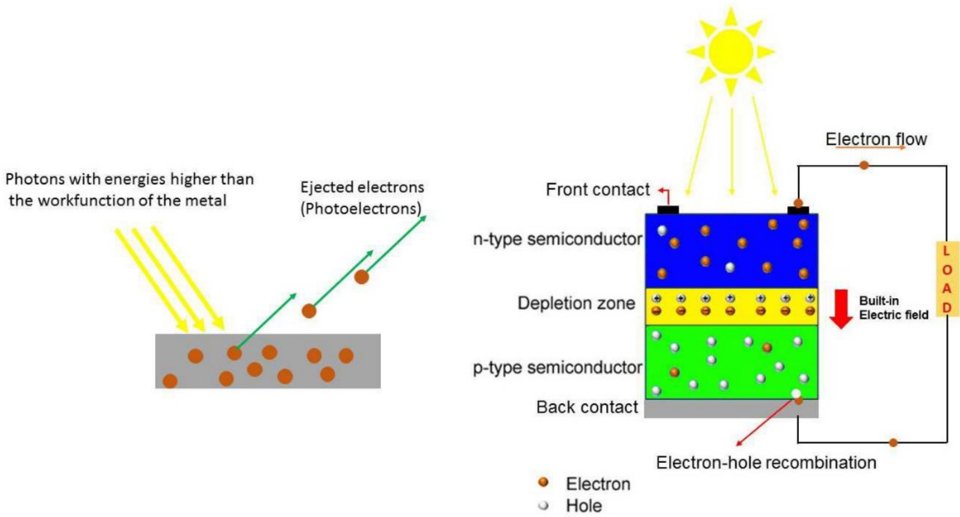

Figure 2. Illustration of the photovoltaic effect [7]

3. Silicon

As it has been mentioned in the previous paragraphs, solar cells are made of semiconductor materials, or materials that are more conductive than insulators like rubber but much less conductive than conductors like aluminum. By far, silicon has been the most popular choice as a material to construct solar cells under comprehensive investigation of multiple factors like quality, costs, efficiency, and durability. In fact, about 90% of the solar panels produced nowadays in the solar market are made of silicon [8]. One of the main reasons why silicon solar cells are so prevalent in the solar market is its relatively low cost. Silicon is the second most abundant materials on earth, ranging after oxygen. According to the Royal Society of Chemistry, silicon actually made up 27.7% of earth's crust [9]. Factories simply have to remove impurities in silicon, which often contains elements like oxygen and nitrogen when first unearthed, using extremely high temperatures. Another important factor is silicon solar cells' long duration. On average, silicon panels can usually last at least 25-30 years before noticeable degradation or decrease in efficiency. Generally, there should only be less than 20% decrease in their efficiencies in this period [10]. One more factor to consider among all is efficiency, which is the percent of solar energy that could be converted into usable electricity. The higher the efficiency, the more electricity the panels could supply a household in a certain amount of time. After the invention of solar panels, scientists have been consistently trying to use different methods to increase their efficiency. Some of the most efficient silicon solar cells nowadays includes mono-crystalline solar cells and perovskites solar cells.

In the recent decades, many different types of silicon solar cells have been invented, improving factors like their endurance in harsh weather and decreasing the cost. In 1955, the mono-crystalline silicon solar cell, which has been mentioned in the previous paragraph, was invented and is produced through a process known as the Czochralski process, which produces pieces of silicon of very high purity. Its efficiency ranges all the way from 16 to 24 percent [11],4 which is quite efficient among all solar cells made of silicon. However, its process of production is expensive and tedious, resulting in tremendous wastes of silicon while also making it energy-wasting. Another type of solar cell, the polycrystalline silicon solar cell, evolved to be much more economical than the mono-crystalline silicon solar cell. Unlike it, this type of panel is manufactured by combining and melting many different debris of silicon together, making its process of production much more efficient. As a result, its cost is much lower than mono-crystalline and is known as one of the cheapest materials for the production of solar panels. In fact, 48% of the solar panels manufactured are polycrystalline solar cells in 2008 [12]. However, because of how the production of polycrystalline combines many pieces of silicon together, the surface of the solar cells are not going to be as perfect as the mono crystalline solar cells. As a result, polycrystalline tends to absorb less solar radiation, making it less efficient than mono crystalline [13]. In fact, its efficiency only sets in the range of 12% to 14% [12]. Although in the previous decades many people preferred polycrystalline over mono crystalline, since around the year 2017, mono-crystalline solar cells have been returning to the public view in the solar market. Although it is indeed more expensive, more people are now willing to spend more money for its efficiency.

From the previous paragraphs, we could see how silicon has been the most popular material to construct solar cells in the modern era. Although it is not the best material in all aspects (like conductivity), it is still rated as the most suitable material for now in the solar market for construction of solar cells.

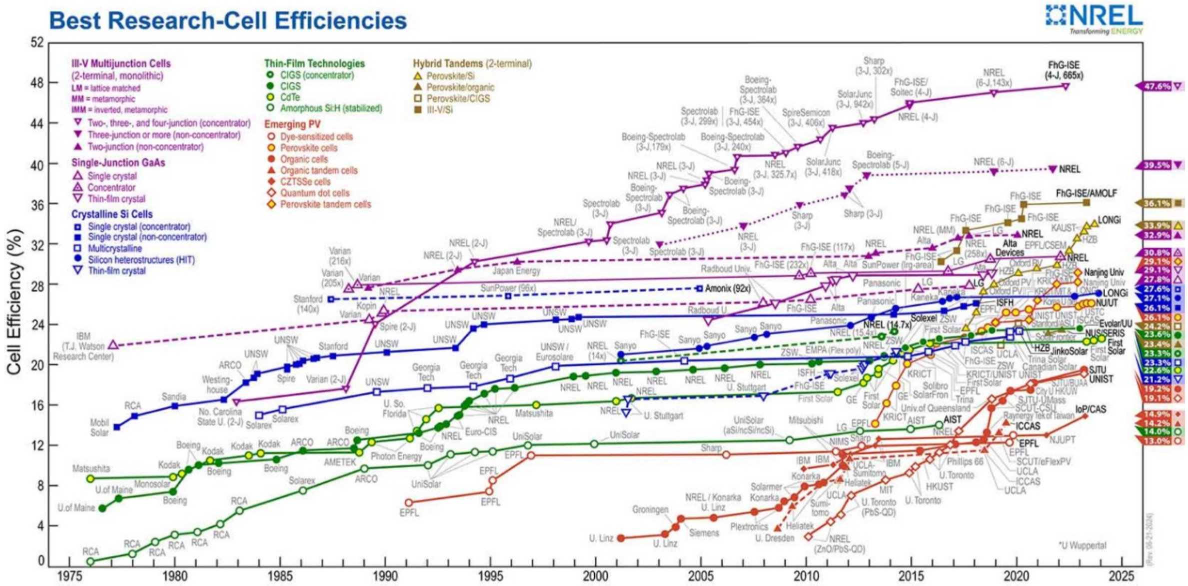

Figure 3. Efficiency comparison between different solar cells [7]

4. Solar technology's environmental importance

Since the 19th century, which is around the time of industrial revolutions, nonrenewable energy sources, including coal, oil, and gas, have risen as the primary energy sources in the modern time. The invention of the steam engine running on coal by James Watt, which is also one of the main drivers of the Industrial Revolution, not only initiated the modern era, but also set the stage of the large-scale usage of nonrenewable energy sources like oil and gas, driving important international technological, social, and economic progress. Nowadays, fossil fuels are more widely used than ever, accounting for the source of about 86% of all energy consumed in the world [15]. According to the BP statistical review of world energy, global consumption of energy has also increased by 2.8% in 2018, with most of the energy consumed by USA, China, and India, and global energy use has been continuously rising over the recent years [16].

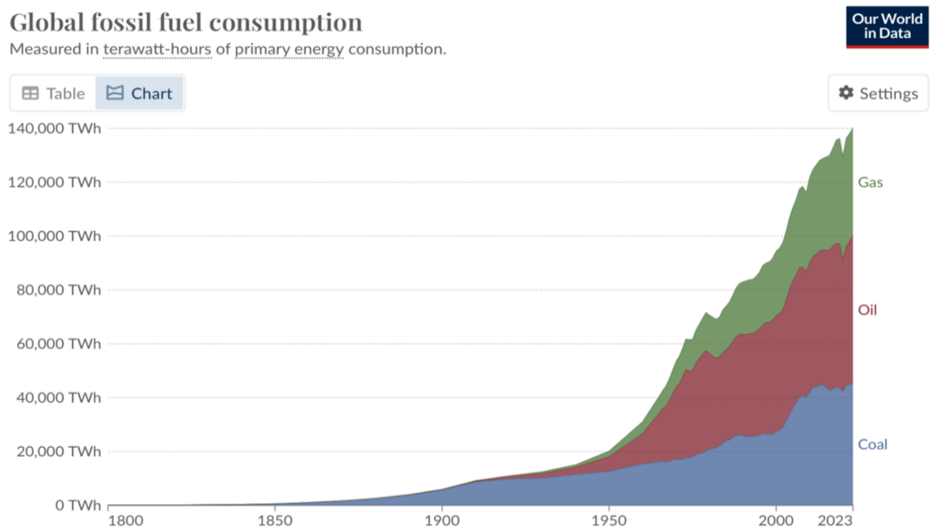

Figure 4. Change in global fossil fuel consumption [17]

The graph above made from data from the BP statistical review of world energy also shows the staggering growth in consumption of fossil fuels including gas, oil, and coal since around the 20th century.

DOI: 10.54254/2755-2721/98/20241116

Although the use of coal has roughly remained constant over the past few years, oil and gas consumption kept on rising to new heights led by countries like USA, also demonstrating the importance of fossil fuels to the modern time [17].

Looking at graphs and data, we have to admit that fossil fuel is indeed the most important energy source used across the globe. However, such wide uses of fossil fuels have led to severe down sides over the last century, with one of the most notable being the tremendous production of greenhouse gases, any gases like carbon dioxide, methane, and nitrous oxide that helps warming up the planet by absorbing infrared radiation. In 2019, the consumption of fossil fuels has caused 74% of all greenhouse gas emissions [18], and this percentage have still been increasing in the past few years, leading to tremendous environmental impacts. According to the intergovernmental panel on Climate Change (IPCC), overuse of fossil fuels, especially coal, have been the most essential cause of global warming [19]. As a result of the large-scale consumption of coal and gas in industries, greenhouse gases, especially carbon dioxide and methane, have been rising drastically in the atmosphere. In fact, the amount of CO2 in the atmosphere have already 50% higher than its amount before the Industrial Revolution in 2022 [20].

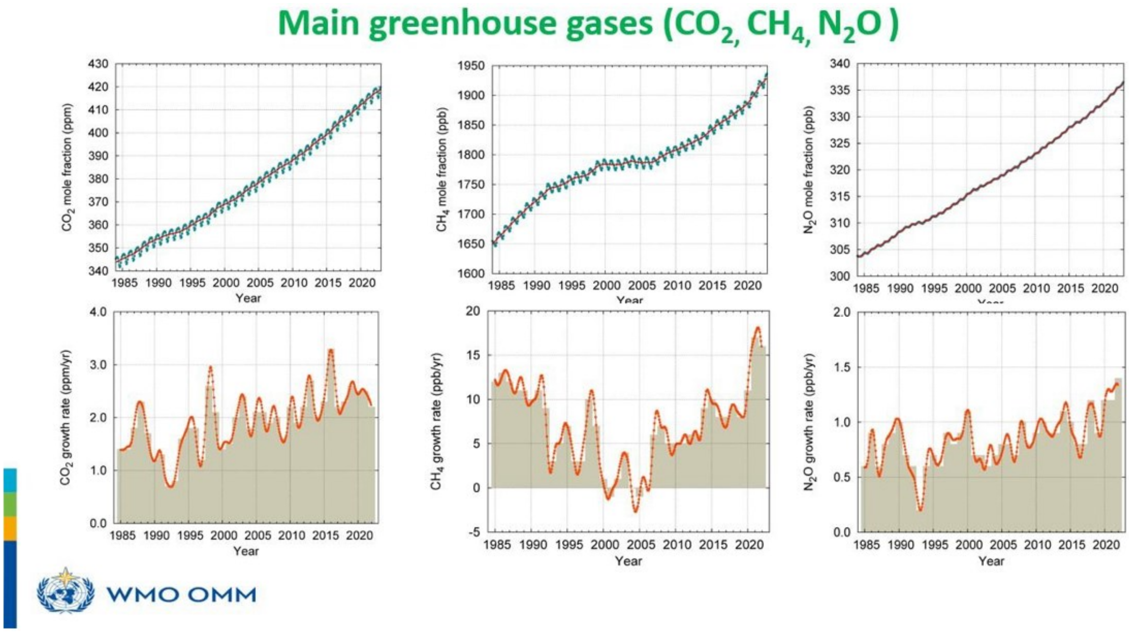

Figure 5. Change in global greenhouse gas emissions in recent decades [20]

According to WMO, greenhouse gases in the atmosphere have been increasing at a staggering rate due to fossil fuel consumption, actually hitting a record from 2021 to 2022 according to the Greenhouse Bulletin [20]. In fact, the last time the total amount of greenhouse gases in the atmosphere is comparable to the amount today is around 4 million years ago, when the temperature was 3 degrees higher [20]. Such a drastic increase in greenhouse gas emissions in the recent decades is currently causing many negative impacts on the environment, with global warming being one of the most detrimental effects. According to the National Oceanic and Atmospheric Administration (NOAA), earth's temperature has increased around 1.36 degrees Celsius from the late 19^{th} century to 2023 [21]. In fact, earth has had the highest temperature in the last ten years. Among all warming effects, carbon dioxide released mainly because of the overuse of fossil fuels accounts for 64% of all increases in temperature, methane accounts for 19%, and nitrous oxide accounts for 7% [20]. With the planet becoming hotter, precipitation is also increasing, with the air being 7% more moist for every one percent rise of global temperature, leading to more extreme storms, weather patterns, and melting glaciers [22]. Among all locations on earth, the arctic is warming four times faster. All of those factors are leading to increases in sea level as well, with an 8-inch rise in level since 1880, with the rate of increase accelerating in the recent decades [23].

Global increases in temperature also greatly threatens to human activities and wildlife. As cases of extreme weather are becoming more common, risks to public safety and heath also increased accordingly. According to the National Oceanic and Atmospheric Administration, there were at least twenty extreme weather events like droughts in the USA in 2021 caused by global rises in temperature that have caused around one billion in reparation [24]. Furthermore, as temperature gradually increases, more people, especially those in the United States, were dying as a result of the heat due to heat exhaustion, asthma, and cardiovascular diseases [24]. What's more, as temperature keeps rising, coastal cities and towns are increasingly threatened by the increase in sea level. Entire islands and areas of low altitudes are exposed to increased chances of floods and tsunami, including major cities like Los Angeles, Sydney, and New Orleans (which is half under water in 2005 blue to Hurricane Katrina) [24]. Much wildlife is also severely impacted. Melting glaciers and rises in sea levels has caused a lot of rapid changes to different ecosystems by disrupting the local habitats, which many animal species have adapted to over centuries. Animals like those in the colder reigns like the north and South Pole are threatened as increases in temperature have melted a big part of their habitat, with one of the most typical examples being the polar bears. Furthermore, populations of animals living in the water have also been declining due to increases in ocean temperature, having difficulties on finding food and mating. In fact, according to IUCN, climate change is impacting at least 6000 species over the whole plant, including plants, animals, and fungi. [25].

As demonstrated by previous data, the misuse of unclean energy sources over the past century has been having tremendous negative impacts on the environment, wildlife, and the human species. However, on the other hand, solar energy, one of the most renowned renewable energy sources nowadays, could provide tremendous benefits as a replacement for fossil fuels. Solar power has the potential to reduce tremendous harms to the environment and reducing the rate of global warming. Most notably, one of the major benefits of using solar power is that it could significantly reduce the amount of greenhouse gases released—much less than burning fossil fuels. As shown from earlier data, the production of greenhouse gases, especially carbon dioxide, has been rising drastically as we continuously used nonrenewable energy sources. However, replacing those with solar energy could tremendously limit the production of carbon dioxide, contributing to environmental protection and public safety. While using solar technologies, the photovoltaic effect in solar cells does not emit greenhouse gases—sunlight is directly transformed into usable electricity without producing any greenhouse gases to the environment [26]. It has to be mentioned, though, that solar panels do emit greenhouse gases after installation at some extent. In fact, its production also emits carbon dioxide, which takes up most of the greenhouse gas emissions in its life cycle [27]. Nevertheless, the amount of carbon dioxide produced during its production process, including everything from mining, manufacturing, to installation, could usually be offsetted by the amount saved during the first three years of using the solar panels compared to using traditional energy sources [28].

Table 1. Amount of carbon dioxide saved by using solar technology [29]

Environmental indicators of SETs

Indicator	Central solar thermal	Distributed solar thermal	Central photovoltaic power generation	Distributed photovoltaic power generation	Solar thermal electricity
CO^2 emissions savings	1.4 kg/kWh or 840 kg/m^2a	1.4 kg/kWh or 840 kg/m^2a	0.6-1.0 kg/kWh	0.6-1.0 kg/kWh	Annually 688 t/MW when compared to a combined cycle plant, 1.360 t/MW when combined to a cola fired plant

On average, solar panels used by common households only emits around 40 grams of carbon dioxide per kilowatt hour [30]. This value is much less than carbon dioxide emissions by fossils fuels, especially coal, which produces around 1 kilogram of carbon dioxide per kilowatt hour [30]. According to the table

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above, solar panels are actually able to save 1.4 kilograms just per kilowatts hour on average compared to using traditional nonrenewable energy sources [29]. When those energy sources could be replaced by solar power and other renewable energies like wind power, there would be a tremendous amount of carbon dioxide saved, significantly contributing to reduction in climate change. Although total replacement of fossil fuels by solar power is not immediately realistic, solar generation of electricity could start to be in charge of a part of the electricity used by common household than completely using electricity from the power grid. For example, solar panel could start powering household heating systems, which accounts for a huge proportion of the carbon dioxide released by common households. Starting to power some electricity from renewable energies for common houses would decrease greenhouse gas emissions from the domestic sector, which is currently around 20% in many countries like USA, significantly, functioning as a huge step toward lowering the global carbon footprint [31]. What's more, fossil fuels, which are nonrenewable, would run out some day, as implied by its name. Estimating from the current rate of consumption, fossil fuels would most likely run out in around a century [32]. As a result, it is critical for humans to find replacement energy sources before fossil fuels are completely gone. Considering the quick improvements in photovoltaic systems and solar storage systems, solar technologies now share tremendous future prospect, having the potential to rise as one of the most important energy sources in the future.

5. Conclusion

Overall, this paper discusses the most essential components of the photovoltaic system, including an explanation for the functioning process of the photovoltaic effect. It also reviews some of the major benefits of silicon and why it remains as the most widely used semiconductor material to construct solar panels. More importantly, the environmental importance of solar technologies is also pointed out. As climate change is becoming more severe after a long history of burning fossil fuels, solar technology has become one of the renewable energy sources with the greatest potential for future prevalence to protect the environment and reduce global warming. Although solar power only accounts for around 5% of total electricity production nowadays, it is quite promising that solar energy would be one of the most widely used energy source in the future.

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