

Main Contributions, Applications and Future Prospect of PV

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Abstract. Nowadays, with the development of society and economy, the disadvantages of traditional fossil fuels are obvious, and people pay more attention to renewable energy. Due to the inexhaustible nature of solar energy, which helps to get rid of the dependence on fossil fuels, photovoltaic technology has been valued and developed. Photovoltaic (PV) technology can use the photovoltaic effect to directly convert solar energy into electrical energy, and it is clean and pollution-free, avoiding harm to the environment. Photovoltaics has significant advantages over other types of renewable energy generation. Photovoltaics has made a significant contribution to social progress and has been widely used in today's society. Therefore, Photovoltaics outpaces other types of renewable energy generation, its development prospect is very impressive and has received strong support. This article aims to introduce the main contributions and applications of photovoltaics from different aspects and analyze development prospects and limitations of PV by explaining its technical principles.

1 Introduction

Energy consumption is rising as a result of population expansion and economic development in order to improve living conditions. However, the burning of conventional fossil fuels will result in a number of significant environmental issues, including acid rain, global warming, and air pollution. Thus, the advancement of renewable energy technologies is only around the corner. A potential renewable energy technology that can tackle the problems of energy scarcity and environmental pollution is photovoltaic.

George Cove invented the photovoltaic panel in 1909, around 40 years before Bell Labs did it in 1950. The first programme to fund photovoltaic roofs (2200 rooftops) was introduced by the German Ministry of Research in 1989. Walter Sandtner oversaw the initiative in Bonn, Germany. Japan launched a similar programme in 1994 and installed 539 household PV systems [1]. Since then, the production and financing of solar systems has increased exponentially in a number of nations.

Without the influence of a heat engine, photovoltaic (PV) technology may transform solar energy straight into electricity. The architecture of photovoltaic equipment is straightforward and dependable, needing little upkeep. Its biggest advantage is that it can provide output from microwatts to megawatts as a stand-alone system. As such, they can be used in power supplies, remote buildings, household solar systems, communications, megawatt-scale power plants, etc. Due to the wide range of applications, people's demand for photovoltaic power generation is increasing year by year. In addition, because solar energy is so accessible, one of the most promising sectors in the renewable energy sector is the generation of electricity utilizing PV panels

to harness solar energy. This suggests that solar PV has long-term competitive potential with traditional fossil fuels and other alternative energy sources.

The quantity of articles that have been published in journals and the amount of research into solar photovoltaics have both grown recently. The PV market is now contentious around the world, particularly in Europe, China, and the United States, because to its strong development potential and high investment levels [2]. Therefore, clarifying the contribution of photovoltaics and its application areas is the primary goal of this study.

The article first explains the background of photovoltaic power generation, then reviews its basic principles and structural composition, and then analyzes and discusses its contribution and application fields from three aspects, then analyzes the advantages and disadvantages of this technology and looks forward to its future.

2 Overview of PV Technology

With the help of solar cells and the photovoltaic effect, photovoltaic power generation transforms solar energy into electrical energy. The physics, photochemistry, and electrochemistry areas all research the photovoltaic effect [1]. A non-mechanical device known as a photovoltaic cell uses sunshine to generate energy. Photovoltaic cells are made of semiconductor materials, which include three types: single crystal, polycrystalline and thin film. Solar particles called photons are what make up sunlight. These photons have energies that vary according to the solar spectrum's various wavelengths. Only the photons absorbed by the semiconductor

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material, when they strike a photovoltaic panel, give energy to produce electricity. The other photons either reflect from the cell, travel through the cell, or are absorbed by the semiconductor material. The semiconductor material will produce an electric current after the sun's energy has been absorbed sufficiently. The photovoltaic cells are electrically connected in an encapsulated, weatherproof photovoltaic panel. Photovoltaic panels vary in size and power generation. Increases in a solar panel's surface area or cell count increase the panel's capacity to produce power. solar modules are constructed by grouping together solar panels. Two to hundreds of solar panels can make up a photovoltaic module. The quantity of power that may be produced depends on how many solar panels are linked together in a photovoltaic module.

The combination of multiple photovoltaic modules is called a photovoltaic system. Photovoltaic cells are the basic building blocks of photovoltaic systems. Photovoltaic systems employ solar modules, each of which includes a plurality of solar cells. As shown in Fig. 1, photovoltaic systems come in two different forms: stand-alone systems and grid-connected systems. Photovoltaic modules, a charge controller, a maximum power point tracking MPPT, a battery and an inverter are all components of the photovoltaic system [3]. Photovoltaic systems can be floating, wall-mounted, roof-mounted, or ground-mounted. This mount can be stationary or mobile, following the sun's position in the sky with a solar tracker [1]. In order to maximise the system's physical and financial performance, most photovoltaic systems have panels fixed in place, often facing the northern hemisphere's south and southern hemisphere's north.

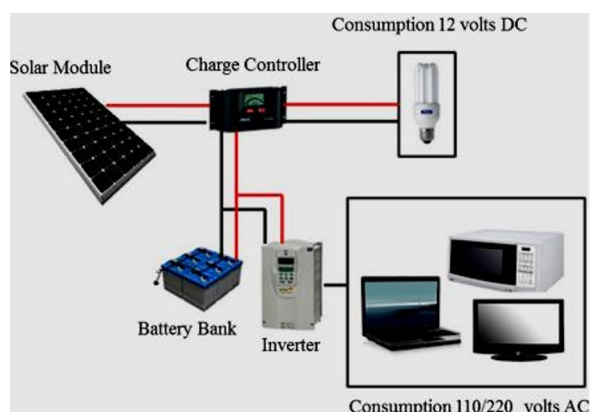


Fig. 1. Typical PV system components [2, <https://doi.org/10.1016/j.rser.2017.02.081>].

3 Main Contribution of PV

3.1 Environmental friendliness

By 2024, it is anticipated that the quantity of energy generated by fossil fuels would have decreased four-fold in just six years (Fig. 2). In the past, reductions in the production of fossil fuels have been rare, frequently happening after significant global energy and financial

crises like the oil shocks of the 1970s and the Great Recession of 2009, when there was a fall in the demand for electricity overall. But in recent years, even as electricity demand has risen, fossil fuel supply has declined because of a strong growth trend in renewable energy generation. This demonstrates how the globe is quickly nearing a tipping point when the production of fossil fuel power starts to drop and is gradually replaced by the production of clean energy power [4].

Traditional fossil fuel-based power generating methods have exacerbated severe environmental issues, all of which constitute a significant danger to human civilization. Compared to other traditional power generating methods, photovoltaics is intrinsically safer. It is also noiseless, plentiful, sustainable, and renewable. Many of the environmental issues brought on by conventional fossil fuels may be avoided by photovoltaic energy generation.

As zero-emission energy systems, photovoltaic systems are those that have little to no effect on greenhouse gas emissions. Zero emissions of CO₂, NO_x, and SO₂ gases during the solar system's operation won't exacerbate the problem of global warming [5].

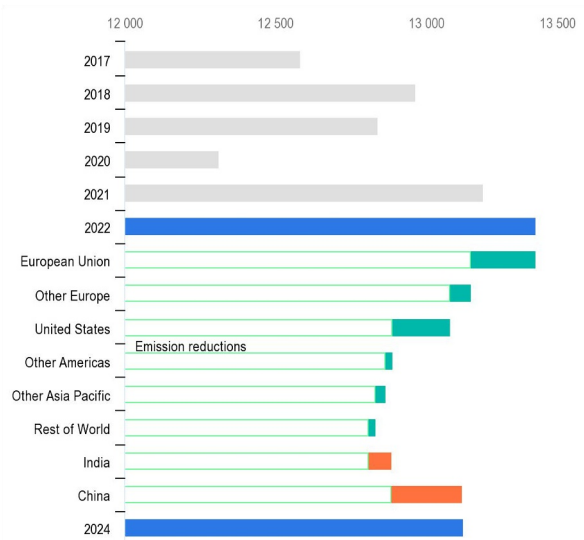


Fig. 2. Alterations in the production of electricity's worldwide CO₂ emissions, 2024 vs. 2022 [4, <https://www.iea.org/reports/electricity-market-report-update-2023>].

3.2 Energy sustainability

Sustainable power generation may be possible with renewable energy. In recent years, renewable energy has received increasing attention and solar power as an electrical source has gained in acceptance. Solar energy is the source of energy that sustains all plant, animal and human life on Earth. Electromagnetic waves from the sun are continually sent into space, and the planet receives these waves as energy. The planet may be thought of as a massive solar collector that absorbs a significant quantity of solar energy in a variety of forms. Solar energy is an inexhaustible, inexhaustible and locally available renewable energy source. It is a clean

energy source that can help achieve local energy independence. Therefore, the more electricity obtained from photovoltaics, the less dependence on the grid and the lower the need for fossil fuels.

3.3 Economy

Many things have contributed to solar's enormous success, but one of the main ones has been its spectacular cost reduction over the last ten years, which has helped it rise to the top of the world in terms of cost competitiveness. Utility-scale photovoltaics are cheaper than new-build conventional generation sources. In addition, combining solar with storage is more cost-competitive than using gas turbines to meet peak electricity demand. This can be seen in the increasing number of countries setting up hybrid renewable energy auctions around the world. Such auctions involve the juxtaposition of different renewable energy sources with battery storage, providing a flexible and versatile solution to meet energy demand [6], as shown in Fig. 3.

Utility-scale photovoltaics continue to be the least expensive renewable energy generating choice in the great majority of nations worldwide, despite growing investment costs caused by rising commodity prices. Due to rising retail electricity prices and increased policy support, distributed solar photovoltaic power generation will also achieve faster growth [4].

Without using any machinery or moving parts, photovoltaic systems directly transform solar energy into electrical energy. There are not many moving parts in a solar system, so it does not require a lot of maintenance costs [5].

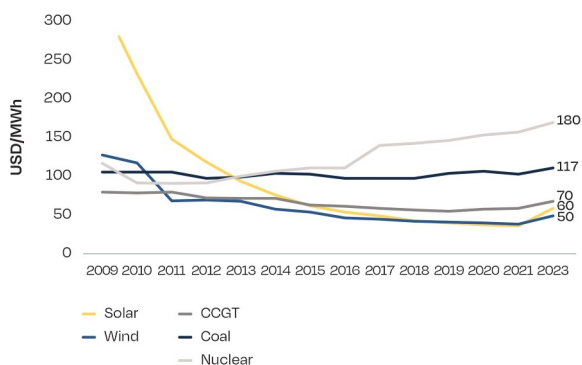


Fig. 3. Cost of solar electricity generation against other energy sources 2009-2023 [6, <https://www.solarpowereurope.org/insights/outlooks/global-market-outlook-for-solar-power-2023-2027/detail#global-solar-market-introduction>].

4 Application of PV

An extremely modular technology, photovoltaics may be produced in massive factories to benefit from economies of scale or used in small batches at a time. This characteristic permits a wide range of applications, from modest rooftop systems for household use to substantial utility-scale power producing facilities [4].

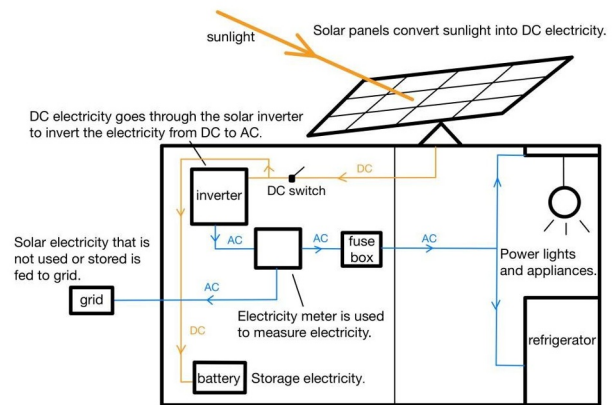


Fig. 4. Process of solar panels providing electricity to a residential [Picture credit: Original].

4.1 Household and commercial PV systems

Solar panels can use the photovoltaic effect to power household and businesses. Solar panels generate direct current (DC) and convert it to alternating current (AC) through solar inverters for household appliances. Fig. 4 shows how a rooftop photovoltaic system powers a small residential.

In general, household and commercial photovoltaic systems are suitable for off-grid. Off-grid systems are often used for the electricity needs of remote buildings that do not have access to the public grid. They are 100% self-contained, so additional solar cells for energy storage are usually required to provide power when the sun is not shining. Since they provide power to isolated rural houses and towns that are not connected to the national grid, these systems are the finest available technology to meet the energy needs of off-grid populations. Typically, these photovoltaic systems provide electricity for low-power uses like lighting and cooling. Tiny quantities of energy have a high value for commercial usage, making photovoltaics' commercial cost more competitive with that of other types of tiny generation. They offer electricity for a number of low-maintenance applications, including telecommunications, water pumping, vaccine refrigeration, and navigational equipment, among others.

4.2 PV power station

Large-scale grid-connected solar power production systems created for utility-scale power delivery are known as photovoltaic power stations. They are distinct from other distributed solar production systems and most building installations in that they provide energy to utilities rather than local consumers. Photovoltaic systems that are grid-connected don't require batteries to store power since they are connected directly to the national grid. To power residential, commercial, and industrial structures, they are frequently included into the built environment. When on-site generation exceeds load demand, power is fed back to the utility grid, which matches well with residential load patterns in hot summer months.

With the ongoing advancement of technology, PV power systems are becoming less expensive, and they are getting closer to grid parity in many market sectors and towards an age of unrestricted market competition [7].

4.3 Agrivoltaics

Due to the increasing demand for food production and energy demand, the use of large tracts of land to build photovoltaic power generation on limited land resources will intensify the competition for land resources. At the same time, the increase in population has intensified competition for land. These problems can be alleviated by the construction of agricultural photovoltaics (that is the development of the same plot of land for conventional agricultural and solar PV). In the past, one piece of land was set aside for food production and another for energy production in order to address the issue of rivalry for land resources. Today, it is possible that both food and energy can be generated on one piece of land.

Farmers are demonstrating that they have the possibility to diversify their sources of revenue thanks to this technology. The production of energy and agriculture together can have good effects on the economy, society, and environment and offer a workable answer to the growing competition for land resources. However, there are challenges with both agricultural PV system components. The main concern with agricultural yields is how shade affects crop growth. Even little shadow can cause significant output and quality losses. These mostly include lower yields for solar power generation owing to dust build-up from agricultural operations and probable panel damage from livestock disturbance.

5 Future Prospect and Challenges of PV

In early 2022, the demand side believes that the current high prices in the solar industry will come down. While prices for silicon, wafers, cells and modules remain higher than they were a few years ago, they eased in the first few months of 2023, allowing the industry to ease after a nearly 18-month upward trend. Prices in the solar industry are expected to continue to decline as new capacity comes on stream, mainly in China. Furthermore, the prediction of many developers delaying projects until 2023 seems to have come true [6], as shown in Fig. 5.

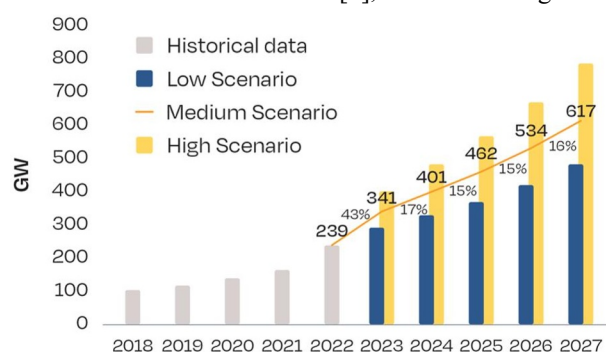


Fig. 5. World annual market forecasts for solar photovoltaics 2023-2027 [6, <https://www.solarpowereurope.org/insights/outlooks/global-market-outlook-for-solar-power-2023-2027/detail#global-solar-market-introduction>].

As shown in Fig. 6, by 2027, the installed capacity of solar photovoltaic is expected to surpass that of coal power generation and become the world's number one. By almost tripling in size and increasing by about 1,500 GW over the projection period, cumulative solar PV capacity will surpass natural gas by 2026 and coal by 2027. In the next five years, the annual increment of solar photovoltaic power generation capacity will increase year by year [8].

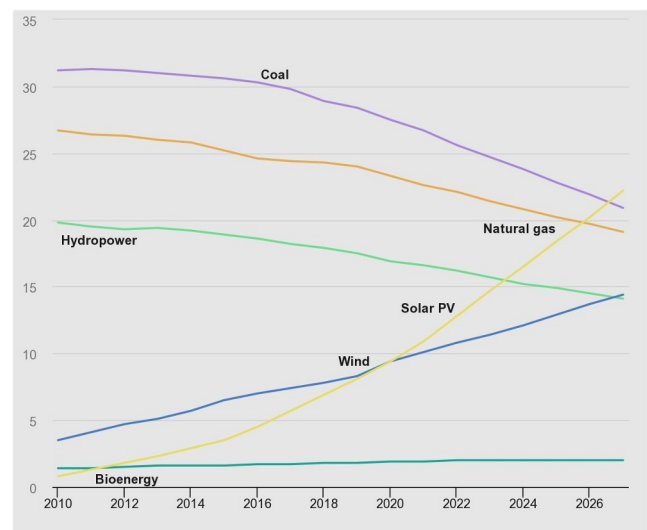


Fig. 6. Technology's share of total power capacity, 2010-2027 [8, <https://www.iea.org/reports/renewables-2022>].

Compared to the production of power using conventional fossil fuels, photovoltaic technology does not cause serious environmental problems in the process of generating electricity. Solar energy may be used instead of traditional fossil fuels without the need for extraction, refinement, or transportation, which is another benefit of photovoltaic technology. But during its lifespan, the production of solar cells, the construction of photovoltaic modules, and the movement of materials all require a lot of energy and produce greenhouse gases [2].

The materials utilised determine the characteristics of various photovoltaic cells. There are some materials have serious flaws that prevent them from competing in upcoming photovoltaic technologies, such as efficiency, material, lifetime, etc. Until at least the middle of the 2030s, other materials will be in use. After 2030, it's anticipated that new materials will be needed to boost photovoltaic systems' efficiency and lower their price [9]. The cost of silicon raw material is the biggest factor affecting the manufacturing cost of photovoltaic power generation technology. Several approaches are being taken to reduce silicon costs, including improving raw materials, producing kerfless wafers, developing ultra-thin silicon, and using bifacial cells [10]. Additionally, it is commonly accepted that thin-film technology has the

potential to offer a workable substitute in the foreseeable future and that c-Si wafer technology cannot achieve the low-cost aim.

The price of a photovoltaic module is determined by the overall cost of production and the module's area-based conversion efficiency. Many methods, such as tandem cells, hot electron extraction, and so-called "third-generation photovoltaics," have been proposed to improve the efficiency of solar cells' ability to convert sunlight into electrical energy. The foundation of 'third generation photovoltaics' will be nanostructures. The ability to leverage novel physical mechanisms to attain better efficiencies than single-junction solar cells is a key benefit of nanostructured solar cells. Solar cells using nanostructures provide a number of benefits. Firstly, by employing novel ideas, it has the potential to outperform the efficiency of single-junction solar cells. Additionally, it has the capacity to go beyond the practical constraints of already-existing devices, such as when lattice matching constraints are bypassed by using nanostructures. Last but not least, self-assembled nanostructures have the potential to build low-cost solar cells [11].

6 Conclusion

Photovoltaic power generation is a very promising way of renewable energy power generation. Photovoltaic power generating is more ecologically benign, energy sustainable, and cost-effective than conventional fossil fuel power generation. Photovoltaic power generation has a wide range of applications, including small-scale independent system solar power generation, large-scale public grid-connected system photovoltaic power generation, photovoltaic power generation combined with agricultural fields, and more application fields. Today, solar photovoltaic power generation dominates the new power generation capacity installed globally, surpassing other renewable energy sources. Photovoltaic power generation has the advantages of environmental protection, low transportation and maintenance costs, easy access, reliable system, and no noise. However, its disadvantages cannot be ignored. Disadvantages of photovoltaic power generation include limited system availability on the market, high initial costs, large installation areas, and demanding geographical and climatic conditions. In the future research and development of photovoltaic technology, we should focus on reducing costs and improving efficiency. At the same time, we must also pay attention to the combination of photovoltaics and other fields to promote the future development of renewable energy.

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