

Research Article

Powering the Future: Advancements and Applications of Photovoltaic Systems with Political, Economic, and Environmental Considerations

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Abstract: The paper explores the significant role of Photovoltaic (PV) technology in the global energy mix and its diverse range of applications, including power generation for residential and commercial buildings, transportation, and industry. Building-integrated photovoltaic systems offer numerous benefits over traditional solar panels, such as enhanced energy efficiency, reduced visual impact, and simplified installation. The critical role of grid integration in photovoltaic systems, the utilization of photovoltaic systems for powering electric vehicles, and the application of floating solar farms are also emphasized. Additionally, the article discusses the influence of various factors, including solar irradiance, temperature, shading, and system design and installation, on the performance of photovoltaic systems during operation. The article also sheds light on emerging technologies, such as software tools, numerical models, and experimental methods, used for performance modeling and analysis. Despite challenges associated with the photovoltaic industry, such as initial investment costs and intermittency issues, supportive government policies and ongoing technological advancements are contributing to the accelerated growth of the photovoltaic industry and paving the way for a more sustainable future for generations to come.

Keywords: PV technology, PV application, photovoltaics, solar energy, Building-Integrated Photovoltaics (BIPV) systems, grid integration, Electric Vehicles (EVs), floating solar farms, performance modeling and analysis

1. Introduction

Employing solar energy as a source of electricity dates back to the 19th century when French physicist Edmond Becquerel first discovered the Photovoltaic (PV) effect, which refers to the generation of electric current when certain materials are exposed to light. However, it wasn't until the 1950s and 1960s that practical applications of PV began to emerge when silicon-based PV cells were developed. Since then, the technology has advanced significantly and the PV systems have become more efficient, reliable, and cost-effective. Today, solar energy is the fastest-growing source of renewable energy. The adoption of solar energy is expected to continue to accelerate in the coming decades.

The objective of this paper is to emphasize the significant role of PV technology in the global energy mix and its various applications. With the growing importance of renewable energy sources and the potential of PV systems, the scope of the paper is to make a significant contribution to the field by providing a comprehensive overview of the diverse applications and critical aspects of PV systems. It highlights the importance of grid integration in PV systems,

the utilization of PV for powering electric vehicles, and the emerging trend of floating solar farms. Furthermore, the paper addresses the influence of various factors on the performance of PV systems and explores the use of advanced technologies for performance modeling and analysis. The novelty of this paper lies in its comprehensive coverage of the economic, environmental, and technical considerations of the PV industry, offering valuable insights for researchers, policymakers, and industry professionals. It consolidates current knowledge and provides a holistic understanding of PV technology's role in achieving a sustainable and renewable energy future.

2. Methodology

This paper utilizes a comprehensive approach to investigate the significant role of PV technology in the global energy mix and its diverse range of applications. The methodology employed includes a combination of literature review, data and information collection, and case studies to gather and analyze relevant information. The paper encompasses three sections: PV technology, PV application, and the sustainability of the PV industry. The flowchart of the paper is shown in Figure 1.

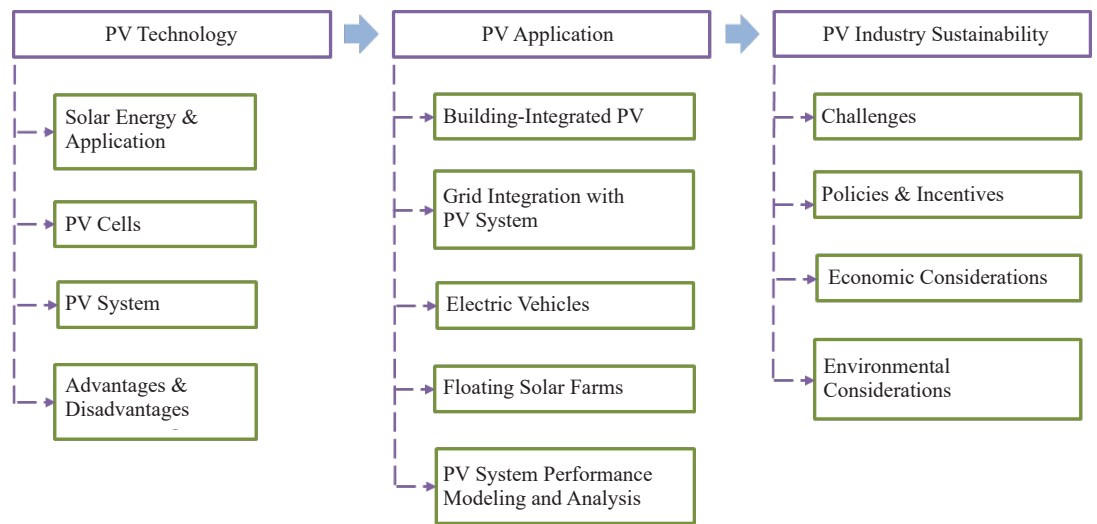


Figure 1. The flowchart of the paper

The initial phase involved an extensive review of scholarly articles, reports, and industry publications to gather a comprehensive understanding of the PV industry, its applications, and associated economic, environmental, and technical considerations. This literature review formed the foundation for the subsequent analysis and discussions presented in the paper.

Data and information collection were conducted to examine the growth and trends in the PV industry, including market dynamics, government policies, and technological advancements. Various sources such as industry reports, statistical data, and government publications were utilized to gather qualitative information for analysis. This analysis provided insights into the current state of the PV industry, as well as the factors influencing its growth and development.

Case studies were also included to illustrate real-world examples and applications of PV systems. These case studies were selected based on their relevance to the different topics discussed in the paper, such as building-integrated PV systems, grid integration, PV systems for powering electric vehicles, and floating solar farms. The case studies provided practical insights into the implementation, challenges, and benefits of PV systems in various contexts.

3. Solar energy and application

The sun is a massive source of energy that emits radiation in the form of electromagnetic waves. This radiation includes visible light, ultraviolet light, and infrared radiation. Solar energy is harnessed by capturing this radiation and converting it into useful forms of energy, such as electricity or heat. The amount of solar energy that reaches the earth's surface is enormous, and it is estimated that the sun's energy could meet the world's energy needs for an entire year in just one hour of sunlight [1].

PV technology is based on the principle of converting sunlight into electricity through the use of solar cells. Solar cells are made up of semiconducting materials, such as silicon, that absorb photons of light and release electrons, generating an electric current [2]. The efficiency of a solar cell is determined by the percentage of sunlight that is converted into electricity. Currently, the most efficient solar cells can convert up to 25.2% of sunlight into electricity, although most commercially available cells have an efficiency of around 15-20% [3]. However, in research and development, scientists have achieved PV cells with sunlight conversion efficiencies near 50% [3].

PV systems can be designed in various configurations, depending on the application and the available space. The most common types of PV systems include rooftop solar panels for residential and commercial buildings, ground-mounted systems for utility-scale power generation, and solar farms for large-scale electricity production.

Solar energy has a wide range of applications in various sectors, including residential, commercial, and industrial [4]. In the residential sector, PV systems can be used to power homes, therefore, reducing dependence on the grid and lowering energy costs. Commercial buildings can also benefit from PV systems, with solar panels installed on rooftops or integrated into building facades. Industrial applications of solar energy include powering remote off-grid locations, such as mining and oil rigs, and providing electricity for water pumping and irrigation in agriculture [5]-[6]. These technologies can significantly reduce energy consumption and carbon emissions in buildings, particularly in areas with high levels of sunshine.

Several recent studies have concentrated on the application and efficiency of PV systems. Research into the design and performance analysis of dual-axis tracking solar systems has uncovered innovative approaches [7]. Another investigation introduces a unique method for assessing energy efficiency loss caused by dust accumulation in PV systems. This study utilizes a coupling model (Dust Concentration and Photoelectric Conversion Efficiency (DC-PCE)), validated through experiments with various dust pollutants, providing a reliable on-site evaluation tool with an accuracy of 83.12% [8]. In the context of the growing role of solar energy, a thorough review examines factors influencing solar cell efficiency, encompassing materials, Maximum Power Point Tracking (MPPT) techniques, and Direct Current to Direct Current (DC-DC) converters [9]. In the pursuit of sustainable energy, a statistical assessment evaluates twenty optimization-based global MPPT methods, offering valuable insights for enhancing PV system efficiency under varying shading scenarios [10]. Additionally, a study introduces a novel MPPT technique using the Yellow Saddle Goatfish Algorithm, demonstrating superior performance in addressing power losses under partial shading conditions through simulations and statistical analysis [11].

4. Types of PV cells

There are three main types of PV cells: crystalline silicon, thin-film, and perovskite [12]. Crystalline silicon cells are the most commonly used and have a long lifespan of up to 25 years [13]. Thin-film cells are lightweight and flexible, making them suitable for use in Building-Integrated Photovoltaics (BIPV). Perovskite cells are a promising emerging technology that has shown high efficiency and low-cost potential [14], but their stability and durability remain a challenge [15].

5. Components of a PV system

A PV system consists of several components, including solar panels, inverters, charge controllers, batteries, and mounting systems [16]. Solar panels are the primary component that absorbs sunlight and converts it into electricity. Inverters convert DC electricity from solar panels into AC electricity that can be used in homes and buildings. Charge

controllers regulate the amount of electricity that flows into batteries, while batteries store excess electricity generated by the PV system for later use. Mounting systems are used to install solar panels on rooftops or in open spaces. For large-scale ground stations, additional components such as combiner boxes and transformers are also incorporated. In such installations, alongside solar panels, inverters, charge controllers, and mounting systems, combiner boxes are employed to combine the outputs of multiple strings of solar panels, and transformers are utilized for voltage regulation and distribution.

6. Advantages and disadvantages of PV technology

The utilization of PV technology offers numerous advantages and drawbacks that must be taken into account. PV technology's primary advantage is its reliance on an unlimited energy source, the sun. Additionally, PV systems require minimal maintenance due to their lack of moving components and ability to endure for several decades. Furthermore, PV systems are noise-free, rendering them a silent source of renewable energy. The usage of PV technology can also notably diminish greenhouse gas emissions, aiding in the fight against climate change [17]. Finally, PV systems can be implemented in remote locations, providing power where traditional grid systems are unavailable.

On the other hand, the high installation cost is the primary drawback of PV technology, although it has substantially decreased in recent years. PV systems require sunlight to generate electricity, making them unsuitable in areas with low sunlight or frequent cloud cover. Large-scale PV systems necessitate substantial land, which could be problematic in regions where land is scarce. Additionally, disposing of PV panels at the end of their life cycle could be challenging due to toxic components [18]. Finally, the efficiency of PV systems may be affected by factors such as temperature, shading, and panel orientation, reducing their overall effectiveness [19].

7. Building-integrated PV

Building-Integrated Photovoltaics (BIPV) is a cutting-edge technology that integrates solar panels into building structures [20]. BIPV systems not only generate electricity but also serve as an architectural element that seamlessly blends into the building's design. BIPV systems have gained immense popularity due to their ability to provide renewable energy without compromising the aesthetics of traditional solar panels.

BIPV systems come in various forms such as solar shingles, solar windows, and solar facades. Solar shingles are designed to replace traditional roof shingles and fit smoothly into the roofline. Solar windows incorporate transparent solar cells into the glass of windows, allowing natural light to enter the building while generating electricity [21]. Solar facades use solar panels as an architectural element to cover the exterior of the building while generating electricity.

BIPV systems offer several advantages over traditional solar panels. Firstly, BIPV systems reduce the visual impact of solar panels on building design, offering a more seamless and visually appealing appearance. Secondly, BIPV systems streamline the installation process as the panels are integrated into the building's design during construction, providing a more efficient and cost-effective solution [22].

Another significant advantage of BIPV systems is their ability to improve a building's energy efficiency by providing shade, insulation, and ventilation, thereby reducing energy consumption. BIPV systems can also contribute to green building certifications such as Leadership in Energy and Environmental Design (LEED) by enhancing the building's overall sustainability [23].

BIPV systems can be used in both residential and commercial buildings. Residential BIPV systems can provide homeowners with a reliable and sustainable source of renewable energy, therefore, improving the energy efficiency of their homes. Commercial BIPV systems can offer a significant source of renewable energy for large-scale buildings to enhance the building's sustainability.

8. Grid integration with PV system

Grid integration can provide a positive aspect of PV systems because it allows for the efficient and reliable

distribution of electricity to homes and businesses [24]. Grid integration refers to the process of connecting PV systems to the electric grid. By connecting to the electric grid, PV system owners can not only transfer their excess power generated by the PV system back to the grid but also can draw power from the grid when the PV system is not producing enough electricity.

One of the benefits of grid integration is that it allows PV system owners to earn credits for the excess power generated by their system [25]. The credits can help the PV system owners offset their electricity bills. This process is known as net metering and is a policy implemented by many countries to incentivize the adoption of renewable energy sources.

Grid integration also helps to increase the stability and reliability of the electric grid. As more and more PV systems are integrated into the grid, there is a greater variability in the supply of electricity [26]. In addition, advancements in grid management technology can also ensure that the electric grid remains stable. The example of grid management includes energy storage systems and demand response programs.

9. Electric vehicles

The transportation sector is one of the largest consumers of energy globally, and it is primarily powered by fossil fuels, which contribute significantly to greenhouse gas emissions [27]. However, with the advancement of technology and the development of renewable energy sources, there is a growing interest in using renewable energy to power the transportation sector. PV systems can be a valuable source of renewable energy for powering Electric Vehicles (EVs), reducing reliance on fossil fuels, and lowering greenhouse gas emissions.

PV systems can be used in two ways to power EVs. The first method involves using PV panels to generate electricity, which is then stored in batteries to power the EV [28]. The second method is known as solar-powered charging stations, where PV panels generate electricity, which is then fed directly into the grid and used to power EV charging stations [29].

The use of PV systems to power EVs has several advantages. Firstly, it provides a clean source of energy, reducing the carbon footprint of the transportation sector. Secondly, it can reduce dependence on foreign oil, which is often a source of geopolitical tensions. Thirdly, it can provide energy security, as PV systems can be installed locally, reducing the risk of supply chain disruptions. Finally, it can reduce the overall operating costs of EVs, as the fuel source is renewable, making it more cost-effective in the long run [30].

However, there are also some challenges associated with using PV systems to power EVs. Firstly, the initial cost of PV systems can be high, making it a less attractive option for some consumers. Secondly, PV systems require sunlight to generate electricity, which means they may not be suitable for all locations or weather conditions. Thirdly, the efficiency of PV systems can be affected by factors such as shading, dust, and temperature changes [31].

Despite these challenges, the use of PV systems to power EVs has significant potential to increase the use of renewable energy in the transportation sector. The development of new technologies and the reduction of costs associated with PV systems and EVs can make this solution more accessible and practical. Therefore, employing PV systems to power EVs is a promising avenue for achieving a more sustainable and environmentally friendly transportation sector.

10. Floating solar farms

Floating solar farms are an innovative and exciting application of PV systems that are gaining popularity worldwide. These systems involve the installation of solar panels on floating structures, such as rafts or buoys, that are placed on bodies of water, such as lakes, reservoirs, or oceans [32].

One of the main advantages of floating solar farms is their ability to utilize otherwise unused space on bodies of water. By using water bodies for solar power generation, there is no need to compete with other land uses, such as agriculture or urban development, for space. Additionally, floating solar farms have been shown to have higher energy yields compared to traditional ground-mounted PV systems due to the cooling effect of the water, which improves the

efficiency of the panels [33].

Floating solar farms also offer environmental benefits. By covering the surface of a water body with solar panels, floating solar farms can help reduce water evaporation and control algae growth, leading to improved water quality [34]. They also reduce the need for land clearance and the environmental impacts associated with land-based solar farms.

Floating solar farms have been successfully implemented in various countries, including Japan, China, and India. In 2020, the world's largest floating solar farm was completed in Anhui Province, China, with a capacity of 150 MW [35]. In 2017, India's first floating solar farm was inaugurated in the southern state of Kerala, with a capacity of 500 kW [36].

However, there are also some challenges associated with floating solar farms. One of the main challenges is the potential impact on aquatic ecosystems, such as fish habitats and migratory patterns [37]. Careful planning and environmental assessments are necessary to minimize the potential negative impacts.

11. PV system performance modeling and analysis

The performance of a PV system is influenced by several factors, including the efficiency of the solar cells, shading and orientation of the solar panels, temperature, and system design and installation. Performance modeling and analysis of PV systems are crucial in assessing the efficiency, reliability, and economic viability of solar energy installations. A PV system's performance is affected by several factors, including solar irradiance, temperature, shading, and the efficiency of the PV modules and inverters [38]. Therefore, accurate modeling and analysis of these factors are necessary to optimize system performance and minimize energy losses.

Performance modeling and analysis can be done using various software tools and simulation models, which range from simple spreadsheet-based models to complex numerical models. These models take into account several parameters, including the system's design and configuration, weather conditions, and performance data collected from the PV system [39].

One of the most commonly used software tools for PV system performance modeling and analysis is PVsyst [40]. PVsyst is a software package that simulates the performance of PV systems using detailed models of PV modules, inverters, and balance-of-system components. The software allows users to input data such as location, module type, tilt angle, and shading conditions to generate an accurate prediction of the system's energy output. The software also provides detailed reports on the system's energy yield, performance ratio, and financial analysis, making it a valuable tool for designing and optimizing PV systems.

Another software tool commonly used for PV system performance modeling and analysis is System Advisor Model (SAM) [41]. SAM is a free software package developed by the National Renewable Energy Laboratory (NREL) that provides a detailed analysis of the performance and economics of renewable energy systems. SAM includes a wide range of PV system models, from small residential systems to large utility-scale installations, and allows users to input detailed system and weather data to simulate the performance of the system over time.

In addition to software tools, several numerical models have been developed to simulate the performance of PV systems. One of the most widely used models is the single-diode model, which describes the current-voltage characteristics of a PV module using a single exponential equation [42]. The model takes into account several parameters, including the module's temperature, irradiance, and current-voltage characteristics, to accurately predict the module's power output. The model is relatively simple and can be used to simulate the performance of PV systems under various weather conditions.

Performance modeling and analysis of PV systems can also be done using experimental methods. Field testing is commonly used to measure the performance of PV systems under real-world conditions [43]. The performance data collected from field testing can be used to validate simulation models and improve their accuracy. In addition, several performance monitoring systems have been developed to monitor the performance of PV systems in real-time. These systems allow operators to identify and address performance issues quickly, minimizing energy losses and improving system reliability.

12. Challenges facing in the PV industry

Despite the many benefits of solar energy, there are still several challenges that need to be addressed to promote its widespread adoption. One of the main challenges is the high upfront cost of PV systems [44]. Although the cost of solar panels has decreased significantly in recent years, the initial investment required to install a PV system can still be a barrier for many individuals and organizations [45].

Another challenge is the intermittency of solar energy. Solar power is only generated during daylight hours, and its output can be affected by weather conditions [46]. This means that PV systems need to be integrated with energy storage systems, such as batteries, to ensure a continuous supply of electricity.

The lack of standardization in PV technology is another challenge facing the industry. With so many different types of solar panels and inverters available, it can be difficult to ensure compatibility and optimize system performance. Industry standards can help address this issue.

13. Policies and incentives

The growth of the PV industry is largely influenced by government policies and support mechanisms. Governments around the world are recognizing the benefits of renewable energy, including PV, and are implementing supportive policies to promote its adoption. Such policies typically include financial incentives, regulations, and targets. To ensure the continued success of these initiatives, it is imperative to advocate for sustained government commitment to renewable energy policies. Stakeholders should emphasize the need for comprehensive, long-term strategies, providing stability for investors and fostering continued growth in the PV industry.

Feed-in-Tariff (FIT) System: One key policy that supports the PV industry is the FIT system. Under this policy, the utility company is required to purchase all the electricity generated by a PV system at a predetermined rate that is higher than the retail electricity price [47]. This provides an economic incentive for individuals and businesses to install PV systems as they can sell excess electricity generated by their PV system to the utility company at a higher rate. To ensure the longevity and relevance of FIT systems, periodic reviews are recommended. These reviews should aim to adapt the predetermined rates to technological advancements and market dynamics, ensuring that the FIT system remains an attractive and effective driver for sustained growth in the PV sector.

Net Metering: Net metering is another policy that supports the PV industry. Under net metering, customers who generate their own electricity from PV systems can receive credits on their utility bills for any excess electricity they produce and feed back into the grid. This allows customers to offset their electricity consumption and reduce their energy bills, which incentivizes the adoption of PV systems. A recommendation in this context is to advocate for universal adoption of net metering policies. Standardized frameworks should be promoted to eliminate barriers and uncertainties, making net metering more accessible to a broader range of consumers.

Tax Incentives, Grants, and Subsidies: Other policies that support the PV industry include tax incentives, grants, and subsidies. Tax incentives such as Investment Tax Credits (ITCs) provide a tax credit to individuals and businesses that install PV systems, reducing the overall cost of the system [48]. Grants and subsidies provide financial support to individuals and businesses that install PV systems, further reducing the cost of the system. To ensure the continued success of these policies, it is essential to lobby for their continuation and expansion. Stakeholders should emphasize the societal and environmental benefits of these incentives, garnering support for sustained government investment in incentivizing PV adoption.

Renewable Portfolio Standards (RPS) and Energy Efficiency Targets: RPS and energy efficiency targets are policies that mandate the use of renewable energy sources such as PV [49]. RPS requires a certain percentage of electricity to be generated from renewable sources, while energy efficiency targets require utilities to reduce the amount of electricity they generate by improving energy efficiency. These policies create a market for renewable energy sources such as PV, driving the adoption of PV systems. Advocacy efforts should focus on the implementation and strengthening of these mandates at both regional and national levels. Stressing the pivotal role of these policies in transitioning towards a sustainable energy landscape is crucial for achieving climate goals.

14. Economic considerations

The economic considerations of the PV industry are complex and multi-faceted, encompassing factors such as costs, incentives, and market trends. When evaluating the PV industry, it is important to keep in mind the following key economic considerations:

High Cost: One of the primary economic considerations for the PV industry is the cost of PV systems [50]. While the cost of PV systems has decreased dramatically in recent years, the initial cost of installation can still be a significant barrier for some. Additionally, ongoing maintenance costs can also be a concern for system owners.

Incentives and Subsidies: In many countries, incentives and subsidies are available to encourage the adoption of PV technology. These can include tax credits, rebates, and feed-in tariffs, which pay PV system owners for the excess electricity they generate and feed back into the grid. Incentives and subsidies can make PV systems more accessible to a wider range of consumers and businesses. Policymakers should advocate for and enhance such incentive programs to facilitate wider accessibility for consumers and businesses.

Energy Market Dynamics: The energy market is constantly evolving, and shifts in supply and demand can impact the economic viability of PV systems [51]. For example, if the cost of fossil fuels rises, PV systems may become more cost-competitive. Changes in government policies and regulations can also impact the industry. Therefore, it is recommended to keep abreast of market dynamics and advocate for policies that stabilize and favor the economic viability of PV technology.

Diverse Financing Options: A range of financing options are available for PV systems, including loans, leases, and Power Purchase Agreements (PPAs). These can help to offset the initial cost of installation and make PV systems more accessible to a wider range of consumers and businesses. The availability of financing options can play a key role in the adoption of PV technology. Policymakers and financial institutions should collaborate to enhance and diversify financing mechanisms, ensuring accessibility for a broad spectrum of consumers and businesses.

Cost-Benefit Analysis: Before investing in a PV system, it is important to conduct a cost-benefit analysis that takes into account the initial cost of installation, ongoing maintenance costs, and potential energy savings over the lifespan of the system. This can help to determine whether a PV system is a financially viable option for a given situation. Encouraging stakeholders to engage in such analyses ensures informed decision-making regarding the financial viability of adopting PV technology.

15. Environmental considerations

The PV industry has significant environmental implications, both positive and negative. While PV systems generate clean and renewable energy, the production, installation, and disposal of PV panels and other components can have environmental impacts. Here are some key environmental considerations of the PV industry:

Clean and Renewable Energy Generation: PV systems generate clean and renewable energy, which reduces reliance on fossil fuels and helps to mitigate climate change. This is one of the primary environmental benefits of the PV industry. By generating electricity from the sun, PV systems can help to reduce greenhouse gas emissions and other pollutants associated with traditional electricity generation.

Production Process Mitigation Measures: The production of PV panels requires energy and resources, such as silicon, aluminum, and glass. The production process can generate greenhouse gas emissions and other pollutants, depending on the energy sources used [52]. However, the environmental impact of production can be mitigated through the use of renewable energy and efficient manufacturing processes. Advocacy efforts should focus on encouraging the widespread adoption of these measures within the industry to minimize environmental impacts.

Installation Impact and Biodiversity Concerns: The installation of PV systems can have minimal impact on the environment, especially in cases where they are installed on existing buildings or structures. However, in some cases, the installation of large-scale PV systems may require land use changes or the clearing of vegetation, which can have negative impacts on biodiversity and ecosystem services [53]. It is recommended to prioritize and advocate for PV installation practices that minimize disturbance to ecosystems. This can involve strategic site selection, reforestation initiatives, and adherence to sustainable installation practices.

End-of-Life Considerations and Responsible Disposal: The disposal of PV panels and other components at the end of their life cycle can also have environmental implications. While PV panels can last for 20-30 years or more, they will eventually need to be replaced [54]. The disposal of PV panels and other components must be managed carefully to minimize environmental impacts. Advocacy should focus on the development and promotion of responsible disposal practices, including recycling programs and the adoption of technologies that reduce the ecological footprint of decommissioned PV panels. This ensures that the positive environmental contributions of PV systems are not offset by inadequate end-of-life management.

16. Future prospects of applications of photovoltaic systems

The future prospects of applications for photovoltaic systems hold tremendous promise as the global emphasis on sustainable energy intensifies. Anticipated developments in technology, coupled with evolving policies and market dynamics, position photovoltaic systems at the forefront of the renewable energy landscape. Innovations in solar cell efficiency, energy storage solutions, and smart grid integration are expected to enhance the overall performance and reliability of photovoltaic systems. As investments in research and development continue to drive advancements, and governments worldwide increasingly prioritize clean energy initiatives, the future outlook for photovoltaic systems appears to be marked by continual growth, technological breakthroughs, and their increasingly integral role in fostering a sustainable energy future.

17. Conclusion

PV technology has come a long way since its invention in the last century. Solar energy has become a vital component of the world's energy mix, with a wide range of applications, including power generation for residential and commercial buildings, transportation, and industry. PV systems offer many advantages, such as low carbon emissions, minimal maintenance, and durability, making them an excellent alternative to conventional fossil fuel-based power generation.

As the applications of the PV system, the use of BIPV systems offers several benefits over traditional solar panels, including improved energy efficiency, reduced visual impact on building design, and streamlined installation. BIPV systems have applications in both residential and commercial buildings and contribute to the overall sustainability of buildings. Grid integration is a critical aspect of PV systems, allowing for the efficient distribution of electricity to homes and businesses, and enabling PV system owners to earn credits for excess power generated by their system. The use of PV systems to power EVs offers a clean, cost-effective, and renewable source of energy, reducing reliance on fossil fuels, and lowering greenhouse gas emissions. The development of floating solar farms offers an innovative solution to utilizing otherwise unused space on bodies of water, providing higher energy yields compared to traditional ground-mounted PV systems.

The performance of a PV system is influenced by several factors, including solar irradiance, temperature, shading, and system design and installation. Performance modeling and analysis of PV systems are crucial in assessing the efficiency, reliability, and economic viability of solar energy installations. Various software tools, numerical models, and experimental methods can be used for performance modeling and analysis. Among these, PVsyst and SAM are commonly used software tools. Field testing and performance monitoring systems are also essential for real-time performance evaluation and optimization. By accurately modeling and analyzing these factors, PV system operators can optimize system performance, minimize energy losses, and improve the overall reliability and economic viability of their installations.

There are some challenges associated with the PV industry, such as the initial investment cost and intermittency issues. Nonetheless, with advancements in technology and economies of scale, the cost of PV systems is continuously decreasing, making them more accessible to a wider range of consumers. Moreover, policy support from governments, such as feed-in tariffs, tax credits, and net metering, has also contributed to the growth of the PV industry.

PV systems have significant environmental advantages, including reducing greenhouse gas emissions, air pollution,

and dependence on non-renewable resources. These environmental benefits have led to increased public awareness and support for the PV industry, which in turn, has helped to accelerate its growth.

The application of PV systems has enormous potential to provide sustainable and affordable energy for a variety of purposes. As a result, it is essential to continue to invest in research and development to improve the efficiency and effectiveness of PV technology. With ongoing advancements in PV systems and supportive policies, the PV industry is well-positioned to become a dominant player in the global energy market and to contribute to a more sustainable future for generations to come.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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