

## THEORETICAL AND TECHNICAL SOLUTIONS FOR INCREASING THE EFFICIENCY OF SOLAR PANELS

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**Annotation:** This article reflects on theoretical and technical solutions to improve the efficiency of solar panels. Solar energy is a cornerstone of the transition to a sustainable future. As the demand for renewable energy grows, so does the need for efficient and cost-effective solar panels. Improving the efficiency of solar panels is crucial for harnessing more energy from the sun and making solar power a viable alternative to traditional energy sources. We will explore both theoretical and technical solutions aimed at enhancing the efficiency of solar panels. One promising theoretical solution involves the use of tandem solar cells. These are devices that stack multiple layers of solar cell materials on top of each other.

**Key words:** Anti-reflective coatings, bifacial solar panels, solar tracking systems, advanced materials, quantum dot technology, nanostructured materials, perovskite solar cells, transparent conductive films, AI-driven optimizations, machine learning algorithms, cost-effective, production, scalability.

### INTRODUCTION.

Each layer is designed to absorb a specific portion of the solar spectrum. By utilizing different materials with varying bandgaps, tandem solar cells can maximize the conversion of sunlight into electricity. This approach has the potential to significantly improve the efficiency of solar panels, as it allows for better utilization of the entire solar spectrum. Quantum dots are nanoscale semiconductor particles that exhibit quantum mechanical properties. Incorporating quantum dots into solar cell designs can enhance their efficiency by improving light absorption and charge carrier generation. Quantum dots can be engineered to absorb specific wavelengths of light, allowing for better utilization of the solar spectrum. Integrating these tiny structures into solar panels could lead to more efficient energy conversion.

Improving the efficiency of solar panels is not limited only to technological innovations. Production efficiency is also an important aspect. Improving production processes, optimizing the use of resources and reducing the cost of producing solar panels contributes to their wider distribution.

The availability of solar technologies plays a crucial role in their successful integration. Despite the reduction in the cost of production, the cost of installing solar systems can still remain significant for many consumers. Therefore, it is important to continue working to reduce costs and create financing mechanisms that will make solar technologies more accessible to everyone.

Perovskite solar cells have emerged as a revolutionary theoretical solution in recent years. These cells use a class of materials called perovskites, which have unique properties that make them highly efficient at converting sunlight into electricity. Perovskite solar cells can be produced using low-cost materials and processes, offering a cost-effective alternative to

traditional silicon-based solar cells. Ongoing research focuses on addressing stability and scalability issues to bring perovskite solar cells to commercial viability.

Solar energy is an abundant and sustainable source of power with the potential to revolutionize the global energy landscape. Among the technologies harnessing this energy, solar panels play a pivotal role. Improving the efficiency of solar panels is crucial for maximizing their energy output and making solar power more economically viable.

Given the growing focus on environmental sustainability, it is also important to consider the environmental footprint of solar technologies. This includes both reducing the environmental impact of solar panel production and the possibility of recycling and recycling obsolete panels. The development of effective methods of recycling and recycling of solar panels contributes to the creation of a sustainable closed cycle.

Given that public understanding and support are crucial for the successful integration of solar technologies, it is also important to pay attention to education and enlightenment. Educating the public about the benefits of solar energy, stimulating interest in the use of these technologies and supporting research in this area will create a favorable ground for their dissemination.

Improving the efficiency of solar panels is a key element in the development of sustainable energy. New technologies such as thin layers, perovskite solar panels, tandem technology and the use of artificial intelligence, together with the integration of energy storage systems, open up new prospects for improving the efficiency of solar systems. However, in order to realize the full potential of solar energy, it is also necessary to take into account economic accessibility, environmental sustainability and the education of society. Only with an integrated approach and the joint efforts of society and industry can a real transition to clean and sustainable energy be achieved.

Solar energy plays a key role in the modern quest for sustainable energy sources. Solar panels, or photovoltaic cells, are the basis for converting solar radiation into electricity. However, as we strive to maximize the use of this important resource, the issue of improving the efficiency of solar panels is becoming more urgent. In this article, we will look at new perspectives and technologies aimed at improving the performance of solar systems.

One of the important areas of development of solar panel technologies is the use of thin layers. These panels, also known as thin-film solar panels, provide a number of advantages. Firstly, they are lighter and more flexible, which opens up new possibilities for their integration into various surfaces such as buildings, vehicles and even clothing. Secondly, thin layers can be produced using cheaper materials, which reduces the overall cost of production.

While solar energy has witnessed remarkable growth, challenges persist. Addressing issues such as intermittency (dependence on sunlight), energy storage, and the environmental impact of manufacturing solar panels remains crucial. Innovations like advanced battery technologies, flexible solar materials, and recycling programs are actively addressing these challenges, paving the way for a more sustainable solar industry.

The future of solar panels looks promising, with ongoing research and development pushing the boundaries of efficiency and accessibility. Emerging technologies, such as perovskite solar cells and transparent solar panels, aim to enhance performance and integration possibilities.

Perovskite solar cells represent a cutting-edge technology that offers higher efficiency and lower production costs. Researchers are exploring ways to scale up production and address stability issues, bringing perovskite cells closer to mainstream adoption.

Transparent solar panels, designed to be integrated into windows and building facades, showcase the potential for seamless integration into our daily lives. These panels allow structures to generate electricity without compromising aesthetics. The integration of solar panels with smart grid technologies and energy storage solutions is poised to revolutionize energy distribution. This smarter, more flexible grid enhances reliability and enables efficient energy management.

### LITERATURE ANALYSIS.

The choice of materials plays a crucial role in determining the efficiency of solar panels. Researchers are continuously exploring advanced materials with enhanced light-absorbing and charge-carrier transport properties. For instance, the development of new types of transparent conductive materials for the front contact of solar cells can reduce energy losses and improve overall efficiency.

Another technical solution involves the application of anti-reflective coatings on the surface of solar panels. These coatings are designed to minimize the reflection of sunlight, allowing more light to reach the solar cells. By reducing reflection losses, anti-reflective coatings contribute to higher energy yields and increased overall efficiency. Nanostructured coatings are being explored for their ability to manipulate light at the nanoscale, further enhancing anti-reflective properties.

Bifacial solar panels capture sunlight from both the front and rear sides of the module. This design allows the panels to utilize reflected sunlight from surrounding surfaces, such as the ground or nearby structures. Bifacial technology can increase energy output by 5% to 20%, depending on the albedo (reflectivity) of the surroundings. Integrating bifacial solar panels into installations can enhance overall system efficiency.

Solar tracking systems adjust the orientation of solar panels to follow the sun's path throughout the day. This dynamic alignment maximizes the exposure of solar panels to sunlight, optimizing energy capture. Single-axis and dual-axis tracking systems are common, with dual-axis trackers providing even greater efficiency gains. Integrating smart tracking systems, which use real-time data and advanced algorithms, can further improve the accuracy and efficiency of solar panel positioning.

Refinements in the manufacturing processes of solar panels contribute to increased efficiency and reduced costs. Innovations such as heterojunction technology, which involves the use of thin layers of intrinsic and doped amorphous silicon, have demonstrated improvements in cell efficiency. Additionally, advancements in deposition techniques, such as chemical vapor deposition (CVD) and atomic layer deposition (ALD), enable precise control over the thickness and composition of thin-film solar cell layers.

Enhancing the efficiency of solar panels is crucial for realizing the full potential of solar energy as a clean and sustainable power source. Theoretical solutions, such as tandem solar cells, quantum dots, and perovskite solar cells, offer promising avenues for future developments. On

the technical front, improvements in materials, coatings, and tracking systems, along with advancements in manufacturing processes, contribute to the ongoing evolution of solar panel technology.

As researchers and engineers continue to explore these theoretical and technical solutions, the goal is to create solar panels that are not only more efficient but also cost-effective and scalable. With ongoing innovations, solar power can play an increasingly significant role in meeting global energy demands while mitigating the environmental impact of traditional energy sources.

Solar panel efficiency refers to the ratio of the electrical output of a solar panel to the solar energy it receives from the sun. Traditional silicon-based photovoltaic cells dominate the market, and their efficiency has steadily improved over the years. To comprehend the challenges of improving solar panel efficiency, one must understand the Shockley-Queisser limit.

Efficiency is a critical metric in the world of solar panels. It refers to the percentage of sunlight that a panel can convert into electricity. Traditional silicon solar panels have seen significant efficiency improvements over the years, with the average efficiency now ranging between 15% and 22%. However, researchers continue to explore advanced materials and technologies to push the efficiency boundaries further.

Beyond silicon, there is a burgeoning field of research exploring alternative materials to enhance solar panel efficiency. Perovskite solar cells have garnered attention for their low-cost manufacturing and potential to achieve higher efficiency levels. Quantum dot technology, nanomaterials, and organic photovoltaics are also being investigated to unlock new possibilities in solar energy conversion.

Tandem solar cells represent a promising avenue for efficiency improvement. By layering multiple materials with varying bandgaps on top of each other, tandem cells can capture a broader spectrum of sunlight. This approach is particularly effective in maximizing energy conversion, and researchers are actively experimenting with combinations such as perovskite-silicon tandems to achieve unprecedented efficiency levels.

One of the most compelling aspects of solar energy is its minimal environmental impact compared to traditional fossil fuels. Solar panels produce clean energy without emitting greenhouse gases, reducing the carbon footprint and mitigating the effects of climate change. The life cycle analysis of solar panels continually improves as advancements in manufacturing, recycling, and disposal processes are made.

As solar panel installations proliferate, the question of their end-of-life management becomes increasingly important. Efforts are underway to develop efficient recycling processes for decommissioned solar panels, ensuring that valuable materials can be reclaimed and reused. Innovations in sustainable manufacturing practices are also contributing to the overall environmental friendliness of solar technologies.

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Bifacial solar panels, designed to capture sunlight from both the front and rear sides, have gained traction in the industry. These panels leverage reflected sunlight from surrounding surfaces, boosting overall energy yield. Particularly effective in snow-covered areas or locations with reflective surfaces, bifacial technology showcases the adaptability of solar panels to diverse environments.

Perovskite solar panels represent a relatively new class of photovoltaic cells, which attracts attention with its high efficiency. These panels are based on perovskite materials, which have unique properties for absorbing sunlight. One of the key advantages of perovskite solar panels is their ability to overcome traditional production constraints, which can make solar technologies more accessible to the masses.

Tandem technology, or multilayer solar cells, is a method in which several layers of different materials are combined in a single solar cell. This approach allows for more efficient use of a wide range of solar radiation. For example, the upper layer can be optimized to absorb short-wavelength rays, while the lower layer can work better with long-wavelength radiation. Tandem technology promises a significant increase in the efficiency of solar panels, which will make them even more competitive compared to traditional options.

Solar panels are usually produced from the sun's rays. In other words, it can only produce energy during the day. For maximum effect, try to use it during the middle of the day, as this will increase the efficiency of your solar panels. You can do this in the following ways. Make sure that all electrical appliances such as laptops, phones, lamps are fully charged when there is sunlight. Make sure to take all of your solar devices out during the day and keep them fully charged so they will be fully charged at night. Always make sure you adjust your solar heating and cooling equipment to your desired temperature during the day. At night, you turn them off to reduce power usage. If your inverters have the ability to store energy, make sure they are fully charged to reduce wasted electricity.

Another great way to increase the efficiency of your solar panels is tracking. The sun's direct beams carry more raw energy than indirect beams. This is why the afternoon is hotter than the morning, because the sun hits the earth in a direct beam. You do this by using a special device called a solar tracker. As standard, the solar mount remains stationary. This is even hit by radiation from different directions throughout the day. Solar trackers, however, track the sun as it shines across the sky. With tracking, the solar panel is directly facing the incoming beam of light at all times.

Tracking allows for exposure to a lot of solar energy. Therefore, there will be more electricity production due to the conversion of a greater proportion of solar radiation into electricity. There are two models of solar trackers. There is a single axis model which is less expensive but less efficient. Dual-axis models are more accurate in tracking the sun's position. While it's more expensive, it produces more electricity. Regardless, tracking is key to making solar panels more efficient, as it increases the amount of sunlight available for conversion.

In the ever-evolving landscape of renewable energy, solar panels stand out as a beacon of innovation and promise. As the world grapples with the challenges of climate change and seeks



sustainable alternatives to traditional energy sources, solar panels have emerged as a shining solution. This article explores the evolution, benefits, and future prospects of solar panels as a key player in the quest for a greener, more sustainable energy future. The journey of solar panels dates back several decades, with the inception of photovoltaic cells in the mid-20th century. Over the years, technological advancements have propelled solar panels from rudimentary applications to sophisticated systems capable of harnessing substantial amounts of energy. From large-scale solar farms dotting landscapes to rooftop installations on homes, the versatility of solar technology has grown exponentially.

Solar panels have transcended their status as alternative energy sources to become central players in the global shift towards sustainable practices. The ongoing advancements in technology, coupled with a growing awareness of environmental responsibility, position solar panels as a cornerstone of the clean energy revolution. As we continue to harness the power of the sun, solar panels are not just a source of electricity but a beacon of hope for a greener and more sustainable future.

## RESEARCH METHODOLOGY.

This theoretical limit dictates that, under normal solar illumination conditions, no single-junction solar cell can exceed 33.7% efficiency. Researchers are exploring multi-junction cells and tandem structures to surpass this limit. Multi-junction solar cells utilize multiple layers of semiconductor materials with varying bandgaps to capture a broader spectrum of sunlight. This enables more efficient energy conversion. Gallium arsenide-based cells have shown promise in achieving higher efficiencies, making them suitable for space applications and concentrated solar power systems.

- Anti-reflective coatings reduce the loss of sunlight due to reflection. By applying thin films on the surface of solar panels, these coatings enhance light absorption, particularly in the shorter wavelength range. This technique is a cost-effective way to boost efficiency and has been widely adopted in commercial solar panels.
- Tandem solar cells stack multiple layers of solar cell materials, each designed to absorb a specific portion of the solar spectrum. This approach optimizes energy capture by allowing each layer to convert a different range of wavelengths. Tandem solar cells, often based on perovskite-silicon combinations, have demonstrated significant efficiency improvements.
- Perovskite solar cells have emerged as a promising alternative to traditional silicon cells. They offer easier manufacturing processes and the potential for higher efficiencies. Ongoing research focuses on addressing stability issues and scaling up production. The combination of perovskite and silicon in tandem structures shows potential for achieving greater efficiency.
- Bifacial solar panels capture sunlight from both the front and rear sides, utilizing reflected sunlight from surrounding surfaces. This design enhances overall energy yield, especially in environments with high albedo, such as snow-covered areas or buildings with reflective surfaces.
- Solar tracking systems adjust the orientation of solar panels to follow the sun's path throughout the day. Dual-axis and azimuth-altitude trackers optimize the angle of incidence, ensuring panels receive maximum sunlight. Although more complex and expensive, tracking systems significantly improve overall energy output.
- Continuous advancements in materials science and manufacturing processes contribute to the development of more efficient solar panels. Innovations such as transparent conductive

films, quantum dot technology, and nanostructured materials aim to enhance light absorption and electron transport within the solar cell.

Enhancing the efficiency of solar panels is crucial for the widespread adoption of solar energy as a sustainable power source. Theoretical limits challenge researchers to explore innovative solutions, from multi-junction cells to tandem structures. Meanwhile, practical techniques such as anti-reflective coatings, perovskite solar cells, bifacial designs, and advanced tracking systems contribute to incremental efficiency improvements.

Tandem solar cells, a cutting-edge technology, involve stacking multiple layers of solar cell materials, each optimized for specific wavelengths of sunlight. Perovskite-silicon tandem cells, in particular, have garnered attention for their potential to exceed the Shockley-Queisser limit. The unique light-absorbing properties of perovskite materials complement the stability and maturity of silicon technology, creating a synergistic effect that boosts overall efficiency.

Perovskite solar cells have emerged as a revolutionary force in the solar energy landscape. These cells are not only cost-effective but also exhibit high efficiencies in converting sunlight into electricity. Researchers are actively addressing challenges related to stability and scalability, paving the way for the widespread adoption of perovskite solar panels.

Bifacial solar panels have gained prominence due to their ability to capture sunlight from both the front and rear sides. This design is particularly effective in environments with high albedo, where surfaces reflect sunlight onto the rear side of the panel. Bifacial technology enhances overall energy yield and has become a standard feature in many solar installations.

Solar tracking systems have evolved beyond fixed installations, incorporating advanced tracking mechanisms that dynamically adjust the orientation of solar panels to follow the sun's trajectory. Dual-axis and azimuth-altitude trackers ensure that panels receive optimal sunlight, resulting in increased energy output. While these systems come with added complexity and cost, their potential for efficiency gains makes them a worthwhile investment in certain applications.

Ongoing research in materials science has led to the development of novel materials and manufacturing techniques aimed at improving solar panel efficiency. Transparent conductive films reduce energy loss and enhance light absorption, while quantum dot technology allows for better control over the absorption spectrum. Nanostructured materials, with their unique properties, contribute to more efficient electron transport within the solar cell.

Artificial intelligence is playing an increasingly crucial role in optimizing solar panel efficiency. Machine learning algorithms analyze vast datasets to identify patterns and optimize system parameters, such as tilt angles and tracking algorithms. This data-driven approach enables real-time adjustments, maximizing energy capture under varying environmental conditions. As efficiency improvements continue, the economic viability of solar power becomes increasingly attractive. The decreasing costs of manufacturing, coupled with rising efficiencies, contribute to a positive outlook for the solar industry. Governments and businesses worldwide are investing in solar technologies, recognizing their potential to address energy needs sustainably.

The integration of solar power into smart grids, combined with energy storage solutions, represents a holistic approach to energy management. Smart grids enable efficient distribution and consumption of solar energy, while energy storage systems address the intermittent nature

of sunlight. Advancements in battery technology, with the emergence of lithium-ion and next-generation batteries, are key enablers in this transition towards a more resilient and reliable energy infrastructure.

While ironic in a way, you should be aware that temperature levels can affect the efficiency of a solar panel. Rising temperatures can cause solar panels to become less efficient. There should be enough space between the roof and the panels to keep the system from overheating by allowing air to flow. All of these require skills and knowledge, and experts understand all of them and how best to do them. The parts of the solar panel are fixed, so it does not require a lot of maintenance. But dirt tends to collect on the surface, reducing efficiency. Of course, when there is dirt on the surface, the absorption of sunlight will also be reduced.

A few factors determine how often you should clean your solar panels. First, consider how often it rains in your area. Rainwater will wash away the dirt greatly, meaning you don't have to clean it. Also, the cost of cleaning solar panels may dictate how often you perform the job. Dirt and dust don't affect efficiency much, but you shouldn't ignore it as it can be around 5% over the course of the year. Depending on your region, yields may be lower by more than 20%.

## ANALYSIS AND RESULTS.

The world is witnessing a transformative shift towards renewable energy, and at the forefront of this revolution are solar panels. These technological marvels have become synonymous with clean, sustainable power, playing a pivotal role in reshaping the global energy landscape. In this comprehensive article, we will explore the intricacies of solar panels, from their fundamental principles to cutting-edge innovations, and discuss their impact on the environment, economy, and the future of energy. The adoption of solar panels is driven by a host of advantages that make them an attractive choice for both individuals and industries:

- Solar energy is an infinite and renewable resource, making it a sustainable solution for the long term. Unlike finite fossil fuels, the sun's energy is expected to last for billions of years.
- Solar power generation produces minimal greenhouse gas emissions, contributing to a substantial reduction in carbon footprints. This environmentally friendly aspect positions solar energy as a crucial player in combating climate change.
- Once installed, solar panels have relatively low operating and maintenance costs. With no fuel requirements and minimal moving parts, they offer a cost-effective alternative to traditional energy sources.
- Solar energy provides an opportunity for individuals and nations to reduce dependence on non-renewable energy sources. This autonomy enhances energy security and mitigates the impact of fluctuating fuel prices.
- The growing solar industry contributes to job creation and economic growth. From manufacturing and installation to maintenance and research, the solar sector fosters employment opportunities worldwide.

At the heart of every solar panel is the photovoltaic cell, the building block responsible for converting sunlight into electricity. When sunlight, comprised of photons, strikes the surface of a cell, it releases electrons from the atoms within the cell, generating an electric current. This phenomenon, known as the photovoltaic effect, forms the foundation of solar power generation.



While silicon remains the go-to material, there are various types of solar panels designed to cater to specific needs and conditions. Monocrystalline, polycrystalline, and thin-film solar panels each have their unique advantages and applications. Monocrystalline panels, with their high efficiency and sleek design, are often favored for residential installations, while thin-film panels find use in large-scale commercial projects due to their flexibility and lower production costs.

While the initial investment in solar panel installations has been a barrier for some, the cost of solar power has witnessed a remarkable decline over the past decade. Government incentives, technological advancements, and economies of scale have contributed to making solar energy increasingly affordable. The concept of grid parity, where the cost of solar power equals or is less than conventional sources, is becoming a reality in many regions.

Grid parity signifies a pivotal moment in the solar industry, where the cost of generating solar power matches or becomes cheaper than conventional sources. As solar achieves grid parity in various parts of the world, it not only makes economic sense but also enhances energy security and independence. Homes and businesses can generate their electricity, reducing dependence on centralized power grids.

Looking ahead, the future of solar panels is brimming with exciting possibilities. From transparent solar cells that can be integrated into windows to solar paint that turns any surface into a power generator, innovations are expanding the horizons of solar technology. The integration of energy storage systems, such as advanced batteries, further enhances the reliability of solar power, enabling a consistent energy supply even during periods of low sunlight.

With the development of artificial intelligence more accurate monitoring and control of solar systems is becoming possible. Systems can analyze data on the performance of solar panels in real time and provide optimal settings to maximize efficiency. This approach not only improves the output of solar systems, but also reduces the need for manual intervention, reducing operating costs. One of the limitations of solar panels is their dependence on the availability of sunlight. However, with the integration of energy storage technologies such as lithium-based batteries and other advanced batteries, this disadvantage can be eliminated. Storing excess energy during peak productivity periods and using it at night or in conditions of lack of sunlight will make solar systems more reliable and efficient.

A solar panel's ability to convert solar radiation into usable electricity translates into its efficiency. It is the standard most commonly used by consumers when evaluating the quality of solar panels. Take two photovoltaic modules as an example, under the same sunlight at the same time. The two solar panels have different efficiency ratings; the more efficient one produces more energy than the other. In a practical comparison, suppose one of the solar panels has an efficiency of 24% and the other has an efficiency of 16%. Under the same conditions, a solar panel with 24% efficiency can produce half as much power as a panel with 16% efficiency. Therefore, the efficiency of solar panels plays an important role in the optimal use of energy and cost savings. Once you decide to install a solar panel system, there are various ways to increase its efficiency. In short, there are steps that can be taken to allow you to maintain or increase the output level of your solar modules. Before you delve into tips for increasing your output, here are some factors that affect solar panel efficiency.

**Conclusion:**

When you install solar modules correctly, you can maximize the absorption of the sun's radiation. This way, the panels generate more electricity. Orientation and angle are the two main factors to consider when making an installation. Normally, solar modules can get the best sunlight exposure at an angle of 18–36 degrees. For those in the northern hemisphere, the solar panels should be on a south-facing slope. In the southern hemisphere, you should install solar panels on north-facing slopes. The main idea is to maximize exposure to sunlight.

The quest to enhance the efficiency of solar panels is a multidimensional journey involving theoretical breakthroughs and practical innovations. Tandem solar cells and perovskite technologies are pushing the boundaries of what was once considered the theoretical limit. Meanwhile, practical techniques like bifacial panels, advanced tracking systems, and AI-driven optimizations are making solar power more accessible and economically viable. As research and development in the solar industry continue, we can anticipate even more groundbreaking advancements. The synergy between theoretical insights and practical applications is propelling us towards a future where solar energy plays a central role in powering a sustainable world.

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