



SCIENTIFIC ANALYSIS AND FUTURE POSSIBILITIES OF SOLAR PANELS

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Abstract: This article presents a scientific analysis of the working principles, energy efficiency, and future development prospects of solar panels. The physical foundations of the photovoltaic phenomenon, different types of solar panels, and their environmental and economic advantages are discussed. In addition, the efficiency of solar panels under the climatic conditions of Uzbekistan was studied using the examples of Tashkent, Samarkand, and Navoi regions, while the effects of temperature and solar radiation were analyzed. The article also examines the prospects of perovskite and tandem technologies, energy storage systems, and intelligent monitoring systems based on artificial intelligence.

Keywords: solar panels, solar energy, efficiency, renewable energy, photovoltaic phenomenon, lithium-ion and sodium-ion batteries, silicon panels, solar radiation, artificial intelligence, carbon dioxide.

Introduction. Solar radiation is one of the most abundant and sustainable renewable energy resources, and the application of artificial intelligence (AI) technologies can significantly improve its efficient utilization. Solar energy is widely recognized as a promising alternative energy source that is expected to play a crucial role in the future global energy system. According to international energy projections, global carbon dioxide (CO₂) emissions are expected to decrease by approximately 75% by 2050 as a result of improved energy efficiency, the widespread adoption of renewable energy technologies, and the transition toward low-carbon energy systems. Among renewable energy technologies, photovoltaic (PV) systems have become an essential solution for addressing the growing global energy demand. Solar panels are environmentally friendly, produce no greenhouse gas emissions during operation, and offer high energy conversion efficiency, making them a key component of sustainable energy development [1, 3, 4].

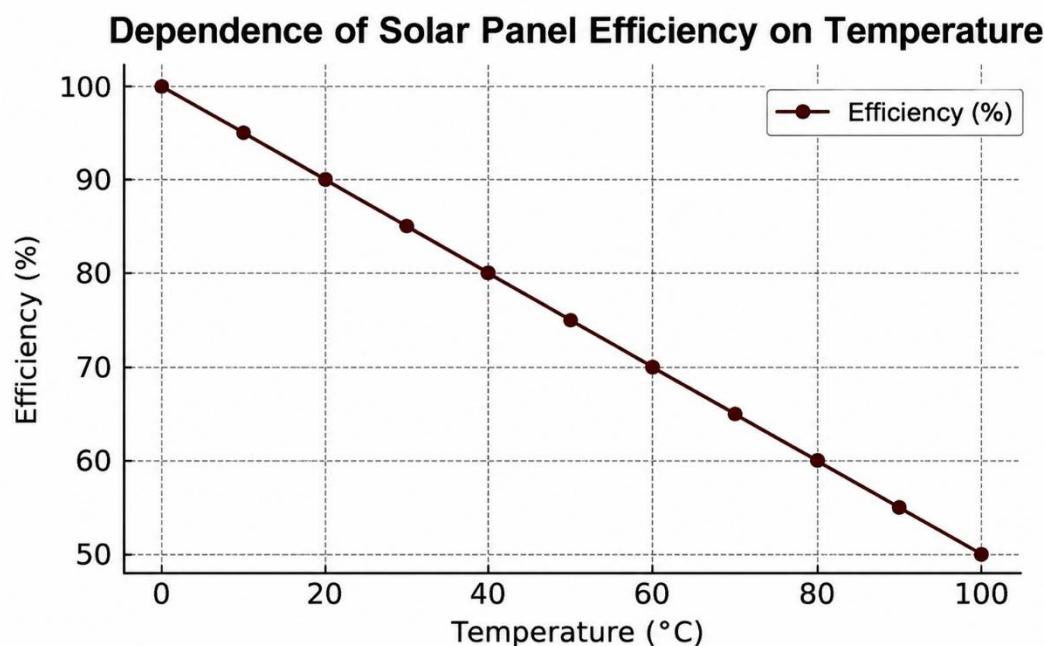


Figure 1. Effect of temperature on solar panel efficiency.

In the conditions of Uzbekistan, an assessment of the efficiency of solar panels was conducted, and the following key findings were obtained:

- **Impact of weather and environmental conditions:** Uzbekistan's climate is highly favorable for solar energy systems. However, in urban areas with elevated levels of air pollution, atmospheric contaminants slightly reduce the efficiency of photovoltaic (PV) panels.

- **Regional differences:** The highest level of solar panel efficiency was observed in the Navoi region, where solar radiation intensity is particularly high. This finding highlights the significant potential for the large-scale deployment of photovoltaic systems in this region.

- **Effect of temperature:** Solar panel efficiency reaches its optimum within the temperature range of **25°C to 45°C**. At temperatures below **25°C**, the amount of generated electrical energy decreases, while temperatures above **45°C** also lead to a reduction in energy conversion efficiency. Therefore, integrating cooling systems with photovoltaic panels can be an effective approach to maintaining optimal performance under high-temperature conditions.

- **Role of advanced technologies:** Perovskite and tandem solar panels demonstrated higher conversion efficiencies than conventional crystalline silicon panels. Their adoption under the climatic conditions of Uzbekistan could significantly improve the overall performance and energy efficiency of photovoltaic systems.

- **Optimization of panel tilt angle:** Proper optimization of the solar panel tilt angle can increase energy conversion efficiency by approximately **5–7%**.

Overall, the results indicate that **solar energy has substantial development potential in Uzbekistan**. Continued technological innovation, together with strategic investments in advanced photovoltaic technologies and system optimization, can further enhance the efficiency and sustainability of the country's solar energy sector.

Analysis and practical recommendations. Under the climatic conditions of Uzbekistan, a one-week experimental study and performance analysis were conducted in the major photovoltaic installation regions of **Tashkent, Samarkand, and Navoi**. During the monitoring period, key parameters, including **solar irradiance, ambient temperature, and photovoltaic**

energy conversion efficiency, were continuously measured and analyzed. The following instruments were used to collect the experimental data:

- **Solar Meter** – used to measure solar irradiance.
- **Digital Multimeter** – used to determine the electrical output power of the photovoltaic system.
- **Data Logger** – used for continuous recording of temperature and solar irradiance throughout the experimental period.

This experimental approach enabled a comprehensive assessment of the performance of photovoltaic systems under different climatic conditions and provided practical insights into the factors affecting solar energy efficiency in Uzbekistan.

The obtained experimental results were calculated and theoretically analyzed using physical models of the photovoltaic effect. Furthermore, the findings were compared with current global trends in photovoltaic technology and solar energy utilization.

The efficiency of the photovoltaic system was calculated using the following equation:

$$\eta = (P_{\text{out}} / P_{\text{in}}) \times 100\%$$

where:

- P_{out} is the output electrical power generated by the photovoltaic system;
- P_{in} is the incident solar power, determined based on the average solar irradiance in Uzbekistan, which is approximately **1000 W/m²** under standard test conditions (STC).

The average performance indicators of photovoltaic panels in **2024** are summarized as follows:

- **Tashkent**: average efficiency – **18%**, maximum output power – **240 W/m²**.
- **Samarkand**: average efficiency – **20%**, maximum output power – **260 W/m²**.
- **Navoi**: average efficiency – **22%**, maximum output power – **280 W/m²**.

The results indicate that the **Navoi region** demonstrated the highest photovoltaic performance due to its greater solar irradiance and favorable climatic conditions, whereas **Tashkent** exhibited comparatively lower efficiency, primarily because of higher atmospheric pollution and less favorable environmental conditions. These findings confirm the significant influence of regional climatic factors on the performance of photovoltaic systems in Uzbekistan.

Technological developments and future perspectives. In recent years, significant progress has been achieved in the field of solar energy technologies. Modern photovoltaic (PV) panels are characterized not only by higher energy conversion efficiency but also by reduced manufacturing costs. Considerable research efforts have been devoted to the development of advanced photovoltaic technologies aimed at improving the conversion efficiency of solar radiation into electrical energy.

Current studies on crystalline silicon photovoltaic panels primarily focus on enhancing their conversion efficiency through material and structural optimization. At the same time, next-generation photovoltaic technologies based on emerging materials, such as **perovskites**, have attracted considerable attention due to their lower production costs, lightweight structure, and mechanical flexibility. These characteristics enable their installation not only on building rooftops but also on building facades and even on various transportation vehicles.

Efficient energy storage is another key factor in maximizing the utilization of solar energy. **Lithium-ion** and **sodium-ion batteries** provide effective solutions for storing surplus electrical energy generated by photovoltaic systems for later use. Furthermore, **hydrogen-based energy storage technologies** are increasingly recognized as a promising approach for

long-term energy storage and grid stabilization, supporting the large-scale integration of renewable energy sources [2, 5].

The integration of photovoltaic technologies into various sectors is also expanding rapidly. Within the framework of **smart city** initiatives, solar energy is being incorporated into transportation infrastructure, including solar roads, electric vehicles, and even aircraft. These developments are expected to accelerate the widespread adoption of renewable energy technologies and promote the transition toward a more sustainable and low-carbon energy future [5].

Future perspectives. **As solar energy technologies continue to evolve, several promising research and development directions are expected to shape the future of the photovoltaic industry:**

1. Nanostructured photovoltaic panels – Solar panels based on nanomaterials and nanotechnology have the potential to significantly improve energy conversion efficiency by enhancing light absorption and reducing energy losses.

2. Integration of artificial intelligence (ai) and the internet of things (IoT) – Intelligent monitoring and control systems powered by AI and IoT technologies enable real-time optimization of photovoltaic energy generation, performance prediction, fault detection, and energy management, thereby improving the overall efficiency and reliability of solar power systems.

Currently, physical simulation software is widely used to model photovoltaic system performance under various operating conditions. In addition, automated control strategies are increasingly being implemented to optimize energy production and enhance the operational efficiency of solar energy systems [5].

Conclusion. Solar energy is one of the cleanest and most sustainable renewable energy resources available today. Continuous technological advancements have significantly improved the efficiency and reliability of photovoltaic systems, making solar power an increasingly attractive alternative to conventional energy sources. The widespread adoption of solar energy can substantially reduce the dependence of households, industries, and public institutions on fossil fuels while enhancing national energy security. Moreover, solar energy contributes to environmental sustainability by reducing greenhouse gas emissions and minimizing the adverse environmental impacts associated with traditional energy production. Consequently, the further development and large-scale deployment of photovoltaic technologies will play a crucial role in achieving global climate goals and supporting the transition toward a sustainable, low-carbon energy future.

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