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# IMPACT OF ENVIRONMENTAL CONDITIONS ON THE EFFICIENCY OF PHOTOVOLTAIC PANELS

*The development of photovoltaics is one of the key elements of the energetic transition in Poland. The use of renewable energy sources enables the fulfillment of global energy needs to be met in sustainable way. The efficiency of photovoltaic panels is strongly influenced by environmental factors such as sunlight, ambient temperature, air pollution, precipitation, and humidity. This article discusses the impact of environmental factors on the energy production efficiency by photovoltaic panels, with particular emphasis on the effect of temperature, based on the example of the annual energy production cycle in a photovoltaic farm.*

**Keywords:** environmental factors, photovoltaic panels, photovoltaic farm, energy production, renewable energy sources (RES), Poland

## WPŁYW CZYNNIKÓW ŚRODOWISKOWYCH NA WYDAJNOŚĆ PANELI FOTOWOLTAICZNYCH

**Abstrakt:** *Rozwój fotowoltaiki stanowi jeden z kluczowych elementów transformacji energetycznej w Polsce. Zastosowanie odnawialnych źródeł energii pozwala na zaspokojenie globalnych potrzeb energetycznych w zrównoważony sposób. Wydajność paneli fotowoltaicznych jest silnie uzależniona od czynników środowiskowych, takich jak nasłonecznienie, temperatura otoczenia, zanieczyszczenie powietrza, opady atmosferyczne oraz wilgotność. Artykuł omawia wpływ czynników środowiskowych na wydajność produkcji energii przez panele fotowoltaiczne, ze szczególnym uwzględnieniem temperatury na przykładzie rocznego cyklu produkcji energii w farmie fotowoltaicznej.*

**Słowa kluczowe:** czynniki środowiskowe, panele fotowoltaiczne, farma fotowoltaiczna, produkcja energii, odnawialne źródła energii (OZE), Polska

## I. INTRODUCTION

Climate change and its negative effects continue to advance. In the context of Poland's average temperatures, 2023 was an extremely warm year. The average air temperature was 10°C and was 1.3 degrees higher than the long-term annual average for 1991-2022. [Klimat Polski 2023]. With the intensification of climate change, there is an urgent need to switch to

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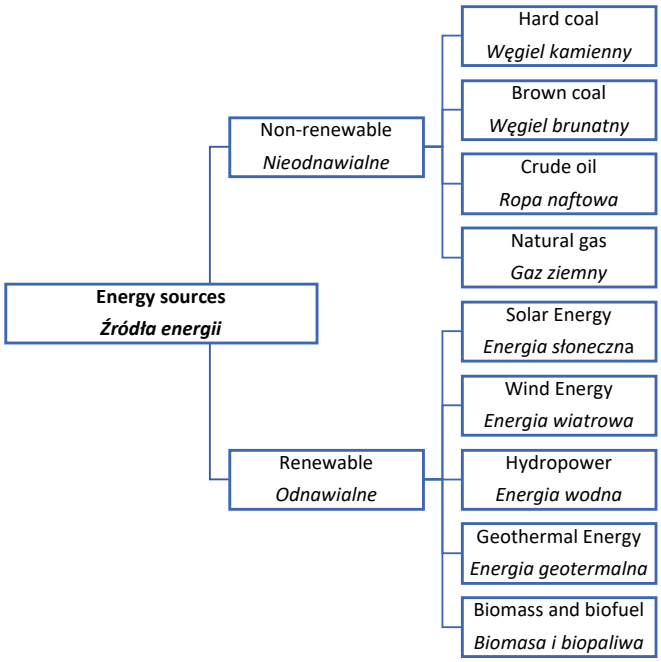
sustainable energy systems. Renewable energy sources (RES), such as solar, wind, hydro, geothermal, and biomass energy, offer a viable alternative to traditional, high-emission, non-renewable energy sources like coal, oil, and natural gas (Fig. 1) [Urbańczyk et al. 2020, Dyndał et al. 2021, Tora et al. 2022]. One of the most important advantages of renewable energy sources is the use of natural forces, which do not run out and do not burden the environment to the same extent as fossil fuels. Advancement in technology enables increasingly cheaper and centralized energy production, which makes it easier and more effective to meet people's growing demand, e.g. for electricity [Tomaszewski and Sekściński 2020].

In recent years, photovoltaic technologies have gained significant popularity as an environmentally friendly and cost-effective method of renewable energy production. Currently, around 60% of the installed capacity in Poland's renewable energy sector comes from photovoltaic systems. By the end of 2023, these systems had reached a total installed capacity of 17.08 GW and were based on micro-installations. At the end of October 2024, this figure had risen to 20.5 GW. An increase in the use of small installations and photovoltaic farms with a capacity above 1 MW was also observed. At that time, the use of the above-mentioned solutions allowed Poland to take fourth place among the European Union countries in terms of the growth rate of new installed capacity. This also resulted in a promotion to sixth place in terms of cumulative installed capacity [Raport ... 2024].




source: own study / *źródło: opracowanie własne*

**Fig. 1.**Types of Energy sources
***Rys. 1.*** *Rodzaje źródeł energii*

The parameter that determines the efficiency of photovoltaic panels is their energy efficiency, i.e. the amount of energy produced by the installation in specific conditions and time. One of the most important and basic environmental factors influencing the operation of

photovoltaic panels is the intensity of solar radiation reaching the Earth's surface at a given time. Panel efficiency improves with greater sunlight availability and is influenced by the climate zone, seasons, and local weather conditions. Temperature plays also a significant role in the operation of photovoltaic panels. It may seem that on a sunny, hot day, the energy production in the installation is the highest. Meanwhile, the higher the ambient temperature, the lower the efficiency of converting energy into electricity. This means that in the mentioned conditions the panels overheat and their efficiency decreases [Figura and Zientarski 2016].

Pollution is another environmental factor that impacts the efficiency of photovoltaic panels. Dust, leaves, bird droppings, and thick snow layers accumulating on the panels can create shading, reducing sunlight exposure and energy production. Regular cleaning and the application of protective coatings are crucial, especially in areas like urban agglomerations and industrial zones, where pollutant levels are higher. Precipitation can be an environmental factor that increases the efficiency of panels by cleaning the surface. On the other hand, too long-term exposure to humidity may accelerate corrosion of electrical components and mechanical damage. Additionally, strong winds and hail pose a risk of causing physical damage to the panels.

## II. MATERIAL AND RESEARCH METHODS

For the purpose of this study, data on electricity production from a 1 MW photovoltaic installation located in the Lubuskie Voivodeship were analyzed. The facility was monitored daily throughout 2023.

The tested photovoltaic farm consisted of the following components: photovoltaic panels mounted on steel structures, inverters, a transformer station with transmission lines, monitoring, control and security systems.

The analysis focused on the efficiency of energy production at the farm and the environmental factors that might influence the performance of the photovoltaic panels, with particular attention to temperature. Monthly average electricity production and standard deviation (SD) were calculated.

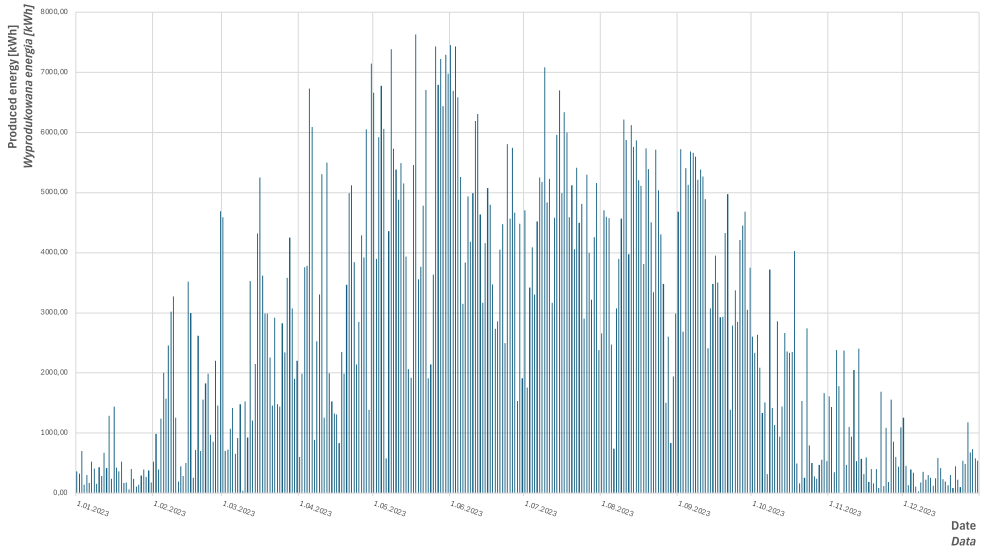
## III. RESULTS AND DISCUSSION

In 2023, the photovoltaic farm generated a total of 1,000,967.60 kWh of energy, which gives a daily average production of 2,742.38 kWh. This amount of energy is sufficient to meet the annual electricity needs of approximately 200 to 400 single-family households, depending on their average yearly consumption. The collected data is illustrated in Fig. 2.

Chart 2 reveals a clear seasonal variation in energy production. The output was significantly higher during the summer months (June, July, August) and notably lower in the winter months (January, December). This result was influenced by the length of the day. In winter, the days are shorter, and the sunlight is less intense.

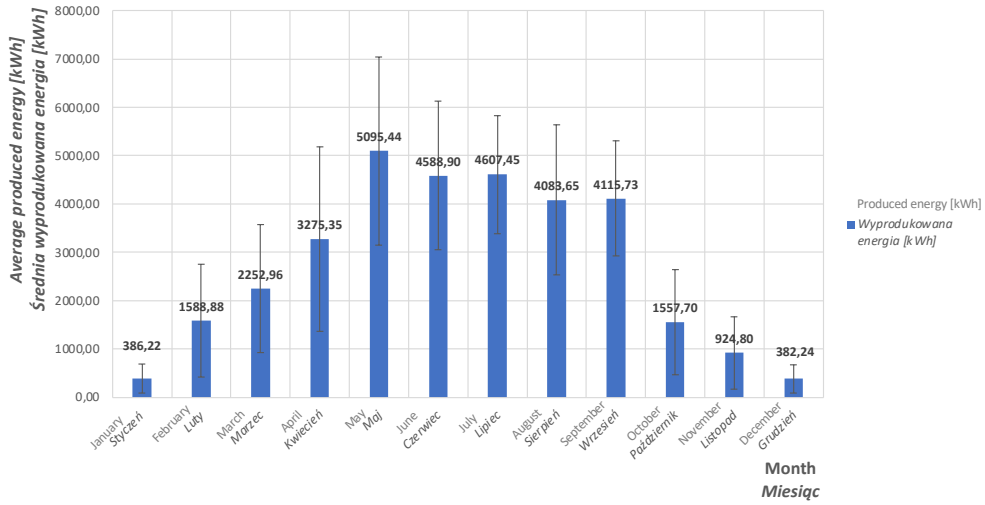
Another factor influencing the result are daily fluctuations in the amount of energy produced. This may be due to changing weather conditions – rain, snow, cloud cover or fog. The highest energy production levels were recorded on days with full sun exposure.

Figure 3 illustrates the average monthly energy production of the analyzed photovoltaic farm. The production increased significantly from January to May.




source: own observations of the tested photovoltaic farm / *źródło: obserwacje własne badanej farmy fotowoltaicznej*

**Fig. 2.** Dynamics of daily energy production in the tested photovoltaic farm in the period 1.01.-31.12.2023
***Rys. 1.*** *Dynamika dziennej produkcji energii w badanej farmie fotowoltaicznej w okresie 1.01-31.12.2023*



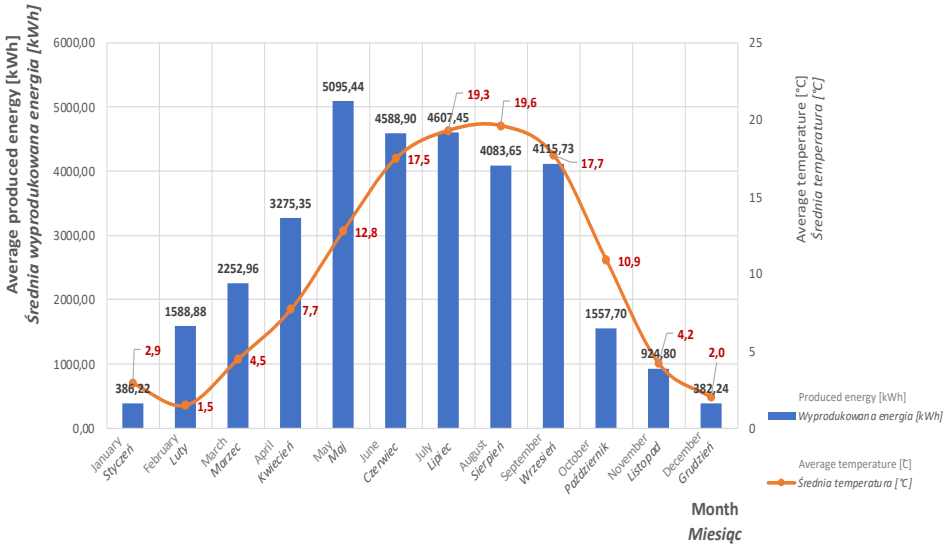

source: data based on the observed photovoltaic farm / *źródło: dane na podstawie obserwowanej farmy fotowoltaicznej*

**Fig. 3.** Average monthly energy production of the examined 1 MW photovoltaic farm in 2023
***Rys. 2.*** *Średnie miesięczne produkcje energii badanej farmy fotowoltaicznej o mocy 1 MW w 2023 roku*

The highest energy production values were recorded in May, with an average daily output of 5,095.44 ± 1,943.16 kWh. Slightly lower, but also high values were observed in the

summer period (June - September). A significant decrease was observed in the autumn and winter period, with the lowest production recorded in December.

The average monthly energy production of the 1 MW photovoltaic farm showed considerable variability (Chart 4). Given the seasonal fluctuations in air temperature throughout the year in Poland, Chart 4 also presents the average daily air temperatures for 2023. It can be seen that the warmest month was August, while the coldest was February. This confirms the thesis that photovoltaic panels work best at moderate temperatures and plenty of sunlight. Such conditions prevailed in May, when the average temperature was 12.8°C.




source: Klimat Polski 2023, own study / *źródło: Klimat Polski 2023, opracowanie własne*

**Fig. 4.** The impact of temperature on the average monthly amounts of energy produced in the tested photovoltaic farm

***Rys. 3.*** *Wpływ temperatury na średnie miesięczne ilości wyprodukowanej energii w badanej farmie fotowoltaicznej*

## IV. CONCLUSIONS

Environmental factors such as temperature, sunlight, pollution and precipitation significantly influence the efficiency of photovoltaic panels. Depending on the conditions, these factors can either enhance energy production or considerably reduce it. The analyzed data regarding daily and monthly energy production by a 1 MW photovoltaic farm showed clear seasonality. The highest values of energy produced occurred in the summer months (especially in May, when the temperatures were moderate), while the lowest occurred in the winter (December and January). Additionally, other environmental factors, not examined in detail in this study, also impacted the performance of the photovoltaic installation. Including such data in future analyses of photovoltaic systems operating under Polish conditions would provide valuable insights.

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