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"Comparative Analysis of Photovoltaic Panel Efficiency in Varying Climatic Zones: A Case Study Approach in Albania."

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ABSTRACT: *This study analyzes the efficacy of photovoltaic (PV) panels in different climatic zones to enhance their performance under varying environmental circumstances. The research assesses the influence of solar irradiance, ambient temperature, humidity, and seasonal fluctuations on the energy generation of photovoltaic systems by examining case studies in different locations in Albania. Data on weather patterns, sunshine duration, and photovoltaic output were gathered over prolonged intervals to evaluate the impact of various environmental factors on panel efficiency. A study of the data reveals notable trends and outliers, indicating certain environmental elements that substantially influence photovoltaic performance. The research delineates appropriate installation methodologies for each climatic zone, taking into account the most suitable panel types, tilt degrees, and orientations. It also offers insights on prospective enhancements in photovoltaic technology and installation methods, such as modifying systems to optimize energy capture in regions with significant temperature variations or frequent cloud cover. The research seeks to improve the efficiency of photovoltaic systems in Albania by providing advice specific to each climatic zone. The results are especially beneficial for manufacturers, installers, and policymakers, offering a basis for the design of photovoltaic systems that are more appropriately aligned with local environmental conditions, hence enhancing renewable energy generation across various geographic areas.*

KEYWORDS: *Photovoltaic, solar irradiance, panel efficiency, renewable energy*.

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I. INTRODUCTION

The worldwide transition to renewable energy has heightened interest in solar power as a sustainable means of fulfilling energy requirements while minimizing environmental effects. Photovoltaic (PV) technology, which directly turns sunshine into power, has become a fundamental element of this transformation. The efficacy of photovoltaic systems is inconsistent and is greatly affected by environmental factors such as temperature, solar irradiance, humidity, and air contaminants. Comprehending these variances is essential for enhancing photovoltaic deployment and guaranteeing its economic and energy efficiency. Albania, distinguished by varied climate zones from coastal Mediterranean to colder alpine regions, presents a distinctive terrain for evaluating the efficacy of photovoltaic systems. Notwithstanding its considerable solar potential, the use of photovoltaic technology in Albania has been comparatively restricted, chiefly owing to inadequate localized performance data and an undeveloped energy infrastructure. These problems highlight the significance of examining the effects of climate variability on the efficiency of photovoltaic panels in the nation. This paper attempts to compare PV panel efficiency across different climatic zones in Albania using a case study technique. This research investigates the relationship between climatic variables and photovoltaic system performance to offer practical insights for stakeholders, such as policymakers, energy developers, and engineers, facilitating the strategic growth of solar energy in Albania. The results will enhance the optimization of photovoltaic systems domestically and provide a reference for analogous places worldwide. This study examines the following questions: What is the impact of several climatic conditions on the efficiency of PV panels in Albania? What tactics may be employed to optimize the performance of photovoltaic systems across various regions? This research aims to reconcile the disparity between the theoretical potential and real implementation of solar energy in Albania by addressing these topics.

II. STUDY LITERATURE

a. Methodology

This study seeks to evaluate the efficacy of photovoltaic (PV) panels in Albania by analyzing their performance throughout the nation's varied climatic zones. The geographical diversity of Albania results in varying climatic factors, including temperature, solar irradiance, humidity, and wind patterns, which can considerably affect the effectiveness of photovoltaic panels. The study examines the impact of meteorological conditions on the energy output and overall efficiency of photovoltaic systems. To do this, empirical case studies are performed in selected places that accurately depict the climatic variety of Albania. The study assesses key performance indicators, including energy production, temperature coefficients, and solar energy utilization efficiency, by examining data from various sites.

This comparative examination of metrics across different climatic zones seeks to find significant trends and variances in PV panel performance. This method offers significant insights into the relationship between climatic conditions and solar energy systems, emphasizing region-specific difficulties and potential. The research findings intend to guide decision-makers and stakeholders by providing actionable recommendations for enhancing the design, installation, and maintenance of PV systems. These insights are anticipated to enhance renewable energy policies in Albania, facilitating the nation's transition to sustainable energy solutions and optimizing its solar energy potential.

The (Solargis, 2025) provides location-specific information through three main models: solar radiation, air temperature, and PV power simulation. The solar radiation model considers attenuation factors of solar radiation as it passes through the atmosphere. The Solargis model calculates solar resource parameters using data from geostationary satellites and meteorological models. The clear-sky model calculates clear-sky irradiance, while meteorological satellite data quantifies the attenuation effect of clouds. The global horizontal irradiance is post-processed by other models to obtain direct and diffuse irradiance and global irradiance on tilted surfaces. The terms solar resource or solar radiation are substituted with solar irradiance and energy.

b. Albania's potential solar energy

Albania, located in the western part of the Balkan Peninsula, has a promising climate for solar energy due to its favorable geographical position. The country has a high intensity of solar radiation, a mild and wet winter, and hot and dry summers, making it a potential energy source for the future. Solar energy is an inexhaustible natural resource distributed globally, clean, and poses no environmental pollution risks. The country is divided into four main climate zones: Field Mediterranean, Hilly Mediterranean, Pre-mountainous Mediterranean, and Mountainous Mediterranean (AKBN, n.d.).

As presented on (AIDA, n.d.) Albania has substantial solar energy potential due to its favorable geographic and climatic conditions. The country receives solar radiation ranging from **1,185 to 1,700 kWh/m² per year**, with an average daily solar radiation of **4.1 kWh/m²**. On clear days, each square meter of horizontal surface can absorb up to **2,200 kWh annually**. Albania enjoys approximately **2,400 hours of sunshine per year**, equivalent to **240 to 300 sunny days annually**.

This abundant solar resource offers significant opportunities for the development of photovoltaic (PV) systems. The untapped potential for PV installations, particularly on infertile land, is estimated at **1,900 MW**. Such capacity could significantly contribute to the country's energy mix, supporting Albania's transition to renewable energy while reducing reliance on other energy sources. This highlights the strategic importance of solar energy in Albania's efforts to harness sustainable and clean energy solutions.

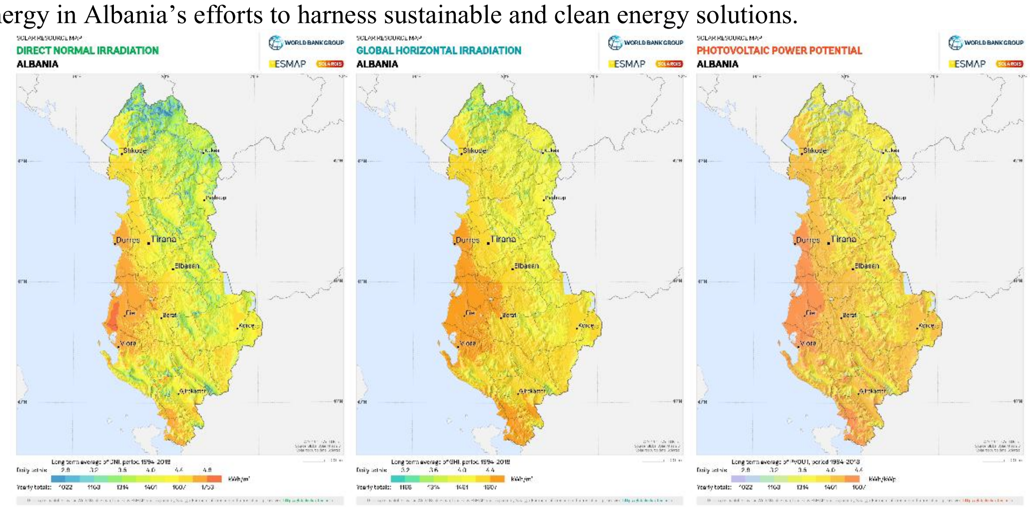


Fig. 1 a) Direct Normal Irradiation, b) Global Horizontal Irradiation, C Photovoltaic Power Potential.source: (Global Solar Atlas, 2018) *c. Photovoltaic Technology*

With increasing global emphasis on sustainable development and environmental concerns, photovoltaic (PV) panels have become a key technology for harnessing renewable energy. PV panels convert sunlight into electricity through the photovoltaic effect, offering a clean, efficient, and sustainable alternative to fossil fuels. Their widespread adoption contributes to reducing carbon emissions, enhancing energy security, and promoting energy independence.

The integration of PV systems in architecture, particularly through Building-Integrated Photovoltaics (BIPV), marks a significant advancement in modern building design. BIPV seamlessly incorporates solar panels into structural elements such as facades, roofs, and windows, enabling architects to merge aesthetics with functionality. This approach enhances building efficiency while contributing to a sustainable urban environment.

d. Principles of Solar Energy Conversion

Solar power transforms sunlight into energy via photovoltaic panels that capture sunlight and emit electrons, as well as solar thermal panels that heat water or other fluids. This renewable and clean energy source lowers greenhouse gas emissions and carbon footprint. Solar power systems can range from residential roofs to extensive farms, offering ecological advantages and energy autonomy. Factors like as panel quality, installation size, and geographical location affect efficiency (How does solar power work?, 2023).

PV panels operate by utilizing semiconductor materials to create an electric field through the photoelectric effect. Photovoltaic cells, composed of multiple semiconductor layers, absorb sunlight and release electrons, generating direct current (DC) electricity. This electricity is then converted into alternating current (AC) for residential and commercial use (How do solar panels generate electricity?, 2024).

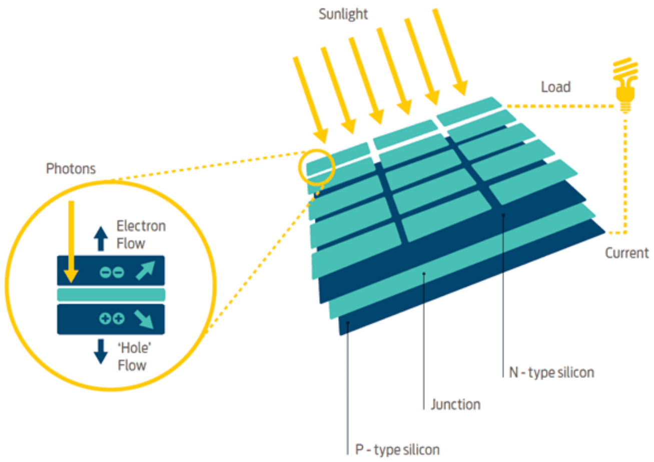


Fig. 2 Schematic view on converting solar energy into electricity. Source: (How does solar power work?, 2023)

According to (Sharma & Singh, 2018) the global formula to estimate the electricity generated in output of a photovoltaic system is:

E = A * r * H * PR

E = Energy (kWh); **A** = Total solar panel Area (m2); **r** = solar panel yield or efficiency (%);
H = Annual average solar radiation on tilted panels (shadings not included);
PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75)

e. Arrangements of Photovoltaic (PV) Arrays

A south-facing PV array with a fixed tilt consists of solar panels installed at an angle tailored to the geographic location to enhance sunlight exposure. The panels are positioned southward (in the Northern Hemisphere) to maximize sunlight exposure during the day. The tilt angle denotes the panel's inclination in relation to the horizontal plane.

In a one-axis tracking photovoltaic array, the panels are mounted on a framework that pivots along a singular axis. The axis of rotation is aligned south, enabling the panels to track the sun's trajectory from east to west throughout the day. This arrangement enhances energy capture relative to a fixed array by following the sun's horizontal trajectory.

A two-axis tracking photovoltaic array consists of panels affixed to a mechanism that permits movement along two axes. This mechanism enables the panels to track the sun's trajectory horizontally and vertically, guaranteeing that the panels remain perpendicular to the sun's beams. This configuration optimizes energy efficiency and production.These designs illustrate an evolution in complexity and energy efficiency, with fixed arrays being the most straightforward and economical, while two-axis tracking systems provide the most energy output at a higher operational expense (Photovoltaics, n.d.).

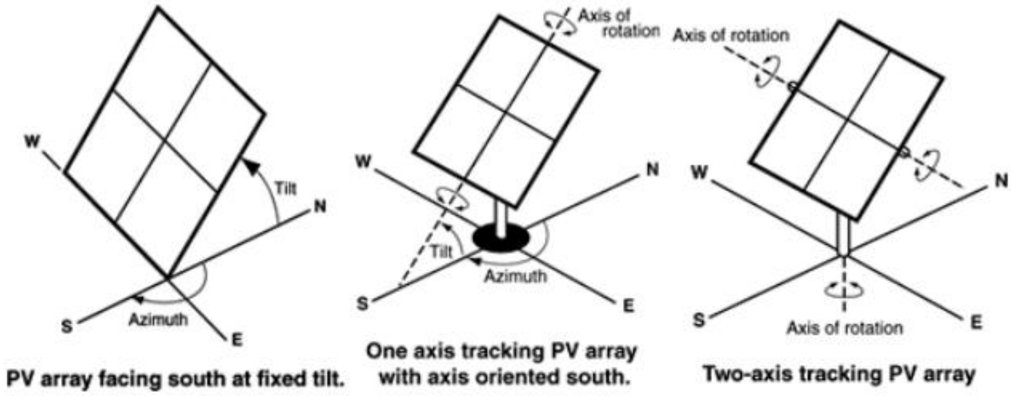


Fig. 3 Arrey of the PV. Panels. Source: (Photovoltaics, n.d.)

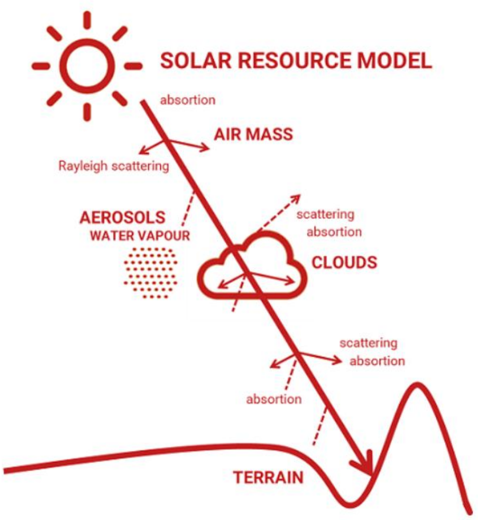


Fig. 4 Solar Resource Mode (Solargis, 2025)

The Solar Resource Model discusses the interaction of solar radiation with the atmosphere and the Earth's surface. Solar radiation traverses the air mass, influencing its trajectory and intensity. Rayleigh scattering affects shorter light wavelengths, whereas aerosols and water vapor contribute to additional scattering and absorption. Clouds significantly influence the reflection and absorption of solar radiation, while the topography absorbs the residual energy, with changes contingent upon surface characteristics. This model is essential for assessing solar energy potential, especially in contexts such as photovoltaic systems or energy-efficient architectural design.

f. Performance ratio

The system efficiency of a photovoltaic power plant, known as the Performance Ratio (PR), is a crucial metric for evaluating the plant's capacity to convert solar radiation into electrical energy. It encompasses both the conversion efficiency of the solar panels and the total power losses inside the photovoltaic system. Comprehending system efficiency facilitates the evaluation of the disparity between actual and theoretical power generation. Increased system efficiency enhances the power-generating performance of the solar power plant (Brian, 2024).

The efficiency of a solar power plant is often determined using the given formula:

System Efficiency (%) = (Actual Power Generation / Theoretical Power Generation) × 100%

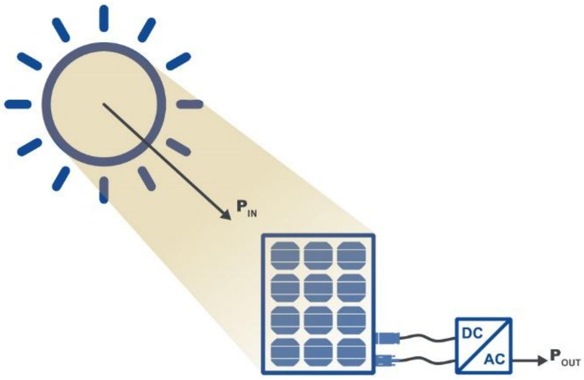


Fig. 5 The system efficiency of a photovoltaic power plant, known as the Performance Ratio (PR), Source: (ReRa Solutions BV, n.d.)

III. CASE STUDY

Choosing research sites that reflect Albania's varied climate zones is crucial to conducting a thorough evaluation of the effectiveness of photovoltaic (PV) panels in Albania. The central, highland, and coastal regions of Albania each have unique environmental traits that affect photovoltaic performance.

Because of the frequent cloud cover, the mountain zone—which includes places like Kukës and Pogradec—has milder summers, colder winters, and erratic sunlight. Wintertime snow and frost provide special difficulties for PV performance, including possible energy losses and snow accumulation-related maintenance problems. This zone is a good place to research the advantages of temperature-tolerant panels and steeper tilt angles for snow shedding, though, because colder temperatures there may increase PV efficiency.

The coastal region of Albania, which is exemplified by cities like Durres and Vlore, has hot summers, humid winters, and moderate winters. The location is favorable for photovoltaic (PV) performance because of these circumstances, which provide steady sun irradiation, particularly throughout the summer. Problems like heat accumulation, condensation, and coastal salt spray, however, can lower panel performance and necessitate regular repair. This area is perfect for researching how temperature and humidity affect photovoltaic systems and investigating potential fixes like heat-resistant panels or better cleaning methods.

Along with urban heat islands in heavily populated regions, mild weather patterns predominate in the middle zone, which includes cities like Tirana and Elbasan. Although the circumstances for solar installations are favorable in this area, shadowing from infrastructure and urban pollution may reduce PV performance. Understanding how rooftop systems function in urban settings and spotting chances to maximize energy production in the residential and commercial sectors depend on this area. Through the analysis of these zones, the study provides localized recommendations to improve PV system efficiency throughout Albania, capturing the country's climatic variability.

Environmental Data

Map data		Kukes	Durres	Elbasan
Specific photovoltaic power output	PVOUT_specific (kWh/kWp)	1358.1	1551.5	1485.9
Direct normal irradiation	DNI (kWh/m²)	1395.4	1706.1	1603.9
Global horizontal irradiation	GHI (kWh/m²)	1462.8	1629	1570.9
Diffuse horizontal irradiation	DIF (kWh/m²)	628.7	614.8	629.5
Global tilted irradiation at optimum angle	GTI_opta (kWh/m²)	1667.4	1897.5	1829.9
Air temperature	TEMP (°C)	12.8	16.8	14.8
Optimum tilt of PV modules	OPTA (°)	33	34	35
Terrain elevation	ELE (m)			

Photovoltaic data:
The panel used will have the following characteristics taken from Vega Solar[1]:

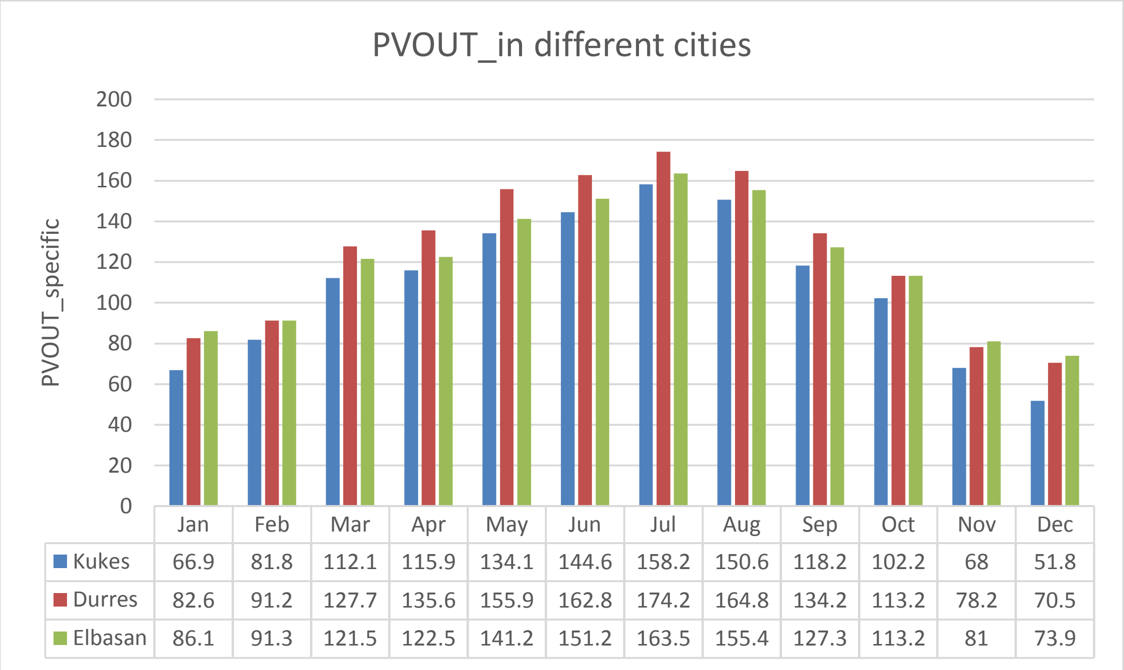
- Manufacturer's name: Luxor;
- Weight of PV panel: 33.5 kg;
- Dimensions of PV panel: 2382 x 1134 x 30 mm;
- Power output of panel: 610
- Wp; Efficiency coefficient: 22.82%;
- Unit price of panel: 150 Euros

IV. RESULTS:

When we use the (Solargis, 2025) we can calculate the energy output of photovoltaic panels. When we choose in the program the characteristics of the panel the program chooses by default the Tilt of PV panels and Azimuth of PV panels, which for the cities taken in to the stude the result are:

City	Azimuth of PV panels:	Tilt of PV panels	photovoltaic power output (kWh per year)
Kukes	180	33	795.479
Durres	180	34	911.259
Elbasan	180	35	872.926

Durres achieves the highest annual photovoltaic power output (911.259 kWh) due to its favorable solar irradiance and minimal shading, while Kukes has the lowest output (795.479 kWh) because of lower irradiance and higher shading losses. Elbasan falls in between with 872.926 kWh, benefiting from moderate irradiance and an optimal tilt angle. All cities use a south-facing azimuth (180°), and slight optimizations in shading management and tilt angles could further enhance performance in Kukes and Elbasan. The reductions of energy production in accordance with Tirana is: for Kukes (12.71%) and Elbasan (4.21%)



Durres consistently shows the highest photovoltaic output overall, peaking at 170.9 kWh/kWp in June, due to its favorable coastal location and high solar irradiance, particularly excelling during the summer months. Elbasan performs moderately, with a peak of 146.9 kWh/kWp in June, but it outperforms the other cities during the winter months due to better diffuse irradiation conditions, recording higher PVOUT values compared to Durres and Kukes. Kukes records the lowest output, peaking at 155.8 kWh/kWp in July, affected by weaker solar irradiance, higher shading potential, and colder temperatures. All cities experience seasonal variations,

[1] Vega Solar- company in the field of renewable energy

with higher outputs from April to August and significant drops in winter months. These results highlight Durres as the best location for photovoltaic installations in summer, while Elbasan demonstrates superior performance during the winter, making it a strong year-round contender. Kukes, however, requires optimization measures to mitigate shading and improve efficiency.

V. CONCLUSION

The photovoltaic performance aligns well with the climatic and geographical conditions of each city. Durres benefits most from its favorable solar irradiance and mild climate, while Kukes' output is constrained by higher shading and lower irradiance. Elbasan performs moderately well but could benefit from further optimizations.

For a strategic approach:

- **Durres** is ideal for large-scale installations, particularly for summer-peak energy demands.
- **Elbasan** offers balanced year-round performance and is well-suited for diverse energy needs.
- **Kukes** requires targeted interventions to maximize its potential, such as optimizing tilt angles, addressing shading, and employing advanced technologies for low-light conditions.

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