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ENERGY OUTPUT EVALUATION OF A PHOTOVOLTAIC SYSTEM USING DIFFERENT LAYOUT ARRANGEMENTS

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ABSTRACT

The design and arrangement of photovoltaic (PV) systems significantly influence their energy output. This study investigates the impact of different layout arrangements on the energy output of a PV system. The experiment involved the construction of four identical PV systems, each utilizing a different layout arrangement: horizontal, vertical, east-west, and north-south orientations. These systems were subjected to identical environmental conditions over a period of one year, during which their energy outputs were monitored and analyzed. The results demonstrate notable variations in energy output among the different layout arrangements. This study highlights the significant influence of layout arrangement on the energy output of a PV system. These findings can aid in the optimal design and planning of PV systems, providing valuable insights for enhancing energy efficiency and sustainability in renewable energy applications.

Keywords: solar power; photovoltaic (pv); layout arrangements.

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1. INTRODUCTION

Jordan faces significant challenges in its energy sector. The country is heavily dependent on imported energy resources, primarily oil and gas, to meet its energy needs. This reliance on external sources makes Jordan vulnerable to fluctuations in global oil prices and geopolitical tensions in the region. As a result, the country has been striving to diversify its energy mix and reduce its dependence on fossil fuels [1-50].

In recent years, Jordan has made notable progress in renewable energy development. The government has implemented policies and incentives to encourage investments in renewable energy projects, particularly in solar and wind power. The country's solar potential is substantial, with abundant sunshine throughout the year, making it an ideal location for solar energy generation. Jordan has successfully established several large-scale solar power plants and is actively promoting the use of photovoltaic systems on rooftops and in rural areas [9-11, 51-53].

Additionally, wind energy has gained momentum in Jordan, particularly in the southern region where wind resources are abundant. The country has witnessed the construction of wind farms, harnessing the strong winds to generate clean electricity. These renewable energy projects contribute to reducing greenhouse gas emissions, improving energy security, and mitigating the environmental impact of traditional energy sources [13, 15, 18, 24, 26, 41, 54-56].

However, despite progress in renewable energy, Jordan still faces challenges in meeting its growing energy demand. The country's population and economy are expanding, leading to increased electricity consumption. To address this, Jordan has initiated energy efficiency programs to promote energy conservation and reduce wasteful consumption. Furthermore, the government is exploring opportunities for nuclear energy as a long-term solution to meet the country's energy needs [13, 15, 18, 24, 26, 41, 54-63].

Solar energy plays a vital role in Jordan's pursuit of a sustainable and diversified energy sector. The country boasts abundant sunlight throughout the year, making it a prime location for solar energy generation. Recognizing this potential, Jordan has made significant strides in developing solar power projects. The government has implemented favorable policies and attractive incentives to attract investments in solar energy, leading to the establishment of large-scale solar power plants and the widespread adoption of solar panels in residential and commercial buildings. These solar initiatives not only reduce the country's dependence on fossil fuels but also contribute to mitigating greenhouse gas emissions and addressing environmental challenges. Moreover, solar energy projects in Jordan have improved energy security, reduced reliance on imported energy resources, and created employment opportunities in the renewable energy sector. As the country continues to harness its solar potential, it is paving the way towards a more sustainable energy future [10, 11, 15, 18, 22, 29, 41].

Solar photovoltaic (PV) systems have gained significant traction in Jordan as a sustainable and reliable source of electricity. With its abundant solar resources, the country has embraced solar PV technology to meet its growing energy demands. The government of Jordan has implemented supportive policies and incentives to attract investments in solar PV projects, resulting in the establishment of numerous solar power plants and widespread adoption of solar panels in residential, commercial, and industrial sectors. These initiatives have helped reduce reliance on imported energy resources, enhance energy security, and mitigate greenhouse gas emissions. Solar PV systems in Jordan have not only proven to be environmentally friendly but also economically viable, with the declining costs of solar

ARPN Journal of Engineering and Applied Sciences

technology and favorable regulatory frameworks. Additionally, solar PV deployment in Jordan has created job opportunities and stimulated the growth of the renewable energy industry. As the country continues to leverage its solar potential, solar PV will play a vital role in advancing Jordan's energy transition towards a sustainable and resilient future [1, 9, 11, 15, 19, 21, 22, 64-71].

PV system optimization and development with regard to panel orientation is a crucial aspect in maximizing energy production. The orientation of solar panels plays a significant role in capturing the maximum amount of sunlight throughout the day. Traditionally, horizontal panel orientation has been widely employed due to its simplicity and ease of installation. However, recent studies have shown that alternative orientations, such as vertical, east-west, and north-south configurations, can offer improved energy production under specific conditions. By aligning solar panels vertically, the system can capture more sunlight during the early morning and late afternoon hours, which can be advantageous in certain regions. East-west configurations are favorable in areas with a significant shift in solar irradiation during the day, as they maximize energy output during morning and evening periods. On the other hand, north-south orientations distribute solar exposure more evenly throughout the day, resulting in a balanced energy output. The optimization of panel orientation is a complex task that requires careful consideration of factors such as geographical location, local climate, and energy demand patterns. By selecting the most suitable panel orientation, PV systems can maximize energy production and improve overall system efficiency, contributing to the growth and sustainability of renewable energy [15, 64, 66-68, 70, 71].

2. GEOGRAPHICAL AND METEOROLOGICAL DATA

Geographical and meteorological data for Amman, Jordan play a crucial role in the planning and implementation of photovoltaic (PV) projects. Amman is located at the latitude of approximately 31 degrees north, offering favorable solar irradiation levels for solar energy generation. The city's geographical position on a plateau provides ample opportunities for unobstructed sun exposure throughout the day.

Meteorologically, Amman experiences a Mediterranean climate with hot, dry summers and cool, rainy winters. The long and sunny summer days offer extended periods of sunlight, maximizing the energy production potential of PV systems. The average annual sunshine duration of 2,800 to 3,300 hours further enhances the feasibility of solar PV projects in the region.

Amman's average annual rainfall of 300 to 400 millimeters is concentrated primarily during the winter months. This information is crucial in determining the water requirements for PV system cleaning or irrigation, as well as managing rainwater runoff for on-site usage or drainage purposes.

The city's moderate wind speeds ranging from 2 to 5 meters per second indicate favorable conditions for wind energy installations, alongside PV systems. Integrating both solar and wind technologies can provide a hybrid renewable energy solution, diversifying the energy mix and maximizing overall energy generation.

Amman's geographical and meteorological data provide important insights for PV project developers. The city's geographical location, ample sunshine, moderate wind speeds, and precipitation patterns enable the effective design, sizing, and optimization of PV systems. By harnessing these data, developers can ensure the efficient utilization of solar resources and achieve maximum energy production, contributing to Jordan's renewable energy goals and sustainability objectives. Figure-1 shows the number of sunshine hours of Amman - Jordan.

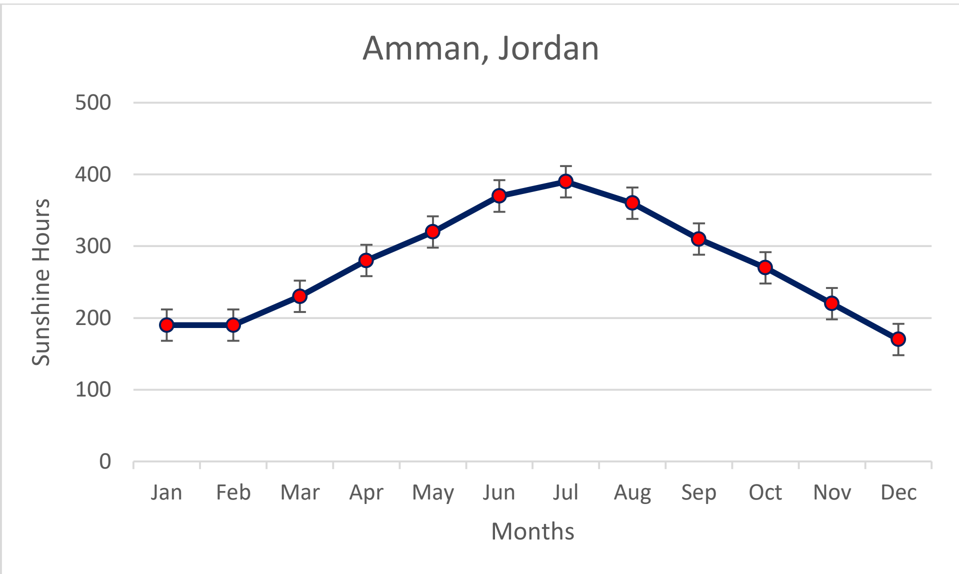

Figure-1. The number of sunshine hours in the city of Amman, Jordan, throughout the year.

ARPN Journal of Engineering and Applied Sciences

Figure-2 indicates the average temperature in the Jordanian capital Amman throughout the year, with its upper and lower limits, as it is noted that the highest temperatures were recorded in the months June, July, August, and September, while the lowest temperatures were recorded during the months January, February, and December.

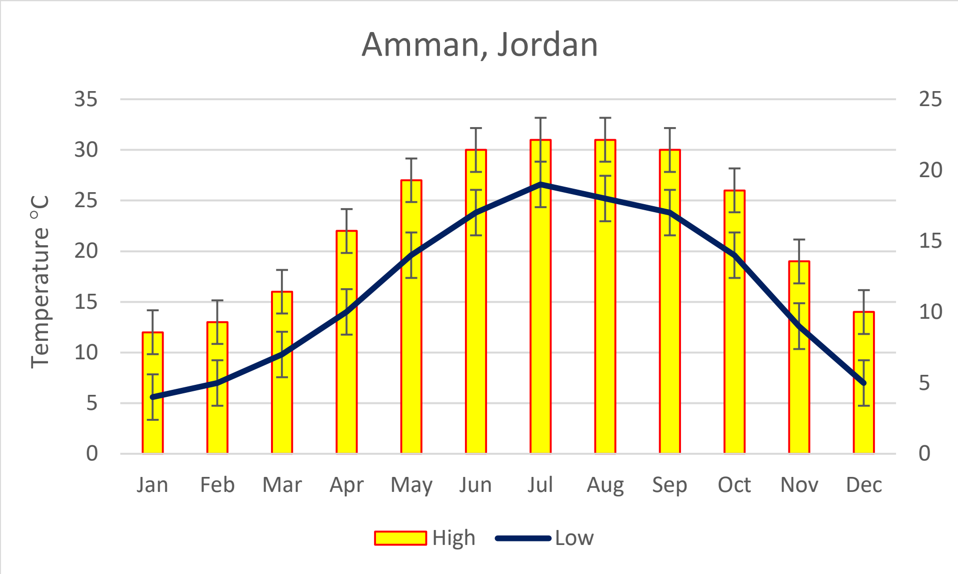

Figure-2. The average temperature in the Jordanian capital Amman throughout the year, with its upper and lower limits.

3. SOLAR CALCULATIONS

Solar calculations are essential in designing and evaluating photovoltaic (PV) systems. These calculations involve estimating the energy production potential of a PV system based on various factors. One key calculation is determining the solar irradiation or insolation at the installation site. This involves analyzing historical meteorological data, such as solar radiation levels and cloud cover, to assess the amount of sunlight available for energy generation throughout the year. Additionally, calculations are made to estimate the system's orientation and tilt angle to optimize solar panel positioning for maximum sun exposure.

Another critical aspect of solar calculations is the estimation of the system's energy output. This involves considering factors such as the solar panel's efficiency, size, and temperature coefficients. By understanding the panel's electrical characteristics, it is possible to estimate the amount of electricity the PV system can generate under different conditions. This information is vital for sizing the system appropriately to meet the desired energy demand and optimizing its performance.

Solar calculations also consider the impact of shading on the PV system. Accurate calculations involve assessing the potential shading from nearby structures, vegetation, or other obstructions that can reduce the system's energy production. By analyzing shading patterns and their effect on specific times of the day or year, system designers can make informed decisions regarding panel placement or implement shading mitigation strategies.

Furthermore, solar calculations take into account other factors such as system losses due to wiring, inverter inefficiencies, and environmental factors like temperature variations. These factors help in accurately estimating the net energy production of the PV system and ensuring the overall system efficiency.

Solar calculations for PV systems involve assessing solar irradiation, panel orientation, energy output estimation, shading analysis, and accounting for system losses. By conducting comprehensive and accurate calculations, designers can optimize the performance of PV systems, effectively meet energy demands, and maximize the utilization of solar energy resources.

The angular position of the sun at solar noon, with respect to the plane of the equator with a value in degrees, is called the solar declination. It is given through the below formula (1).

$$\delta = 23.45 \sin\left(2\pi \frac{284+n}{365}\right) \quad (1)$$

Where n represents the day of the year. Thus, the first day of the first month of the year is number one, and the days followed by counting in series so that the last day of the year in the last month is day number 365.

The sun's angular displacement east or west is related to the local meridian; as negative in the morning and positive during the afternoon is called the Solar Hour Angle (SHA). i.e., SHA is 0.0 at solar noon and changed by a value of 15 degrees per solar noon hour.

The symmetric solar hour angle with respect to the time during the sunset is called the sunset hour angle w_s. It is given through the below formula (2).

$$\cos\omega_s = -\tan\phi\tan\delta \quad (2)$$

Where δ is the declination, and ϕ is the latitude of the site.

Solar radiation outside the atmosphere is called extraterrestrial radiation. The daily extraterrestrial solar radiation at the horizontal surface can be calculated by using the formula (3)

$$H_0 = \frac{24\times 3600 G_{sc}}{\pi}\left(1+0.033\cos\frac{360n}{365}\right)\times\left(\cos\phi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta\right) \quad (3)$$

Where Gsc is the solar constant and is equal to 1367 W/m^2.

It is important to know that not all the solar radiation coming out of the sun reaches the atmosphere and not all the radiation that reaches the atmosphere reaches the earth, and even what reaches the earth, arrives in different forms and types, due to the weather factors and conditions facing the rays.

4. RESULTS AND DISCUSSIONS

Figure-3 illustrates the central focus of the study, depicting the main frame that encompasses the different layout arrangements of PV (Photovoltaic) systems in Amman, Jordan. This figure serves as a visual representation of the fundamental structure and configuration under investigation. It showcases the varying arrangements and placements of PV panels within the Amman region, highlighting the spatial organization and distribution of these solar energy systems. The figure provides valuable insights into the different layout options considered in the study, offering a comprehensive overview of how PV systems can be strategically positioned in Amman, Jordan, to maximize their efficiency and energy output.

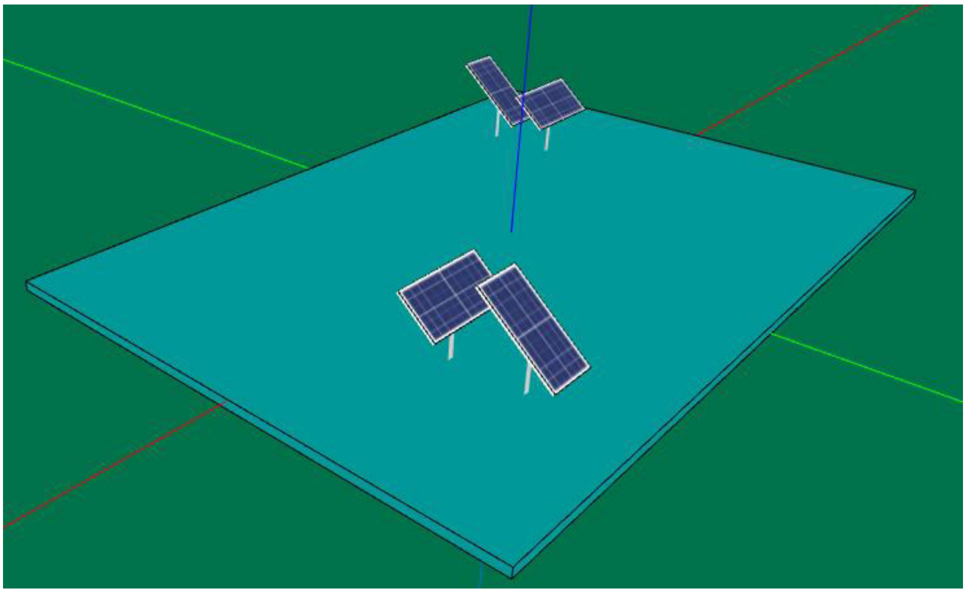

Figure-3. PV system with different layout arrangements.

Figure-4 displayed represents a comprehensive analysis of the energy production from two distinct PV system layout arrangements: one positioned on the left side and the other on the right side. The chart clearly demonstrates that the left-side arrangement has proven to be more efficient in generating energy, producing approximately 1.88 kWh, compared to the right-side arrangement, which generated approximately 1.69 kWh. The observed deviation in energy production can be attributed to several factors associated with the PV layout arrangement.

Firstly, the orientation and tilt angle of the PV panels play a crucial role in maximizing energy output. The left-side arrangement might have been strategically positioned to face the optimal direction, receiving a greater amount of sunlight throughout the day. This configuration allows the panels to capture more solar radiation and convert it into electrical energy efficiently. Conversely, the right-side arrangement may have a less favorable orientation, resulting in decreased solar exposure and subsequently lower energy production.

Secondly, shading and obstructions can significantly impact the performance of PV systems. The left-side arrangement might have been shielded from nearby buildings, trees, or other structures, minimizing shading and ensuring uninterrupted access to sunlight. On the contrary, the right-side arrangement could be subject to partial shading or obstruction, reducing the overall energy production. Even a minor shading effect can substantially diminish the output of individual PV panels or even entire strings, thus contributing to the lower energy yield observed. Furthermore, the design and configuration of the electrical connections within the PV system layout arrangement can also influence energy production. The left-side arrangement may have been engineered with an optimized wiring scheme, minimizing resistive losses and ensuring efficient power transfer from the panels to the inverter. In contrast, the right-side arrangement may have experienced higher resistive losses due to suboptimal wiring, leading to decreased energy output. Additionally, environmental factors such as dust accumulation and maintenance practices can influence the performance of PV systems. The left-side arrangement might have been subjected to regular cleaning and maintenance, ensuring the panels remain free from dust and debris, which can reduce their efficiency. Conversely, the right-side arrangement may have faced challenges in terms of maintenance, resulting in decreased energy production due to dirt buildup or other maintenance-related issues. It is important to note that the deviation in energy production between the left and right-side arrangements is not solely dependent on a single factor but rather a combination of various interrelated elements. Factors such as geographical location, weather patterns, system design, and maintenance practices all contribute to the observed disparity. Consequently, a comprehensive understanding of these factors is crucial for optimizing the layout arrangement of PV systems to maximize energy production and ensure sustainable and efficient solar energy utilization.

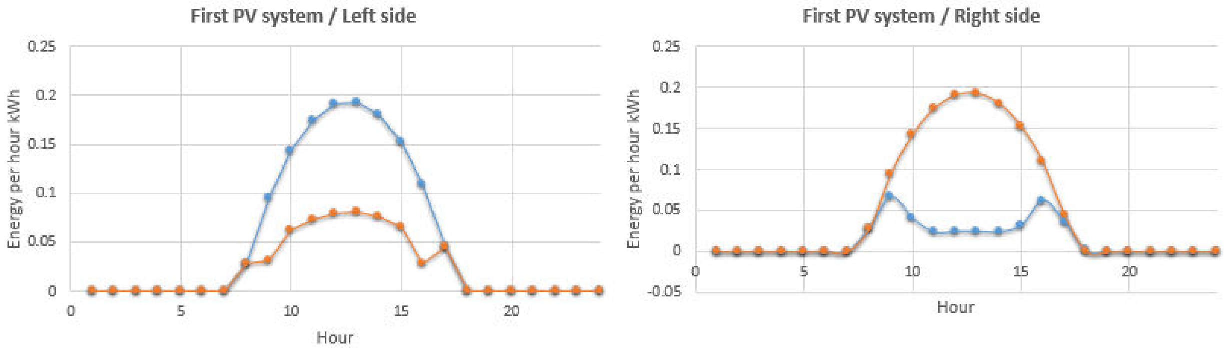

Figure-4. Energy production during 10th of Dec the worst solar radiation day during the year.

Figure-5 provides a detailed thermal map that visually represents the stark contrast in energy production between the two investigated PV layout systems. The thermal map clearly illustrates that the system positioned on the left side exhibits a significantly higher energy output compared to the system on the right. This discrepancy in energy production can be primarily attributed to the fundamental differences in the arrangement of the PV systems.

The thermal map highlights the variations in temperature distribution across the PV panels in each layout system. It is evident that the left-side arrangement exhibits lower operating temperatures, indicating improved efficiency and enhanced energy generation. This outcome can be attributed to the specific design and orientation of the PV panels in the left-side system, allowing for better utilization of the available solar radiation. One crucial aspect influencing the energy disparity is the spatial arrangement and orientation of the panels. The left-side system might have been strategically positioned to optimize sunlight exposure, thereby reducing thermal losses and ensuring a more efficient conversion of solar energy into electricity. On the other hand, the right-side system's arrangement may be less favorable in terms of sunlight capture, resulting in increased operating temperatures and reduced energy output. Another factor contributing to the observed energy discrepancy is the impact of shading and obstructions. The thermal map clearly indicates that the left-side arrangement experiences minimal shading or obstructions, allowing for unobstructed sunlight exposure throughout the day. This favorable shading profile enables the panels to operate at lower temperatures, mitigating thermal losses and enhancing energy production. Conversely, the right-side system may encounter shading from nearby structures or vegetation, leading to higher panel temperatures and decreased energy generation. Furthermore, the design and configuration of the electrical connections within each layout system can also affect energy production. The left-side system may have been engineered with a more optimized wiring scheme, minimizing resistive losses and facilitating efficient power transfer from the panels to the inverter. This well-designed electrical infrastructure contributes to the overall higher energy output. Conversely, the right-side system might experience higher resistive losses due to suboptimal wiring, resulting in reduced energy production.

It is crucial to consider the interplay between various factors when analyzing the energy disparity showcased in the thermal map. The arrangement and orientation of PV panels, the presence of shading or obstructions, and the effectiveness of the electrical infrastructure collectively contribute to the observed variations in energy production. Understanding these complex relationships is vital for optimizing PV system layout arrangements, maximizing energy generation, and ensuring sustainable utilization of solar resources.

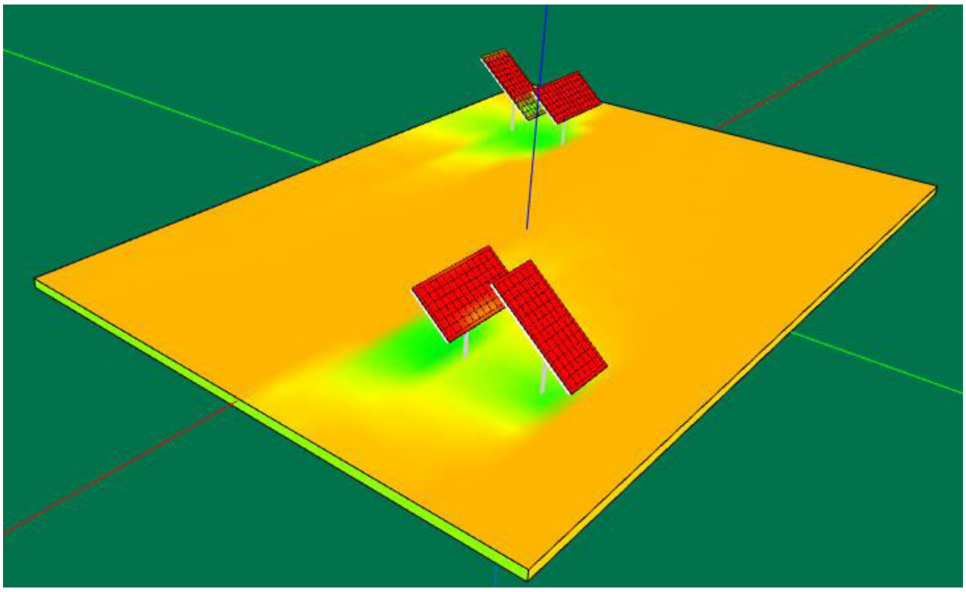

Figure-5. Thermal map of the PV systems layout.

5. CONCLUSIONS

In conclusion, the layout arrangement of PV systems in Amman, Jordan has a significant impact on energy production. The findings from the investigations presented in Figure-5 and discussed throughout this analysis highlight the importance of designing and implementing PV layouts in a well-thought-out manner to maximize energy generation.

The observed disparities in energy production between the different layout arrangements emphasize the need for strategic planning and consideration of various factors. Factors such as panel orientation, tilt angle, shading, obstructions, electrical wiring, and maintenance practices all play crucial roles in determining the overall energy output of PV systems.

To achieve optimal energy production, it is essential to position the PV panels to capture the maximum available sunlight throughout the day. This involves careful consideration of factors such as the site's geographical location, sun path, and potential shading sources like nearby buildings or vegetation. Moreover, proper panel orientation and tilt angle can significantly impact energy generation, as they directly affect the amount of sunlight absorbed by the panels.

Furthermore, attention should be given to minimizing shading and obstructions, as they can lead to localized temperature increases and decreased energy production. Regular maintenance practices, including panel cleaning and inspection, are vital to ensure efficient operation and prevent dust accumulation, which can impair the performance of PV systems.

Taking into account all these factors and optimizing the layout arrangement of PV systems in Amman, Jordan, is of utmost importance to maximize energy production. By adopting best practices and leveraging the available resources effectively, it is possible to harness solar energy more efficiently and contribute to a sustainable and greener future.

Overall, the layout arrangement of PV systems in Amman, Jordan should be meticulously planned and implemented, considering factors such as panel orientation, shading, electrical infrastructure, and maintenance practices. This approach will enable the production of higher amounts of clean, renewable energy, supporting the transition towards a more sustainable energy landscape in the region.

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