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Energy Assessment & Comparative Study of Mono and Poly Solar PV Technologies Using Advanced PVsyst Software

Wahidullah Zgham[1,*], Safiullah Shirzad[1] and Sayed Ahmad Zamir Fatemi[1]

[1] *Energy Engineering Department, Ghazni Technical University, Afghanistan*

Abstract: This study evaluates and compares the energy output of mono-crystalline and poly-crystalline solar photovoltaic (PV) technologies, under specific climatic conditions, with the help of advanced PVsyst software. This study aims to provide realizations into selecting the most effective PV technology by considering specific climatic and geographical conditions. In this study, monthly and yearly output energy, along with performance ratios, are evaluated for two conditions: firstly, for a 10.23 KWp system, and subsequently, for a 58.2 m^2 solar panel area. Both conditions demonstrate that mono-crystalline solar PV technology consistently outperforms poly-crystalline technology in terms of monthly and yearly output energy as well as performance ratio. Specifically, mono-crystalline panels generate 78 kWh more electricity annually in a 10.23 KWp system and 2469 kWh more in a system based on a specified PV module area. Additionally, they exhibit high-performance ratios in both scenarios. These findings strongly advocate for the preference of mono-crystalline technology within this region. Furthermore, the study offers valuable insights for addressing similar energy challenges in regions with comparable conditions, as far as solar panels energy outputs are affected by the climate conditions at most; so that for similar climate conditions in region would be effective. This research significantly contributes to facilitating well-informed decision-making processes, thereby augmenting energy accessibility.

Keywords: energy assessment, comparative study, mono-crystalline and poly-crystalline Solar PV technologies, PVsyt software

1. Introduction

The key function for development and quality of life is energy [1]. Beside other factors, life standards of any region are calculated by the rate of energy consumed by the population in that area [2]. There are various sources for power development: renewable sources and non-renewable sources. As of today, the world is concerned about and affected by global warming and climate change, causing a shift from non-renewable to renewable sources [3]. Among these, Afghanistan stands out, having more than 300 sunny days, and people require electricity around the clock [4]. This indicates that Afghanistan possesses the greatest capacity for solar energy compared to other forms of renewable energy. Additionally, southern areas receive more insolation and solar energy per square meter [5]. Solar photovoltaic (PV) technology holds promise due to abundant sunlight.

The inconsistent electrical grid presents a notable obstacle, prompting residents to explore solar power alternatives for their energy requirements. In particular, they are examining the potential of mono-crystalline and poly-crystalline solar photovoltaic technologies. Nonetheless, there are lingering inquiries about which technology offers the optimal balance of power generation and efficiency [6]. This research addresses by evaluating and comparing these solar technologies using PVsyst software to determine the most effective option for the region. The goal is to offer valuable insights for informed decision-making and enhance energy-related choices.

*Corresponding author: Wahidullah Zgham, Energy Engineering Department, Ghazni Technical University, Afghanistan. Email: zghamafg@gmail.com

By conducting a comprehensive analysis of mono-crystalline and poly-crystalline solar PV technologies using advanced PVsyst software, this research provides valuable insights into choosing the best solar energy solution for the Ghazni region. Given the challenges of inadequate electricity and population growth, making informed decisions about solar technology adoption becomes crucial. The study's findings will empower residents, businesses, and government with data-driven knowledge to confidently select the most efficient solar technology [7]. This not only enhances energy access but also contributes to overall socio-economic advancement. Additionally, the study's contribution to the broader understanding of solar technology performance in diverse settings extends its significance beyond Ghazni, offering valuable insights into similar energy-related challenges in other regions to assess and compare the energy assessment of mono-crystalline and poly-crystalline solar PV technologies in Ghazni, Afghanistan [6]. Through the use of advanced PVsyst software, the evaluation seeks to identify the optimal solar energy approach to address local issues like limited energy availability and increasing population [8]. The scope of this work covers technical evaluation, energy production efficiency, and potential outcomes for sustainable progress.

Solar photovoltaic (PV) technologies comprise a number of methods designed to harness solar energy for electricity generation [9]. These techniques utilize the photovoltaic effect, which directly converts sunlight into electrical energy using semiconductor materials. Mono-crystalline and poly-crystalline solar panels are the most used types. These technologies represent unique strategies for the conversion of sunlight into electrical power [2, 10].

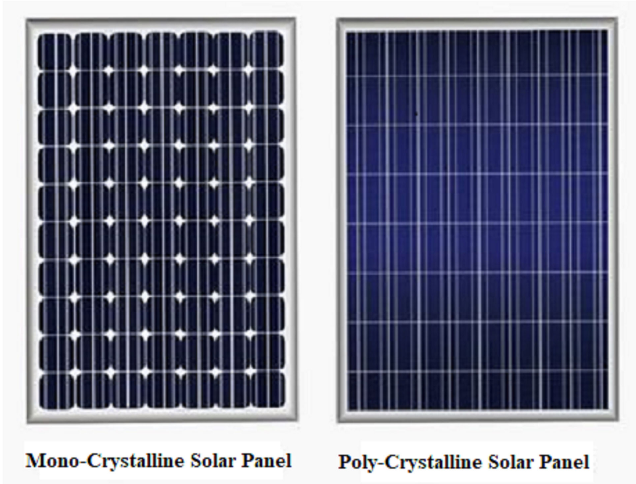
Cells crafted from pure mono-crystalline silicon are known as mono-crystalline silicon cells. In these cells, the silicon possesses a single, uninterrupted crystal lattice structure with minimal defects or impurities. The primary benefit of mono-crystalline cells lies in their high efficiency, typically reaching around 15% [11]. The disadvantage of these cells is that a complicated manufacturing process is required to produce mono-crystalline silicon, which results in slightly higher costs than those of other technologies [3].

Multi-crystalline cells are formed by employing multiple grains of mono-crystalline silicon. In the manufacturing process, liquid poly-crystalline silicon is spilled into plates, which are then cut into extremely thin wafers and assembled into the finished cells [12]. The production of poly-crystalline cells is more cost-effective than mono-crystalline cells, as it involves a less complex manufacturing process. However, it is important to note that poly-crystalline cells typically have slightly lower efficiency, with an average of efficiency around 12% [13].

The choice between these technologies depends on factors like efficiency, cost, space, and environmental conditions [14, 15]. Figure 1 [16] shows both types of solar PV technologies. Afghanistan has the highest amount of solar energy capacity compared to countries around and due to the poverty and lack of access to the energy, particularly Ghazni residents rely on solar panels, so it will help them to select best between alternatives.

Saeed et al. [17] have carried out a study on "Comparative performance investigation of mono- and poly-crystalline silicon photovoltaic modules for use in grid-connected photovoltaic systems in dry climates," in Kerman, Iran. In this study, the design and performance of a real 11.04 kW grid-connected photovoltaic (PV) system is investigated. This plant is composed of two types of 5.52 kWp common crystalline PV technology with almost similar characteristics. Thus, the performance evaluations of two types of crystalline PV technology are examined in this groundbreaking study, and it is discovered that the output power from p-Si PV modules is higher when factors related to PV power plant design are taken into account. For mc-Si, the capacity factor (CF), performance ratio (PR), and yearly average daily final yield (Yf) are found to be 23.20%, 80.81%, and 5.24 kWh/kWp day, respectively. Moreover, estimates for Yf, PR, and CF for p-Si are 23.81%, 82.92%, and 5.38 kWh/kWp day, respectively.

Figure 1
Mono and poly solar PV technologies



Ayadi et al. [10] carried out research together on "In a sunny climate, an experimental comparison of mono-crystalline and poly-crystalline solar systems". The thin film system had the lowest efficiency of 7%, while the Mono system achieved the best efficiency [9]. In a similar vein, the Mono system achieved the highest performance ratio while the Poly system obtained the lowest. The thin-film system produced the highest specific yield in terms of installed capacity (kWh/kW), whereas the Poly system produced the lowest.

2. Research Methodology

2.1. Site selection

Ghazni, strategically situated in the southern region of Afghanistan at 33° 18' 54" N latitude and 67° 49' 44" E longitude, is the focal point of this research due to its unique energy landscape and potential. The city faces a substantial energy deficit, with electricity supply to residential and commercial sectors severely limited by the grid [18]. Figure 2 [16] shows the location of target province in Afghanistan.

Figure 2
Location of Ghazni province in Afghanistan

2.2. Data collection

2.2.1. Weather condition

The summer months in Ghazni are marked by high temperatures, dry conditions, and clear skies, whereas winters are more cold, often followed by snowfall, and generally clear. During the year, the temperature typically varies from −5°C to 33°C and is rarely below −11°C or above 36°C. The hot season lasts for 3.9 months, from May 22 to September 17, with an average daily high temperature above 27°C. The hottest month of the year in Ghazni is July, with an average high of 33°C and low of 19°C. The cold season lasts for 3.0 months, from December 2 to March 3, with an average daily high temperature below 10°C. The coldest month of the year in target area is January, with an average low of −5°C and a high of 5°C [19]. Figure 3 [19] shows the average high and low temperatures during the year in Ghazni.

The duration of daylight for the selected location experiences significant variations throughout the year. The shortest day, occurring on December 22, is 9 h and 56 min of daylight, while the longest day, coming on June 21, is 14 h and 23 min of daylight. Sunrise times will also vary, with the earliest sunrise at 4:45 AM on June 13, and the latest sunrise occurring 2 h and 16 min later, at 7:01 AM on January 8. Additionally, the earliest sunset will take place at 4:47 PM on December 5, and the latest sunset will arrive, at 7:10 PM on June 29 [19]. This information is graphically represented in a sun path diagram for Ghazni province in Figure 4 [18].

As far as wind has also its impact both on economic of a project and its energy output, in a way that strong structures are needed to be made to stand against wind force and this can keep the surface temperature of the panels low, so that losses would be lower and we would have much energy output. Winds flow 4.7 months in a year, starting from January 23 and extending to June 12, with average wind speeds of 3.1 meters per second. March is particularly notable as the windiest month in target area, highlighting an average hourly wind speed of 3.6 meters per second. The calmer time of year lasts for 7.3 months, from June 12 to January 23 [20]. The calmest month of the year in Ghazni is August, with an average hourly wind speed of 2.6 meters per second, and Figure 5 [19] shows the Average wind speed in the selected location.

2.2.2. Solar insolation

From May 6 to August 28, or 3.7 months, is when the year is brightest, with an average daily incident shortwave energy per square meter exceeding 7.8 kWh. With an average brightness of 8.9 kWh, June is the brightest month of the year in Ghazni. From November 8 to February 13, or 3.1 months, is when the year is at its darkest, with an average daily incident shortwave energy per square meter of less than 4.5 kWh [20]. The darkest month of the year in Ghazni is December, with an average of 3.5 kWh, Figure 6 [19], shows Average Daily Incident Shortwave Solar Energy in Ghazni.

In Table 1 [18], global horizontal irradiance, horizontal diffuse irradiance, and ambient temperature from January to December are summarized for Ghazni province. Moreover, the annual global horizontal irradiance is 2085 kWh/m², horizontal diffuse

Table 1
Monthly global horizontal irradiations, horizontal diffuse irradiations, and ambient temperature in Ghazni

Months	GlobHor KWh/m^2	DiffHor KWh/m^2	T_Amb °C
Jan	81.6	36.33	−0.74
Feb	82.6	53.18	−1.21
Mar	159.7	64.98	5.94
Apr	198.1	66.61	12.22
May	239.8	70.42	14.63
Jun	251.9	66.3	21.09
Jul	249	68.45	22.71
Aug	229.4	64.89	22.29
Sep	201.2	39.5	18.47
Oct	170.6	30.54	13.47
Nov	120.1	28.56	6.71
Dec	101	26.15	0.45
Year	2085	615.91	11.34

Figure 3
The average high and low temperature in Ghazni

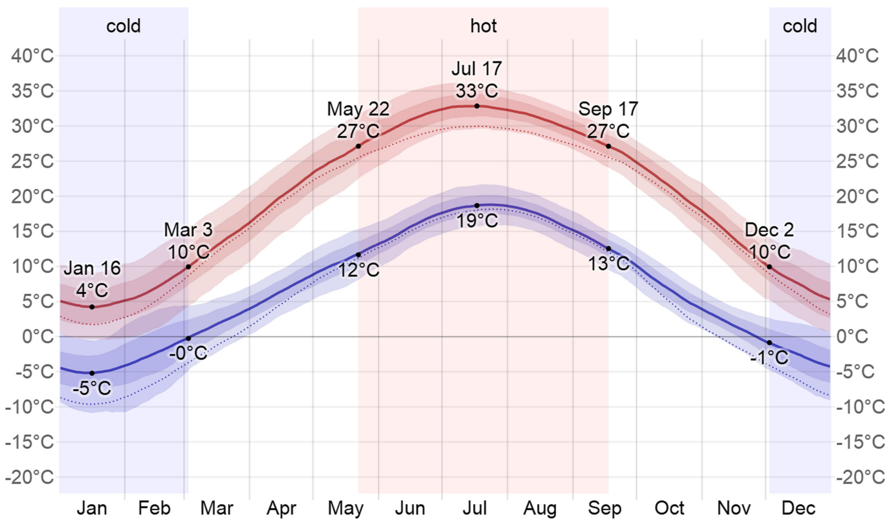


Figure 4
Solar elevation and azimuth in Ghazni

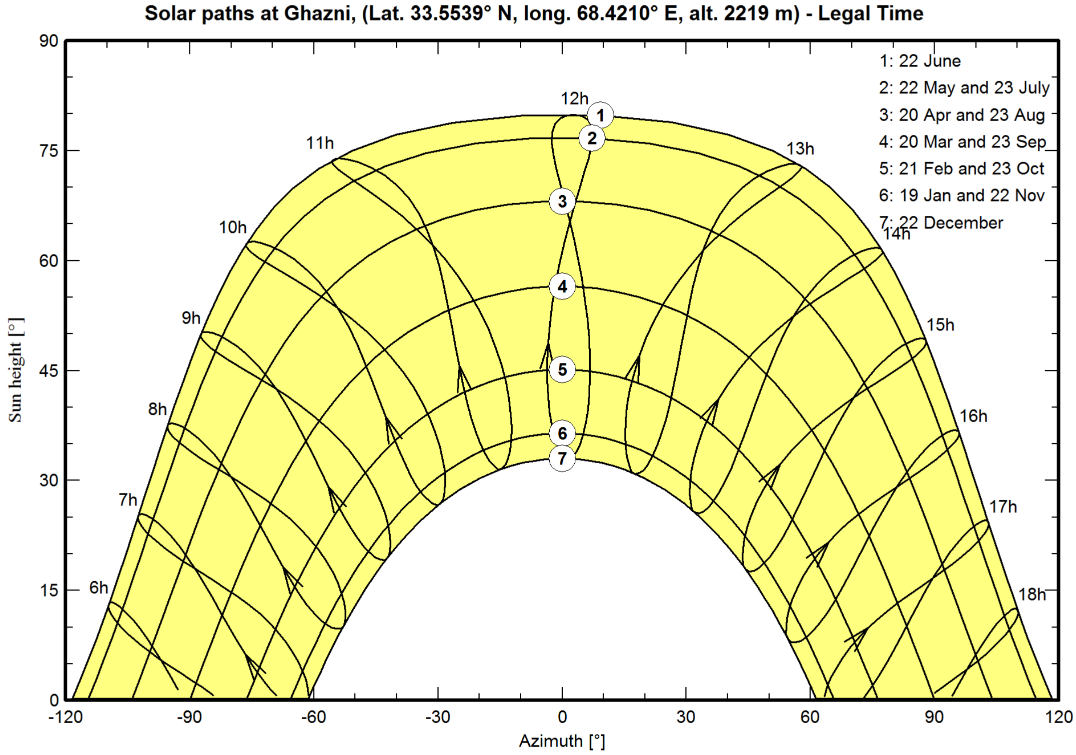
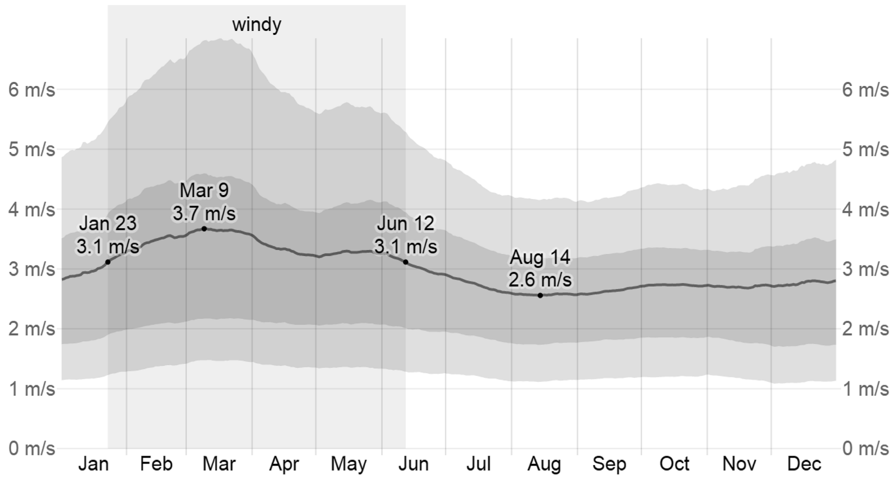


Figure 5
Average wind speed in Ghazni



irradiance is 615.91 kWh/m², and the mean ambient temperature is 11.34°C [19].

2.3. System design

2.3.1. Based on available area

At this coordinate, sun has different positions during a complete year. In summer, it is higher, while in winter, it is lower [21]. To maximize sunlight capture year-round, finding the right balance is crucial [11]. After careful analysis, it is been determined that a 30-degree tilt angle is ideal here. This angle strikes the perfect balance between maximizing summer energy production and ensuring sufficient winter sunlight. At 30 degrees, the panels capture maximum sunlight during summer when the sun is high, resulting in more energy. Even during the lower winter sun, this angle still allows for significant sunlight, preventing a sharp drop in energy production. Setting the panels at a fixed 30-degree tilt optimizes energy generation throughout the year, boosting overall efficiency and electricity output.

Table 2 shows the specifications of the building roof the targeted area is the available area for solar PV modules installation and is 60 m^2 due to the south with a 30° tilt angle. The drawings for the tilt angle and the building are shown in Figure 7.

Figure 6
Average daily incident shortwave solar energy in Ghazni

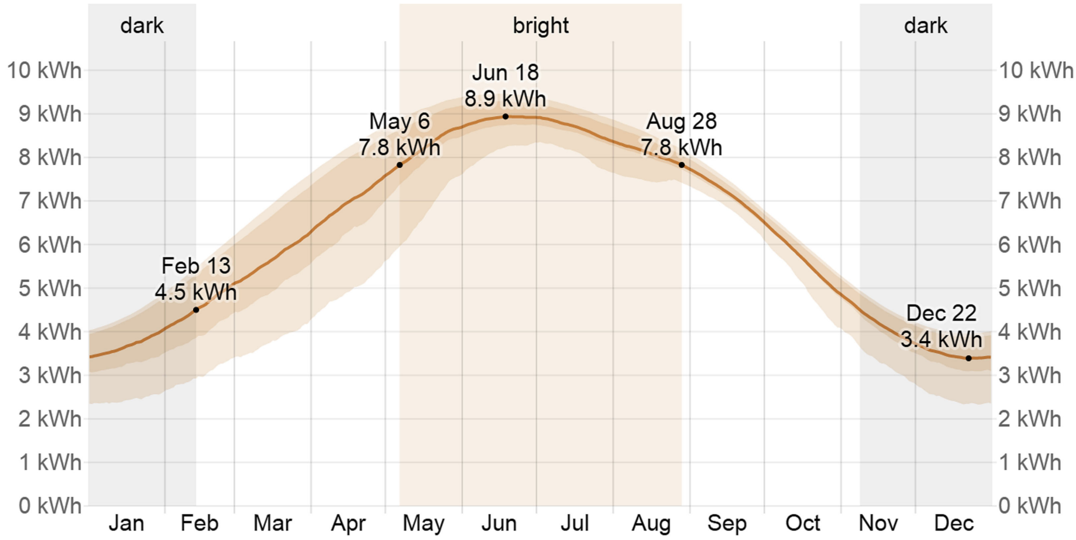


Table 2
Specification of the building's roof

No	Items	Level
1	Dimension	15 m, 10 m, 3 m
2	Available area	60 m^2
3	Orientation	South
4	Tilt angle	30 degree
5	Total area	150 m^2

Figure 7
Tilt angle for the building's roof

2.3.2. Based on capacity

The system design for the research was approached based on capacity, specifically focusing on a 10.23 KWp (kilowatt peak) system. This design choice was made to ensure a standardized and directly comparable assessment of both mono-crystalline and poly-crystalline solar PV technologies. By opting for a fixed 10.23 KWp system capacity, we aimed to eliminate any capacity-related variables that could introduce bias into the comparative analysis. This design not only allowed for a clear evaluation of energy output and performance ratios but also ensured a consistent and equitable assessment of the two PV technologies under consideration, ultimately enhancing the reliability and objectivity of the research findings.

2.4. PVsyst simulation

PVsyst is a widely utilized software tool in the field of solar energy. Designed to model and simulate photovoltaic systems, PVsyst aids in the design, optimization, and assessment of solar power generation projects [22]. It enables users to analyze various factors, including solar irradiance, shading, module characteristics, and system performance, providing valuable insights into energy production estimates, financial projections, and the overall feasibility of solar installations [23]. With its comprehensive features and advanced algorithms, PVsyst plays a crucial role in supporting informed decision-making for efficient and effective utilization of solar energy resources [5].

A typical set of meteorological parameters drawn from historical data from 2000 to 2014 is provided by the NREL and NSRDB TMY dataset [24]. This dataset contains data on temperature, wind speed, sun irradiation, and other pertinent meteorological factors. The performance and potential for energy generation of PV systems are precisely examined in this research using TMY data [25].

3. Results and Discussion

The design of both scenarios is carried out by PVsyst, and its results are summarized in Table 3 and Table 4.

Table 3 presents the monthly output energy and performance ratio for both mono-crystalline and poly-crystalline solar PV technologies in each 10.23 kWh system. Table 4 is for the 58.2 m^2 area system. The yearly output energy from the poly-crystalline solar PV system is 20,763 kWh, 18,813 KWh for system based on capacity and area, respectively, and also mono-crystalline solar PV system is 20,843 kWh, 21,320 KWh for system based on capacity and system based on solar panel area, respectively, which in both cases are higher than poly-crystalline solar PV system. Additionally, the yearly average performance ratio for the poly-crystalline solar PV system is

Table 3
Monthly output energy and performance ratio for both mono and poly (10.23 KWp) solar PV systems

Months	Output power from (10.23 KWh) system		Performance ratio of (10.23 KWh) system	
	Mono	Poly	Mono	Poly
Jan	1153	1143	0.893	0.885
Feb	949	942	0.901	0.894
Mar	1737	1721	0.857	0.85
Apr	1861	1846	0.827	0.82
May	2021	2007	0.815	0.809
Jun	1948	1948	0.783	0.783
Jul	1946	1956	0.773	0.777
Aug	1949	1960	0.774	0.779
Sep	1964	1965	0.787	0.787
Oct	2013	2002	0.815	0.81
Nov	1698	1683	0.857	0.85
Dec	1604	1590	0.893	0.886
Year	20843	20763	0.822	0.818

Table 4
Monthly output energy and performance ratio for both mono and poly solar PV systems from (58.2 m^2 module area)

Months	Output power from 58.2 m^2 module area		Performance ratio from 58.2 m^2 module area	
	Mono	Poly	Mono	Poly
Jan	1174	1038	0.91	0.908
Feb	967	856	0.919	0.917
Mar	1768	1561	0.872	0.869
Apr	1896	1673	0.841	0.837
May	2061	1818	0.83	0.826
Jun	2000	1763	0.803	0.798
Jul	2007	1769	0.796	0.791
Aug	2012	1773	0.797	0.793
Sep	2018	1778	0.807	0.802
Oct	2056	1813	0.83	0.826
Nov	1728	1526	0.87	0.867
Dec	1633	1445	0.907	0.905
Year	21320	18813	0.839	0.835

81.8% and 83.5% for system based on capacity and system based on area, respectively, whilst that of the mono-crystalline solar PV system is 82.2% and 83.9%, respectively, which are also higher than the poly-crystalline solar PV system.

Figure 8 shows the performance ratio for both technologies from January to December, in the system based on capacity, and Figure 9 is for the system based on solar panel area. Firstly, the performance ratio of both technologies in both cases is higher in January, February, March, October, November, and December and is less from April to September because of the hot weather. This chart also illustrates that the performance ratio of poly-crystalline solar PV systems is a bit more than mono-crystalline solar PV systems in July and August but during 10 other months the performance ratio of mono-crystalline solar PV systems is much more than that of poly-crystalline solar PV system.

Figure 8
Comparison of monthly performance ratio for both mono and poly solar PV (10.23 KWp) systems

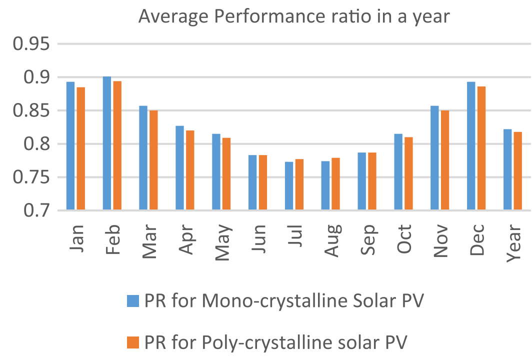


Figure 9
Comparison of monthly performance ratio for both mono and poly solar PV systems from 58.2 m^2 module area

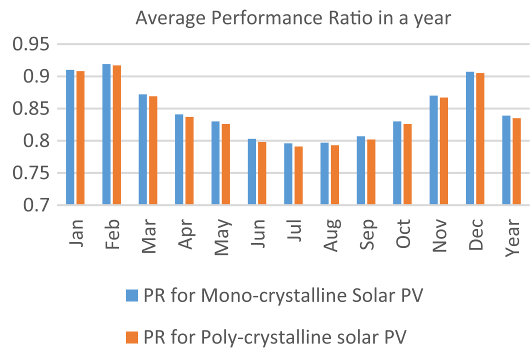


Figure 10 graphically shows a comparison of monthly output energy from both mono-crystalline and poly-crystalline solar PV (10.23 KWh) systems.

Figure 11 presents a comparison of monthly output energy from both mono-crystalline and poly-crystalline silicon solar PV systems from a 58.2 m^2 module area. In this graph, we see that monthly

Figure 10
Comparison of monthly output power for mono and poly solar PV (10.23 KWp) systems

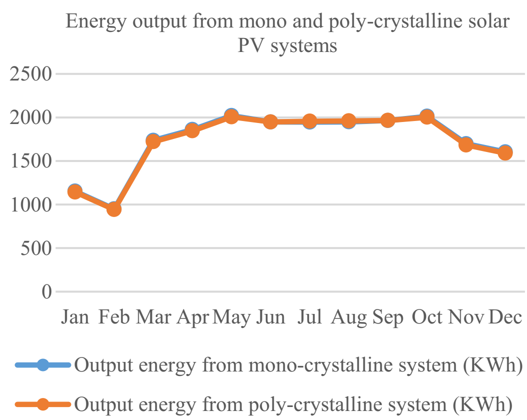
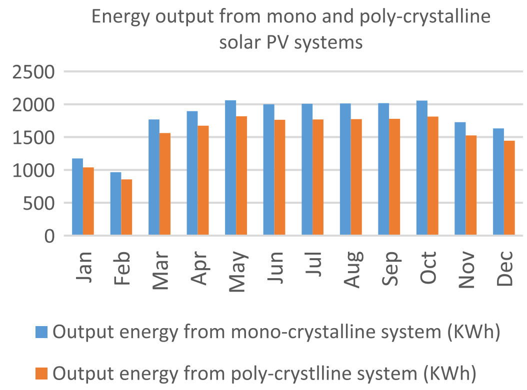


Figure 11
Comparison of monthly output energy for mono and poly solar PV systems from 58.2 m^2 module area



energy output from mono-crystalline solar PV systems is more than poly-crystalline solar PV systems in all 12 months of the year.

As a result, we found that for both systems (according to the output power 10.23 KWp system and from the given PV module area) monthly average and yearly output energy and the performance ratio are more than poly-crystalline silicon solar PV system. From an output power-based system, mono-crystalline solar PV system yearly generates 78 KWh more electrical energy, and from a module area-based system, mono-crystalline silicon solar PV system yearly generates 2469 KWh electrical energy.

4. Conclusion

In summary, this research study evaluated and compared the monthly and yearly output energy of mono-crystalline and poly-crystalline solar PV technologies for Ghazni, Afghanistan using advanced PVsyst software. The outcomes of this research offer insights into selecting an effective solar energy solution for the region. The study's results indicate that mono-crystalline solar PV technology consistently outperforms than poly-crystalline PV technology in terms of monthly and yearly energy output and performance ratio.

Based on the available area we had, the selected technologies could produce a maximum of 10.23 KWp, and as solar panels capacity are measured by KWp, therefore the given area could provide a capacity of 10.23 KWp, the annual output energy from mono and poly-crystalline Solar PV systems is 20843 KWh and 20763 KWh, respectively, with mono-crystalline generating 78 KWh more than poly-crystalline. The annual average performance ratios for mono and poly-crystalline PV systems are 82.2% and 81.8%, respectively. With a solar panel area of 58.2 m^2, the annual output energy from mono and poly-crystalline PV systems is 21320 KWh and 18813 KWh, respectively. This shows a difference, indicating that the annual output energy is higher in the mono-crystalline system than in the poly-crystalline system by 2507 KWh. The performance ratios for mono and poly-crystalline systems are 84% and 83.5%, respectively. This indicates that, in such a climate condition to install and design economically with better energy production and energy output we are required to select mono-crystalline solar panels between the selected two technologies.

To sum up, this study shows for Ghazni conditions mono-crystalline has more energy output and high-performance ratio (PR) than poly-crystalline silicon PV systems.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data are available from the corresponding author upon reasonable request.

Author Contribution Statement

Wahidullah Zgham: Conceptualization, Methodology, Software, Formal analysis, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Safiullah Shirzad:** Software, Formal analysis, Resources, Writing – review & editing. **Sayed Ahmad Zamir Fatemi:** Formal analysis, Resources, Writing – review & editing.

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