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A Survey of Monocrystalline Silicon Photovoltaics in Saudi Arabia

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Abstract - As a global leading oil producer, Saudi Arabia is fully aware of its responsibility in advancing the fight against climate change and its pioneering role in stabilizing energy markets. The country continues this role to achieve leadership in renewable energy by launching various projects. Producing solar electricity contributes to the Kingdom's strategic goal of diversifying its non-oil economy and developing the renewable energy sector to provide alternative energy sources.

Monocrystalline photovoltaic cells are one of the most popular options on the market, with higher levels of efficiency and longevity. However, the work that covers this topic in Saudi Arabia seems very limited, encouraging the purpose of this work.

This article focuses on developing monocrystalline photovoltaic panels in Saudi Arabia and reviews the latest literature on this topic. The paper aims to understand the monocrystalline photovoltaic panels from multiple aspects, their development for the last two decades, and tackle the challenges to contribute and provide support to future works..

Index Terms - photovoltaic technology, silicon production, single crystal silicon, solar challenges.

INTRODUCTION

Conventionally, most of the electrical power in Saudi Arabia is generated using resource energies such as fossil fuels and nuclear energy. Among all, coal has been used widely in electricity generation for decades. However, soon after, gas prices have dropped, which led to electrical power being generated using gas.

Considering the effect of carbon dioxide emission on global warming and the risk of nuclear power, the country rescinds to cleaner electricity generated from renewable energy resources [1].

In renewable energies, electricity power is derived from sustainable resources such as sunlight, wind, water, and other natural processes. Solar energy can constantly reload.

There is no doubt that the potential of solar energy in the Kingdom of Saudi Arabia (KSA) is enormous, given its location within the "global sunbelt," which is generally characterized by high solar radiation [2].

While the earth receives a tremendous amount of power from sunlight, estimated to be a hundred thousand terawatts, Saudi Arabia receives a maximum of 7.004 kWh/m2 of solar power irradiance daily [3], [4]. That is ten thousand more than the total energy use [4]. Hence, it has a massive potential for solar photovoltaic (PV) deployment [5].

The PV technology generates electric power by using solar cells to convert energy from the sun into a flow of electrons by the PV effect [6]. Thus, the country started to invest in solar PV power systems [3] as it is the best way for the government to employ solar energy.

In fact, according to some analytical reports utilizing 1% of the country can result in 470 gigawatts of solar PV capacity [5]. The government of the KSA supports the process of diversifying energy resources through the comprehensive national development strategy included in Vision 2030 [7], and the government has set to generate 60 gigawatts of renewable energy by 2030 and 40 gigawatts coming from solar energy [8]. There are three types of first-generation photovoltaic panels: monocrystalline silicon (mono-Si) panels, polycrystalline silicon (poly-Si) panels, and amorphous panels that are all made of silicon [9].

Mono-Si solar cells are the most popular option on the market and the most efficient form of silicon-based solar panels. Although it might be an expensive selection, mono-Si panels can guarantee higher levels of efficiency in all weather conditions, making them a perfect choice. Several environmental factors can affect PV panels' performance, such as solar irradiance, angle, humidity, temperature, and dust [10].

This paper will essentially focus on developing mono-Si PV solar panels in Saudi Arabia and review the latest literature on this topic.

The paper structure will be as follow. The first section offers an introduction. The second section provides an overview on the works related to this paper. The third section presents a background on the topic. The fourth section is the discussion section that will tackle the challenges and discuss the situation of the mono-Si PV panels in the KSA for the last twenty years. Finally, the fifth section is the conclusion of this work.

RELATED WORK

Some of the survey work was wider and more concerned with distinguishing the differences between the types of silicon PV panels in terms of production and performance. In more specific work, the reviews discuss how a system of monocrystalline silicon panels is manufactured, maintained, or installed.

A review article highlights the tradeoff where monocrystalline silicon cells have a higher efficiency and production cost, while polycrystalline cells are slightly less efficient and cheaper [11], [12].

A survey article discussed the production of PV technologies comprehensively along with their main features, advantages, and challenges [13]. It states that most first-generation and second-generation PV technologies have undergone several alterations involving some aspects to achieve higher efficiency.

Another paper reviewed the potential of using rice husk ash with the highest silica content (94-96%) as a semiconductor material in monocrystalline silicon panels [14]. In other review work, the authors study the deformation of monocrystalline silicon under scratching and polishing [15].

A review article provided a broader investigation to enhance the manufacturing process of wafer-based monocrystalline silicon panels [16]. Some articles evaluate the performance of monocrystalline silicon systems mentioning the environmental factors that impact the system effectiveness [11], [17], [18].

It appears that dust accumulation is the main issue, especially for systems that are often installed under arid climatic conditions [11], which led us to another work that reviewed various automatic cleaning systems, categorizing them into active and passive systems [19]. The article suggests that electrostatic cleaning systems are ideal for scarce water regions, while robotic cleaning systems are not preferred in windy areas [19].

As for the studies conducted in Saudi Arabia, more theoretical work was done than real-life experiments. Some studies have only mentioned monocrystalline silicon panels briefly without any elaboration on their situation locally [1], [20]–[22].

In one relatively old study that analyzes the material in the Tawil Sandstone, the results show that non-undulatory, monocrystalline quartz dominates the quartz fraction (78% of total quartz grains). Monocrystalline grains with slight extinction constitute 21% of full quartz grains [23].However, some of the conducted studies included the monocrystalline silicon panels in their theoretical and experimental work.

A study exploring applying PV systems in unregulated building rooftops for a district in Al-Khubar showed that the study area amounting to 14.21 km2 is estimated to deliver 796 gigawatts of PV electricity [24] annually. Furthermore, it is found that 21% and 28% of the respective apartment and villa rooftops can be effectively used for PV application.

The authors in [22] used monocrystalline silicon panels to investigate the impact of installing a residential solar system in hot-humid climates in the eastern area of KSA using geographic information systems and PV simulation tools. The monocrystalline silicon PV system meets 19% of the electricity demand when 25% of the building roof is utilized. In addition, the cooling load is reduced by 2% due to the shading effect from the panels, and the annual electricity generation of tilted panels has better potential than flat application [22].

Another case study investigates a wind and solar hybrid system for the western coastal area of KSA. The results show that the PV array produces more electricity than the wind turbine generator and that the cost of a hybrid system is dominated by batteries and wind turbine expenses [25].

A study that incorporated monocrystalline silicon panels in their research has done a pilot testing for utilizing mosque rooftops in the middle region called Riyadh [26]. The theoretical and the physical installation results are compatible, and the measured capacity from the system is 18%.

Recent work introduced a nature-inspired spherical mono-Si PV cell, fabricated using a corrugation technique capable of capturing light three-dimensionally and increasing the power output by up to 101% than flat cells [27].

Last but not least, some case studies observe the performance of monocrystalline silicon panels in different regions besides the gulf regions and Saudi Arabia [28]–[31].

Table 1. Related works

No.	Ref.	Topic discussed	Aspects
1	[32]–[35]	Recycling materials of mono-Si panels.	Manufacturing
2	[36]	Detecting crack in mono-Si cells using ultrasonic waves.	Maintenance
3	[28], [29], [37], [38]	Studying the effect of dust accumulation, soiling, irradiance, and temperature on the performance of mono-Si PV system.	Degradation
4	39], [40]	Texturizing the mono-Si panels.	Production
5	[41], [42]	Cutting the mono-Si wafers.	Manufacturing

While further study is warranted, the work took three distinct directions in approaching this topic, which includes (i) surveys and reviews, (ii) case studies in Saudi Arabia, and (iii) cells manufacturing, module installation, system performance evaluation taking into consideration the effect of some environmental factors.

The work covering the monocrystalline silicon PV in Saudi Arabia looks pretty narrow, encouraging the primary purpose of this research to offer a new perspective on monocrystalline advances and tackle challenges that limit the evolution of evolution photovoltaic panels in Saudi Arabia.

BACKGROUND

This section provides a historical background of photovoltaics, how photovoltaic panels work, and explains the process of manufacturing and installing monocrystalline silicon panels and the breakthrough of monocrystalline photovoltaics in Saudi Arabia.

I. History

Physicist Edmond Becquerel discovered the PV effect in 1839 after observing that a cell made of metal electrodes in a conducting solution produced more electricity when exposed to light [43], then Charles Fritz created the first working selenium solar cell in 1883 [44]. Even though the main focus is silicon, this was a significant precursor to today's technology [45]. Afterward, Einstein provided a theoretical explanation of the photovoltaic effect in 1905 [45], allowing better understanding and usage.

Forty years after, the first silicon monocrystalline solar cell was constructed in 1941 [46]. And through the 1950s, Bell Laboratories concluded that semiconducting materials such as silicon were more efficient than selenium. As a result, they managed to create a solar cell that was 6 percent efficient [47], and during that time, silicon solar cells were still cost-prohibitive. Also, producing single-crystal cells to create a solar panel is expensive, making it cost even more for the public to purchase.

However, there have been many solar cell improvements throughout the decades where the efficiency increased, and the cost dropped [45], [48], [49].

As for the history of solar panels in Saudi Arabia, the country was late yet aware of the importance of its global position, which encouraged investing in solar panels for the last decades.

It started in the 1990s and 2000s; Saudi Arabia, with the United States, set up a research station in Al-Uyaynah. King Abdulaziz City for Science and Technology (KACST) operates the station. In 2010, the agency established an experimental assembly line to manufacture solar panels [50].

The first solar power plant was commissioned in 2011 on Farasan Island, a 500 kilowatts fixed-tilt photovoltaic plant [51].

II. How monocrystalline silicon photovoltaic panels work

The modern PV technology is based on the principle of electron-hole creation in each cell composed of two different layers, p-type and n-type materials, of semiconductor material. An electron is ejected by gaining energy from the striking photon when a photon of sufficient energy impinges on the p-type and n-type junction. It moves from one layer to another, which creates an electron and a hole in the process and generates electrical power [52].

According to [53], various semiconducting materials are applied for photovoltaic solar cells, mainly silicon, cadmium-telluride, copper-indium-gallium-selenide, and copper-indium-gallium-sulfide.

The first generation of solar cells is divided into monocrystalline silicon cells and polycrystalline silicon cells. The following part of this work explores the production of monocrystalline silicon panels.

III. Manufacturing

The first stage in monocrystalline cells production is extracting pure silicon such as silicon dioxide, silica, or quartzite gravel from the quartzite gravel to produce metallurgical silicon.

The raw quartzite gravel is converted to silicon through the following reaction $SiO2 + 2 C \rightarrow Si + 2 CO$. The silicon dioxide is first placed into an electric arc furnace (of over 1900ºC), and a carbon arc is applied later to emit the oxygen, producing molten silicon and carbon dioxide [54]. The produced silicon still has one percent impurities, but it can still be used in various industries [49], [54]. Pure silicon can undergo further purification through a procedure known as floating zone. This involves passing the silicon rod through a heated zone several times [54].

The next production stage is to purify the silicon using the Siemens process.

First, Si with HCl is converted to trichlorosilane or SiHCl3 in a fluidized-bed reactor (FBR) through the reaction $Si + 3HCl \rightarrow SiHCl3(g) + H2$. This reaction removes most impurities, but further work is still required [55]. FBR lowers the energy consumption in this step of production [56].

Second, the gas is left to cool down and become liquid for distillation. Then the liquefied trichlorosilane, which boils at 32°C, is distilled to reach the required purity [49], [55].

Third, the liquified trichlorosilane is heated then cooled to remove further impurities.

The $SiHCl_3$ is then mixed with H_2 and moved to a different isolated reactor with a hot rod. The chemical compound is broken down in a reducing atmosphere at around 1000°C via $SiHCl_3 + H_2 \rightarrow Si + 3\ HCl$ reaction. Then, it vaporized again at a temperature of up to 1500ºC. The chemical vapor deposition process leaves thick rods of 99.99% pure silicon [55].

The third step is to create an ingot which was very difficult to get until the Czochralski (Cz) method was discovered and used to produce bulk single crystals for photovoltaic panels [57].

The silicon material is put into a cylindrically shaped crucible until entirely molten. Then, a small pure silicon rod with a diameter of a few millimeters is dipped in the molten feed material (i.e., polycrystalline silicon).

The seed is rotated as it's pulled out and left to solidify, forming a cylindrical ingot of pure silicon.

The fourth step is to cut the ingot into wafers. Silicon wafers are sliced using a wire saw whose inner diameter cuts into the rod one or many times with a multiwire saw [54].

The wafers shaped into a rectangle with round corners is so that they can be fitted together, therefore utilizing all available space on the front surface of the solar panel [54]. Finally, the wafers are polished, improved, diffused, and assembled.

The Silicon wafers having a rough surface or residual damage left on the wafer surface from the cutting are more prone to break than polished wafers [58]. However, sometimes polishing the wafers from saw marks can reflect the light away, so etching the surface is usually opted for by manufacturers since rougher cells absorb light more effectively [59].

The reason behind diffusing wafers is that silicon wafers are positively charged and act as a p-type junction. A p-n junction is required to conduct electricity by adding a phosphorus layer to each wafer and moving it to a special 1652ºF furnace to inject the phosphorus with nitrogen [49]. The temperature and time assigned to the process are carefully controlled to ensure a uniform junction of proper depth [54].

Monocrystalline cell manufacturing is very energy-intensive and results in a lot of silicon waste. As a result, it is considered the most expensive type of silicon photovoltaic panels.

Their efficiency may reach 26.1% in the laboratory, while commercially deployed cells have an efficiency of no more than 24.4%, with a life span of 30-40 years or more [60].

As for their recyclability, 80% of monocrystalline silicon wafers are recyclable, whereas, for the mounting system, the glass and metal can be reused or recycled. The monocrystalline silicon solar cell will temporarily lose 0.3% to 0.5% of its efficiency in case the temperature rises by one degree Celsius [49].

Nowadays, thin films offer lower-cost materials, potential scalability and automation of the fabrication processes, and efficiencies competitive with the predominant technology [61]. Most importantly, the flexibility of thin films enhances solar power availability. Therefore, many works explored the monocrystalline thin-films technology to advance towards a newer generation.

IV. Installation

In general, there are grid-tied, also called grid-connected PV systems with or without batteries and off-the-grid systems. The grid-tied systems enable free electricity created from the solar system and electricity from the National Grid. The most common type of installation is off-the-grid installation, offering electricity to any isolated location.

Mono c-Si PV systems are like most solar systems consisting of panels, an inverter, a mounting system, and a controller. As for off-the-grid systems or backup systems, a battery and connected load storage are required. The solar panels generate a direct electric current from sunlight then the inverter converts the produced electricity into alternating current to be suitable for use. Finally, the controller operates the solar system and guarantees the best performance.

There are different methods and ways to install any PV system. Three main categories will be discussed: (i) distributed generation (DG): residential, commercial, and industrial. (ii) utility-scale: large, ground-mounted power plant systems, and (iii) more special installations: hybrid systems.

In residential solar, the property owners benefit from the system by sending the electricity produced directly to the property and any excess back to the grid to balance expenses.

The panels are installed on a business's property in commercial and industrial installations, from rooftops to parking lot shades to vast open fields.

Residential and commercial are called distributed generation (DG) systems generally installed on rooftops or ground-mounted if possible. On the other hand, utility-scale systems can be only ground-mounted and require a relatively large land area [62].

When it comes to having photovoltaic systems as an element in building design, there are two ways to mount panels to buildings: integrated PV systems and attached PV systems [9].

The system is integrated into the construction of new buildings as an elementary or supplementary electrical power source. The integrated system elements intend to perform the work of the conventional components as rooftops, windows, and facades to substitute in the building.

The attached PV system is incorporated into the building after the construction, which is the most frequently used method. Attached PV systems are more preferred than new construction integrated PV systems, where the cost is expensive, and the process is complex in terms of mounting and maintaining the structure.

According to [63], the residential PV power generation capacity of Saudi Arabia can contribute to 30% of total residential electricity demand.

Additional studies investigate the overall impact of rooftop PV systems on the energy performance of residential buildings in hot-humid climates and Saudi Arabia [64], [65].

The installation depends on large power plants to offer electricity for thousands of homes and businesses for the utility-scale.

As for large power farms, there are two types of installation to fit the system at an angle: ground-mounted fixed plants and tracking solar plants that follow the sun.

A feasibility study is conducted to analyze a ten MW production capacity grid-tied power plant for 44 sites in KSA using RETScreen and a monocrystalline solar module [66]. The results showed that Bisha is the best site for the installation, and Sulayel is the worst due to solar radiation intensity and sunlight duration [66].

Hybrid systems and special solar applications improve the efficiency of conventional solar systems. Combining monocrystalline photovoltaics and a high-efficiency solar thermal collector (PV/T) in one system is an excellent example of hybrid systems. Although PV/T collectors provide both electric and thermal energy generation due to their cooling effect on the PV module, it has higher efficiency at a lower cost price than separate similar efficiency PV and Thermal systems [67]. Furthermore, it saves installation costs, with only one installation being required.

In a simulation study covering grid-tied power plants in Saudi regions Yanbu and Rabigh, the estimated results showed that the best tilt angles are 26.4º and 25.8º, respectively [68]. The authors also covered Al Shuaiba and Al Shuqiq, where the best tilt angle for both is 21º [69]. The production capacity estimated for all stations is better with the tracking system than the original one.

V. The current situation in Saudi Arabia

Saudi Arabia is still working on many investments, projects, and research to transform to more sustainable energy, decrease carbon emissions, and achieve a balanced mixture of renewable energy. Several projects are summed up in Table 2, initiated under The National Renewable Energy Program (NREP) in line with the Saudi vision 2030.

Table 2. Renewable energy projects in Saudi Arabia [7].

Project	Production capacity	Location
Sakaka Solar Power Plant	300 MW	Aljouf
The Shuaibah IPP PV Project	600 MW	Jeddah
The Rabigh IPP PV Project	300 MW	Rabigh
Qurayyat IPP PV	200 MW	Aljouf
Medina IPP PV	50 MW	Madina
The Rafha IPP PV Project	20 MW	The Northern Borders
Sudair IPP PV	1500 MW	Riyadh
Water Desalination Project Using Solar Power	60,000 m^3/day of clean water	KASCT, Riyadh

Water Desalination Project Using Solar Power 60,000 m^3/day of clean water KASCT, Riyadh

A study that reviews renewable and sustainable energy in Saudi Arabia provided a historical sequence of solar power projects in the KSA and their applications and production capacity [70].

KACST has implemented, developed, and produced many solar energy technologies to support the industrial base and achieve leadership for the Kingdom in owning its technologies. Starting with the research and manufacture of silicon used in the production of semiconductors, such as in solar cells and electronics, by being reliant on the white sand available in large quantities in the Kingdom [71].

The city is developing and manufacturing three types of monocrystalline silicon solar cells. The first type of monocrystalline silicon wafer is doped with trivalent material with an efficiency of up to 21 percent. The second type of monocrystalline silicon wafer is doped with pentavalent material between two amorphous silicon layers. It reaches an efficiency of 16 percent and is working on improving it to get the worldwide record of 23 percent. The third type depends on gallium arsenide, which is characterized by absorbing sunlight, as 3 micrometers of this material is sufficient to absorb about 95 percent of sunlight.

Recently, Longi Green Technology, one of the biggest monocrystalline silicon makers, has been looking to set up more overseas manufacturing plants, including Saudi Arabia [72].

Another project is Riyadh Metro Project, already holding a bid to tender for monocrystalline PV modules set on the rooftops of metro infrastructure and signing deals with production companies [73].

Although KSA is still absent in producing PV panels, a Saudi electric company has assigned a 1.2 GW factory located in the industrial district of Tabuk, where the manufacturing facility will produce monocrystalline modules provided by Spain's Mondragon Assembly [74].

Researchers at the "KAUST" have come up with a new technology to produce solar cells based on a mixture of perovskite and traditional silicon cells [75]–[77]. Conventional solar cells use only one semiconductor to convert sunlight into electricity, but their theoretical efficiency is limited to about 33 percent. However, this project increased this percentage to 44 percent by placing two semiconductors inside a tandem solar cell, using perovskite and silicon.

Another study converts large-scale rigid monocrystalline photovoltaic cells with interdigitated back contacts (IBCs) into a flexible version with a preserved efficiency and improved thermal dissipation [78].

KAUST also developed a nature-inspired spherical monocrystalline solar cell capable of capturing light three-dimensionally [27]. In addition, the spherical cells can provide a ten percent lower maximum temperature than flat monocrystalline cells while accumulating less dust.

DISCUSSION

Saudi Arabia has great potential and competitive capabilities in manufacturing various materials used in solar energy technologies, including the high purity of silica, which is the backbone of the photovoltaic industries. It holds the lowest prices as a producer of renewable energy as well as a producer of oil.

This fact makes Saudi Arabia a strong candidate to become a substantial lead for renewable energy production, especially since monocrystalline cells take a long time to produce. In addition, the country can depend on its abundant silica resources that are available in white sand.

As for the ingot and wafer industries, KSA has not been present in the scene, but it is one of the main targeted industries for PV component localization in the future [21].

I. *4.1 The first challenge is to increase the efficiency of monocrystalline solar cells and mitigate the degradation of the cell, which evolves the following.*

Enable monocrystalline panels to capture the maximum amount of sunlight

The direction of the solar panels must be determined first, towards the south or the north. If the region is north of the equator, the direction of the panels must be to the south and vice versa; therefore, it depends on the movement of the earth's rotation on its axis.

Determining the inclination angle of panels depends on the measurement of the latitude passing through the installation area. If the latitude is 23º, it is preferable to install the solar panels at an angle of 23º in respect of the direction (towards the south or north).

As for most of Saudi Arabia's region, an analytical study showed that tilt angles of 20◦, 25◦ , and 30◦ towards the south are the best depending on the location, in which 82 sites are defined to three distinct solar energy zones in Saudi Arabia [79].

Dealing with ambient temperature and reducing heat generation

The increase in temperature reduces the productivity of the solar system. Therefore, installing the panels at the height of 50 cm from the surface is necessary, as the air gets heated by convection from the earth's surface, so the higher we rise, the colder the air. Also, making the back of the panels an open place for air to pass through will reduce the temperature. And finally, painting the pillars or the structure of the mounting system with white paint as light colors absorb and emit a small amount of heat.

Mitigate dust accumulation problems.

Dust accumulation is one of the main challenges, especially for countries like Saudi Arabia with vast deserts. Where it reduces the transmittance of solar irradiation to the cells as studies showed that dust reduces the module's performance in terms of power output by 50% over six months. And therefore, Stakeholders must include a periodic maintenance and cleaning system.

Eliminate the effect of humidity

West and east costs in Saudi Arabia have a relatively high humidity degree. The water particles can collect on the panels and reflect or refract the sunlight away, affecting the system's efficiency. For example, it is proven that relative humidity reduces the performance of monocrystalline PV modules by 50% more than the impact of temperature. Some manufacturers take further precautions to prevent humidity from degrading solar panels faster, such as edge sealants and low ionic conductive materials.

II. *Another challenge is establishing the Kingdom's presence in the industrial PV market by production and installation.*

Reduce the environmental impact of the waste

As the installation of monocrystalline PV modules rapidly increases, the volume of modules that reach expiration will grow at the same rate, which causes enormous material waste. Therefore, the only way to deal with the environmental impact would be to reuse and recycle some old materials.

Limit installation and production costs

Installation and maintenance costs are another problem that holds monocrystalline and other photovoltaics adoption. For example, the amount of sunlight and the angle that panels are set to face can impact the absorbed amount. Cells must be vertically facing the sun using movable solar panels that track different angles of where the sun falls throughout the year. However, moving panels installation is expensive compared to fixed panels installation and the wasted energy. Also, residential system installation is viewed as unnecessarily expensive considering the energy generated, which is often lower than what is regularly consumed.

This issue also applies to the production process of monocrystalline silicon. Although monocrystalline silicon panels have the best efficiency, temperature coefficient, and lifespan among silicon-based panels, people in the industry and clients still opt for polycrystalline panels.

While these panels cost more due to the production method of monocrystalline ingots, people resolve to enjoy the benefits of clean energy and the potential for lower electricity bills by using a polycrystalline PV system, especially now that polycrystalline is catching up in efficiency with monocrystalline cells. However, many works are done to improve monocrystalline panels' efficiency and life span, which is the only way to widen the gap and gain advantages to benefit commercially.

To protect the solar energy sector in Saudi Arabia from low-quality products that may negatively affect the Kingdom's economy, the first laboratory has been set up to simulate the climatic and environmental conditions in the Kingdom and their impact on the components of the solar system [80].

CONCLUSION

Saudi Arabia showcased many efforts and showed great awareness of its obligation to reduce carbon emission and fight against climate change given the important projects by the renewable energy sector.

This paper offers an additional perspective on monocrystalline advances locally and tackles challenges that limit the evolution of photovoltaic panels in Saudi Arabia.

The paper extends to cover more as the origins of this technology, the production, the installation, and the performance.

There are two common types of the first and famous generation of photovoltaic panels, and while monocrystalline silicon cells are the expensive ones, they are the best choice because this type of photovoltaics has better efficiency, temperature coefficient, and lifespan.

The various scientific research and technical approaches discovered and recommended by literature must be taken into account to determine the best way to decrease the production expenses, install solar panels, and improve the performance of monocrystalline photovoltaics.

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