Polycrystalline photovoltaic panels in Saudi Arabia: Development and challenges

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***Abstract*—**

Throughout the years, oil has always been the primary energy source that was most commonly used worldwide. However, with the skyrocketing cost of oil the world is facing nowadays, including the high rate of carbon emission and pollution, which is increasing day by day, Saudi Arabia and other developed countries started to aim for using renewable and sustainable energy and its sustainability by harvesting the solar energy for their nations.
Solar energy is considered one of the essential energy sources on earth; there can never be life without solar energy. It is known that the solar radiation amount which reaches the earth is commensurate to how much life needs on earth, which we utilize a small portion of it. Unlike any other energy, solar energy can be viable, sustainable, cheaper, and environmentally friendly.
The fact that Saudi Arabia lies within the sunbelt near the equator encouraged it to acquire photovoltaic technology.
The fundamental objectives of the paper are to establish an understanding of the polycrystalline photovoltaic panels from multiple aspects, their development for the last two decades, and the challenges in the hope of providing support to other researchers future work. In addition, this work includes a significant number of references for further interpretation.

***Index Terms*—**Polysilicon, photovoltaic technology, silicon production, solar panels installation, solar challenges
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I. Introduction

The earth intercepts enormous solar power, which is estimated to be 137,000 TW. That is 10,000 more than the world's total energy use [1]. This fact encouraged many researchers to study solar energy and discover how to utilize it.

The best way to utilize it is through the photovoltaic (PV) technology which generates electric power by the use of the solar cells that has the ability to convert the energy captured from the sun into a flow of electrons; this is done by the photovoltaic effect.

Solar photovoltaic cells are made of certain materials, which are semiconductor materials like silicon, forming an electrical circuit to produce from sunlight a direct current of electricity. It can be used to provide power for equipment or even to recharge batteries.

After discovering the solar photovoltaic effect, many countries started to invest in solar photovoltaic power stations, also known as solar fields or solar plants, which are large-scale photovoltaic systems designed to supply power into the electricity grid.

Solar photovoltaic power is essential to generate sustainable, environment-friendly, and cost-effective energy that supplies electricity at a larger scale. It is more important in Saudi Arabia, where the solar radiation is extremely high and can be used as an alternate for viable energy. Moreover, the country aims to decrease carbon dioxide emission (CO_2) and back efforts to supply clean energy to the world.

As a result, the country started to adopt solar power and its technologies to advance energy efficiency and conservation and become less reliant on conventional energy. The country started investing in solar fields, and there are also distributed solar panels installed on rooftops.

People have grown familiar with solar photovoltaic panels that have managed to reap all the solar energy advantages, and both cost and efficiency have been slowly improving.

Some factors influence the efficiency of these panels. These factors could be due to production, installation, or environmental variables [2]. For example, the type of panels, the angle where the sunlight hits the panels, solar irradiance, dust, ambient temperature, and wind speed can impact the performance [3].

On a production level, there are three popular kinds of PV panels that are produced from silicon [4]. The polycrystalline (poly c-Si), the monocrystalline (mono c-Si), and the amorphous (a-Si) panels.

First, poly c-Si PV cells are made of multiple crystals of pure silicon fragments formed together. Second, Mono c-Si PV cells are made of a single pure silicon crystal. Finally, amorphous solar cells are the non-crystalline form of silicon, also known as thin films[5].

Out of the three, the most cost-effective and accessible panels are polycrystalline [6]. Recently, polycrystalline silicon panels have been catching up in efficiency and competing with monocrystalline over the most efficient panels.

Although poly c-Si PV panels are among the most obtainable panels in Saudi Arabia, research on this topic is still limited and very narrow.

The literature usually approaches this topic under a broad range that discusses solar panels with a brief mention of polycrystalline panels.

This fact motivated the purpose of this work, which is to accumulate the state of the art in polycrystalline photovoltaic panels in Saudi Arabia and to addresses the challenges that stand in the way of this technology.

The paper will essentially focus on the development of polycrystalline silicon photovoltaics and offer the latest literature on this topic by discussing production, installation, climatic factors, and performance evaluation.

The structure of this paper will be as follow. The first section is the introduction, and the second section is an overview of the related works. The third section provides a background on the topic. The fourth section is the discussion that will tackle the challenges and discuss the development of the polycrystalline PV panels in Saudi Arabia for the last twenty years. Finally, the fifth section concludes this work.

II. Related Works

This section provides a thorough literature review on polycrystalline photovoltaic panels. It offers insights about review and survey research in the same topic presented from different perceptions and supported by further related work, impacting this research on a statistical and theoretical level.

The literature varied in perceptions, starting with surveys and reviews and following up with experimental work. Some of the work addresses production, and other focus on system evaluation. Most of the work discusses environmental variables considering that climate change and the ambient temperature are the biggest challenges.

For the manufacturing of solar panels, most of the work considered the scale of the production and the types of material involved. One of the earliest reviews covers the technical advances of a distinct technology production called polycrystalline thin-films solar panels and their future [7]. The polycrystalline thin-films PV panels technologies are based on copper indium diselenide (CIS) and cadmium telluride (CdTe). The thickness of cells found in this technology is in nanometres to ten micrometers, much thinner than the first-generation crystalline silicon solar cell with wafers of two hundred micrometers thick. Another paper reviews the commercial status of CIS and CdTe-based photovoltaic modules, compares the commercial products' performance, and concludes that among all, CdTe and CIS provide advantages that are cost-competitive over the crystalline silicon [8].

Research paper reported the poly c-Si production advancements in two years, focusing on cutting down the wafers to ultra-thin to produce cells which have efficiencies of at least 15.4% at a total yield overriding 95% [9], which established a rise in the capacity of the silicon feedstock industry's production. Additional survey work reported new refinementsto the poly c-Si PV module and the manufacturing technologyat the time [10] and commercialization [11]. A more recent review presents the new progress in the metallurgical and chemical routes for the production of silicon photovoltaic [12].

For the experimental work, some work introduces a mathematical model based on the indentation fracture mechanics to study the surface formation, and the effect of the position angle of the abrasive in wire saw surface on the material removal mode [13]. There is also a theoretical experiment to forecast the surface roughness of poly c-Si wafers in paper [14].

The literature considered environmental and climatic impacting factors such as wind speed, ambient temperature, solar irradiance, and the sunlight angle hitting the panels.

A review paper studies the individual efficiencies of absorption, thermalization, fill factor, thermodynamic, and the overall conversion efficiencies of a poly c-Si PV cell [15]. The paper concludes that the poly c-Si PV cells are more suitable for the temperature rise than the mono c-Si cells and that the temperature generally leads to the degeneration of silicon PV cells' performance. Another case study conducted in Bahrain showed that mono c-Si panels have failed under the same conditions and developed severe corrosion; meanwhile, poly c-Si panels showed a drop in the output [16]. A different study investigates the degradation of four poly c-Si modules from different manufacturers installed in desert climatic conditions in the United Arab Emirates. Some of them showed 0.2% degradation and deviation due to the optical losses which result from the sand abrasion [17].

Most of the experimental work addresses temperature as the main challenge for solar panels performance. The solar radiation absorbed by a PV panel is converted into electric power and contributes to increasing the module's temperature, therefore decreasing the electrical efficiency. Knowing this fact encouraged the researchers to improve hybrid PV/thermal collectors (PV/T) that generate electricity and produce hot air or hot water [18] and contribute to the efficiency improvement of the poly c-Si panels by using the thermal control water spraying cooling [19]. Another work surveys the impact of temperature on the output performance to predict panel performance under different temperature conditions in Malaysia [20].

Other experimental work studies the impact of impulse voltage on changing the electrical behavior of poly c-Si PV panels. The outcomes revealed that the optimal power output gradually decreases [21].

Another exciting study investigates the CO_2 emission of Poly c-Si and CdTe compared to gas-powered thermal power plants [22]. It shows that PV panels save 1.72 tons of CO_2 emissions than the thermal power plant; therefore, photovoltaic panels appear to be 9.52 times more environmentally friendly.

Another environmental concern for the poly c-Si PV performance is solar irradiance that goes hand in hand with ambient temperature. This work introduced hot spot mitigation techniques to guarantee a decrease in the shaded photovoltaic cell temperature, and therefore a rise in the photovoltaic output power [23]. Another work conducted in Morocco looks into the output power of a fixed panel equipped with poly c-Si PV cells under different temperatures and irradiances [24]. The regional study estimates the real irradiance potential using an accurate radiation model and suggests a suitable solar tracking technology concerning the chosen site.

In further work, an article explains the sufficient amount of underwater solar power that can be utilized using PV cells to operate various devices and systems, providing practical evidence and statistical analysis [25].

Furthermore, the literature consisted of case studies based in a specific region to report on the advances of poly c-Si panels and their performance, such as in countries with similar environmental conditions [26]–[28].

There are a few papers that address poly c-Si PV in Saudi Arabia.

A theoretical study conducted in the east of Saudi Arabia on poly c-Si panels showed that module efficiency decreases by 1.2% when the temperature increases by 10 °C, which means it has a temperature coefficient of -0.12 ΔE/ºC [29].

Another experimental work studied installing a novel thermal photovoltaic system under harsh climates conditions in Saudi Arabia showed that the liquid immersion technique protects the PV panel from the hot spot equipment and leads to better heat dissipation [30].

While further study is warranted, the work took three distinct directions in approaching this topic, which includes (i) the production, (ii) the system installation, and (iii) the system performance evaluation taking into consideration the effect of some environmental factors.

Upon review, the work that covers the poly c-Si PV in Saudi Arabia seems very limited. Thus, the primary objective of this research is to offer the state of the art of polycrystalline panels and tackle the solar challengesin Saudi Arabia.

III. Background

This section provides a historical background of photovoltaics and explains the process of manufacturing and installing poly c-Si PV panels in addition to their breakthrough in Saudi Arabia.

A. History

The PV effect was primarily discovered in 1839 by physicist Edmond Becquerel after observing that the cell made of metal electrodes in a conducting solution produced more electricity when it was exposed to light [31].

Fifty years later, after discovering the PV effect, Charles Fritz created the first working selenium solar cell in 1883 [32]. Although silicon is more used in the cells for modern solar panels; however, this solar cell was a significant precursor to the technology used nowadays [33].

Einstein provided a theoretical explanation of the PV effect in 1905 [33]. This interpretation allowed other scientists to understand better and use it.

The first monoc-Si solar cell was constructed in 1941 [34].

Through the 1950s, Bell Laboratories concluded the semiconducting materials, where these materials such as silicon were of more efficiency than selenium. As a result, they created a solar cell that was 6% efficient [35].

At the time, it was still expensive. Silicon solar cells were costly to produce, and accordingly, combining several cells to create a solar panel was even more expensive for the public to buy.

However, there have been many solar cell improvements. In the 1950s, the efficiency increased from 1% to 10%, and the cost was around $300 per watt [33]. Soon after, solar panels reached 14% efficiency in the 1960s. In addition, using the solar panels in the space program raised production, which slowly caused the reduction of the price to around $100 per watt [33].

In the 1970s, the boost of innovative research in this field led to producing a less costly solar cell, reducing the cost to about $20 per watt. Ever since the 1980s, the cost of solar panels has dropped on an average of 10% per year [36]. The first solar panels made of poly c-Si were introduced to the market in 1981 [37].

Currently, home solar panels reached an efficiency between 15% and 18% and have a cost as low as $0.50 per watt [38].

Many physicists played a part in solar cell invention in a way or another. For example, Becquerel had the attribution of uncovering the potential of the PV effect, and Fritz's was with actually creating the ancestor to all solar cells.

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 all started in the 1990s and 2000s when the United States and Saudi Arabia set up a solar-research station in Al-Uyaynah village. The village lies 30 miles northwest of Riyadh. It had no electric supply at that time. King Abdulaziz City operates the station for the sake of Science and Technology. In 2010, the agency instituted an experimental assembly line to manufacture solar panels [39].

The first solar power plant of Saudi Arabia was commissioned in 2011 on Farasan Island. The solar power plant was a 500 kilowatts fixed-tilt PV plant [40].

Providing that the expenses of the solar projects decreased by nearly 90% in the 2010s, petrostates in the Middle East have advanced their ambitions. For example, in 2020, Saudi Arabia had a renewable electricity capacity of around 500 megawatts. The Saudi government has a target of 60 gigawatts, where most of it could come from solar PV and concentrated solar power by 2030 [41].

B. *Manufacturing*

The modernistic PV technology is based on the principle of the electron-hole creation in each cell composed of two different layers, n-type and p-type materials, which are semiconductor materials [42].

The n-type semiconductor is an extrinsic semiconductor doped with electron donor atoms, whereas the p-type semiconductor is doped with acceptor atoms.

An electron is ejected by gaining energy from the photon striking when a photon of sufficient energy impinges on the n-type and p-type junction. Moving from one layer to another where an electron creates a hole in the process and thus generates electrical power [42].

According to [43], different semiconducting materials are being applied for the PV solar cells, mainly silicon (mono c-Si, poly c-Si, a-Si), copper-indium-gallium-selenide (CIGS), copper-indium-gallium-sulfide (CIGS2), and cadmium-telluride.

The first generation of solar cells is divided into monocrystalline and polycrystalline silicon cells. This section of work explores the production of polycrystalline silicon panels.

Pure silicon is considered the fundamental component of a solar cell, known as silicon dioxide, Silica, or quartzite gravel.

The first step in the manufacturing process of polycrystalline cells is the extraction of pure silicon from quartzite gravel to make metallurgical silicon.

The conversion of raw silica sand into silicon happens through a certain reaction. This reaction is: $SiO_2 + 2\ C \rightarrow Si + 2\ CO$. The raw material of silicon dioxide (SiO_2) is first placed into an electric arc furnace, where a carbon arc is used for the release of oxygen at temperatures of over 1900ºC. The reaction leaves behind carbon oxide (CO) and 98% to 99% of pure silicon (Si), which despite the high purity, requires further purification [37], [44].

The next step is the purifying step, where the aim is to purify the silicon using the Siemens process.

First, Si with hydrogen chloride (HCl) is converted to hydrogen (H_2) trichlorosilane (TCS) or $SiHCl_3$ in a fluidized-bed reactor (FBR) through the reaction $Si + 3HCl \rightarrow SiHCl_{3(g)} + H_2$. Although this step of the process removes most impurities, further purification is still needed [45].

Second, the gas is cooled and liquefied for distillation. Finally, the liquefied TCS, which boils at 32°C, is distilled to reach the required purity [37], [45].

Third, the liquefied TCS is heated then cooled to remove further impurities. Then, the $SiHCl_3$ is mixed with H_2 and moved to another insulated reactor with a hot rod. It is broken down in a reducing atmosphere at around 1000°C via the following reaction $SiHCl_3 + H_2 \rightarrow Si + 3\ HCl$, then vaporized again at a temperature of up to 1500ºC. The chemical vapor deposition process leaves thick rods of 99.99% pure silicon [45].

The third step is to create ingots made of many different silicon fragments.

The molten silicon is left for a while to cool down and fragment, then it is melted in furnaces and accordingly poured into cubic-shaped growth crucibles [37].

The molten silicon afterward is set to thicken, and the ingots are cut into thin wafers. Silicon wafers are sliced using a wire saw whose inner diameter cuts into the rod one or many times with a multiwire saw [44].

The reason behind the rectangular-shaped wafers used in polycrystalline solar cells is their ability to be fitted together perfectly, therefore using all the space available on the front surface of the solar cell [44].

These wafers are polished, improved, diffused, and assembled. However, sometimes polishing the wafers from saw marks is not opted for by some manufacturers because it was found out that rougher cells absorb light more effectively [14]. At the same time, silicon wafers which have a rough surface or residual damage left on the wafer surface from the cutting are more liable to break than the polished ones [46].

The reason behind diffusing wafers is that silicon wafers are positively charged and act as a p-type junction. Where a p-n junction is required to conduct electricity, for that matter, each wafer has a negatively charged layer of phosphorus added to it. Then it is moved to a special 1652ºF furnace to inject the phosphorus with nitrogen. It will create an n-type layer, resulting in a very effective p-n junction wafer [37]. The time and temperature assigned to the process are carefully controlled to guarantee a uniform junction of proper depth [44].

Most of the poly c-Si cells have efficiency rates between 13% to 16%. Although the difference between mono and polycrystal cells is not that big, many companies have been able to elevate the efficiency of polyc-SiPV panels. Recently, the panels available on the market are now similar to the efficiency of mono panels, reaching about 21%, and their lifespan reaches 20-35 years and sometimes even more [47].

The agreeable maximum temperature of polycrystalline solar panels is 85 °C, while the agreeable minimum temperature is -40 °C [42].

When the temperature elevates by 1 ºC or 32 ºF, the polycrystalline silicon solar cell will tentatively lose 0.3% to 1% of its efficiency [37].

The national renewable energy laboratory (NREL) has recently applied its energy and expertise to develop the polycrystalline thin-film PV, including CdTe and the CIGS solar cells [48].

Polycrystalline thin films offer lower-cost materials, automation of the fabrication processes, potential scalability, and efficiencies competitive with the presently predominant poly c-Si technology [49]. Therefore, many works explored the polycrystalline thin-films technology as an advancing step towards a newer generation of poly PV panels based on multiple semiconductive materials[48]–[56].

C. Installation

This section explores poly c-Si PV system installation, reviews some points ahead of installation, and explains the available techniques and procedures.

Most systems consist of solar panels, a solar inverter, a mounting system, and an automated controller.

The solar panels have the ability to produce direct electric current from sunlight. The inverter then converts the generated electricity into alternating current to be suitable for use in the household. The controller operates the solar system and guarantees the best performance. A battery and a connected load are required for an off-the-grid system or a backup system [57].

There are different methods and ways to install any PV system. However, when it comes to having photovoltaic systems as a new element in building design, there are two types of residential installation which are building-integrated PVs (BIPV) and building attached PVs (BAPV) [47].

BIPV are PV materials that are used to substitute the conventional building materials in parts of the building. They are integrated into the construction of new buildings as an elementary or supplementary electrical power source. The PV materials intend to perform the work of the conventional components they replace in the building, like the windows, the roof, or the facades.

In BAPV systems, photovoltaics are incorporated into the building after the construction. This type of installation is the most frequently used one.

BAPV system installation is more preferred than a new construction BIPV system, where the cost is expensive, and the process is complex in terms of mounting and maintaining the structure.

Besides residential system installation, large utility-scale, such as solar farms and power stations, is another essential type of installation because utility-scale systems can generate electricity and energy for many consumers.

The generated electricity is fed into the transmission grid powered by central generation or combined with one or several domestic electricity generators to feed into a small electrical grid.

For utility-scale systems, it is possible to mount the poly c-Si PV panels on rooftops by attaching the arrays directly to the roofing material, but after ensuring that the roof will bear the weight of the array.

Generally, poly c-Si PV systems are installed to guarantee the highest energy yield for a given investment. In order to optimize system output, the PV arrays can be pitched at any angle and made to face due south, regardless of the roof's orientation [58]. Changing the optimum tilt angle monthly and seasonally will elevate the harvested energy by

7.74% and 6.38%, respectively, over a fixed tilt angle [59].

Work [59], [60] described the mathematical models for determining the solar radiation received on a tilted polycrystalline silicon panel and calculating the optimum slope angles for the panel at any time of the year.

Another system installation type is underwater panels in which the traditional poly c-Si cells are encapsulated to prohibit damage from the environment. The experimental analysis gave a better understanding of poly c-Si solar cells underwater.

The experiment uses earlier work-established equations that are modeled using MATLAB. For instance, the total solar irradiance was modeled using the following equation (1).

$$I_x = \int_{\lambda 0} I e^{-u(\lambda)x} f(\lambda) d\lambda \quad (1)$$

where Ix is the solar irradiance concerning the water length, while λ is the wavelength, and *I* is the intensity transmitted, λ0 is the wavelength limit of the solar spectrum, *f*(λ) is the spectral distribution as a function of the wavelength, and finally, *u*(λ) is the extinction coefficient of water. The results show that solar radiation, salinity, and other impurities impact the performance of the solar cells underwater [25].

Photovoltaic-thermal system installations are must be mentioned as an additional hybridized technique. This technique uses the traditional polycrystalline photovoltaics with a thermal collector to generate electrical and thermal energy [47]. An experimental work studies meteorological parameters' influence on the polycrystalline temperature and electrical efficiency [18], [23].

The equation used is the most known model, which is given by the following (2).

$$\eta = \eta_r [1 - \beta (T_c - T_r) + \gamma \log \emptyset] \quad (2)$$

Where η_r is the reference module of efficiency at a poly c-Si photovoltaic cell temperature Tr and at a solar irradiance $\emptyset$, where γ and β are, respectively, the solar irradiance and temperature coefficients for the photovoltaic module, T_C is the environmental-dependant cell temperature [18].

In recent work, multiple experiments have been tested during different environmental conditions. The module current-voltage characteristic curve (I–Vcurve) was evaluated in each test to analyze the output power performance of the hot-spot mitigation techniques proposed. Both techniques ensured a decrease in the shaded photovoltaic cell temperature; therefore, there is a rise in photovoltaic output power [23].

In another study, a solar collector cooling algorithm was developed and designed by using a thermal control feedback system that increased the efficiency of the polycrystalline silicon panel array by 16.65% [19].

D. Polycrystalline Silicon PV panels for the past twenty years in Saudi Arabia

The Kingdom of Saudi Arabia has a distinct geographical location and a unique climate that makes renewable energy sources economically viable and supportive of its energy diversification efforts.

The National Renewable Energy Program is considered a strategic initiative for renewable energy and Vision 2030, aimed at maximizing the share in renewable energy production, balancing the mix of local energy sources, and reducing carbon dioxide emissions. Through this program, the country diversifies the national energy mix used in electricity production by increasing the share of gas and renewable energy sources [61].

The Kingdom aims to achieve the perfect energy mix, with the most efficient and least expensive electricity production, by replacing the liquid fuel with natural gas in addition to renewable energy sources, which will account for nearly 50% of the energy mix for electricity production by 2030.

Saudi Arabia is the most competitive manufacturing and energy-generating location for PV solar technology. An integrated manufacturing value chain will let the photovoltaic energy be produced locally at an applicable cost.

It also contributes to the Kingdom's strategic goal of diversification of its non-oil economy and developing the renewable energy sector to provide alternative energy sources.

Some projects provide electricity, and some are powered by electricity generated from the solar power plant, in line with the Kingdom Vision 2030.

The Poly c-Si Technology Company, located in Jubail city, is considered the first to contribute to this industry by investing in a factory with a 3000 metric ton capacity that uses the hydrochlorination–Siemens process [57], [62].

King Abdulaziz City for Science and Technology (KACST) is collaborating with Stanford Research Institute (SRI) in order to transfer the knowledge and technology which was developed at SRI providing high-purity silicon with the purpose of designing, building, and also operating a pilot plant [57].

A project by IDEA Polysilicon Company (IPC) has signed an agreement with Technip E&C Limited, which is in the United Kingdom is set to produce a high-purity poly c-Si that has a total capacity of 10,000 tons per annum, where 4000 tons of which will be converted to ingot and solar wafers in Yanbu Industrial City [63].

A project in the Al-Khafji desalination facility incorporates an ultra-high concentrator PV plant to provide power for the desalination plant. The medium-voltage solar power plant is fitted with polycrystalline PV solar cells designed by KACST [64]. The plant has a capacity of 15 megawatts. It is also connected to both the national grid and the desalination plant. Therefore, it produces sufficient power during peak operation that will be enough to maintain the desalination plant's energy requirements. In addition, water production is elevated during the peak of the power supply from the photovoltaic plant. Furthermore, technology tracking is installed to maximize the availability of solar power [65].

IV. Discussion

Saudi Arabia is steadily heading towards the optimal mix of renewable energy in order to produce electricity and enhance its efficiency and consumption in line with Vision 2030.

The National Renewable Energy Program projects proved that Saudi Arabia has the lowest prices as a producer of renewable energy, just as it has historically been obtaining the lowest cost producer of oil.

The past months have witnessed the launch of the Skaka solar power plant, the first project of the National Renewable Energy Program with a capacity of 300 megawatts[66].

In addition to setting records in new projects, as Shuaiba, one of the Saudi projects announced, set a world record for the lowest cost of purchasing electricity produced from solar energy, reaching 1.04 US cents per kilowatt-hour [66]. Sudair is also considered one of the largest solar power plants globally, which is another project announced by Saudi Arabia with a high number of investments with a production capacity of 1,500 megawatts[66].

In addition to a wind power plant project, all these projects have a production capacity of 3,670 megawatts and will provide electricity to more than 600,000 housing units and reduce more than 7 million tons of emissions.

The Kingdom aims to have a 50% share of gas and renewable energy sources in the energy mix by 2030, especially with energy consumption growth expected to double to 120 gigawatts in 2030 from the past levels [67].

Completing these projects will reinforce the region's capabilities in producing electricity that meets the national need, increase the electrical grid reliability, and support the plans to become one of the top countries in producing and exporting electricity by using renewable energy.

Although Saudi Arabia has declared its intention to become a significant solar producer before, its contribution amount to much less than 50 megawatts compared to the thousands of megawatts the other countries are adding per year. Although part of this is because Saudi Arabia is new in the scene, some environmental problems limit the performance and affect the efficiency and the maximum output energy, which is the biggest challenge.

The environmental factors that can influence the performance of polycrystalline cells include temperature, the intensity of the solar radiation, dust, and the thermal properties of semiconductors the cells are made of, as the temperature has a considerable effect on decreasing the capacity of the cells.

The efficiency of solar PV panels in Saudi Arabia has been shown to decrease by up to 70% due to dust [68]. Therefore, solar cells should be regularly cleaned every four days, especially after dust storms, since the dust has a significant impact on decreasing the electrical power generated by photovoltaic cells.

The challenge for producing poly c-Si is that about 40% of the energy is used to produce silicon feedstock. Therefore, decreasing energy consumption in this step is critical to reduce the energy payback time of the installed capacity. Fluidized bed reactors are considered the most promising alternative to the conventional methods is [69].

As poly c-Si accounted for almost 25% of the total production expenses today, some facilities try to decrease the cost by integrating processes with material and energy recycling routes. Also, some specialized companies started converting the silica-rich sand into polyc-Si[70]. While poly c-Si production is cost-effective and for a country with many resources such as sunlight and sand, the wafer and ingot industries have not been introduced into Saudi Arabia yet.

Another challenge facing the development of polycrystalline and other photovoltaics techniques in Saudi Arabia is installation cost.

This challenge brings us to the optimal challenge: the amount of sunlight consumption in which 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.

V. Conclusion

This paper offers the state of the art and tackles challenges that limit the growth of polycrystalline panels in Saudi Arabia. It covers the origins of this technology, the production, the installation, and the performance.

First, the paper touches on the distinct geographical location and climatic conditions in Saudi Arabia. The countryreceives a substantial amount of sunlight for the average daily hours that can extend in summer for more than 16 hours a day, accompanied by high heat and a high ability to oxidize different materials, hence the importance of choosing suitable types of panels containing solar energy-harvesting cells.

There are two common types of the first and famous generation of solar panels: polycrystalline silicon cellsand monocrystalline silicon cells. The best solar cells are selected based on the circumstances.

The most important of which is the suitability of solar cells to the nature of the region. For example, polycrystalline silicon cells are suitable for desert areas where radiation is intense. This type of cell is more sustainable due to the lower purity of the primary material, and the performance quality is not thatfar from the monocrystalline silicon type. While in areas where the radiation is low, the appropriate cells are monocrystalline silicon to benefit from the higher efficiency this type can achieve.

The scientific research approaches that are 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 poly c-si PV systems.

For the installation, the country has vast areas of open desert that seemly fit for solar panel arrays. The best way to install solar panels is to face the sunlight for the most extended period of the day. Therefore, the panels are usually installed at a tilted angle of 20-40 degrees towards the south. Since Saudi Arabia is north of the equator, the panels should be fixed to the south at a tilt angle slightly above the latitude of the place where the cells are to be installed to ensure the most significant amount of energy from these cells.

Cells can also be vertically facing the sun by using moving solar panels that track the different angles of where the sun falls throughout the year. However, moving panels installation is expensive compared to the lost energy when fixed panels are used.

Besides high temperature, dust is the second higher environmental challenge that can affect the performance of the installed system, especially during periods where dust winds are active. Therefore, the cells must be cleaned regularly, especially after dust storms, or else dust will reduce the electrical capacity of photovoltaic cells.

As for the production of polycrystalline, ingot and wafer industries have yet to be introduced to the country. However, the country is making its way to dominate and localize PV components.

Finally, the paper addresses local projects and work conducted in Saudi Arabia in the hope of providing support to other researchers' future work.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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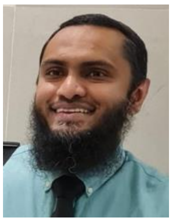

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