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Review

A Review on Techno-Economic Study for Supporting Building with PV-Grid-Connected Systems under Saudi Regulations

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Abstract: As the demand for electricity continues to grow in Saudi Arabia, finding ways to increase power generation becomes increasingly important. However, conventional power generation methods such as burning fossil fuels contribute significantly to environmental pollution and harm human health through the emissions of greenhouse gases. One potential solution to this problem is the use of solar energy, which has the advantage of being abundant in Saudi Arabia due to its location in the sun belt. When compared to conventional power generation methods, solar energy is a viable alternative, particularly when the indirect costs of fossil fuels, such as harm to the environment and human health, are considered. Using photovoltaic cells to convert sunlight into electrical energy is a key method for producing clean energy. Despite the initial cost of investing in solar energy infrastructure, it is ultimately less expensive than electricity derived from fossil fuels. In recognition of the potential of solar energy, the Saudi government has outlined an ambitious plan to install 41 GW of solar capacity and invest USD 108.9 billion by 2032. Additionally, financing and significant tax benefits have been provided to promote the development of the solar industry. This research article reviews the techno-economic analysis of PV power plants and examines previous policy papers and the existing research on the topic.

Keywords: solar energy; PV system; building energy; rooftop; PV-grid-connected; techno-economical

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1. Introduction

Saudi Arabia primarily occupies the Arabian Peninsula. It is located far southwest of Asia, in the Middle East, between the latitudes 16° N and 33° N and longitudes 34° and 56° E. Almost two million square kilometers of the nation are uninhabited. Seven-rated arid sand and soil desert make up most of the country outside the mountainous south. In the west, along the Red Sea, Saudi Arabia has a coastline of approximately 1100 square kilometers; in the east, along the Arabian Gulf, it has a coastline of approximately 610 square kilometers. As a result of the presence of the two holiest cities in Islam (Makkah and Madinah), the nation receives about two million Muslim pilgrims every year for the Hajj. Saudi Arabia has thirteen different provinces, each governed by a minister in the Ministry of Interior. A 640,000 km^2 area in the southeast of the country is uninhabited, known as the Rub Al-Khali. Figure 1 shows Saudi Arabia's electrical grid, using color to indicate which facilities have been turned on (green), which are currently being built (red), and which facilities are still in the planning stages (blue) (dark blue).

Energy shortages are present in all countries, even those with abundant resources. Despite being a significant oil producer, Saudi Arabia is well aware that it will need to secure its energy supplies shortly. As domestic consumption far outpaces domestic production, some analysts forecast that the United States will be a net importer of oil by 2038 [2]. Fossil fuels, particularly the oil and natural gas found and extracted within Saudi Arabia's borders, provide the majority of the energy used by the country.

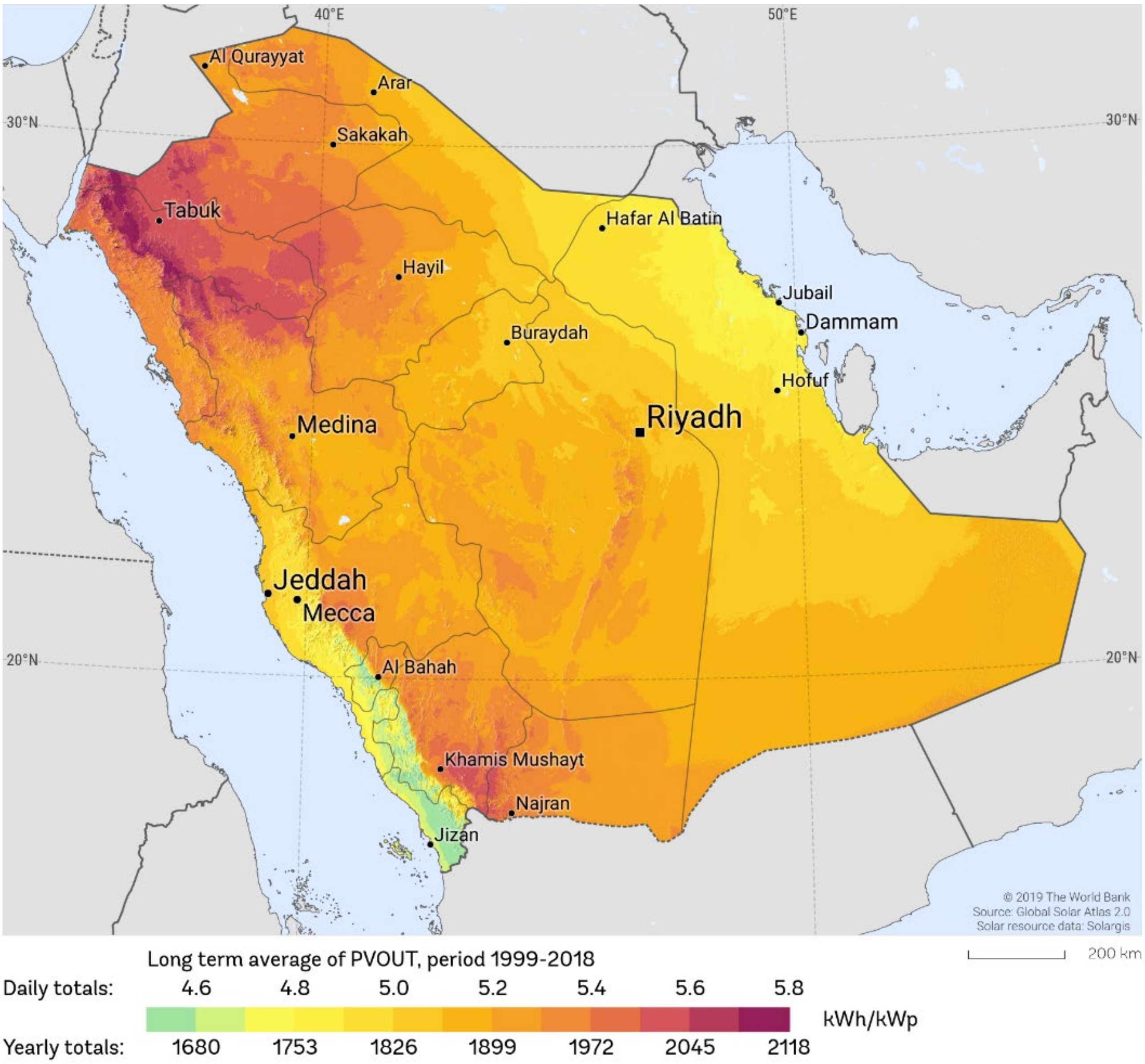

Figure 1. Solar potential of Saudi Arabia [1].

The emission of greenhouse gases (GHGs) is a significant contributor to climate change, and energy production and consumption are two of the primary sources of GHGs [3]. In 2014, Saudi Arabia released 494.82 MTon of CO_2, placing it in the top eleven on a list of the largest emitters. Although the Saudi government currently spends more than USD 40 billion per year on electricity-generation subsidies, additional funds will be required in the future [4]. In addition, the government will only be able to continue subsidy programs if individuals are encouraged to waste more money. It is also essential to reduce the rate of the increase in greenhouse gas emissions. At the 2015 Paris Climate Conference, also known as the 21st Conference of the Parties (COP), more than one hundred countries, including Saudi Arabia, pledged to keep global warming below 2 degrees Celsius by the end of the century [5]. Due to these threats, the government feels compelled to economically diversify away from hydrocarbons. Renewable energy sources (RESs) are a potential strategy for justifying the global warming effects and the increase of electricity production to meet rising demands.

The Saudi Arabian solar power market is anticipated to grow by more than 10% between 2022 and 2030 [6]. The OPEC agreement to cut oil production by 3.1 million barrels per day, beginning in April 2020, was damaged by the COVID-19 pandemic in the first quarter of that year [7]. Supply chains in the industry were impacted, and other solar power projects were delayed. The market is predicted to be driven by a declining reliance on fossil fuels, increased efforts to meet the electricity demand with solar energy, and more.

Saudi Arabia's unique location and climate make it economically feasible to use renewable energy sources, particularly solar energy sources. This supports the country's efforts to diversify its national energy mix. In the years to come, it is predicted that Saudi Arabia's 439 MW of installed solar power capacity will increase [8]. Furthermore, more than 98% of Saudi Arabia's renewable energy mix comes from solar generating capability. The government has targeted diversifying its energy mix and boosting its renewable energy generation capacity by 2030 to minimize oil consumption and produce a more sustainable future. The National Renewable Energy Program, which will aid in creating future renewable energy legislation and pave the path for their widespread implementation, is one of the most crucial initiatives the government can accomplish. Saudi Arabia is focusing on using gas, efficient energy use, and renewable energy sources to carry out its Nationally Determined Contributions (NDC) under the Paris Agreement (United Nations Framework Convention on Climate Change 2019 [9]).

As part of Vision 2030 and the National Transformation Program 2020, Saudi Arabia announced an ambitious plan to invest over USD 100 billion and generate 60 GW of power from renewable sources by 2030 [10], including 43 GW from solar and 16 GW from wind (NTP). One renewable resource alone can satisfy most of the nation's energy needs. Environmental and economic benefits are sought through the development of renewable energy sources. For example, if the government reduces its consumption of fossil fuels, it will find it easier to meet its climate change obligations under the Paris Agreement. Saudi Arabia has created a regulatory framework and support and subsidy programs for renewable energy, intending to expand the use of renewable energy [11]. The Saudi Arabian energy sector is increasing at a rate of 7 to 10% per year. Even so, it is anticipated that demand will increase even further in the future. According to Saudi Arabia's national strategy, the country's energy consumption will triple by 2030. It is predicted that without the use of alternative energy sources, export revenues from fossil fuels could fall by up to 25 percent [12]. Strategic goals, specific targets, strategies, goals, indicators of the desired outcome, and sector success are all included in the 2030 vision. The vision can be translated into several actionable initiatives using a comprehensive framework created by the Council for Economic and Development Affairs (CEDA). Plans for renewable energy at the national level reveal a significant need for more cost-effective renewable energy. The United States has only just begun to tap its vast, untapped resources.

The amount of energy consumed in the region is predicted to triple by 2030. The strategy anticipates a requirement of 9500 GW of renewable energy by 2050 [13]. A significant portion of this ambitious goal is earmarked for the growth of the solar energy industry. The vision suggests bringing the manufacture of domestic parts for renewable energy sources into the national economy to attain these objectives. Following the formal introduction of the King Salman Renewable Energy Initiative, additional stages are expected. As the strategy is executed, each renewable energy plan and the legislative and regulatory framework will be thoroughly evaluated to clear the way for private firms to invest in this area. As part of the 2030 target, private enterprises are encouraged to contribute to expanding the renewable energy infrastructure in their respective locations. To keep the renewable energy industry competitive, the vision also asks for the liberalization of the fossil fuels market (Saudi Vision 2016, 2030 the King Abdulaziz City for Science and Technology (KACST)). The first liberalization of fuel prices occurred in 2018. The Saudi government prioritizes the indigenous manufacturing of solar modules and components as part of its 2030 agenda. The government plans to give them substantial assistance to assist national firms in expanding domestically and internationally. Renewable energy technology is expected to provide more jobs than fossil fuel infrastructure technologies over its lifetime [14].

Solar photovoltaics are the most labor-intensive form of renewable energy but also generate the most jobs per kilowatt-hour. According to recent estimates, Saudi Arabia has a 10.7 percent unemployment rate. The production of solar equipment in the area could increase the number of available jobs (Solar Power Europe, 2016 'Brussels 1040, Belgium'). The government's plans center on growing the local economy. As a result, more jobs will be available, and economic growth is expected to remain stable. A lack of local production of the components that make up the solar value chain means that all modules and most members must be imported [15]. Despite the progressive nature of Saudi Arabia's manufacturing sector, this is the case. Currently, solar photovoltaics are in their infancy in terms of industrial production. The ambitious goals outlined in the 2030 vision and the potential demand for solar power have increased the competition to invest in domestic manufacturing to secure and diversify the country's ability to meet its future energy requirements. In the immediate future, the 2030 vision is expected to substantially boost the solar photovoltaic market industry in the country. If the solar industry can establish a local value chain, it will attract local investors who are interested in partnering with international solar manufacturers [16].

The objective of this paper is to thoroughly review and identify the potential roles solar power could play in Saudi Arabia. We aim to provide a comprehensive overview of the current state of the Saudi electricity system including an analysis of the country's energy challenges and the drivers of its electricity consumption. We will also present detailed information on the solar industry in Saudi Arabia, including its current status, growth trends, and future potential. Furthermore, we will thoroughly review solar photovoltaics in Saudi Arabia, including the technology's potential for power generation, its cost-effectiveness, and any barriers to its widespread adoption. This review will also consider the Saudi government's policies and initiatives on renewable energy. Through this analysis, we aim to provide a clear understanding of the opportunities and challenges facing solar power development in Saudi Arabia.

This research is structured as follows:

In Section 2, we will present an overview of solar energy in Saudi Arabia, including its current status and potential for future growth.

Section 3 will provide a background on the research topic, including a review of previous studies and relevant literature.

In Section 4, we will delve deeper into the main topic of the research, discussing the potential roles that solar power could play in Saudi Arabia and examining the challenges and opportunities facing its development.

Finally, in Section 5, we will present the conclusion of our research, summarizing our findings and discussing any potential implications or areas for further study.

2. The Solar Industry in Saudi Arabia

The Vision 2030 plan for economic and social development in Saudi Arabia includes a goal to reduce the country's reliance on fossil fuels. The nation intends to become a global exporting powerhouse to increase economic growth and minimize import dependence [17]. Self-sufficiency in producing solar components may be possible if the majority of raw materials for the whole value chain are secured. This region is home to solar-cell producers, module manufacturers, inverter manufacturers, tracker manufacturers, mounter manufacturers, cable manufacturers, and professionals in administration, planning, and consultancy. In addition to having access to a sizable pool of researchers, public institutions such as universities also have access to crucial public sector laboratories and workshops, all of which are essential for the PV supply chain. Due to increased cooperation between these organizations and the adoption of legislative measures that prioritize renewable products, it is anticipated that the local PV industry will gain momentum and expand. Manufacturing, project development, sales and marketing, and installation are just a few of the PV-related vocations anticipated to grow in Saudi Arabia [18]. New rules, pricing, and regulations are expected to be implemented in the domestic power system market. This study requires two illustrative localization examples. Khafji city was the first to acquire a 10 MW PV plant as part of a national initiative to desalinate water using solar power. Although this project was small in scope, the authors, who oversaw the team that carried it out, learned a significant amount about the relative weight of the various parts (Figure 2). Furthermore, this PV project is a good illustration of how a project might be implemented in a particular location.

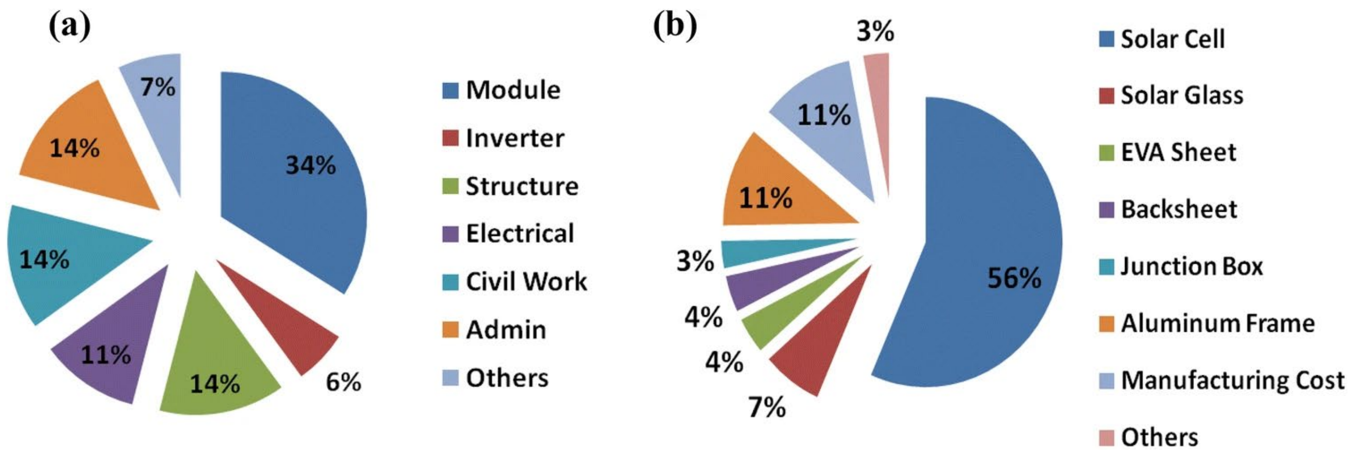

Figure 2. Breakdown of costs in the (**a**) PV industry for a 10-MW system and (**b**) a PV module of the system [19].

The assembly line provides useful information on the various components of the PV module, as can be seen in Figure 3. As a result, we can forecast each element's potential for localization. Figure 3 [20], which was gathered during this investigation, along with the 10 MW project and the KACST PV assembly line, completed in 2018, shows the percentage of locally made members for each item category. The civil engineering and electrical sectors also source their personnel and materials domestically.

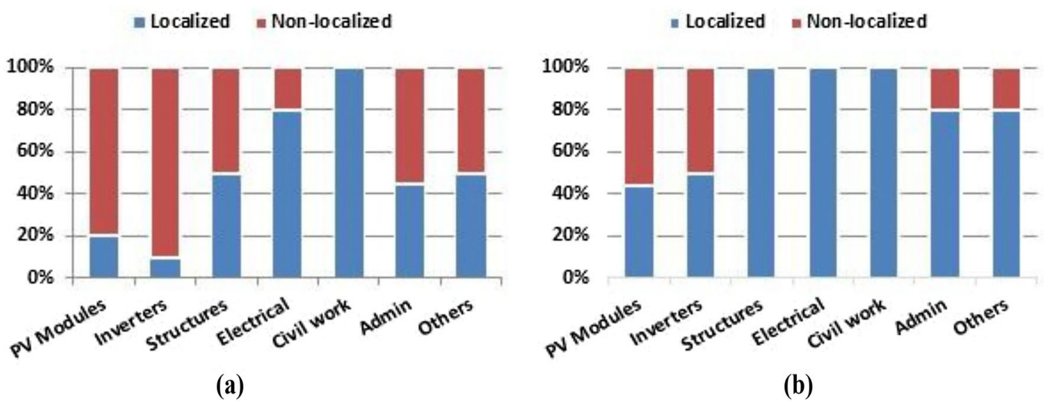

Figure 3. Components of the PV value chain (**a**) supplied locally and externally in 2018 and (**b**) anticipated values for 2023 [19].

The availability of materials in other industries depends on a network of outside suppliers. It is notable that, at less than 10%, the local share of the global inverter supply is among the lowest. PV system costs are split 80 percent by electrical installation and 20 percent by modules. The highest levels of regional availability were seen in the civil and electrical work sectors, which have already made a name for themselves in the Saudi Arabian market. However, due to their relative youth in the Saudi market, inverters and PV cells are still primarily imported. Significant additions to renewable energy are anticipated for the future domestic energy mix for electricity generation. This development encourages Saudi Arabia's localization of the PV sector [21].

Due to the rapid expansion of several enterprises in each industry sector, structural and electrical work is anticipated to localize completely within a few years. Over 80% of the explosive development under PV administration is anticipated to be regional by 2023. As previously noted, all of the components in Figure 3 can be localized except for solar cells. As a result, a localization of PV modules of approximately 43% is anticipated. The "others" category includes specialized hardware, software, infrastructure, personnel, management, research, and consulting skills. The commercial sectors gain new knowledge and technology as these fields of research advance. The hardest industry to relocate would be the industry that makes PV modules and inverters. By the end of the 2023 fiscal year, these industries are anticipated to grow an astonishing 50% or more. These localization levels might be substantially higher if new rules are implemented to support the renewable energy sector's expected cumulative growth rate of 75% by 2023.

The pace of localization In the PV business would be accelerated by Saudi Arabia's genuine efforts to wean its economy off of petroleum production. It is challenging to make more exact forecasts regarding these values due to the uncertainty surrounding the adoption of future laws and regulations that may significantly impact them. These projections can be used to inform policy decisions and encourage cross-sector collaboration throughout the supply chain. This research is useful, even if it is only the first step toward forecasting and facilitating the localization of the PV industry in Saudi Arabia. In keeping with Saudi Arabia's ambitious goals for the deployment of renewable energy, a boost in PV localization is expected to create a significant number of new jobs. According to the International Renewable Energy Agency's annual review of employment in 2017, 10.3 million people worked in the renewable energy sector (including hydropower), representing an increase of 5.3% from 2016. Jobs related to renewable energy account for more than 70% of all employment in China, Brazil, the United States, India, Germany, and Japan. With a record 94 GW of PV installations in 2017, the PV business currently employs 3.4% of all renewable energy sector workers, an increase from 3.1% in 2016 [22].

Saudi Arabia is now soliciting bids for seven solar PV projects with a combined capacity of 1.51 GW [23]. These initiatives are anticipated to produce 4500 additional positions during construction [23]. According to REPDO employment figures, developing 20 GW of PV projects by 2023 would create around 60,000 jobs. The establishment of Saudi Arabia's petrochemical industry in the 1980s is viewed as a prelude to the PV industry's rapid job growth. However, some unemployment is to be expected as a result of the conventional power industries' reluctance to change in the face of the potential elimination of PV power; this may lead to changes in the industry to fill newly created roles, which will affect the analysis of PV job creation [24].

In addition, the advancement of PV manufacturing technology and economies of scale will affect the quantity of new employment, with some workers being replaced by automated equipment in cutting-edge plants [24]. To fulfill the potential 75% localization by 2023, Saudi organizations, including the Ministry of Labor (job creation), Ministry of Education (solar training and education), Ministry of Finance (budget allocation), and the Saudi Electricity Company Electric power distribution company (Riyadh, Saudi Arabia), must adopt a well-thought-out plan. This localization has the potential to revolutionize major portions of the economy, resulting in favorable social and industrial effects.

3. Research Background

The Saudi Arabian Water and Electricity Regulatory Authority (WERA) approved and published rules for small-scale PV solar systems in February 2020. These regulations will enable consumers to produce excess electricity and export it to the utility system. Many investigations have been performed to determine if solar panels could be used to generate electricity [25].

Due to the technology's lowering capital costs, solar photovoltaic (PV) systems mounted on mosque rooftops are becoming more and more financially viable. In countries where energy prices are thought to be high, the commercial case is even more strong.

A mosque of average size in a nation such as Jordan, whose electricity costs have doubled since 2012, may have an annual bill of close to $17,000. Officials from the Jordanian government recently announced that the 6300 mosques in the nation would generate electricity using solar power [26]. Jordan has good sun conditions, but its energy needs are imported [27]. As a result, solar energy has a special attraction in Jordan, a nation whose energy demands are met nearly exclusively by imports. Similarly, Morocco launched a bold plan to add PV to 600 mosques by 2019 and more in the future. Morocco is home to almost 50,000 mosques, which is noteworthy.

Saudi Arabia is planning a large-scale installation of solar photovoltaic (PV) systems in its mosques [28]. Although these deployment initiatives, launched around the Muslim world, may share certain commonalities at a high level, Saudi Arabia has several distinct characteristics: the hot climate, the size of the mosques, and the presence of approximately 94,000 mosques in Saudi Arabia all contribute to the need for air conditioning.

The authors of reference [29] present what they believe to be the first detailed techno-economic analysis of constructing a solar PV system on the roof of a mosque in Riyadh, the capital of Saudi Arabia. This essay examines the ramifications of installing photovoltaic (PV) systems on mosque rooftops from both a financial and a policy perspective. In the end, this study was used as a foundational component to assist authorities in determining whether or not it is appropriate to implement a statewide PV-deployment program in mosques across Saudi Arabia and the rest of the world.

In the past twenty years, only a few feasibility studies have been published that examine the potential financial and environmental benefits of installing renewable energy systems in energy communities around Saudi Arabia [4].

In these studies, hybrid systems and microgrids (which may include solar and wind power generation systems) were investigated as potential solutions for meeting the need for electrical power in communities located in diverse parts of Saudi Arabia [30]. The majority of the research that has been published focuses on developing hybrid, fuel-based generators with renewable energy systems to meet the electricity needs of remote areas or individual buildings in Dhahran, Rawdat Ben Habbas, Dhahran, and other cities that are representative of the four regions of Saudi Arabia [29,30]. In the literature, just a few studies have been performed on grid-connected photovoltaic systems in Saudi Arabian communities. These studies are described in more detail in the sections that follow.

Cost-optimization research was conducted to build hybrid systems for a grid-connected residential community of 200 dwellings in Yanbu, Saudi Arabia [31]. Both photovoltaic arrays and wind turbines were deemed capable of meeting the community's total or partial power demand. The ideal design of hybrid power systems for supplying residential neighborhoods in Khobar, located in the eastern portion of Saudi Arabia, was assessed [32]. First, the energy consumption of the residential communities was evaluated by employing prototype models of single-family homes, apartment complexes, and a single school, all of which were planned according to contemporary architectural principles. Next, the community's energy consumption was cut by implementing various cost-effective energy efficiency measures that could be applied to different types of buildings. This included installing high-efficiency air conditioning systems and installing thermal insulation in walls and roofs.

The case of the Al-Shumaisi cluster, which may be found in the western part of the Makkah Province in Saudi Arabia, was presented by Seedahmed et al. [33]. A hybrid wind/DG/fuel cell/battery/electrolyzer system was suggested (see Figure 4), in addition to a techno-economic study for a commercial load profile of the Makkah transport company (MTC). This study presented two hybrid setups: a wind/DG/FC/battery system and a wind/FC system. Research is also being conducted on a different structure that uses DG units.

Recent studies [34] investigated what configuration of photovoltaic panels, fuel cells, and batteries would be most effective in meeting the daily energy needs of a small community in NEOM city, were estimated to be 500 kWh. A new metropolis called NEOM (which means "new future") will be built along the coast of the Red Sea in northwest Saudi Arabia. It will include an urban core, villages, research centers, places for sports and entertainment, and tourism spots to entice individuals from all over the world to invent and develop new technology. The analysis was carried out with the assistance of the HOMER analysis program, with the following cost data being utilized: (a) USD 1000/kW for PV systems, (b) USD 500/kW for fuel cells, (c) USD 300/kW for electrolyzers, (d) USD 200/kg for hydrogen storage tanks, and (e) USD 175/360-Ah for batteries.

The technical, environmental, and economic considerations for identifying potential sites for grid-connected solar power plants with an installed capacity of 10 MW were addressed in Saudi Arabia [35]. The available photovoltaic modules are evaluated, and one is selected for further examination. Using RET Screen software, meteorological data such as global solar radiation, sunshine duration, dry bulb temperature, and relative humidity were utilized to analyze the viability of the 44 sites with respect to energy output, greenhouse gas (GHG) emissions, and financial aspects.

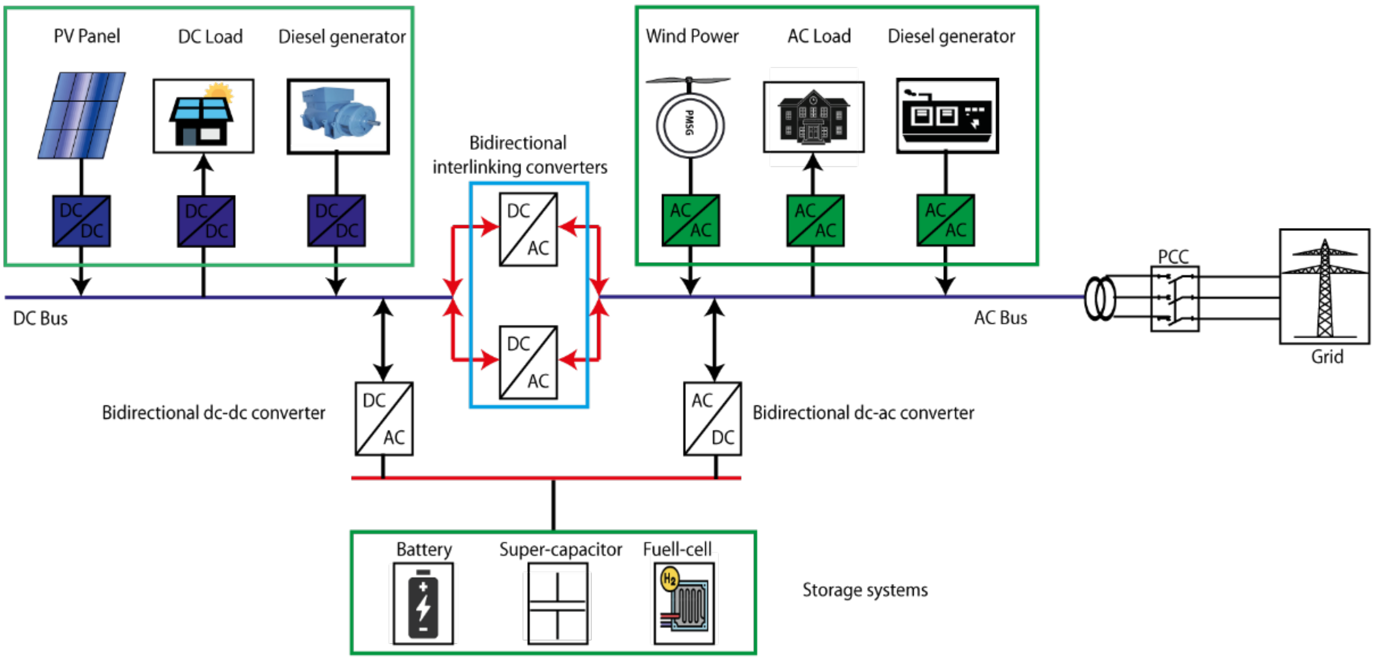

Figure 4. Configuration of a grid-connected PV system with battery backup.

There has been a significant amount of investigation into the production of energy from renewable sources, including the costs, capacity, savings, and environmental benefits of doing so. The findings of several studies that contrast diesel-powered power plants with PV-based power generating systems reveal that the results are encouraging and that the systems can be implemented if adequate support and financial incentives are provided for renewable energy sources. In [36], a techno-economic evaluation of two photovoltaic (PV) power plants with capacities of 67 and 144 megawatts is carried out, and the results are compared with those of diesel power plants located in two cities inside Saudi Arabia. According to the feasibility research findings, it is technically and economically possible to switch fossil-fuel-dependent power plants in this country to more environmentally friendly production processes. The analysis was carried out with the completion of that particular objective. A poly-Silicon (Si) solar PV panel from Canadian Solar (CS6X-300P) with a rating of 300 W was taken into consideration in this investigation. The board had a specific surface area of 6.4 m2/kW, which enabled it to attain an impressive module efficiency of 15.6%.

The authors of reference [37] suggested investigating the viability of installing a solar system with a power output of ten kilowatts peak (kWp) on residential structures in several different locations around Saudi Arabia. The efficiency of a photovoltaic plant with a capacity of 10 kWp is first evaluated with the assistance of the Solargis PV Planner program, which contrasts the performance ratios and energy outputs of four distinct types of PV modules. This evaluation was carried out to determine how effective the plant was. Next, an economic study on installing PV systems for residential buildings in eleven major cities in Saudi Arabia was carried out with the help of the PVsyst program. This program considers two different arrangements for the cost of electricity. The results of the simulations indicate that the a-Si PV technology has the highest energy yield and performance ratio. On the other hand, the findings suggested that every type of PV module possesses a performance ratio greater than 75%. In addition, the data pointed to the city of Tabuk as the best location for installing photovoltaic (PV) systems in residential buildings. There would be a resultant reduction of 330.88 tons of carbon dioxide (tCO_2) in annual greenhouse gas emissions, which results in a Levelized cost of electricity (LCOE) of 0.027 dollars per kilowatt-hour.

Research was conducted on a combination of hybrid and microgrid systems based on the HOMER open-source platform to establish whether or not it is suitable for the electrification of rural areas. The economic performance of the photovoltaic-fuel-cell-electrolyzer (PV-FC-EL), water-gas-fuel-cell (WT-DG-FC), and photovoltaic-battery (PV-Battery) systems were evaluated [14]. This paper has concluded that the DG has lower costs associated with its installation, with the GPC steadily increasing throughout.

A new optimization model for sizing a solar–wind grid-connected system based on mixed-integer linear programming was proposed in [38]. The suggested hybrid system was intended to meet the load requirements of a Saudi Arabian industrial site. The proposed model calculated the optimal number of solar modules and wind turbines, the optimal hourly energy taken from the grid, and the excess hourly energy produced and sold to the grid. The model results indicated that, in addition to the grid, seventy-seven solar modules and seven wind turbines were required to meet the load requirement. The system generated 450,734 kWh annually, equivalent to 82% of the annual load demand. In addition, the system generated 72,752 kWh of excess energy, which was worth USD 6184 to the industrial site.

A mixed-integer, programming-based, multi-objective model for sizing a grid-connected photovoltaic–wind system was proposed in [39]. The model attempted to combine the economic and non-economic aspects by reducing greenhouse gas emissions and the grid contribution share across the life cycle. The hybrid system met the energy needs of a desalination facility that used reverse osmosis to provide potable water for a Saudi Arabian residential area. Decision-makers could select from a set of Pareto-optimal options that the model generated based on their preferences. To show how the grid and the renewable energy system were interchangeable, three plans were selected from the Pareto-optimal options. For example, the system may supply 18% of the plant's energy requirements while producing the least amount of carbon dioxide by using 100 photovoltaic panels and 94 wind turbines (equivalent to 90,899 kg of CO_2 per year).

The initial goal set by Saudi Arabia is to install 27.3 GW of renewable energy by 2024 and 58.7 GW by 2030. Significant advancements in the power system must be developed to reach these goals. Therefore, this work addresses these developments by investigating a variety of long-term scenarios with varying levels of penetration of renewable energy. On the other hand, many forms of renewable energy depend on the weather; as a result, their output might vary significantly. Increasing the production of renewable energy without appropriate planning may jeopardize the reliability of the power system due to the unpredictability and inconsistency of renewable energy sources when compared to fossil fuels.

In a small building in Dhahran, Saudi Arabia, Rashwan et al. [40] conducted a cost-effectiveness and environmental feasibility analysis on switching the power supply from the electrical grid to renewable energy provided by solar PV modules. A 12-kW capacity for the PV power plant was estimated using the worldwide PV Project Model. They determined that installing solar PV systems in areas with high electricity rates was feasible after evaluating three scenarios, including those in which the cost of grid electricity was 4.0 cents per kWh, 8.0 cents per kWh, and with a partial grid electricity supply.

As was previously indicated, numerous research on photovoltaic (PV) systems were conducted, each backed by a unique model; however, the technical and economic analyses lacked any theoretical justifications. Additionally, previous research on PV systems with and without batteries and certain types of batteries has yet to be conducted, making it challenging to judge the best PV system that should be built in Riyadh, the capital of Saudi Arabia. The goal of this study was to use the set of equations to describe the I-V properties of the PV unit cell, arrays, inverter, and system model, and to then combine these values into the system advisor model (SAM) program to acquire the technical parameters [41].

The U.S. National Renewable Energy Laboratory (NREL) created SAM [19] to calculate energy costs and the system performance for various renewable energy systems. The system's design, operation, and installation cost projections are presented. The program includes several computational models for solar modules, arrays, inverters, converting direct current to alternating current, efficiency, different battery types, storage capacities, and other topics.

Salah Ud-Din et al. [42] investigated the feasibility of a solar photovoltaic (PV) technology analysis for two 60 kW PV system projects with battery storage in two locations in Saudi Arabia: Riyadh and Hofuf. Calculations were made using a variety of metrics for each area so that the results could be compared and the best possible location was chosen. The two systems' overall effectiveness was discussed, including capacity factors, performance ratios, Levelized costs, and net system savings. The purpose of the study was to establish whether it is possible to install energy storage systems powered by solar energy in the eastern regions of Saudi Arabia. This research will be expanded to discover additional viable spots in the vicinity for installing PV systems.

The authors in [43] presented a detailed and methodical description of solar thermal technologies, substantiated by examining their economic and technological implications. The research began with analyzing and classifying these technologies, emphasizing their application within Saudi Arabia. A theoretical study was carried out to evaluate which solar thermal technology would be most suitable for Saudi Arabia, during which the technical parameters of several different solar thermal systems were computed and compared. It is necessary to design and simulate the plant using four different heat-transfer fluids to arrive at an optimal design for a 10 MW, parabolic, trough-based plant, including nano-fluids, molten salts, and four collectors.

In [44], there was a proposal for the techno-economic analysis of photovoltaic systems in Saudi Arabia that have manually adjustable tilt mechanisms. The authors provided a technological and economic analysis of 1 MW in the capacity of photovoltaic power facilities. The first step of this process identified the ideal tilt angles for fixed and regularly adjusted (monthly, seasonal, and semi-annual) photovoltaic (PV) systems in Turkey. These sites have different sun qualities. Thus, the tilt angles need to be optimized accordingly. Economic research was then carried out, and a sensitivity analysis was also performed.

Alqahtani et al. [45] investigated the most efficient methods by which Neom city, Saudi Arabia, could minimize its reliance on the national grid by putting photovoltaic panels on the rooftops of residential buildings. A techno-economic model of rooftop photovoltaics (PV) with battery storage is being developed as part of this research project. This model is designed to be suited to the existing residential building types that are likely to be constructed in Neom city (villas, traditional houses, and apartments). In addition, the study analyzed the most efficient orientation of the PV panels, the optimal battery storage capacity, and the most effective PV panel size. HOMER Pro was utilized within the research project scope to ascertain not only the Present Net Cost and Levelized Cost of Energy but also the ideal orientation of the photovoltaic panels and the optimal size of the photovoltaic systems. The optimal capacity of the photovoltaic system for an apartment is 10.3 kW.

In [46], the authors proposed a new technique based on machine learning (ML) algorithms for forecasting how much power a PV system installed on a residential building will produce. Several experiments were made to assess the predictability of a variety of well-known machine learning algorithms, based on the power generated using a photovoltaic system, pyranometers, and weather station data collected from a station at King Khalid University in Abha (Saudi Arabia).

Finally, [47] aimed to analyze and compare the technical and economic performance of grid-connected hybrid energy systems that included photovoltaic and fuel cell (FC) technologies by employing basic PV-tracking techniques. This work proposed the topology, design principles, and a detailed technical explanation of the components of a hybrid system. This article also presented economic criteria, which were utilized to evaluate the economic viability of various PV-monitoring approaches and seek the ideal configuration of system components.

4. Discussion

The capital cost of a PV system is the only natural financial barrier preventing it from being installed. Two traditional sources have always provided money for public buildings, including mosques. Government funding for the project is an option, as is the adoption of the "third party ownership" (TPO) model. In the TPO financing model, an energy services company (ESCO) installs the solar system and is typically in charge of most of the CAPEX and system upkeep. The ESCO would receive its money back through a power purchase agreement or a lease arrangement [48]. TPOs are well-liked throughout the world, particularly in the U.S. There are additional methods for completing tasks and earning money [48]. An increasing number of people are interested in endowment development and return management, especially in Saudi Arabia. In Saudi Arabia, the Investment Funds Project was created to do this by the General Authority of Islamic Affairs and Endowments. This project aims to help non-profits become financially stable and remain that way [49]. Solar PV systems would not make any money if they were installed on the roofs of mosques, but they would save a significant amount of money. The same is true for other things in the same orbit, such as programs to save energy. It has been proven that placing PV systems on the rooftops of significant residences and mosques in Saudi Arabia is a financially sound concept, even without aid from the government. It is noteworthy that when the net metering system was assessed, the initial model results suggested that roughly 250 kW should be installed to decrease the NPC. In particular, it was found that the installation's energy bill was practically zero, showing that the energy imported and exported were virtually equal. The annual payment was more than 50% lower after installing 124 kW with net metering. The mosque was a net importer of energy. Therefore, the net export energy price, considered at USD 0.02/kWh, did not factor into our research. The mosque explicitly imported a net amount of energy from the grid, which totaled 194,000 kWh after the billing cycle [50].

The PV system installed on the mosque and home roofs fits within the concept of distributed generation (DG). Although the building will benefit from installing PV, it would be excellent if the utility was also helped. Despite a few drawbacks, DG provides several advantages for the grid. For instance, DG can assist in lowering peak loads, managing and adjusting frequency, and delaying the utility's capital expenditures to keep up with rising demand [51].

On the other side, distributed generation (DG) such as photovoltaics (PV) might present difficulties, such as the possibility of overloading the distributed network [52] and protection malfunctions due to the two-way flow of energy. In addition, the installation of DG systems results in a loss of revenue for the utility company because users will no longer depend on the grid to meet all their energy requirements. When determining the appropriate policy framework for deployment, it is necessary to put the decrease in payments and the benefits and difficulties described earlier into perspective and evaluate them to the greatest extent possible.

A comparative study was conducted using a thermal cycling stress test to understand the impact of a concrete slab on the performance degradation of crystalline Si PV modules.

The study aimed to compare the PV modules' failure and degradation behaviors with and without a concrete slab. The electroluminescence (EL) tests showed that the defects caused by thermal cycling stress were reduced in the PV modules with a concrete slab. The study aimed to evaluate the impact of the concrete slab on the performance degradation of PV modules [53,54].

The review of solar photovoltaics and the technological study of PV-system installations in Saudi Arabia were the main topics of this paper. As previously mentioned, such a deployment would have advantages and disadvantages. Customized studies would be required to fully evaluate the impact on utility and society due to the uniqueness of each distribution network in various jurisdictions, even within the same nation.

5. Conclusions

In the past decade, the integration of solar PVs into the grid network and the number of stand-alone PV applications have expanded significantly. However, the value of PV systems can only be maximized to a certain level due to their structural efficiency and the period of sunshine. Solar photovoltaic panels can create more power by increasing the amount of solar radiation on their surface. Investments are unfeasible because tracking systems provide high energy absorption in exchange for higher installation expenses. In contrast, systematic tilt adjustment methods can significantly boost energy production without structural costs. This paper analyzes the economic implications of installing a PV system on the roofs of mosques and buildings in Saudi Arabia. Even in the absence of government assistance, it is currently economically viable to install photovoltaic systems on buildings, given the cost of power and the PV CAPEX expenses. It is essential to remember that there is a trade-off between investing money and reducing the cost of electricity. This must be kept in mind. Additionally, financial resources may be available to build up a system with a particular quantity of space; however, the area in question may need to be expanded. Large changes cannot be made to existing mosques and buildings. Still, it is suggested that future mosques be built with the possibility of installing a PV system in mind. Although this article has mostly considered buildings, the same ideas can be used for other places of worship or public places where people gather.

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