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Review

Solar- and Wind-Energy Utilization in the Kingdom of Saudi Arabia: A Comprehensive Review

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Abstract: Utilizing renewable energy (RE) sources can provide a realistic answer to the problem of many nations' energy needs. This paper reviews the current status of using RE to produce electricity in the Kingdom of Saudi Arabia (KSA). The primary aim of the review is to identify and analyze the solar- and wind-energy utilization, problems, and future trends in KSA while taking into account all relevant aspects, associated development hurdles, and suggested solutions. All involved parties will receive useful results and conclusions from a thorough examination and analysis of the pertinent literature that can assist them in understanding the potential of solar and wind energy, considering all the linked issues.

Keywords: global warming; fossil fuels; decarbonization; energy consumption; energy utilization; renewable energy; solar energy; wind energy

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1. Introduction

For practically all human activities, electricity has become a necessity, and every nation now uses energy as an effective tool for social and economic development. Oil, coal, and natural gas are some of the fossil fuels (FFs) that make up the majority of energy sources [1,2]. These resources take hundreds of millions of years to be made. When FFs are used to create energy, they release dangerous greenhouse gases like carbon dioxide into the atmosphere [3,4]. The overall quantity of FFs being wasted worldwide is rising quickly [5,6]. In order to combat the high cost of energy and the unfavorable environmental impacts of using FF resources, the development of sustainably produced energy is thus promoted by all relevant organizations and governments [7–9].

In the long run, it would be preferable to switch from traditional nonrenewable energy to renewable energy. As RE sources originate from nature, they are ample, universal, and constantly regenerating. A few typical sources of RE include the sun, wind, geothermal energy, hydropower, oceans, and bioenergy [9]. RE must replace FFs to meet near-global net-zero pledges, global warming control, decarbonization, green-energy transition, and to secure a global energy supply [10–13]. This shift, however, would necessitate the employment of energy-intensive technologies for both building and upkeep to compensate for the low energy return on investment (EROI) associated with the energy production from RE sources [7,8]. RE creates three times as many jobs as FFs and is offered at a lower cost in most countries [14].

Middle Eastern countries have solid foundations on which to construct a greener, more sustainable future. The region has the potential to significantly lower its carbon footprint due to the predominance of regular sunlight and wind, the abundance of space, and significant advancements in hydrogen generation [3,10,15]. Numerous Middle Eastern states and Gulf Cooperation Council (GCC) members have started a variety of initiatives that will quicken their transition to greener energy [12,16].

Many studies have addressed the RE issue on both the global scale [8,17–22] and the regional scale [23–34]. These studies broadly discuss the relationship between resource availability and the need for RE deployment. The studies in [17–19] addressed possible scenarios and applications of renewable sources, while the studies in [20–22] looked into market barriers and government reactions. The studies in [23–34] explored the current state of RE in KSA, as well as prospects and problems, from various perspectives. Unfortunately, there is a lack of topic-oriented research on geographically and category-bonded RE issues. The strength of such studies and reviews is that they are more focused and further beneficial for various concerned parties.

This review article will try to fill the gaps mentioned in the literature related to RE utilization in the KSA. This paper will provide a detailed discussion on the current state, development, applications, and future prospects of solar and wind energy sources and their use in the KSA. This study will consider and review various correlated measures to address the role and impact of RE in the KSA, with special emphasis on solar- and wind-energy categories. To confirm category-bonded research, other sources of RE like hydro, biomass, etc., are not investigated in this review.

To present the investigation outcomes, this article is structured as follows: Section 1 delivers an overview of the issue, emphasizing the importance of this study. Section 2 reflects the procedures used to consider suitable review references. The previous related studies are presented in Section 3. A description of the KSA's present and future state of energy use is provided in Section 4. The national distribution of RE and the present state of solar and wind energy in the KSA are presented in Section 5. The market environment and RE deployment within the KSA are provided in Section 6. In Section 7, the prospect of RE in the KSA is described. The barriers related to the RE industry in the KSA are then discussed in Section 8. Finally, Section 9 concludes the review by summarizing the key results, underlining the boundaries and discussing the future of RE in the KSA and by what means it could unfold.

2. Methods

The assessment will be a combination of the topical collected works on a range of issues, covering matters such as current statuses and types of electricity production, actual RE utilization, challenges, and short-term aspects, all with a foundation in science. More hypothetical investigations into the future of RE in the KSA will also be included. The first choice was made to collect the following types of related studies:

- The most recent related literature that was distributed after the KSA announced Vision 2030 and addressed its goals, specific statistics, reports, and news;
- Studies that specifically address RE utilization in the KSA;
- Studies that implicitly addressed real cases of RE utilization in the KSA;
- Emphasis on solar plants and wind farms, as they are the more commonly applied types of RE projects in the KSA.

The review of the present dispersion of RE technologies in the industry and updates on their development features have been collected from several general RE reports and official sources.

For energy statistics, standards, analyses, and forecasts, this assessment mainly depended on data available from national and international energy organizations and companies such as the Electricity and Cogeneration Regulatory Authority (ECRA), Saudi Electricity Company (SEC), King Abdullah City for Atomic and Renewable Energy (KACARE), the Arabian American Oil Company (ARAMCO), Saudi Arabia Renewable Energy Investment Forum (SAREIF), National Renewable Energy Program (NREP), Renewable Energy Project Development Office (REPDO), Saudi Arabian Monetary Agency (SAMA), Gulf Cooperation Council (GCC), Organization for Economic Cooperation and Development (OECD), British Petroleum (BP), the Energy Information Agency (EIA), the International Energy Agency (IEA), the Organization of the Petroleum-Exporting Countries (OPEC), the World Energy Council (WEC), the International Monetary Fund (IMF), the International Renewable Energy Agency (IRENA), Food and Agriculture Organization (FAO), and many other related governmental organizations.

Up-to-date weather reports from the Intergovernmental Panel on Climate Change (IPCC), along with other organizations that provide detailed global and regional solar and wind data and atlases, were used to evaluate the KSA's climate.

Various published reviews and real case studies on RE's status and implementation in the KSA have also been considered. The selection of cases was based on two motives: they should be within the mentioned review scope, and they should cover different regions of the KSA.

Depending on the six different themes and points of view covered, seventy-six references published during a range of thirty-three years have been taken into consideration and comprehensively reviewed. The breakdown of these references is detailed in Figure 1.

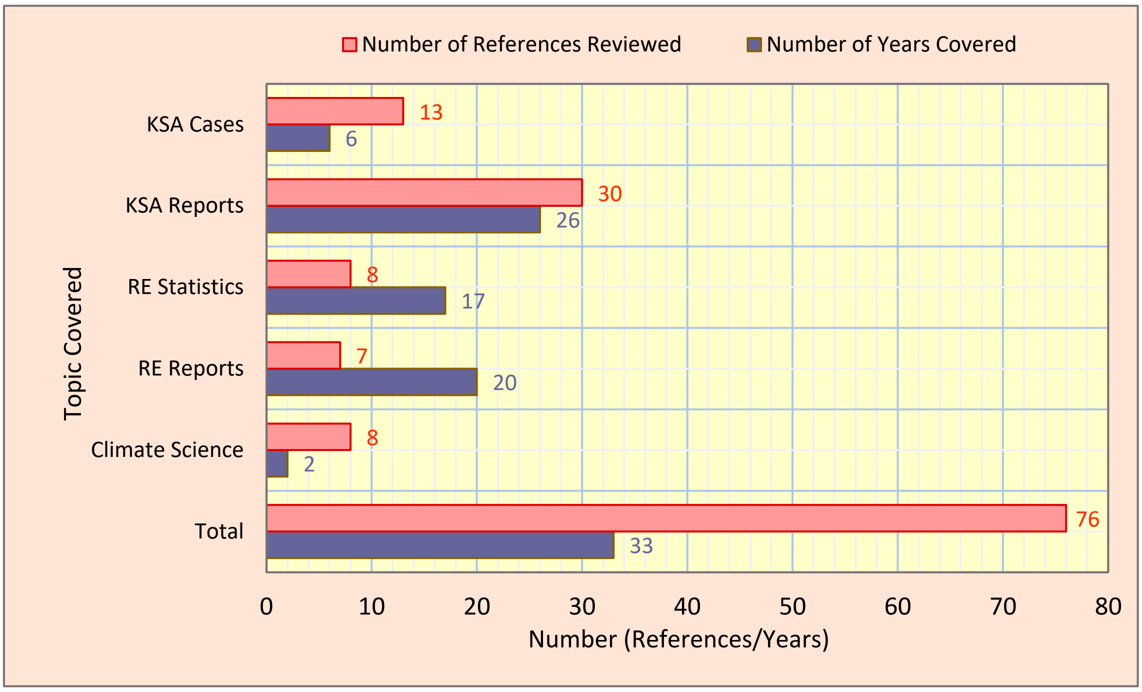


Figure 1. Breakdown of references considered in this review.

3. Previous Related Studies

Many studies [35–47] have been conducted to assess the potential of RE in the KSA and explore various proposed and/or implemented applications.

Many wind-energy parameters have been thoroughly examined in [35]. For all the parameters investigated in the study, discernible repeated patterns were detected. Lower concentrations of unrest were seen at higher elevations. The analysis discovered that the wind turbines were not operating for nearly 4.0% of the year and functioned at full capability for nearly 9.0% of the year.

Based on earlier observations, two fuzzy logic systems were constructed in [36], using spatially and temporally independent data to precisely predict GHI in the KSA. The second model employed the simulated annealing process, whereas the first model employed the subtractive clustering strategy. The second model had a decent modeling accuracy of 88%.

A study that used the multi-criteria decision-making (MCDM) technique and the Analytical Hierarchy Process (AHP) to criticize the alternatives and accordingly locate optimum sites for solar-energy projects within the KSA was carried out in [37]. The study concluded that 16% of the investigated zone is suitable for installing utility-scale PV power plants, especially in the north and northwest.

A grid-connected hybrid system has been technically and economically analyzed in [38], where the potential of RE resources in four cities has been evaluated utilizing Hybrid Optimization of Multiple Energy Resources (HOMER) software (HOMER Pro

Version 3.11.3). The proposed system was found feasible in Yanbu because of its high RE penetration. Yanbu's system reflected the best results in terms of energy costs, energy produced, and CO_2 release.

A sensitivity analysis to examine the impact of techno-economic constraints on PV-system performance was conducted in [39]. With a performance ratio of 78%, the paper concluded that operative energy management can be achieved with such systems in a typical local apartment.

A study in [40] investigates the energy consumption, feasibility, and economics of implementing PV systems in school buildings. Interviews were carried out at various schools in Arar city for data collection, and then a school building was chosen as a case study. The study disclosed that supplying school buildings with PV energy is economically practical, although more administration encouragement is required.

Many feasibility studies on wind energy were also carried out. The generation of electricity in Al-Aqiq City using wind energy was conceded in [41]. The mean wind speeds and wind power were calculated using data collected from a wind-monitoring station located at King Saud Airport in Al-Aqiq. The highest capacity factors of 40% and 48% at heights of 50 m and 100 m, respectively, were recorded for the Yinhe GX103-2 wind turbine.

Another study to assess the wind energy potential in Medina was presented in [42]. The paper investigated the energy production from an Aventa AV-7 wind turbine using the Weibull probability distribution. An annual power generation of 8648 kWh was recorded for the turbine, which is only 15.2% of its maximum power output. However, the amount of power is expected to be maximized at a wind speed of 7 m/s.

A work reported in [43] examined the prospect of wind-power generation for several places in the KSA. The mean wind speed of multiple sites at heights of 10 m and 100 m was employed to calculate the Weibull parameters and illustrate the frequency distribution of the wind in each place. The wind-power equation was then used to compute the power density for each location. The mean wind energy was then estimated to determine the suitability for the installation of various wind turbines.

The wind energy at six different sites in the KSA is also studied in [44] to investigate its impact on sustainability. The study investigates and presents the distribution of % frequency at different wind speeds at 12 m over the entire geography of KSA over two decades.

An investigation of long-term wind statistics for annual and monthly variations in the Al-Baha region of southern Saudi Arabia is presented in [45]. Wind power was examined for 17 various-size wind turbines. The most energy produced by the Soyut Wind 500 machine was discovered to be 1420 MWh/year. The research determined that generating power from wind in the northeast of the Al-Baha region has potential.

Some studies like [46] and [47] have also addressed the issues of potential investment pathways for RE in the KSA, the legislation and regulations needed, and the required promotion plans.

The most suitable approach with respect to investment costs, domestic electricity consumption, compatibility with the current grid, time needed for asset return, and enduring benefits for several KSA provinces was explored in [46]. According to the study, the most popular method for promoting RE is the feed-in tariff (FIT). The study claimed that a useful and attractive FIT could be used to integrate solar energy into the main grid. The paper's conclusions can be applied to evaluate the FIT's effects on the environment and economy.

An analysis of RE-investment scenarios in the KSA was also carried out in [47]. The Internal Family Systems (IFS) model is used in this study to address the ambiguity surrounding the track record of RE investments. Constructed on the outcomes of Leontief's input–output (Leontief's IO) model, three types of investment have been anticipated: based, alternative 1, and alternative 2. When validated using sensitivity investigation, the first two investment types were found to be the best compromise, while the third was found to be less desirable.

4. The Current and Future State of Energy in the KSA

Administratively, the KSA comprises five regions: eastern, central, northern, western, and southern. These regions are divided into 13 provinces. The population size in 2022 amounted to 32,175,224 [48].

The KSA enjoys a huge reserve of crude oil and natural gas. In 2022, the KSA ranked as the top producer of crude oil and condensate worldwide, the leading exporter of crude oil, and the leading producer of crude oil within the OPEC [4,49,50].

Between 2010 and 2020, the electric energy generated grew by 52.6%, from 225.7 GWh to 344.5 GWh. Furthermore, there was a 32.5% rise in the amount of electrical energy consumed throughout this period [50]. The KSA consumed 289.3 gigawatt hours of electricity in 2020. The Saudi Electricity Company produces 54.2% of the total amount of electrical energy. The SEC produces 45.4% of its power from steam generators, 31.7% from combined-cycle generators, and the rest from gas generators. Desalination plants produced 40.59% of the nation's electricity, with other plants contributing 5.17% [51–55]. The production and use of electrical energy in the KSA over the past ten years are shown in Figure 2 [51].

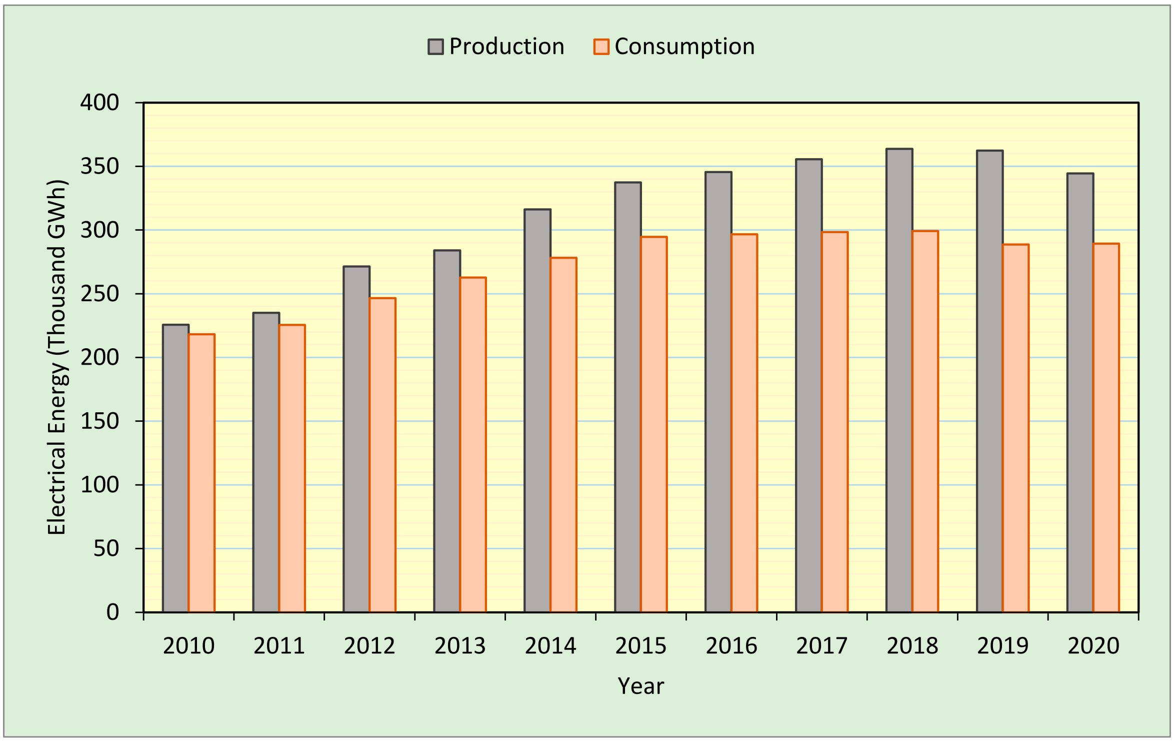


Figure 2. The total energy production and consumption in KSA between 2010 and 2021 (plotted based on data obtained from [51]).

Between 2020 and 2021, the production and consumption of natural gas rose by 2% to 4.1 trillion cubic feet (Tcf) [4]. According to Aramco, natural gas-fired power generation is anticipated to drive a 3.7% annual growth in local natural gas demand from 2021 to 2030 [56]. Vision 2030 also calls for the KSA to start exporting natural gas. Currently, the income earned from crude oil and natural gas resources accounts for 90% of the Kingdom's entire revenue. This concentration has made these products an essential non-RE resource [57].

As reported in [4], the KSA generated about 375 terawatt hours (TWh) of electricity in 2022, compared to 367 TWh in 2021. In total, 67% of electricity generation in 2022 will come from natural gas, 33% from oil, and less than 1% from renewables.

In terms of how consumption was split up across the various sectors in 2020, the residential segment leads the sectors by approximately 47% of total electrical energy used. The agriculture segment comes in last with only 2% of electrical energy consumption. Figure 3 displays the breakdown of energy use in the KSA by sector [54].

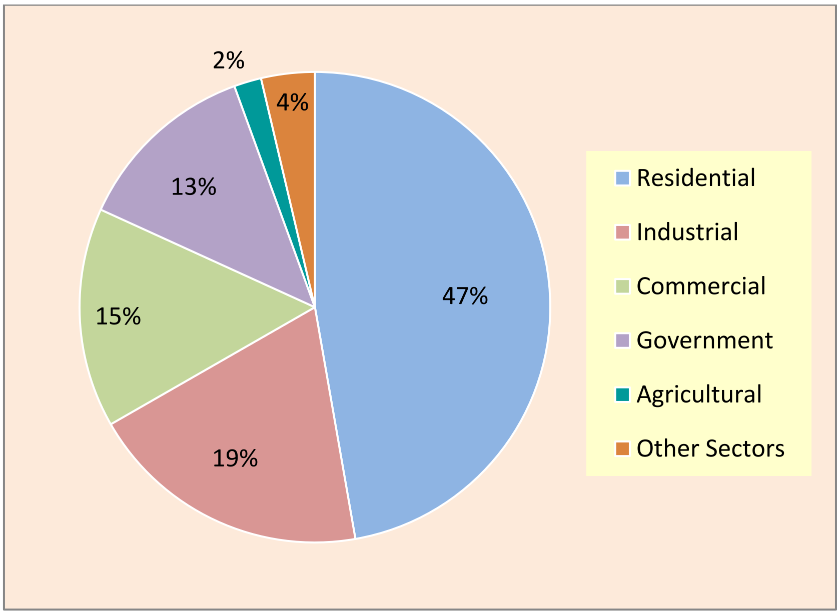


Figure 3. The breakdown of energy use in KSA by sectors (plotted based on data obtained from [54]).

The power industry is expected to be driven by an increasing diversification of energy sources and supportive government policies. The electricity market in the KSA is expected to reach 433.7 TW by 2028, representing a 3.75% CAGR from an estimated 360.86 TW in 2023 [58,59]. Figure 4 depicts the energy outlook for the KSA for a 5-year forecast data period (FDP) that spans from 2023 to 2028 [58].

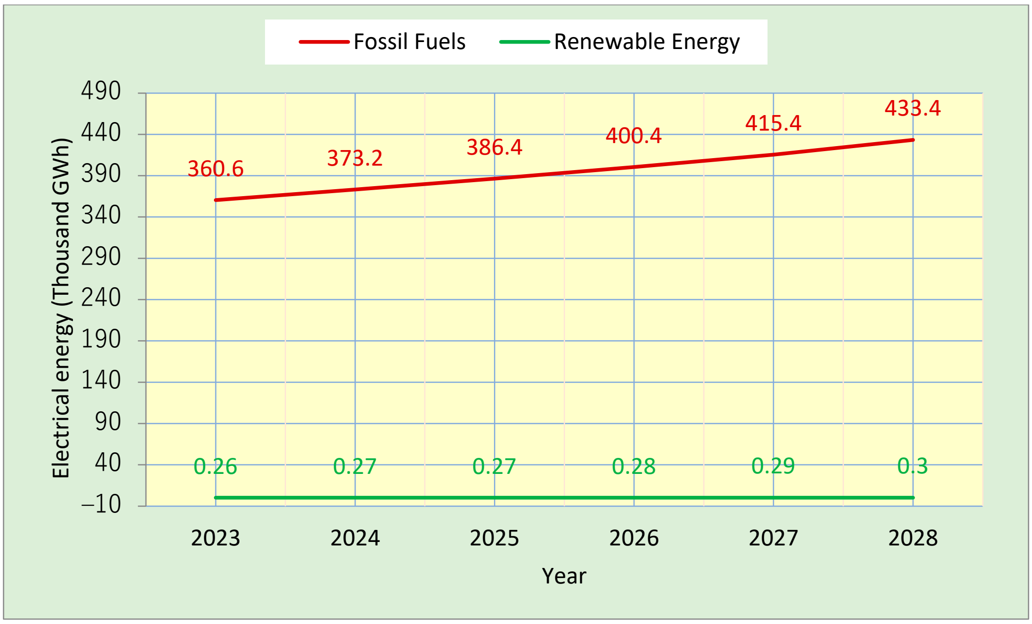


Figure 4. The energy forecast for KSA (plotted based on data obtained from [58]).

5. RE in KSA

As can be seen from Figure 2, the KSA now produces the majority of its electricity from FFs, with very little coming from RE sources. However, a number of factors, including the unique geographic and climatic conditions, falling costs associated with RE technology, an increase in the demand for clean energy sources, and supportive laws and regulations that promote grid mixing, are expected to drive the RE industry in the years to come. The KSA government intends to increase the share of renewables through several RE projects [59].

The expansion of RE also offers a chance for the growth of a new industry backed by funds from the business sector and collaborations between the public and private sectors.

The NREP, a strategic initiative proposed by the Ministry of Energy, intends to optimize the potential of RE sources to account for around half of the nation's energy mix by 2030 [59]. The national center for RE data has also been founded by KACARE [54]. This resource atlas offers up-to-date and thorough information on various national RE-related topics.

In line with the scope of this review article, the following subsections are entirely focused on solar and wind resources in the KSA.

5.1. Solar Energy in KSA

The solar energy resources of any country depend on its geographical and climatic profile. The main geographical facts about the KSA in this regard are summarized in Table 1 [3,60].

Table 1. Geographical and climatic profile of KSA.

Location	Above the equator and part of both the northern and eastern hemispheres
Subregion	Western Asia, the Middle East
Latitude range	16°23′ N–32°14′ N
Longitude range	34°50′ E–55°30′ E
Area	2,149,690 square kilometers
Climate	Generally hot in summer and cold in winter with frequent rain fall
Topographies	Seaside, valleys, highlands, molten rocks, soil hills, and sequences of mountains

A variety of models and substantial digital data sets obtained from meteorological stations and/or satellite observations can be used to create solar-resource maps. Solar-resource maps can be generated based on various models and extensive digital data sets derived from satellite observations and/or meteorology stations [61,62]. The locations of solar-monitoring stations around the KSA are illustrated in Figure 5 [54].

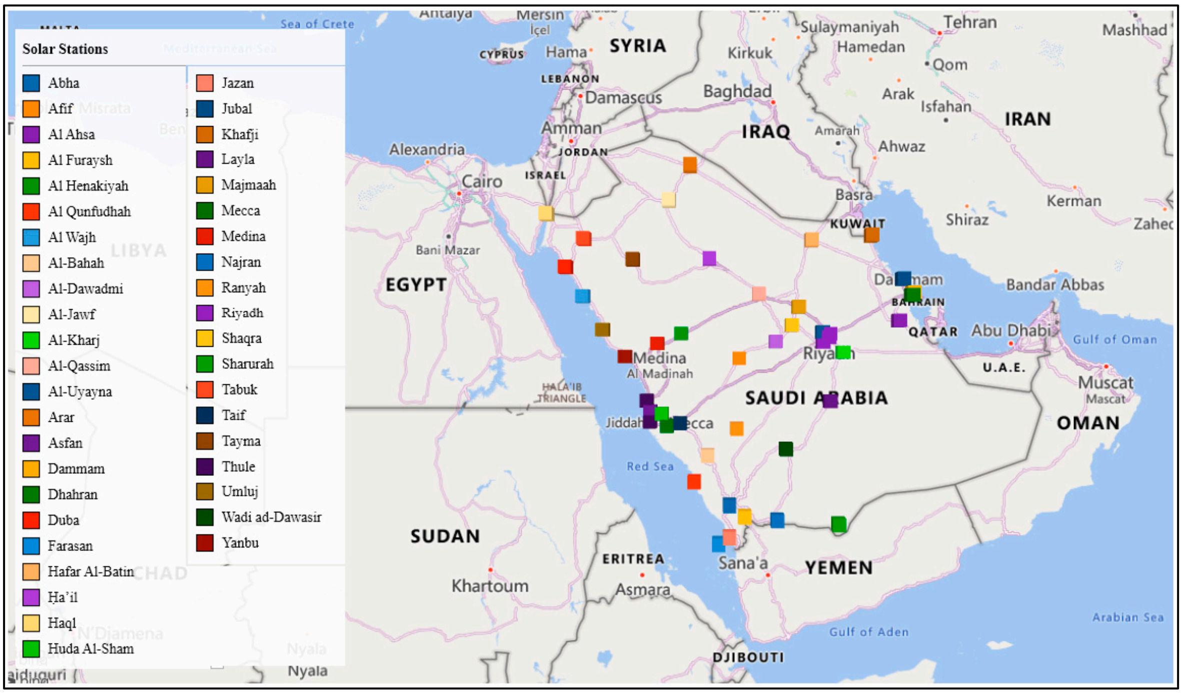


Figure 5. The locations of solar-monitoring stations in KSA (plotted based on data obtained from [54]).

The solar elements generated from these stations are for direct normal irradiation (DNI), diffuse horizontal irradiation (DHI), and global horizontal irradiation (GHI). DNI is the radiation incident on a surface perpendicular to the sun's vector. The DNI is used to calculate the energy captured by a tracking concentrator. DHI is scattered radiation from the sky that is incident on a horizontal plane. DHI can be used in conjunction with DNI to calculate energy input into collector systems or building surfaces. GHI is the sum of direct and scattered astronomical radiation falling on a horizontal surface. GHI is useful for weather-variation research. The average daily irradiation across the regions of the KSA is depicted in Figure 6 [51], while the solar GHI, DNI, and DHI maps for the KSA are shown in Figure 7 [60–63]. The GHI and DNI are given as a long-term average for the period from 1999 to 2018, and the DHI is given as an annual average.

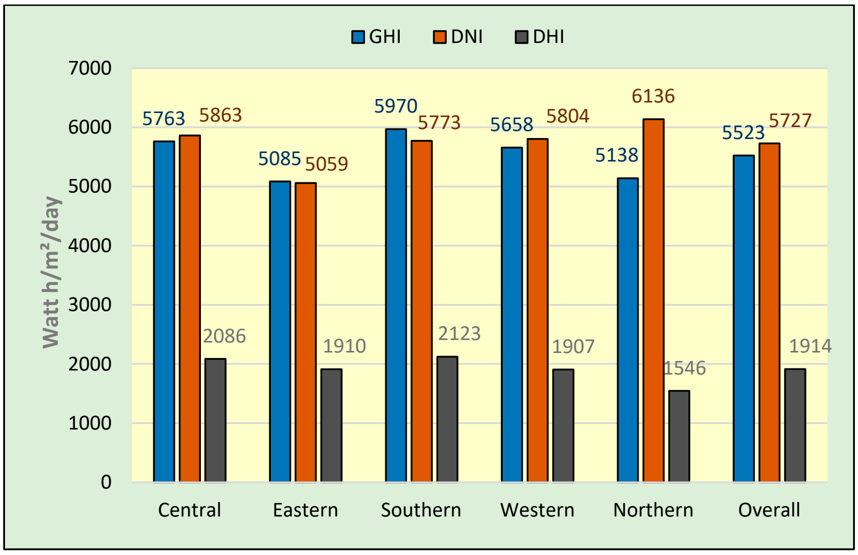
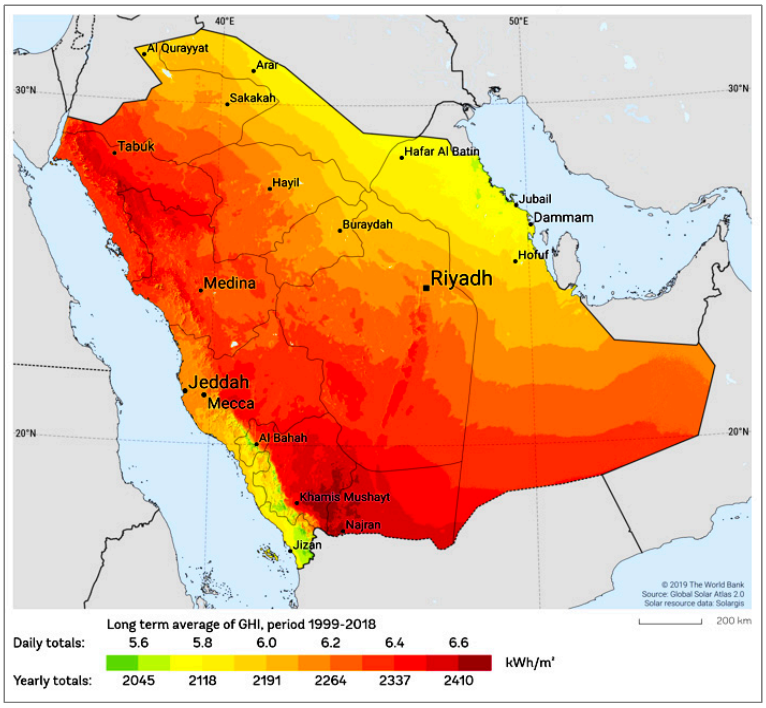
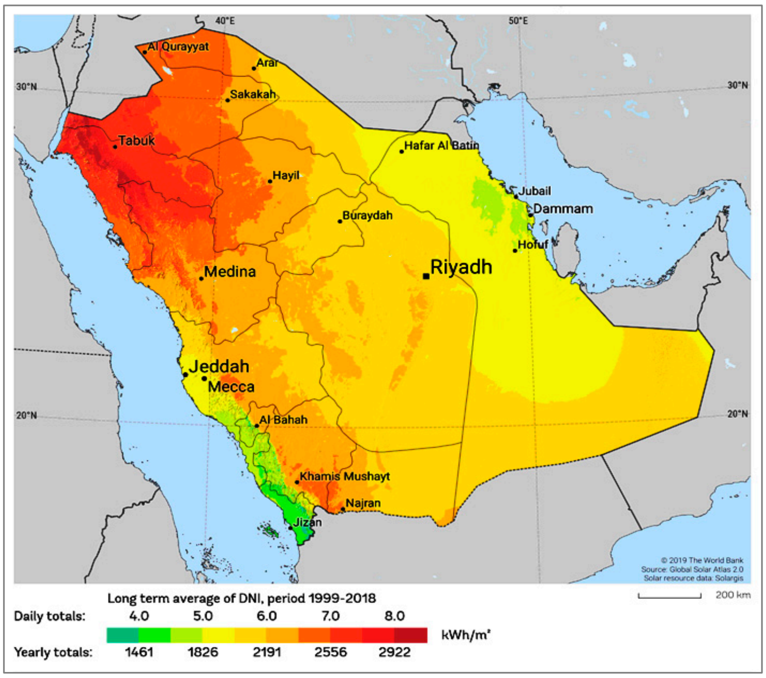


Figure 6. Average daily irradiation across KSA's five regions during 2020 (plotted based on data obtained from [51]).



(**a**)

Figure 7. *Cont.*



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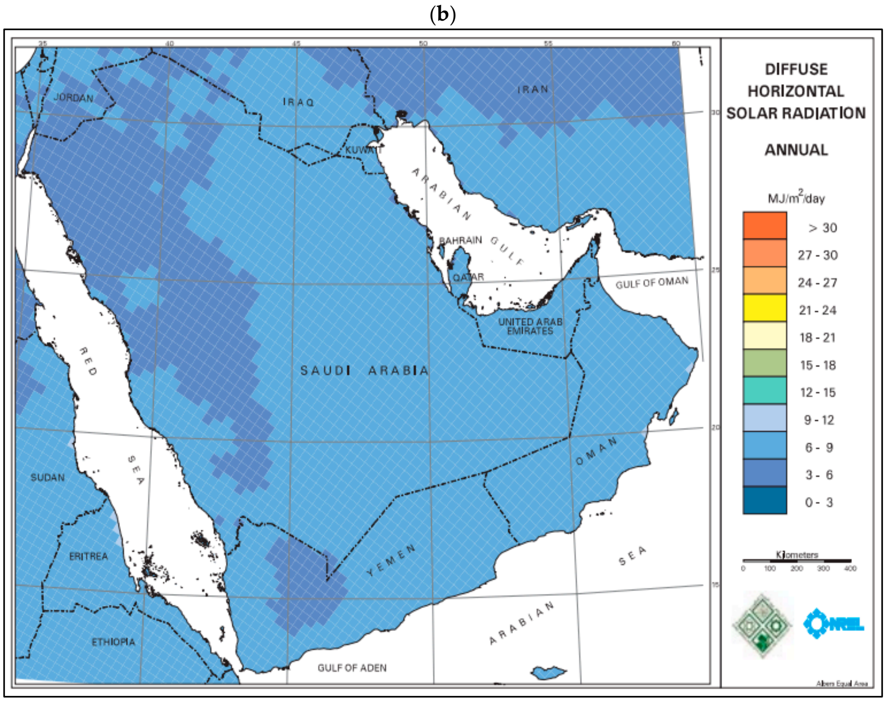

(**c**)

Figure 7. The annual solar radiation maps for KSA's (**a**) GHI, (**b**) DNI, and (**c**) DHI. Available for free download at [60,61,63].

The KSA comes in at the sixth rank among the top 10 countries regarding the potential for solar energy production [23]. A high photovoltaic power potentials and rich solar energy, resources are sufficiently distributed all over the large country zones of the KSA, with various amounts of irradiation depending on the different latitudes of each zone [3,23,62]. The photovoltaic power potential of the KSA is illustrated in Figure 8 [60,61].

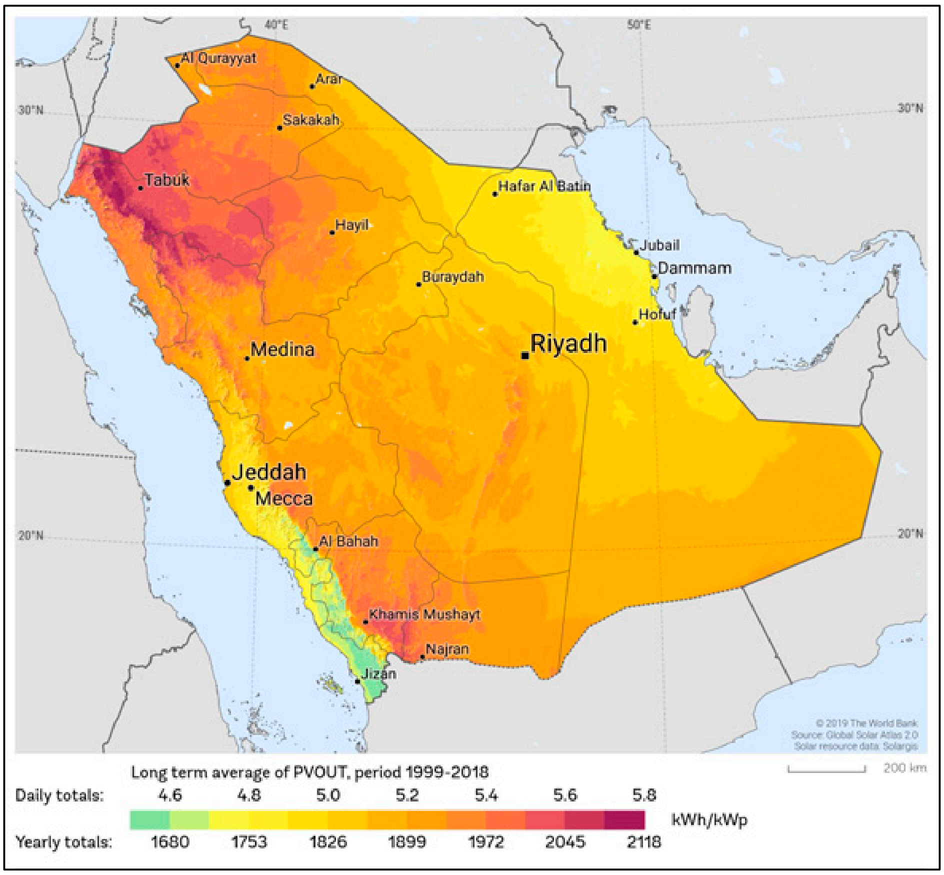

Figure 8. The photovoltaic power potential of KSA. Available for free download at [60,61].

5.2. Wind Energy in KSA

Wind energy is expected to become an important source of RE as it is advancing rapidly compared to other forms of energy. Although the use of wind energy may lead to the death of some birds and the destruction of some forests, it is environmentally friendly and less harmful to the environment.

As illustrated in Figure 9, KACARE has set up meteorology-measurement stations in ten locations, which have been distributed to efficiently support the government in gaining a deeper comprehension of the potential of wind resources at the municipal and provincial levels [63].

The KSA comes in at the 13th rank among the top 15 countries regarding the potential for onshore wind production [23]. The KSA has many attractive regions for wind-power generation, especially around the coastal areas. The KSA wind atlas for mean wind speed is given in Figure 10 [64]. Figure 11 presents the offshore wind technical potential in the KSA [65]. It can be noticed that the country is characterized by high wind speeds in areas near the northeastern, central, and western mountains [66]. The high wind speeds at 100 m and promising capacity factors in the KSA are plotted in Figure 12 [54].

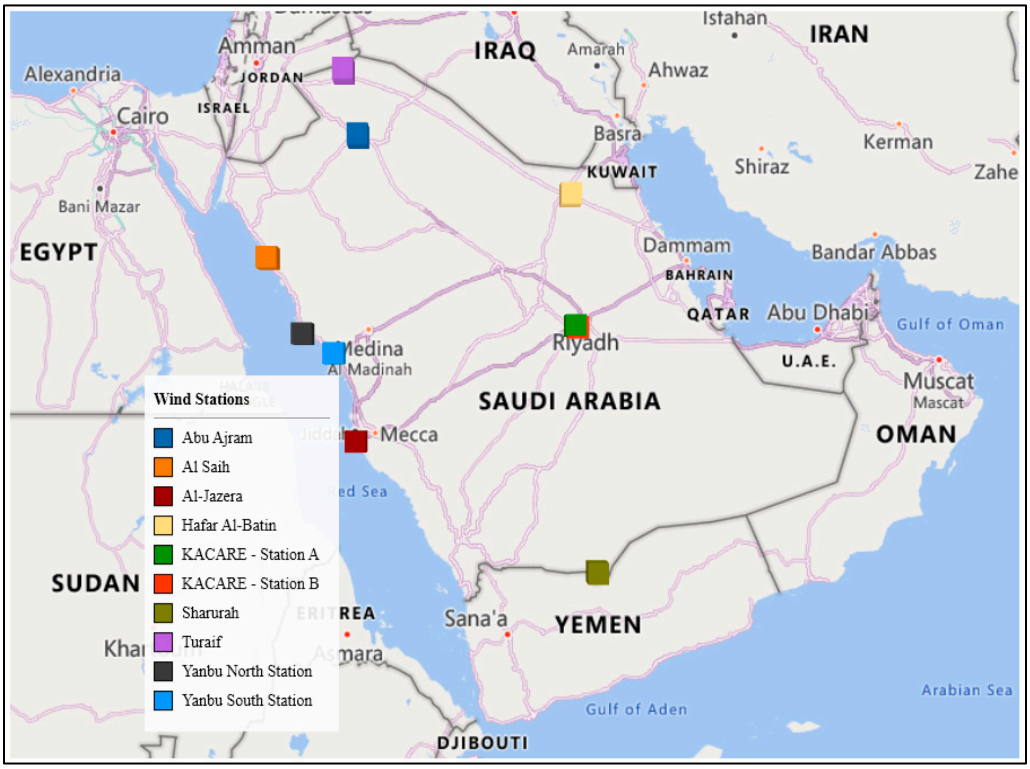

Figure 9. KACARE wind-monitoring stations (plotted based on data obtained from [54]).

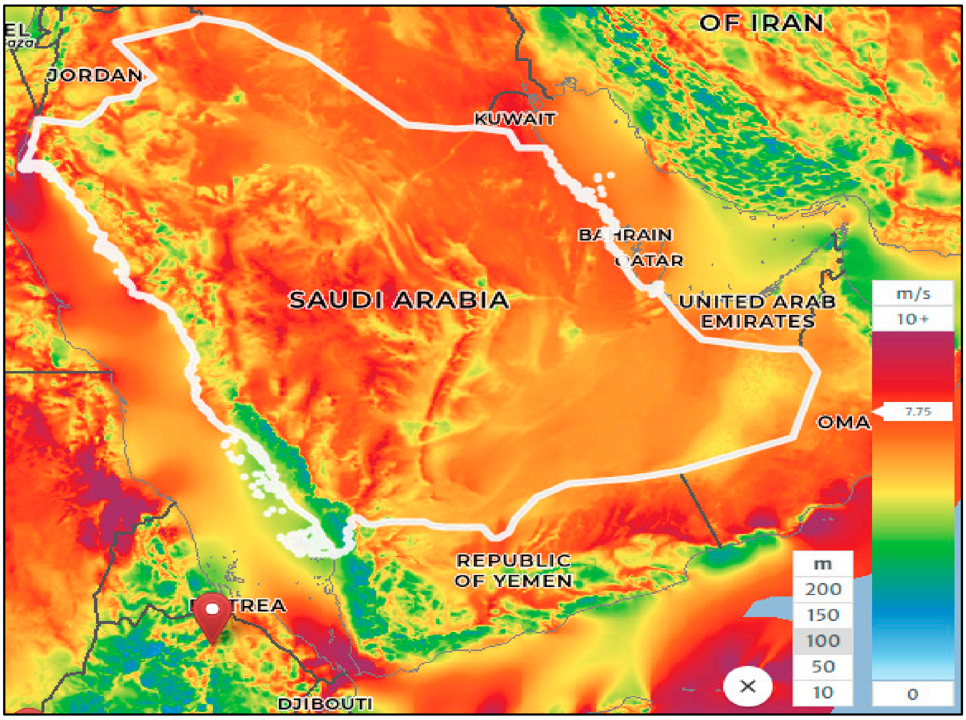

Figure 10. KSA wind atlas for mean wind speed [available for free download at [64].

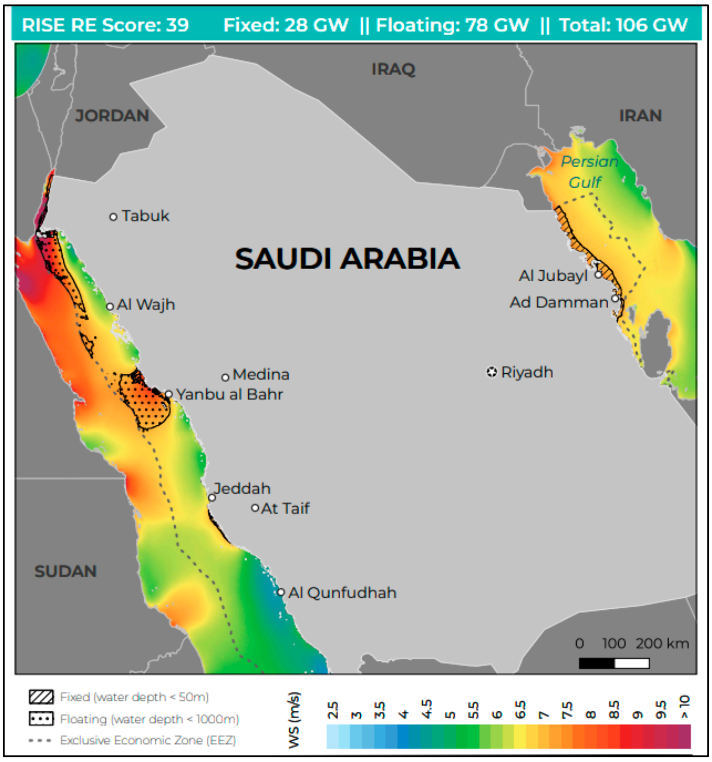

Figure 11. The offshore wind technical potential in KSA [available for free download at [65].

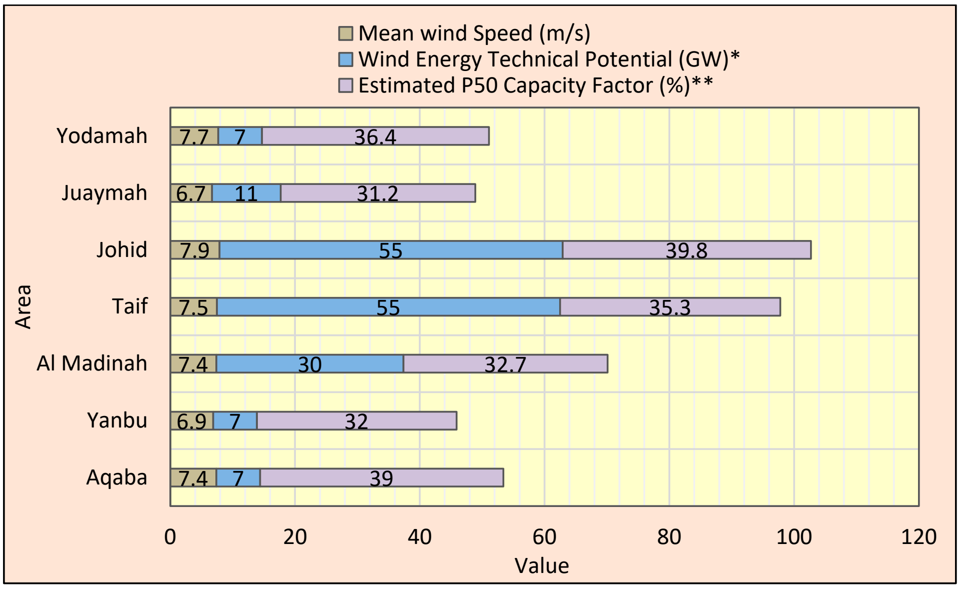

Figure 12. High wind speeds and promising capacity factors in KSA (plotted based on data obtained from [66]). (*) Assumption: 1/3 total land usable for wind turbines deployment; 3.45 MW, 126 m rotor wind turbine used for calculations; inter-WTG distances 4 × 8 rotor diameters. (**) The P50 value represents the level of production, with an estimated output surpassing 50% throughout the project duration [67]. In total, 15% energy losses are assumed due to wake effects, electrical performance, and availability.

6. The Market Environment and RE Deployment in KSA

The Public Investment Fund (PIF) program, a key economic driver for the KSA, embodies the goal of the government to diversify its economy and make investments both domestically and abroad [68]. The PIF program seeks to support non-oil GDP development and make investments in various industries. The utilities and renewables (U and R) sectors are one of PIF projects which have grown more important as they align with the goals for climate action and affordable and clean energy defined by the UN.

The NREP program is also dedicated to keep the promises made to reduce CO_2 emissions in the KSA. The NREP has an elegant and detailed plan for creating the RE business and promoting the growth of this field in order to expand the variety of energy sources within the community.

The Ministry of Energy oversees the management and implementation of the NREP through the REPDO, which was founded in 2017 [68]. The REPDO consolidates leadership in the areas of RE research, regulation, predevelopment, and placing tenders. REPDO is operating with the sector's main players, such as KACARE, ECRA, and the SEC, to build independent power projects (IPP) which will be deployed in more than 35 parks across the country [23].

The NREP announced numerous RE projects to replace liquid fuels and secure the 50% energy-mix objective. The REPDO planned to deploy these projects in several phases. The first phase started in 2017. More than 80% of the planned projects are for PV-energy production, while the rest are for wind-energy production. Other non-REPDO projects have also started being built. The RE market in the KSA is moderately split. ACWAPOWER, Alfanar, Masdar, Electricite de France SA, and Engie SA are some of the key firms effective in the industry [69]. The deployment of various solar- and wind-energy projects in the KSA is detailed in Table 2 [70,71]. The objectives of the first three phases of REPDO projects are listed in Table 3 [72].

Table 2. Solar- and wind-energy projects deployment in KSA [70,71].

Project Developer	Round and Tender Year	Status	Projects		Project Type	Capacity (MW)
REPDO	First 2017	Operating	1.	Sakaka	PV	300
			2.	Duwmat Al Jandal	Wind	400
	Second 2019	Partially Operating	3.	Al-Shuaiba	PV	600
			4.	Jeddah	PV	300
			5.	Rabigh	PV	300
			6.	Qurrayat	PV	200
			7.	Madina	PV	50
			8.	Rafha	PV	20
	Third 2020	Under Construction	9.	Layla	PV	80
			10.	Wadi Aldwaser	PV	120
			11.	Ar Rass	PV	700
			12.	Saad	PV	300
	Forth 2022	Power purchase agreement (PPA) Signed	13.	Yanbu	Wind	700
			14.	Al Ghat	Wind	600
			15.	Waad Al Shamal	Wind	500
			16.	Al henakiyah	PV	1100
			17.	Tabarjal	PV	400
	Fifth 2023	Request for quote (RFQ) Released	18.	As Sadawi	PV	2000
			19.	Almas'a	PV	1000
			20.	Al henakiyah 2	PV	400
			21.	Rabigh 2	PV	300
		Permitting stage	22.	Al-Shuaiba 2	PV	2031
			23.	Sudair	PV	1500
			24.	Ar Rass 2	PV	2000
			25.	Saad 2	PV	1125

Table 2. *Cont.*

Project Developer	Round and Tender Year	Status	Projects	Project Type	Capacity (MW)
Others	-	Under Construction	1. Red Sea	PV	340
			2. Alkahfa	PV	1425
			3. Almaala	PV	410
			4. NEOM	PV	2200
			5. NEOM	Wind	1650
			6. Al-Faisaliah	PV	600
			7. Duba 1	PV	550
			8. Dhahran	PV	10.5
			9. Medyan Umluj	Wind	400

Table 3. The announced objectives of NREP's first three phases' projects [72].

Expected annual energy generation (MWh)	15,108,701
Impact on CO_2 emissions (tCO_2/year)	9,828,156
Expected reduction in liquid fuel consumption (MBDOE)	66.91
Expected number of jobs to be created	7870
Expected number of homes to be supplied	692,557

7. The Prospect of RE in KSA

The European Joint Research Center (JRC) predicts that as traditional energy becomes more expensive, the global energy landscape will shift. Approximately 30% of the energy supply in 2030 will come from renewable resources, and 10% will come from photovoltaic power [73]. The JCR anticipated that these shares would reach 80% and 60%, respectively, at the end of the century.

With an ultimate goal for the Kingdom to become an electricity exporter, some USD 270 billion will be spent on low-carbon energy projects by 2030 [71]. The government would aim to invest in modernizing its grid and expanding the country's transmission and distribution network. Even though RE generation currently has a small share in the energy market of the KSA, authorities have recognized its importance and included goals for renewable resource utilization in the strategic planning of Vision 2030 accomplishments [14,57].

In total, 439 MW of solar PV was installed in the KSA in 2021, and this number is anticipated to rise. This capacity accounts for over 98% of the total RE used. With an average capacity factor of 35.2%, the KSA can generate over 200 GW of onshore wind energy, surpassing the majority of nations that are leading the way in wind-energy generation [66,74].

With more than 8 GW and 13 GW of RE in development, the KSA has more than quadrupled its ability to produce renewable energy, going from 700 MW to over 2.2 GW in 2022. In 2024, it also intends to tender about 20 GW and establish itself as a major supplier of green hydrogen [74].

Renewable-energy projects aim to produce 43,698 GWh of power annually when linked to the grid. It is anticipated that these projects will help provide power to almost 2.6 million housing units each year. Furthermore, they will help cut carbon dioxide emissions by about 24.8 million tons a year [72].

Based on an FDP from 2024 to 2029 and a historical data period (HDP) from 2020 to 2022, the KSA is expected to have a medium-sized RE market with a 13.00% CAGR [59,75].

8. The Developmental Barriers of RE in KSA

The rapid development of the KSA RE industry is challenged by various policy, financial, market, and technology barriers.

Firstly, there is a real need for a fast and uniform procedure for obtaining approvals and permissions in order to realize RE progress.

Secondly, upfront capital is a real challenge for RE development in the short term, and the absence of uniform financing procedures for RE projects may mislead and deter prospective backers.

Thirdly, unreliable grid infrastructure is still present in some places, especially in rural or underdeveloped areas. This is a problem for companies trying to integrate RE systems into the grid because it can necessitate large expenditures for upgrades to the grid's infrastructure.

Finally, the expertise of RE is missing in the KSA's universities. The technology barrier is also noticeable in the lack of up-to-date equipment and skilled personnel in business.

To alleviate the energy demand, numerous short-, mid-, and long-term actions can be implemented. Some required actions include the following: enhancing building architecture and hastening the adoption of energy-efficient appliances [76]; identifying and resolving blockages in the volume of RE sources by supporting domestic solutions, supply chains, and labor training investments; encouraging the transition to green energy; initiating plans and policies to put new energy-performance standards into place; and encouraging private-sector participation in the deployment of RE.

9. Limitation of the Study

This study aims to provide an overview of the topic by using representative cases and references that have been chosen and examined comprehensively. Although the study tried to address the lack of topic-oriented research on geographically and category-bonded RE issues, taking KSA as a study case, some limitations can be pointed out and recorded. The limited number of real cases of solar and wind in the KSA may have cast shadows on the depth of the review. Another observed limitation is that less than 25% of the deployed REPDO projects are now operational, and consequently, their performance and impact are yet to be real. The review could have been conducted on a solid basis with later timing. The delay in releasing the official reports and statistics can also be considered a limitation, since the review has been forced to rely on relatively old documents for some issues.

10. Conclusions and Recommendations

Due to the rapid growth of society, the public demand for power will expand quickly, which encourages the need for sustainable energy creation. The future of energy lies with RE because, in the medium term, if business-as-usual (b-a-u) rules remain, the reserves and EROI levels of FFs will be too short to support the functioning of FF-dependent economies. The International Energy Agency and major oil firms have projected that the world's oil demand will peak after 2030. Consequently, KSA's economy will no longer be based solely on oil income in the long run.

This paper discussed the current state, development, applications, and future prospects of solar and wind energy in the KSA. Even though these RE sources are only expected to play a small part in achieving national energy sustainability at this time, specific interconnected strategies involving changes in social and political structures, advancements in energy-efficiency technology, and the strengthening of RE utilization will lead to long-term sustainability prominence.

This review study is focused and is further beneficial for various concerned parties. The up-to-date information, data, and statistics provided are anticipated to be useful for all those who are participating or will participate in the solar and wind RE industry on a national, regional, or global scale. The main findings of the study are the following:

- The KSA has gradually decreased its reliance on oil in the production of electricity by substituting natural gas and RE sources;
- The potential for solar energy production in the KSA is high and fairly distributed (sixth rank globally);

- The potential for onshore and offshore wind production in the KSA is also very promising (it has the 13th rank globally);
- The study fully comprehends that the KSA government has made renewable energy a priority in its latest National Transformation Plan (NTP) and implemented proactive policies and regulations to enhance the energy framework;
- Since 2017, a total of 28 solar-energy projects and six wind-energy projects have been deployed by the REPDO under the NREP all over the KSA;
- More than 24,650 MW of generated power is expected to come from these projects;
- The shift to renewable economy is a complicated, long-term process that should involve close cooperation among administration, the nonprofit sector, and traditional energy industry to jointly address all sustainability issues.

In conclusion, this paper attempted to offer an in-depth analysis of the chosen subject; nonetheless, there is still much potential for more investigation. In particular, more should be done to deal with the following issues:

- The complementarity of the renewable resources in the KSA can be investigated in both time and space domains;
- This study can expand to cover other RE categories such as biogas, geothermal power, biomass, low-impact hydroelectricity, and wave and tidal power.
- A real-life case study can be picked from the operational REPDO projects to investigate its after-deployment economic and environmental impact.

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