



Renewable energy resources and workforce case study Saudi Arabia: review and recommendations

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Abstract

Energy is linked to the most economic and social issues which affect sustainable development of countries. To diversify its economy sources, Saudi Arabia has planned to exploit renewable energy sources. The objective of this study is to analyze the resources of renewable energy in Saudi Arabia and the capabilities of their exploitation in terms of human resources. Indeed, studies show that the country has huge resources of renewable energy such as wind power, solar power and geothermal energy. However, the main source for electrical energy in Saudi Arabia is the fuel due to the high quantity of fuel produced. Using renewable energy does not have just economic aspect. Indeed, the protection of the environment and the planet is another objective of such policy. Wind and solar power will contribute remarkably in the energy future of Saudi Arabia. In fact, clear policy established by the higher authority of Ministry of Energy, Industry and Minerals resources, set a target to produce more than 40 GW of electricity from renewable energy by 2030. The renewable energy production chain will include research and development, industrial manufacturing of equipment and higher education to prepare qualified human resources. Therefore, the number of college and faculty of engineering offering courses in renewable energy should increase to prepare graduates able to manage renewable energy projects. Recommendations are addressed in this paper to advance, boost and enrich the higher education and scientific research in renewable energy field.

Keywords Renewable energy · Workforce development · Higher education

Introduction

To slow down the changes in environment and diversify their electricity sources, many countries have developed their own policies in renewable energy projects developments and managements during the last decades [1]. Nowadays, most of implementers in renewable energy are involved to make new policies in aim to improve the efficiency, increase the amount of incomes and meet the indicative targets [1, 2]. Renewable energy is linked to financial, legislative and politic points [3]. Added to the financial issues, the development of renewable energy is facing some obstacles linked to the qualified workforce. The renewable energy is considered as economic engine. It helps to create jobs and improve the life quality [3, 4]. Germany, USA, Sweden and Portugal are the leaders in renewable energy production. The total global solar capacity of Germany at the end of 2014 was 38.2 GWh [4]. According to the last statistics, power consumption in the Kingdom of Saudi Arabia is expected to reach approximately 400 billion kilowatt hours within 10 years [5, 6]. A great

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consumption of fossil fuels is observed in the kingdom of Saudi Arabia in order to encounter its electricity consumption supplies [7, 8]. The domestic and industrial sectors are the largest consumers of electricity in the kingdom [5]. Consumption of electricity in Saudi Arabia has augmented considerably in the last decades because of the escalating power demand secondary to the noteworthy population shift from rural areas to urban areas and the significant industrial development [7]. The housing and air-conditioning sectors consume the half of electricity production. However, 21% of the electricity is consumed by the industrial sectors. The trade sector consumes 15% and the government facilities represent 12% of total electricity consumption [9, 10]. In Saudi Arabia, the main source for the production of electricity is the fuel. To support the Saudi Electricity Company, the government provides supported fuel worth about SR 150 billion each year [8]. The rapid growth of domestic oil utilization reaches 3 million barrels per day. This increase in oil consumption is 37% faster than its incomes [8, 11]. Due to the rapid growth of country's economy in the last decade, the electrical power generation authority aims to augment the generating capacity to 120 GW by 2032. To deal with the kingdom's growth demand for electrical power with minimum of oil consumption, a new program is under implementation to produce electricity from renewable energy resources [5, 6, 12]. To reach a capacity of 40 GW of the renewable energy by 2030, Saudi Arabia planned to implement photovoltaic (PV) and wind power projects with a combined capacity of 11 GW by 2022. Increasing the capacity increases the rate of return of renewable energy projects [5, 13, 14].

An overview of climatic conditions shows that the country receives profuse solar radiation all over the year which provides huge potential for photovoltaic power generation [15, 16]. With an area of more than 2 million km², many small expenditures will profit from solar energy applications for water pumping or electricity generation. If the exploitation of solar energy is conducted with a major breakthrough, the country will be a leader in producing and exporting the electrical power produced from solar power [17–19]. Being located within the equatorial Sunbelt, the wind speed in Saudi Arabia shows a capability of the production of high quantity of electricity from wind power per year [20–24]. Therefore, investing in wind power allows to generate electrical power for domestic and industrial cities. Technical and review studies show that more than 20 locations are suitable for investment in wind power stations. Yanbu, Rafea, Skaka and others cities have a good potential in wind power [24]. All the countries of the Gulf region have high capabilities and renewable energy sources. United Arab Emirates is the leader in the gulf region of the renewable energy projects with a total area of 83,600 km². Saudi Arabia, with an area of 2,150,000 km², is able to install many renewable energy projects in its different provinces [23, 24]. On

the other hand, industrial cities have been implemented in these locations. Therefore, renewable energy projects allow to increase the income from industrial projects by providing electrical power, generated from wind power, at lower prices. Geothermal energy is among the cleanest and most sustainable energy resources. Geothermal was used to produce heat and electricity in many countries around the world [25–29]. Efficiency analysis of some geothermal projects provides evidence that such projects are important to diversify the energy projects [26, 30, 31]. In the south of Saudi Arabia, many locations have high geothermal sources. These promised sources are found especially in Jizan, Al Ardah and Al-Wakrah. However, the geothermal energy is not yet exploited in Saudi Arabia [32–35]. In Saudi Arabia, the most of gas and fuel production and extraction projects are located at the eastern region, e.g., Dammam and the western region, e.g., Yanbu which are characterized by their high potential of wind and solar energy. Therefore, renewable energy can be used in Saudi Arabia for the production of fuels, which allows to increase the efficiency of these projects [29].

With more than 30 universities distributed in the country, Saudi Arabia has a good ability to prepare the manpower for all sectors. However, the specialized manpower for renewable energy projects is considered insufficient [36]. Despite the research centers and excellence centers located at the King Fahd, for petroleum and minerals, King Saud and King Abdul Aziz colleges of engineering, there is a little qualified manpower for renewable energy. Indeed, these centers are specialized in research. Undergraduate studies should focus on renewable energy studies and technologies to prepare skilled persons. This will help Saudi Arabia to improve effectively its income from renewable energy projects.

Despite many research papers presented on the renewable energy sources in Saudi Arabia, the workforce linked to renewable energy was not discussed. Preparing qualified workforce is the aim of the universities installed in the country. In this paper, we discuss the renewable energy sources in aim to push their best exploitation by preparing qualified workforce. Therefore, some programs provided in Saudi Arabia universities are discussed. The first analysis shows that only a few courses related to renewable energy are provided in Al Qassim University and King Abdullah University for Science and Technology.

This paper is organized as follows. The next section is consecrated to a short review on the electricity production and consumption in Saudi Arabia in the previous years and the near future. A short comparison with other countries is provided in this section. In the third section, the renewable energy capacities in Saudi Arabia are presented. The fourth section presents the main different renewable energy projects under construction and tests. The presentation and the discussion of the main programs linked to renewable

energy offered in Saudi universities is depicted in section five. Finally, conclusion and recommendations are summarized in section six.

The sector of electrical power in Saudi Arabia

Electricity consumption in Saudi Arabia

The total electricity consumption around the world has increased with 10% during the last decade [3, 4, 37]. In Saudi Arabia, the electricity consumption increased by 20% [5]. The domestic electricity consumption is growing rapidly over the last 10 years. Figure 1 shows the Saudi Arabia electricity net consumption from 1980 to 2014. In 1980, the total consumption was about 19 billion kilowatt hours [6]. In 2014, the total consumption increases to more than 271 billion kilowatt hours [8]. This huge increase is due essentially to the growth in the population and the development of the industrial sector. Indeed, the total number of people living in Saudi Arabia augmented from 10 million in 1980 to 50 million in 2010 [5].

The distribution of energy consumption shows that the housing and air-conditioning sectors consume the half of electricity production. Twenty-one percent of the electricity produced is consumed by the industrial sectors [3]. The trade sector consumes 15%, and the government facilities represent 12% of total electricity consumption [3]. The energy consumption distribution in Saudi Arabia is presented in Fig. 2.

Electricity production in Saudi Arabia

The production of electricity in Saudi Arabia is completely based on the conventional power stations such as steam power station and thermal power station. The coal, the fuel

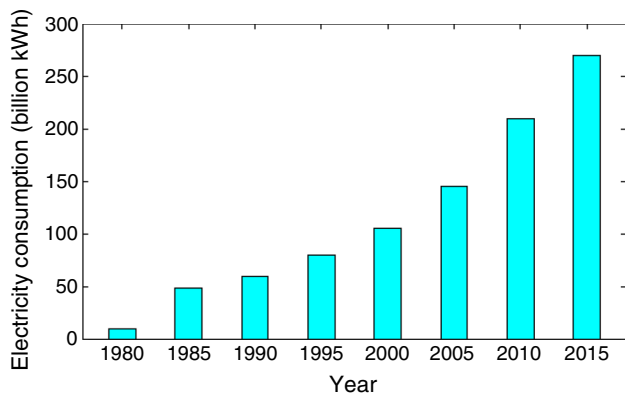


Fig. 1 Saudi Arabia electricity consumption [3]

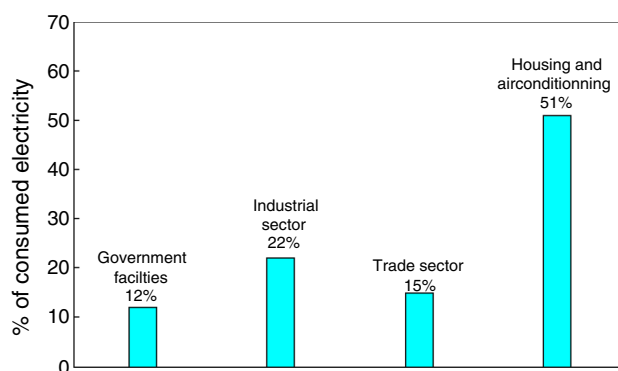


Fig. 2 Distribution of electrical power consumption between different sectors

and the natural gas represent the main elements of energy used to produce electricity in Saudi Arabia [5]. As known, these elements are main sources of environment pollution. In fact, the carbon dioxide CO₂ emission in Saudi Arabia reached 601,047 kilotons in 2014 [25].

The coal evolution consumption in Saudi Arabia is depicted in Fig. 3. The average value during the period [2000–2014] was 31.11 thousand tons with a minimum of 0.01 thousand tons in 2000 and a maximum of 87 thousand tons in 2014. The oil consumption in Saudi Arabia average value during the last period is 1557.06 thousand barrels per day [8]. The consumption of oil was 610 thousand barrels per day in 1980. In 2014, Saudi Arabia’s oil consumption reached 3141 thousand barrels per day [8] (Fig. 4).

Electrical energy sources in the world

During the past 15 years, unprecedented change in the energy consumption has been seen. Due to the policy of many countries to move to green energy, unexpected high growth in the renewables market, in terms research,

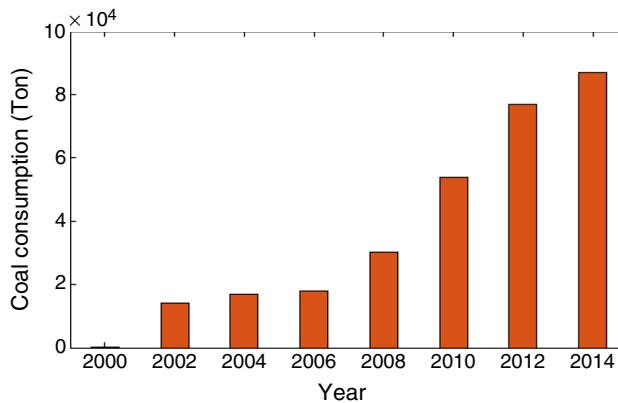


Fig. 3 Coal consumption in Saudi Arabia [3]

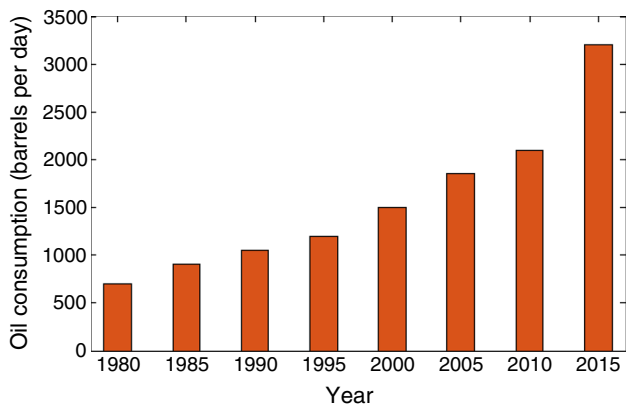


Fig. 4 Oil consumption in Saudi Arabia [3]

development, investment and new capacity rates in emerging countries, has reformed the scene for the energy sector [38, 39].

The total energy produced is about 97.14 Quadrillion Btu where the renewable energy represents 8.95 Quadrillion Btu [3]. The wind power represents 1.6%. The biomass represents 4.7%. The hydroelectric represents 2.6%, and the electricity produced from the solar is 0.09% [3]. Figure 3 shows the distribution of the sources of electrical energy production around the world.

The renewable energy target (GW) in Middle East and North Africa (MENA) by 2050 is shown in Fig. 5. The solar power in its both forms, the solar concentrator and the photovoltaic, represents the main source of renewable energy. Indeed, the initial solar power target by 2050 is 41 GW. The wind power is the second source for renewable energy production with 9 GW. The waste and the geothermal energies will be converted to 4 GW. Hence, Saudi Arabia with its economic and geographical capabilities will be the leader of the MENA countries in renewable energy production [37] (Fig. 6).

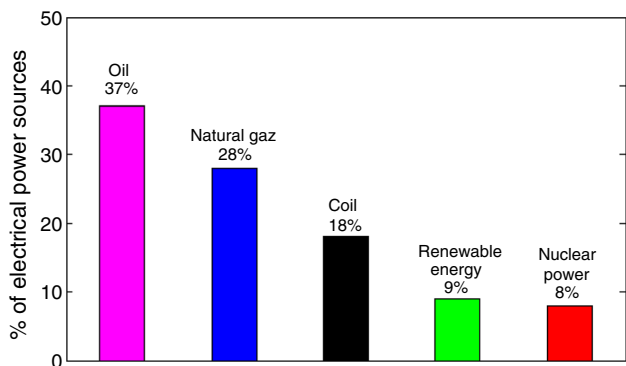


Fig. 5 Sources of electrical energy, 2013 [3]

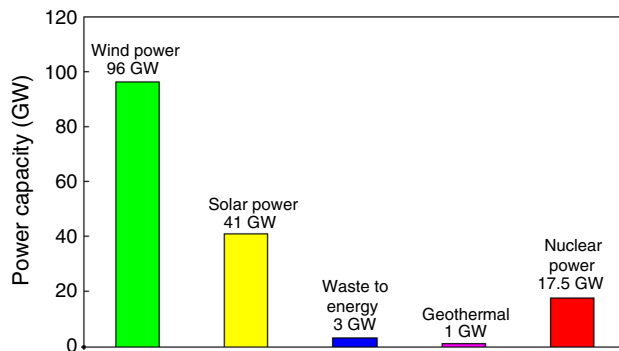


Fig. 6 Energy target by 2050 in Middle East and North Africa [4]

Renewable energy capabilities in Saudi Arabia

The capabilities of Saudi Arabia in renewable energy sources production, transmission and development are multiple. Indeed, the country connects Africa continent to Asia Continent with a total area equals to 2.15 million km² as the largest country in the Middle East and the second in the Arab world [9]. On the other hand, the development in Saudi Arabia shows an economic growth with an average change of real GDP equals to 5.31%. Hence, all the geo-economic conditions will help Saudi Arabia to invest in renewable energy projects. In this section, the different renewable energy sources in Saudi Arabia are presented (Fig. 7).

Solar energy

Solar energy is considered a noteworthy resolution for energy-deficient issues, particularly in areas having high solar radiance such as the Middle East and North Africa countries. Saudi Arabia has very high solar radiation potential for both direct solar radiation (DSR) and direct normal irradiance (DNI) [38]. Figure 8 shows the regional DNI map distribution. The average of solar radiation distribution in Saudi Arabia is about 2300 kWh m⁻². The abundant solar resources combined with the large area will make this country among the most gifted areas for the setting up of solar power stations for generating electricity [39].

Photovoltaic (PV) systems

- The solar PV technologies are suitable for use in all Saudi Arabia for generating electricity for local consumption or exporting to neighboring countries.

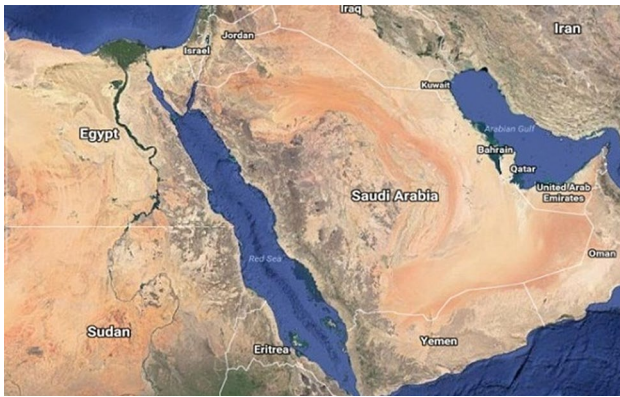


Fig. 7 Location of the Kingdom of Saudi Arabia [Google maps]

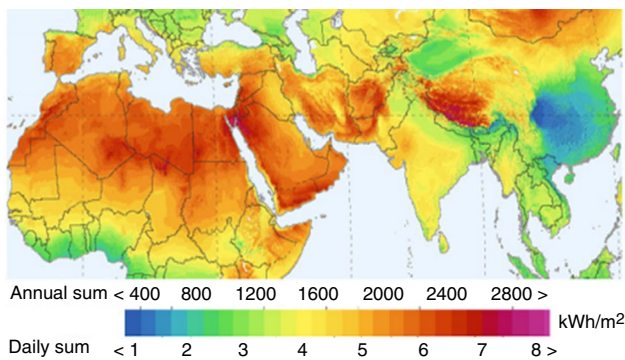


Fig. 8 Solar radiation distribution over the MENA countries

- Saudi Arabia is able to install its solar photovoltaic industry to develop and manufacture high-stability photovoltaic devices.
- The new PV module technology will have the following characteristics:
 - Very low initial investment (< USD 0.25 per Wp per year)
 - High efficiency (> 20%)
 - High module lifetime (> 35 years) and low degradation (< 0.3%/year) [5].

Solar thermal plant

- Concentrator solar power are expected to be very well suited to the weather conditions in Saudi Arabia, and steps are in place in Saudi Arabia to develop the first large-scale solar power plant.
- King Abdullah City for Atomic and Renewable Energy (K.A.CARE) developed a renewable energy program to increase the overall power capacity. The solar power gen-

erated in Saudi Arabia is expected to be around 41 GW of overall power capacity by 2032.

Wind energy

- The distribution of the wind power in Saudi Arabia, given in Fig. 9, shows high resources in the wind power especially in the region of the North West [20].
- Maximum wind power is located in west region of Saudi Arabia especially in RAS Alsheikh Hamid city, Fig. 10 [22].
- Many wind power can be installed in Saudi Arabia near the following cities: Hail, Tabuk, Al Madina, Mekka, to produce large quantity of electricity [23].

Tidal energy

Generating electricity from tidal stream technology has become important source for renewable energy production. A number of tidal power plants are installed in United Kingdom to produce more than 10 GW. Due to its geographical position between the red sea and the Persian Gulf, Saudi Arabia has good capabilities to produce renewable energy from tidal power. However, no studies are published about tidal energy in Saudi Arabia. Indeed, the electrical energy produced from tidal power depends essentially on the velocity of traveling waves on the ocean. Hence, tidal energy optimal sites characterization for marine turbine installation is required.

Geothermal energy

Saudi Arabia has several geothermal resources situated mostly at the southwestern and western parts of the country. The capacity of these resources is mainly correlated to the general tectonic activity of the Red Sea. The region of Jizan city is still estimated as a favorable geothermal area embracing many structural-related hot springs with surface temperature ranging from 46 to 78 °C [6]. Hence, the thermal parameters are estimated to be 144 mW m⁻², 318 kJ kg⁻¹ and 133 °C, respectively, for heat flow, discharge enthalpy and subsurface temperature [6]. This huge thermal energy can be used to push the sustainable development in the southwestern of Saudi Arabia. Indeed, many cities based only on geothermal energy are installed and developed around the world. The official authorities will invest and encourage private sectors to produce electricity from geothermal energy in this area of Saudi Arabia.

Renewable fuel

Hydrogen and methanol produced from renewable energy and stored in special tanks provide another way to produce

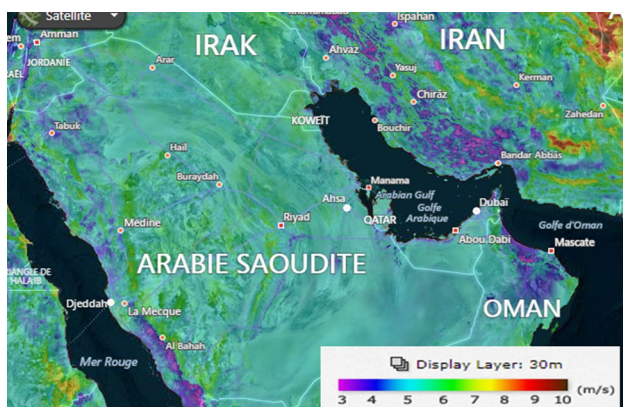


Fig. 9 Wind resources map of Saudi Arabia

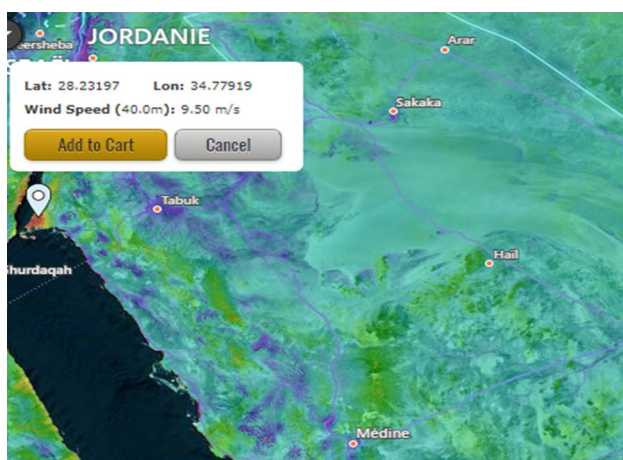


Fig. 10 Location of maximum wind power site in Saudi Arabia

and store energy from renewable sources. A brief comparison between methanol and hydrogen shows that the storage of the methanol is safer and the storage tanks of the classic fuels can be used for the storage of the methanol. In addition to its safety, methanol is used as fuel for the fuel cells or mechanical engines. Saudi Arabia can go through this strategy to become the leader in the Middle East for the production of renewable fuels. Heat, that can be produced from renewable energy, can be stored and transferred according the needs. This theory was explained and justified through numerical studies [40–43].

The heat transfer will have high performances and efficiency in near future [44]. Potential advantage will be considered for this technology [45, 46]. Therefore, developed countries can use this technique to transfer and increase the efficiency of its renewable energy systems. Some research projects funded by Saudi Arabia universities and research centers supported the design and the modeling of energy transfer systems [47–49]. Solar concentrator is another technology that can be installed in different regions to produce

electrical power and heat. Some developed technologies to enhance the efficiency of solar concentrators are mainly based on physical studies of the flow of heat can be considered [50–54].

Renewable energy projects

Renewable energy program has a crucial contribution in Saudi Arabia's vision in the provision of less polluting energy. That is why, since 2018 it is attracting more and more interest of the international solar business. The forthcoming six years will embrace significant revolution through the kingdom's power sector in order to reach 9.5 GW of renewable energy capacity by 2023 [55–60].

The Renewable Energy Project Development Office (REPDO) lately nominated 27 enterprises for its solar plans and 24 enterprises for its wind schemes selected among more than 120 establishments that acquiesced statements of qualification for Round 1 including of 300 MW solar power projects and 400 MW wind power projects, for which proposals are intended to be granted in September of 2018 [61–69]. Around \$50 billion will be devoted on renewable energy development projects by 2023 in the kingdom. The latter is a substantial market which enhanced its budget expenditure in 2018 by eight percent achieving \$237 billion. In 2023, organic compounds would stay a primary component in the energy mixture achieving approximately 60 GW. This will also be reinforced by nuclear energy with a production capacity of 17.6 GW, solar power at 41 GW, of which 16 GW will be produced by photovoltaic cells and the balance of 25 GW by intense solar power, wind power at 9 GW, waste-to-energy at 3 GW and geothermal energy at 1 GW [70].

The National Transformation Program 2020 shows an important increase in interest and support of the government toward use and investment in renewable energy resources [71–78]. Hence, the government has put a program to encourage private sectors to invest and produce electricity from renewable energy. The kingdom established an initial objective to produce 9 Giga watts and 40 Giga watts of renewable energy by 2020 and 2030, respectively [7, 8].

The cost of projects in renewable energy target by 2032 in Saudi Arabia is estimated up to 50 Billion dollars [79]. Many companies will be installed in the country to install and develop renewable energy projects such as wind power plants and photovoltaic plants. In the next years, electricity will be generated from solar energy in the kingdom by relying on photovoltaic (PV) technology and concentrated solar power (CSP) technology. The main renewable energy projects are recorded in Table 1.

Due to the decline in the prices of renewable energy systems during the last years, the efficiency of hybrid renewable

energy will increase considerably. Especially in Saudi Arabia, where the market is characterized by its low value added tax, the renewable energy projects will have high efficiency [80–87].

Renewable energy curriculum in Saudi universities

More than 30 college and faculty of engineering are installed where most of them are part of governmental universities. These colleges offer different tracks and engineering courses like mechanical, electrical, civil and industrial engineering. Table 2 shows the top 4 colleges of engineering in Saudi Arabia. The courses offered in these colleges are not linked to the policy of Saudi Arabia in terms of renewable energy research and development programs. Hence, we suggest updating the programs and proposing new programs of master in power and renewable energy systems. A list of proposed courses is given in Table 3. The programs seek to produce graduates with high skills and knowledge that can master and manage huge projects of renewable energy that will be installed in Saudi Arabia in the near next years. None of the universities from the given table are offering renewable energy courses in under graduate program (UGC) [88–91].

Table 2 Master degree offered in the top 4 colleges of engineering in Saudi Arabia

University	Offered master degree in electrical engineering
King Saud University	Communications Electronics Electrical machines and power electronics Electrical power Control systems and computers
King Fahd University of Petroleum Et Minerals	Master of science in electrical engineering Master of science in telecommunication engineering
King Abdullah University of Science and Technology	Solid-state electronics: Electromagnetics and optics Communications and signal processing
King Abdul Aziz University	Power systems and electrical machines Electronics and communications Computer engineering

Table 3 List of courses proposed in renewable energy systems

Compulsory courses	Elective courses
Renewable energy production: Geothermal, biomass, wind and solar. Integration of renewable energy sources into power grid Smart grid Power electronics applications in Renewable energy systems Energy storage	High-voltage DC transmission systems Energy efficiency in the power sector Power quality Advanced power system protection Power system stability Energy efficiency in the power sector

Table 1 Main renewable energy projects in progress

Project	Location	Capacity
Solar power	Sakaka	300 MW
Wind power	Dumat Al Jandal	400 MW
PV powered water desalination plants	Al-Khafji	2500 MW (electrical power) 10 ⁶ m ³ (fresh-water)

Conclusions and recommendations

The most important accomplishments and endorsements on renewable energy development in both industrial projects and higher education can be summarized as follows:

Renewable energy projects

- Solar energy density in Saudi Arabia is among the highest in the Middle East and North Africa. Hence, Saudi Arabia will be one of the leaders in electricity generation from solar energy by the both methods: the photovoltaic and the concentrated solar power.
- It is found that significant wind energy exists in the north and the west of Saudi Arabia. The regions of Hail, Tabuk, medina, Mekka and Abha are the best sites for electricity wind power plants.

- The ministry of Energy, Industry and Mineral sources has confirmed a short list of two projects:
- The geothermal energy in Jizan region would be a good source for renewable generation. It will also create hundreds of jobs for Saudi people.
- Research studies need to be carried to investigate tidal energy resources.

Research and Higher education:

- It is required to optimize the renewable energy power plants and determine the best layout for balancing energy output with construction costs. Hence, there is a need to update the old programs in engineering and establish new engineering programs according to renewable energy trends.
- Graduates from both bachelor and master programs in renewable energy science and engineering will assist as workforce in promoting renewable energy projects.
- Enhancement and funding of research projects in renewable energy must be a priority of universities.

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