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Seeking Sustainable Development: Prospects for Saudi Arabia's Transition from Oil to Renewable Energy

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Abstract

The Kingdom of Saudi Arabia (KSA) is the world's largest producer and exporter of oil with one quarter of the world's known oil reserves, i.e., more than 260 billion barrels. The KSA is also a major oil consumer, refining 2.5 million bbl/day in 2016 and consuming 3.2 million bbl/day. Of this, a substantial proportion was crude oil burned directly in power plants. Electricity demand has been rising rapidly; from 2006 to 2016, the annual average rate was 6.2

Index terms— renewable energy, energy efficiency, solar, wind, oil, sustainable

1 Introduction

resently, energy is the most valuable tool for human communities. The present civilization would not be possible without electricity, crude oil, natural gas, and other energy sources [1]. Globally, fossil fuels are the main source of energy for the provision of electricity, heating, and transportation. Starting during the oil crisis in the 1970s, western countries began to find solutions for maintaining a source of sustainable energy that included renewables. Moreover, serious concerns about climate change and CO2 emissions have motivated many countries to look for clean and renewable sources of energy [2]. On the contrary, the expected depletion of crude oil due to

Author: e-mail: a.abokhalil@mu.edu.sa rapidly growing consumption in the Asian countries has imposed a burden on all the developed countries to find a permanent solution for sources of energy. It is common now to see wind farms, PV parks, geothermal plants, electric vehicles, and many other transformative forms of renewable energy application.

However, the world is still dependent on conventional oil (namely crude oil, condensate, and natural gas liquids). In 2008 it constituted 97% of the world's energy sources and by 2030 will remain at 90% [3]. A decline in the production and use of conventional oil is expected when the renewable sources become cheaper, more mature and their production can fill the gap in energy needs [4], [5].

World reserves of conventional oil may be depleted after several decades [6], [7]. Other researchers have expected that conventional oil would not be depleted in the next 50-60 years [8], [9] and that oil and gas depletion will not be an issue for this generation. In contrast, others contend that new discoveries of liquid fuels, and other types such as oil sands, would occur due to the rising prices and will make production sufficient to meet world demand throughout the 21st century [10], [11].

According to estimate submitted by The Kingdom of Saudi Arabia (KSA) government to Organization of the Petroleum Exporting Countries OPIC, the KSA has confirmed oil reserves of 266 billion barrels. Based on this number, the KSA's oil reserves will last for more than 70 years if the production rate is constant at 9.93 million barrels per day as reported this year. Unfortunately, the KSA is also considered as one of the top-ranking countries for CO2 emissions and accounts for 1.4% of global emissions [12]. Therefore, emissions related to conventional oil must be reduced.

Considering these challenges, the KSA authority has launched Saudi Vision 2030, a comprehensive plan targeting the reduction in the KSA's oil dependence socially and economically. In January 2017, the KSA announced its first competitive bid for utility-scale solar power giga projects. The latest plans are described by a top-level executive in the renewable energy industry as "the highest-level commitment to renewable energy ever seen from the KSA." Additionally, the KSA has started to adopt policies for energy efficiency measures, and several initiatives have been introduced for the development of renewable energy projects. In 2012 the government started its ambitious plans for a $109 billion investment in renewable energy targeting the solar industry sector that would generate 30% of the KSA's electricity by 2032 [13]. The renewable energy target is shown in Fig. **??**.

2 Fig. 1: Targeted renewable energy capacity in Saudi Arabia

Moreover, the KSA, a member of the Conference of Parties (COP21), submitted its Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC). These recent plans and commitments are indications of a steadier approach from the KSA authorities regarding moving in a sustainable direction [14].

Fortunately, the KSA has various renewable energy sources such as solar, wind, and geothermal energy. The Kingdom plans to have one of the world's largest programs in renewable energy [15]. These programs have unprecedented investments and will eventually create numerous public benefits, including job creation, industrialization, energy savings, energy security, and reducing CO2 emissions. The potential benefits of adopting such targets are estimated based on the real situation in 2017 as a reference year and 2030 as a target year [16].

Moreover, the KSA has adopted a new policy for improving energy efficiency. In October 2017, the Public Investment Fund (PIF) wanted to collaborate with international partners for finding 40 GWh of energy savings in 2018. Meanwhile, National Esco, which was started with a budget of $500 million, is responsible for taking energy efficiency measures in all public buildings with 30,000 square meters or more of floor space, such as schools and mosques. All the government buildings have implemented the new energy efficiency measures to achieve the KSA's targets [17].

The KSA is increasing its dependency on renewable energy and insisting on energy efficiency measures. Several steps have been taken to transition toward a sustainable energy grid and a green economy. The aim of this paper is to demonstrate and discuss the current and future progress in the KSA's transformation to renewable energy sources especially in the solar and wind energy areas.

3 II.

4 Current and Future Demand

According to the General Authority for Statistics, in 2018, the KSA's population was 33,543,987capita, whereas in 2017, it was 32,552,336 capita, i.e., a growth rate of 2.52%, as shown in Fig. 2. By 2030, the population will reach up to 39.1 million, i.e., an increase of16.7% from 2018, whereas by 2060, it is predicted to reach 47.7 million [18]. Following the population increase, electricity demand has also increased annually; the electricity use in the KSA has increased from the end of last century by approximately 8% annually. Between 2004 and 2017, there was an increase from 28 to 62.5 GW [19]. In the KSA, electricity demand has grown rapidly, for example in 2000, it was 114,161,021.00 MWh, whereas by December 2016, it increased to 287,442,172.00 MWh. By 2030, this growth in demand will require the power generation capacity to increase to 122.6 GW, as shown in Fig. 3 [20].

The main consumer demand for electricity is in the residential sector. This sector is the largest with 52% of the KSA's total electricity consumption, the second largest is industrial buildings with 18%, then commercial buildings with 12%, whereas governmental buildings and agricultural activities are 11% and 3%; respectively **??**21]. The hot climatic conditions in the KSA results in an increased electricity consumption due to the use of air conditioners (ACs) that accounts for70% of the electricity consumption [22], as shown in Fig. 4, with summer consumption more than twice that of winter. On the contrary, the KSA has the largest water desalination plants worldwide, with 30 plants across the KSA with a capacity accounting for 18% of the total world production of desalinated water. By 2030 the KSA plans to increase the plants' capacity and add more double the water production. To achieve this capacity, an extremely high amount electricity (20%)will be required for water desalination [23]. In a related context, the governmental data shows that 99.19% of the residential, commercial, industrial, and governmental consumers are connected to the public utility-grid, while 0.61% have their own electricity grid. In rural areas 0.13% of households have their own electricity generators as shown in Fig. **??** [24].

These statistics show that fossil fuel demand for power, industry, transportation, and desalination are estimated to grow from 3.0 million barrels of oil equivalent per day in 2013 to 8.3 million barrels of oil equivalent per day in 2028 [25]. The oil consumption over two decades is shown in Fig. **??**.

Taking these factors into consideration, the present path of energy and electricity consumption is not acceptable in the KSA. With these levels of consumption, crude oil is not a sustainable long-term source of energy. Saudi Aramco's CEO mentioned that increasing domestic energy consumption could cost the KSA more than 3 million barrels per day of crude oil by the end of the current decade. By 2038, the KSA could become a net oil importer without a significant reduction in oil consumption in the energy sector [26]. To avoid this and reduce the dependency on crude oil, the KSA has developed a strategy to increase the use of renewable energy, gas, and nuclear power alternatives.

Increasing energy consumption is accompanied by low energy efficiency. This is due to electricityintensive lifestyles in buildings and transport (for AC), encouraged by the low price of electricity. The Saudi Energy Efficiency Centre was established in 2010 to develop both renewable energy and the KSA's energy efficiency policy [27].

In 2012, this developed into an interagency effort through the launch of the Saudi Energy Efficiency Program, which outlined guiding principles with strong participatory governance among key implementation agencies. These were focused on the building, transport, and industrial sectors, and covered 90% of energy consumption in the KSA, as shown in Fig. [28]. In January 2018, the electricity and water tariffs were increased, which impacted residential customers who consume more 4,000 kWh per month. The new prices boosted the economic efficiency, curbed the consumption of natural resources, and increased the share of the non-oil sector in power generation [29], [30]. In 2017, the KSA's PIF founded the National Energy Efficiency Services Co. with a capital of $600 million. The purpose of this company is to improve the energy efficiency of governmental buildings across the KSA and to assist in the promotion and establishment of a culture of energy efficiency in the KSA. This in line with the goals of Vision 2030 to have a sustainable diversified economy and environment. Moreover, the company missions will fund and supervise remodeling projects for the low efficiency government buildings and facilities. These buildings constitute 70% of total governmental and non-governmental facilities. Additionally, it is expected that these projects will help to decrease the cost of electricity in governmental buildings. By reducing this cost, the consumption of total oil that is used in power generation will also be reduced. The money saved can then be directed to replace and maintain old power system components in the generation, transmission, and distribution sectors. In addition, on March 1, 2018, the KSA standards, Metrology and Quality Organization (SASO) reviewed and modified its most important requirements of the new KSA standards for a number of electrical appliances including air conditioners, washing machines, dryers, refrigerators, and water heaters [31] - [33].

In the same year, PIF released a plan to establish a recycling waste to energy company with a clear mission to collect and use recyclable materials across the KSA. Before this, 90% of recyclable materials were sent to landfill sites that may cause long term damage to the environment. The KSA's Vision 2030 solved this issue by designing environment plans to improve recycling across the KSA. The KSA's recyclable materials are currently 50 million tons. With the new company, 85 % of these materials will be recycled and used as an alternative energy source for the industrial sector [34], [35].

5 III. The KSA's Location and Geography

Understanding the KSA's location and geography is crucial to discerning the future viability of alternative energy in the country. Additionally, this information can tell us what kind of future alternative energy sources may play a part in the economy. The KSAis located between 17.5?N and 31?N latitudes and 36.6?E and 50?E and longitudes. The land elevation varies between 0 and 2600m above the mean sea level [36]. Based on this data, the KSA is blessed in terms of its location and its suitability for diversified renewable energy resources. Most of the KSA is a perfect location for solar energy and several parts in the north are suitable for generating wind energy as shown in the map in Fig. 8 [37], [38].0

Based on these two promising resources, the KSA's renewable energy program was started. A deep investigation of the renewable energy potential in the KSA was carried out. The successful use of solar modules to generate electric power by installing a solar plant depends on several factors. The first key factor is 'geographic location'. When considering this factor, the solar radiation, altitude and the height above sea level should be determined and researched to assess the expected output from the solar plant and to decide if a plant is suitable for the chosen location.

The King Abdullah City for Atomic and Renewable Energy (K.A. CARE) developed a Renewable Resource Monitoring and Mapping Solar Measurement Network to provide different environmental information to support the increasing needs of the KSA for solar power generation. This enables the application of predetermined renewable energy contribution plans in the future of the country.

By using 30 stations distributed across the country (Table 1) that include information about the latitude, longitude, and elevation of each station, the data were collected and analyzed to determine the energy available and the viability of each location as a site for solar plants [39], [40].

From the analysis of the data in Table 2, it was found that the Global Horizontal Irradiance (GHI) values are high with a low variability at all locations in the country. Apart from the temperature variations these GHI values are well-suited for strong photovoltaic (PV) technology performance at any location with a low cost of electricity. To summarize, the west part of the KSA receives solar energy of over 2473 kW h/m2/year. This is greater than the eastern sites that havea total of 2011 kW h/m2/year as shown in Fig. 10 [41], [42]. The average wind speed in the northeast, central, and mountainous regions to the west is 33% above the levels needed for wind energy to become economically viable. The summary of average and maximum wind speed in various locations in the KSA is given in Table **??** 3. From these data, part of K.A. CARE's renewable energy program involves the installation of 9 GW of wind power capacity by 2032 [43].

6 IV. Renewable Energy Initiatives and Projects

As mentioned earlier, due to the geographical location and climate, the KSA is an excellent candidate for renewable energy projects. Moreover, in 2012the KSA was considered the seventh worldwide on the list of the 10 best places for clean energy [44]. Besides, the country's current initiatives are to promote and finance the application of renewable energy up to 2032 [45]. The KSA's past, present, and future renewable energy projects are assessed and discussed in the next sections.

7 a) Solar Energy

On an average, bright sunshine is available for 8.89 h, and the average horizontal solar radiation is 5591 Wh/m2. These figures clearly indicate that solar radiation is uniquely available in all areas of the KSA at a high intensity throughout the year. The KSA will play an effective role in the Middle Eastin providing clean energy. New and large investments in the energy sector have occurred to take advantage of the anticipated economic developments. Thus, the transformation from conventional sources to renewable needs to be verified between theory and practice by applying innovation systems (Al-Saleh, 2007; Foxon and Pearson 2008). Hence, to assess the transition from complete dependency on conventional oil to partially using renewable energy, a list of the major initiatives, programs, and projects in the solar power sector in the KSA in the past, present, and future are been discussed below:

Hysolar: In 1986 cooperation began between Germany, the USA and KSA, specifically, the US Department of Energy, the Saudi Arab National Centre for Science and Technology and the Solar Energy Research Institute. In 1991 the first part, a research and development project to study, test, enhance, and develop of hydrogen production technologies was started [46], [47].

Soleras: Established in 1975 and commenced in 1997 [48], [49] as a joint project between the KSA and the USA [50]. This project is considered among the first of its type in the Gulf region and the Middle East to study the viability of remote power not connected to a public grid. This cooperation led to the installation of the first solar-powered desalination plant in 2010 [51], [52]. Hitachi Zosen: In 2011, a contract was signed between Hitachi Zosen (Japan) and the Saline water Conversion Corporation (KSA) for 3years to reduce the production cost by exchanging expertise and knowledge and using the solar energy complex [53].

Technip E&C: A contract was signed between IDEA Polysilicon Company and Technip E & C to install the largest high-purity polysilicon for PV solar energy factory in the Middle East. Located in the province of Yanbu, this factory will be the beginning of an industrial chain in the KSA that starts with polysilicon installation and researching the needs of the KSA energy market and will end with meeting the growing demand for electricity [54].

Kyoto Protocol: In 2005 and 2011, the KSA submitted its vision and strategy for the reduction of greenhouse gas emissions as a member of the global community [55]. To achieve this, the KSA will promote the utilization of renewable energy sources to reduce CO2 emissions in line with the Kyoto protocol. The KSA showed its commitment to policies and measures to reduce CO2 emissions [56].

Conergy: In 2010, cooperation commenced between two leading solar system companies: Conergy (Germany) and Modern Times Technical Systems (KSA). A 200kW solar plant was installed in Riyadh and another 330 MWh plant will be installed in the King Abdullah Financial District to power the main computers outside the national grid [57].

8 Fig. 12: PV factory in the KSA

9 Association of California Water Agencies (ACWA) & Canadian Ministry of International Trade (CMIT):

A joint cooperation between CMIT, ACWA, and K. A. CARE to establish several solar plants in 6 provinces. Meanwhile, ACWA is seeking an opportunity to take part in renewable energy projects worth $7.4 billion [58], [59].

10 NYSE-IBM:

Based on the KSA's plan to reduce the cost of water desalination by reducing the energy and water cost, a research collaboration between IBM and KACST was signed to power the desalination plants by solar energy [60].

11 General Electric (GE):

In 2014, the Saudi Electricity Company (SEC) signed a contract with GE worth $1.2 billion to establish conventional and solar power plants in the Tabuk region [61]. the solar resource assessment capability by installing a high-quality 12-station network for monitoring all parameters that affect solar energy, such as irradiation and diffuse radiation, among others [69]. -To study the reliability of the PV modules in the KSA's weather conditions, a 3 kW PV system was used at the solar village site with different orientations in the four axis to evaluate the best orientation, reliability, the effects of fine dust, the performance and efficiency at different temperatures [70]. the hot water needs of all the 40,000 students on the campus. The solar water heaters are mounted on the roofs of the university buildings with total collector surface area. -One year later, the first large-scale, 500 KW, PV power system was commissioned in the KSA. power station. This plant is the largest power project in the Middle Eastand has a cost of $1.2 billion, which is shown in Fig. 16. Duba city is located at the northwest of the KSA where solar irradiation is promising for solar energy projects. Hence, the station capacity is over 605 Megawatts, including 50 Megawatts derived from solar energy. Over 600,000 houses will be powered by this plant for a year. Moreover, it is expected to have an energy surplus that can be exported to the world. -In April 2015, construction of a 1,390 MW power plant began at Waad Al Shamal. 50 MW of this power will be solar energy. The plant will provide electricity for more than 500,000 houses. The project costs $1 billion, and it is expected to be completed by the end of 2018.

-Table **??** lists all the solar projects in KSA.

12 b) Wind energy

Wind energy systems are used to extract the dynamic power of wind and convert it into electrical energy. The air dynamic energy of mass m moving at speed can be written as [71]:Volume Xx XI Issue I V ersion I Global Journal of Researches in Engineering ( ) F 2 2 1 ? m E k = (1)

During a period, t, the mass of air with the same speed and density ? pass through an area A can be written as:t A m ? ? = (2)

The wind power is then calculated from equation (**??**) and (**??**) [72]:3 2 1 ? ?A P = (3)

It is obvious that the wind power depends on the wind site characteristics and the cube of the wind speed. The turbine blade power is less than the mechanical power by the power conversion coefficient P C and the rotor power can be expressed as [73]: Based on the height, the wind speed changes as following [74]- [76]:? ? ?) (1 2 1 2 h h = , (**5**)

where h is the height of point under consideration, ? is the corresponding wind speed and ? is the empirical parameter that depends on the terrain roughness and its range varies as in [77].

The theoretical vertical wind speed profile for a site with a mean wind speed of 10 [m/s] at different surfaces is shown in Fig. 17.

From the equations, the extracted power from the wind depends on the height of the hub and cubic of the wind speed. By increasing the hub height and selecting a high average wind speed, the output power will be increased.

Wind energy utilization is the second promising source of renewable energy in the KSA. The importance of wind power as an alternative energy source emerged after intensive studies on wind resource assessment and its viability in separate locations. Beginning in 1986, a plan was established for a wind atlas by using the measured wind speed at low heights from 8 to 12 m above the ground level for 20 separate locations in the KSA [78]-[83]. During the period 1970-1982, wind characteristics data such as the average wind speed and direction were measured for 24 hours to develop a wind atlas. This atlas was incorrect due to the low heights of 8 to 12 m that were used to measure the wind data. In addition, the sites were selected randomly and were located near turbulent sites like airports. In 1996, new heights of 20, 30 and 40 m were selected to measure the wind speed average values and directions in separate locations in the KSA [84]. For accurate and reliable results, [85]used six anemometers in every wind tower, with two anemometers placed at each of the three heights. The annual average wind speed at 40 m at separate locations was found to be between 4 and 5.3 m/s at most sites [86]. The average annual energy was measured around the KSA and it was found that the energy yield is 120,000 MWh/year from 40 1500KW wind turbines in a 60 MW wind farm [87]. Due to the potential To assess the selected site's wind characteristics at the different hub heights, the average wind speed at 30,40,50,80 and 100m hub heights were measured as shown in Fig. 22.

To have a steady source of wind energy, wind speeds more than 4.5 m/s are considered acceptable in the wind energy assessment. It is noted that the wind speeds at the Haql and Al Wajh sites have average values more than 4,5 m/s at 10m [89]. The wind speeds at the Duba site have values more than 4.5 m/s at a height above or equal to 20m. On the contrary, the Tabuk, Umluj, and Timaa sites do not show wind speeds greater than 4.5 m/s at 100m. However, at the Haql site, the average wind speeds rise to 8.27 m/s at 20 m. The maximum wind speed that can be obtained at 100m is 10.5 m/s meaning the Haql site is a suitable location for wind power plants. In conclusion, wind turbines with high hubs can be used to generate power in the Tabuk region.

Between 1980 and 2012 studies of 20 promising locations were carried out. The data collected from 20 meteorological stations was then analyzed [90]. Samples of the updated and revised data including the pressure, average and maximum wind speeds for the different sites are listed in Table **??**. It is noted that the maximum wind speed is 16.5 m/s at the Guriat station, while the minimum wind speed is 7.7 m/s at the Jizan station. The maximum average wind speed is 4.43 m/s at the Alwajh station, while the minimum wind speed is 2.1 m/s at the Nejran station. Previous studies have shown that these wind generators are efficient at 4.5 m/s or higher.

The cities of Dhulum and Arar are potential sites for off-grid, remote wind turbines and they also proved the viability of using grid-connected wind turbines to partially power the two coastal cities of Yanbu and Dhahran [91]. KAPSARC found that the wind speed varies significantly from region to region and from season to season [92]. When the wind speeds are measured in a 3-hour period between 14:00 to 17:00 across all regions and seasons, the highest wind speed of 8 m/s is found in the eastern region in spring and fall. In summer, the highest wind speed in the eastern region is 6.7 m/s; in winter, the highest wind speed is 7.4 m/s [93].

The largest wind energy project in the KSA presently is the Dumat Al Jandal wind power project in the Al Jouf region. The Renewable Energy Project Development Office of the KSA's Ministry of Energy, Industry and Mineral Resources is implementing the project. The 400-MW Dumat Al Jandal wind power project is part of the first round of the National Renewable Energy Program that seeks 9.5 GW of renewable energy by 2023. The second round will also be 400MW but the location has not yet been determined. However, it will be at one of the circled sites shown below [94].

13 c) Biomass

Biomass power generation was first used in Denmark in the 1970s during the global oil crisis. Denmark started various renewable energy projects including systems to convert straw and waste to energy. Biomass technologies have been developed in different countries and presently represent 14 % of the world's final energy consumption [95]. By 2050 it is expected that 50 % of the world's primary energy use will be from biomass generation [96].

During 2014, 15.3 million tons of Municipal Solid Waste (MSW) was produced in the KSA, with an average daily rate of 1.4 kg per person [97]. By 2033 MSW is projected to be 30 million tons per year due a 3.4% growth in population. Currently, the collected MSW is sent to landfills. There is some sorting and recycling of paper and cardboard but this is a small percentage of the total MSW produced [98]. To contain this large amount of waste (up to 2.8 million m2/year), there is a high demand for new landfills. These waste management practices will become aserious public health and environmental issue if no action is taken to recycle part of this waste Therefore, the KSA considered the generation of electricity from MSW as a part of the shift from conventional oil to renewable energy. There are primarily five wastes to energy technologies widely used and implemented for MSW management, namely incineration with energy recovery, pyrolysis or gasification, plasma arc gasification, refused derived fuel, and biomethanation.

It is estimated that 250 -300 tons per day waste-to-energy plant can produce around 3 -4 MW of electricity [99] and a network of such plants in cities around the country could also make a difference in waste management.

KSA's 2030 vision [100] put forward a strong regulatory and investment framework to develop the KSA's waste to energy sector. By 2025 an ambitious target of 3GW of energy from waste is to be achieved.

14 d) Geothermal

Geothermal power is generated by heat due to elevated temperatures in the Earth and can be used as a direct source of electricity. The geothermal heat gradient increases with depth and pipes can be extended into the Earth to several kilometers to circulate water that is converted to steam on its way out to the surface as shown in Fig. 17. Throughout history people have used geothermal heat in a simple direct way for baths and spas due to their beliefs of the healing effects of this hot water. Presently, geothermal energy is widespread in a variety of forms. The main types of geothermal direct applications, with the percentage of total installed capacity attached; are bathing/ balneology at 19.1%, space heating at 15.4%, greenhouses at 5.0%, geothermal heat pumps at 54.4%, industry at 1.7%, aquaculture at 2.2%, agriculture at 0.6%, cooling or snow melting at 1.3% and other uses at 0.3% [101].

The KSA has rich geothermal features, with 10 hot springs discovered in the regions of Gizan and Al Laith in the southern part of the country [102]. In addition, a large volcanic region is being explored in the western part of the KSA. Nonetheless, research into the geothermal potential in the KSA is not proportional to the availability and the abundance of geothermal power [103], [104].Even though geothermal resources may be the least potential source for renewable energy in the KSA, the necessity for achieving sustainable development in terms of energy calls for a serious exploration of all viable options.

15 Potential Benefits of Renewable Energy and Energy Efficiency

Implementing the KSA's national renewable energy plans and objectives could have a significant impact on the whole region as following: Minimizing CO 2 emissions: According to the World Resources Institute, the KSA's emissions are 594.71 million tons of CO2 per year, which is 1.4% of the world's total emissions [105]. Using renewable energy sources will decrease these emissions. For example, a solar plant with an estimated power plant area of 1.25 km2 has a capacity of 20 MW and generates about 200-300 GWh/year. This would save 500,000 barrels of oil and avoid 200,000 tons of CO2 emission per year in the KSA [106].

In 2015, the KSA submitted its INDC to the Paris climate summit that seeks to avoid emitting up to 130 million tons of CO2 by 2030 (UNFCCC). This target can be achieved in four ways: the use of renewable energy, energy efficiency, carbon capture and storage, and public transport.

Job creation: One of the most important benefits of renewable energy is job creation. It is a component of the socio-economic benefits that emerge from the establishment and spread of renewable energy and energy efficiency technologies. By achieving the KSA's targets, more than 137,000 direct jobs are expected to be created [107]. By 2030these numbers could reach more than 430,000. Most of these jobs will serve the community and reduce the unemployment rate.

16 Creation of a local renewable value chain:

Several countries have adopted such a policy by including local content requirements for the equipment they use in several industrial sectors. The KSA designed its renewable energy and energy efficiency to boost the local renewable value chain and attract foreign direct investment in the KSA, bringing prosperity to our citizens as part of the goals established in Vision 2030.

17 VI.

18 Challenges for Solar Energy

Development in the KSA a) Technical barriers Inadequate technology and a lack of the infrastructure necessary to support these technologies present the main technical barrier to the development of renewable energy. The lack of physical facilities for the transmission and distribution networks, as well as the equipment and services necessary for power companies is a major infrastructural challenge for renewable energy development in most developing countries. Also, a lack of trained personnel to demonstrate, maintain, train, and operate renewable energy structures, especially in regions with low education levels, mean that people are unwilling to import the technologies for fear of failure.

Moreover, as in all countries, parts of the KSA's utility-grid are outdated and inefficient. Old transformers, transmission lines, and other infrastructure will be replaced to save energy. The replacement and addition of more equipment will be completed by 2020, with $4 billion invested in distribution projects annually [108] - [110].

19 b) Socio-cultural barriers

A review of the impact of socio-cultural barriers to using renewable energy reveals several factors; for example, households' unwillingness to adopt renewable energy for fear of unreliability forms, as one of the basis for failure to adopt renewable energy technologies in some countries. For example, public disinterest and disengagement in wind energy development were identified as the main social issues hindering renewable energy development in Saskatchewan, Canada [111].

Further, another challenge to development is a lack of knowledge and awareness of renewable energy technologies and systems among rural communities. For example, many people in Sub-Saharan Africa are uneducated and, therefore, they do not understand the concept of renewable energy. These uneducated people in the region do not understand the technical and environmental impacts associated with over-use of combustible fuels [112]. Taken together these factors have reduced the rate of development, circulation and usage of renewable infrastructure and technological knowledge. Therefore, the KSA should ensure the creation of awareness of renewable energy among communities and a critical focus on their socio-cultural practices are in place.

20 VII.

21 Conclusions and Recommendations

The KSA has a great natural potential for renewable energy resources and an ambitious national plan to boost the contribution of renewable energy to meet the domestic electricity demand. In this regard, the KSA has taken a crucial step in the development of renewable energy projects with a focus on solar power by 2030. A comprehensive investigation of the past and present status, and the future direction of renewable energy in terms of solar desalination, solar hydrogen production, solar and wind power generation is presented. The barriers to renewable energy development are also presented such as the lack of a skilled workforce, social awareness, and outdated segments of the power grid.

Throughout the review, it was obvious that there are several KSA commitments both to the Vision 2030 and the national transformation programs to re-position the country on the path to sustainability. These commitments emerge from different factors such as rapid population growth, water desalination demands, the excessive consumption of crude oil, a low energy efficiency in buildings due to the heavy use of AC, the desire to increase the domestic resident employment levels and the high emissions of CO_2 .

Simultaneously, the KSA authority aspires to have a greater energy diversification -this provides an added push for the growth of renewable generation capacity. Currently, renewables seem poised to move from peripheral applications (such as remote areas or research sites) to the mainstream utility-scale electricity markets, creating diffuse economic, social, and environmental benefits in the process.

In this regard, the KSA has taken steps to shift its dependency from oil to solar, wind and nuclear sources of energy, and plans to secure half of the country's electricity needs from alternative sources of energy in the next 20 years. The government has announced an ambitious plan to install 54 GW (including 41 GW of solar power. and 13 GW of wind) of renewable energy and invest totally $108.9 billion by 2032. To execute this plan, the KSA has cooperated with different governments, institutes, and companies. Starting with cooperation with Germany and the US department of Energy in 1986, this has developed projects of water desalination, electricity generation and agricultural applications. To strengthen the information about renewable energy resources in the KSA a collaboration with US (NREL) for establishing the Solar Radiation Atlas began in 1986. More cooperation with the USA, Canada, Japan, and France to exchange expertise knowledge has established a solid foundation for the development of renewable energy. The KSA now has several prominent energy institutes who led the planning and implementation of the transition from oil to renewable such as K. A. CARE, KACST and NERP. These institutes have determined the KSA's energy policies and sustainable economic and societal plans. Before 2000, small-scale renewable energy projects such as the installation of 1100 solar flat plate collectors on the roof of one building in KACST, a 350 KW solar production plant, and A 3 kW photovoltaic power system were developed to evaluate their reliability, performance and efficiency in the KSA environment.

After providing a route to implement the plans and policies and gathering information about the wind and solar energy potential in all regions, and creating the necessary centers to implement the KSA's orientation, a major plan was announced to start the transition to a sustainable economy and society. Based on this plan several mega projects have begun such as a large-scale solar system of 2 MW on the roof of KAUST, installation of 120 wind turbines of 2.75MW in Huraymila, 80 km north to Riyadh, in January 2017, a solar plant of 25MW in Princess Nora University, a wind farm of 400MW in the north part of the KSA, the commencement of a solar plant with a 100MW capacity at a cost of $640 million in Makkah in 2017, and a 1,390 MW solar power plant of 1,390MW at a cost of $1 billion launched in Waad Al Shamal to be completed end of 2018, as shown in fig. 17 and Fig. 22.

With these projects, more jobs are to be made available in this sector with 95% of employees created being KSA nationals. Meanwhile, K.A. CARE, KACST, the SEC and Saudi Aramco, along with the manufacturing and delivery of modules, are also working on the knowledge to be transferred to semigovernment and private sectors to establish fully integrated manufacturing facilities.

The new Vision 2030 increases the publicprivate collaboration in this regard and will assist in creating a public-private partnership in the KSA.

From January 2018, electricity tariffs were increased to 5, 10, 18 ha/kWh for different consumption categories. This produced two major impacts: an increase in the monthly bill and a corresponding reduction in the consumption. At the same time, the increased tariffs will impact the small-scale PV system, for example, the payback period will be ~5-7 instead of ~10-15 years, which is attractive considering the 25year lifecycle of the system.

Expanding the use of PV solar plants will cause the PV price to drop. This will result in solar energy becoming feasible, cost-effective and competitive. Globally, the cost of the construction of wind and solar power projects has been reduced by 20 and 60%, respectively.

However, there are key challenges relating to economy and efficiency. Fortunately, there are 6 key drivers that will accelerate the adoption of this technology:

-Net-Metering Regulations: Net-metering is an enabling policy designed to foster private investment in renewable energy. In August, the Electricity and Cogeneration Authority issued a regulatory framework for electricity consumers to operate their own, small-scale solar power (<2 MW) generating systems and export any unused power to the national grid, offsetting this amount against their own consumption. This creates a significant financial incentive and accelerates private sector investment in small-scale renewable energy applications. This will come into force in July 2018 and pre-qualified, registered installers must carry out the work for the system to be eligible. -Feed-in tariff: Feed-in tariffs are increasingly considered to be the most effective policy for stimulating the rapid development of renewable energy sources and are currently implemented in many countries. F

policies is to offer guaranteed prices for fixed time periods for electricity produced from renewable energy sources. To encourage investment, the KSA announced that it will move quickly to feed-in tariffs to build out the program. 90% of the capacity will be assigned through the application of technologydifferentiated feed-in tariffs. -Fossil fuel quota and renewable energy incentives: KSA should launch guidelines, incentives, or regulations that certain industries must have 10%, or even 20%-30%, of their energy from renewable sources. Also, a quota system will ensure the success of green certificates by encouraging all generators to develop new renewable sources and reduce the wastage of existing renewable. Taxing large companies, factories, and institutions can implement this when they use a certain percentage of fossil fuels(e.g., 90%). -Private investors: K.A. CARE suggested that private investors share and participate in building, operating and owning the solar and wind plants for 20 and 25 years, depending on the nature of the project. The proposal states that the government will not own the plants. -Integrated local renewable energy industry: To help reducing the payback period and increasing employment, a complementary industrial sector should consider and make policy for regulating the contribution of the private sector. -Solar Technology Advancement: Two challenges that limit the efficiency of the PV panels are dust and elevated temperatures. Research has been conducted into solutions to overcome these challenges such as electrodynamics screens, coatings and air blowers. These advancements will maximize the efficiency and output of solar solutions, while yielding significant financial gains and accelerating their wide-scale adoption.

[1] [2]

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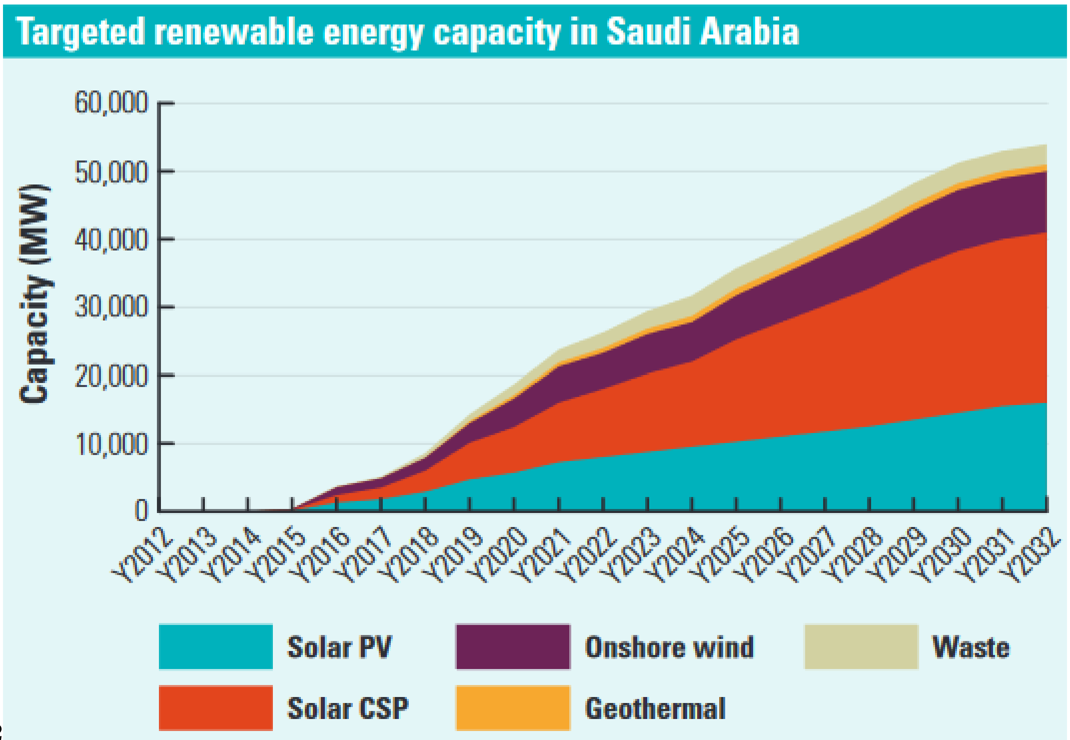

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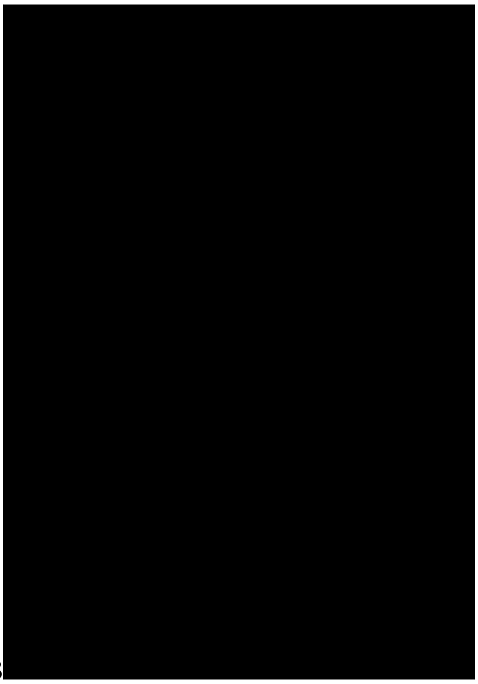

Figure 2: Fig. 3 :

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Figure 3: Fig. 4 :

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Figure 4: Fig. 5 :Fig. 6 :

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Figure 5: Fig. 7 :

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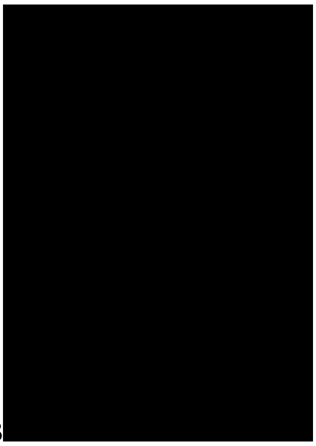

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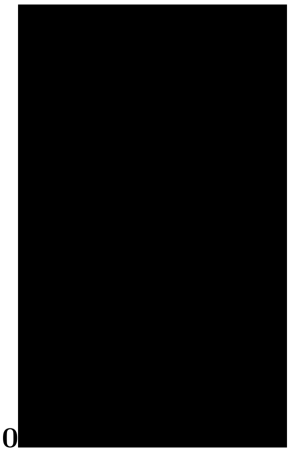

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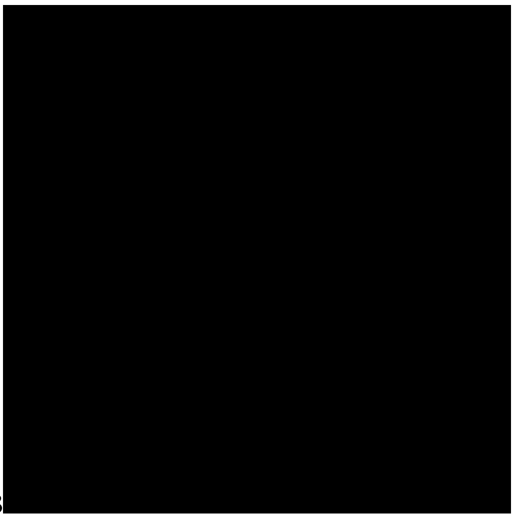

Figure 8: Fig. 13 :

Figure 9:

14

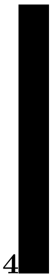

Figure 10: Fig. 14 :

15

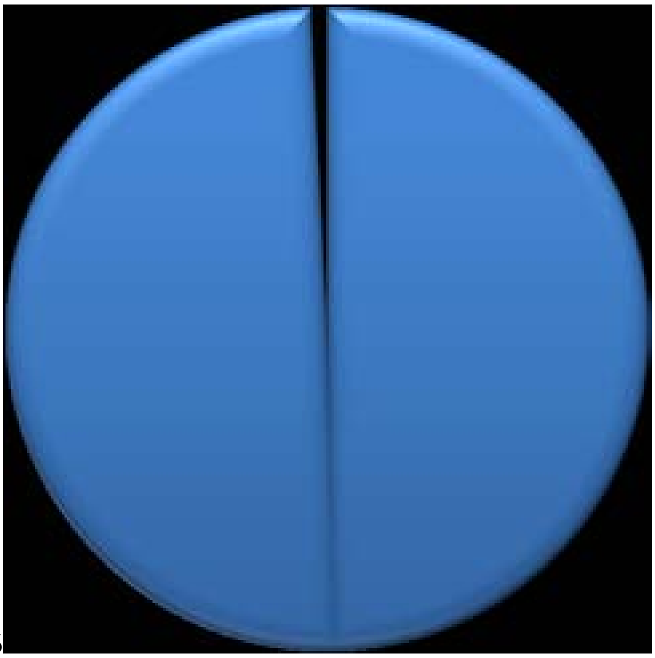

Figure 11: Fig. 15 :

16

Figure 12: Fig. 16 :

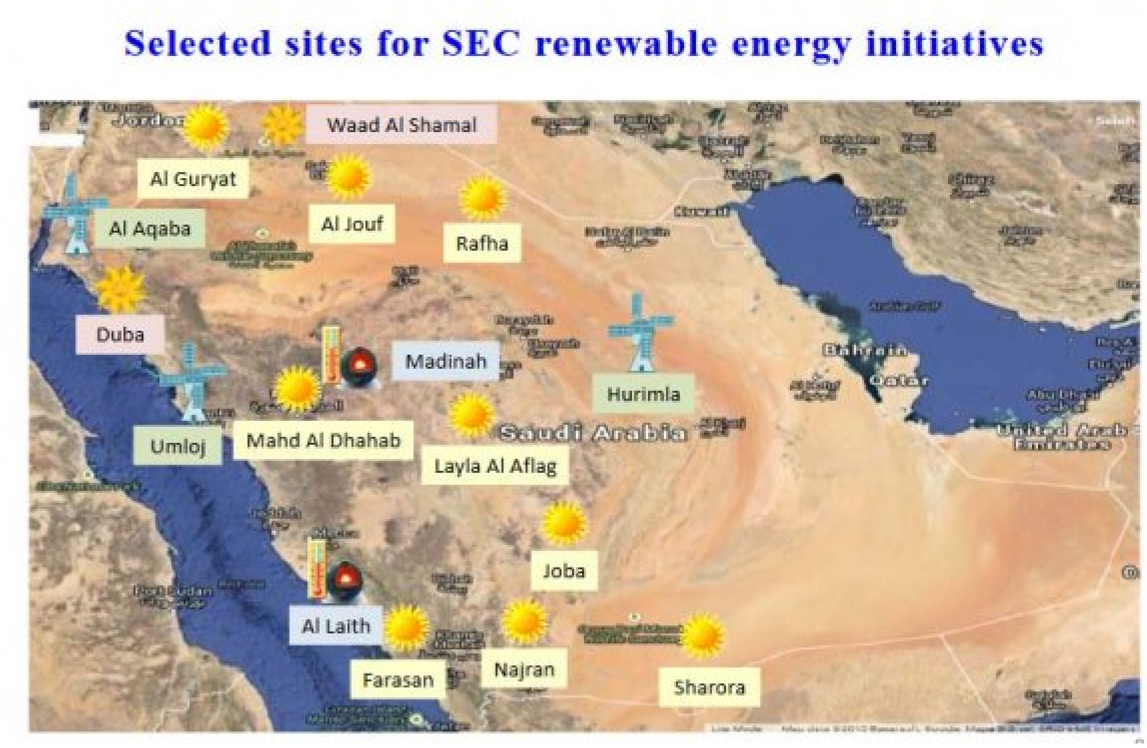

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Figure 13: -Table 4 :

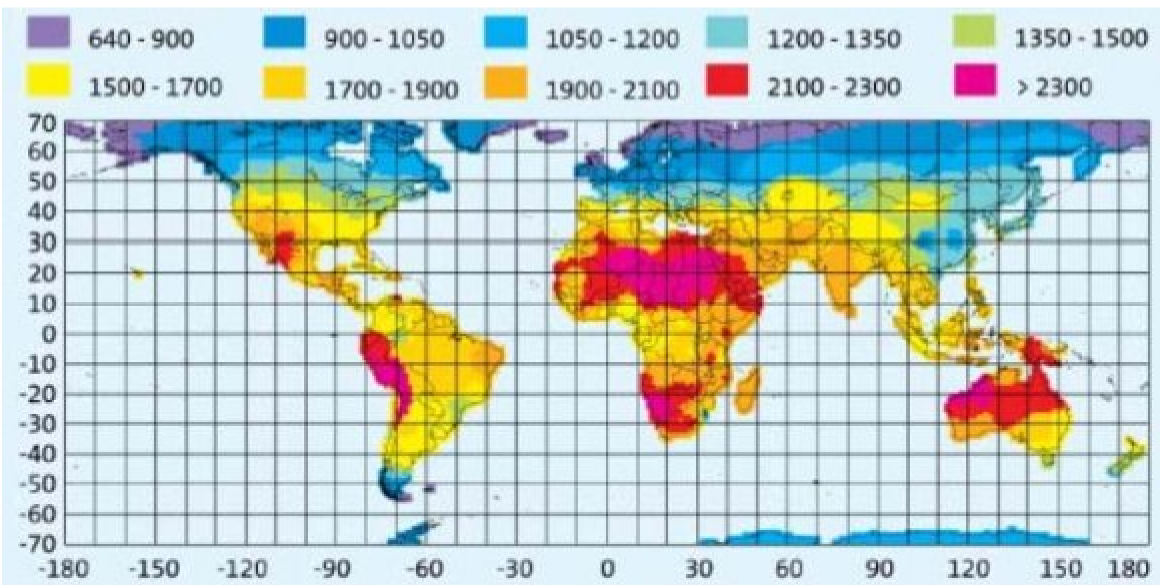

Figure 14: C

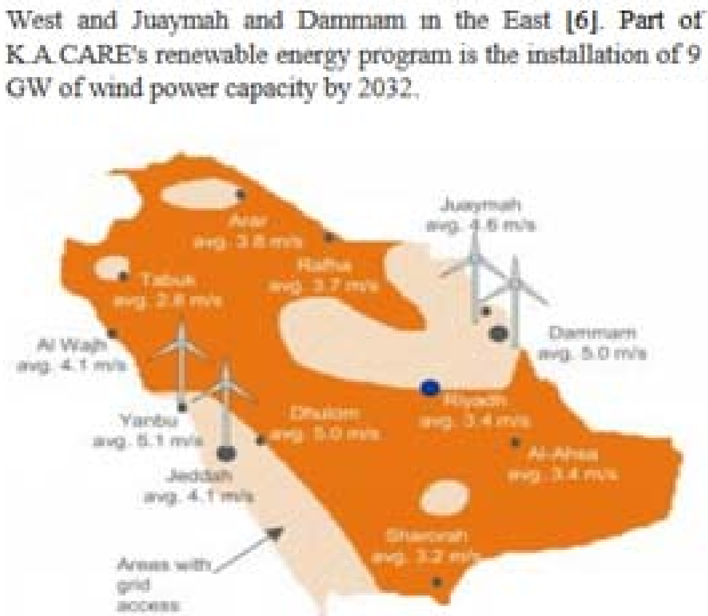

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Figure 15: Fig. 17 :

Figure 16:

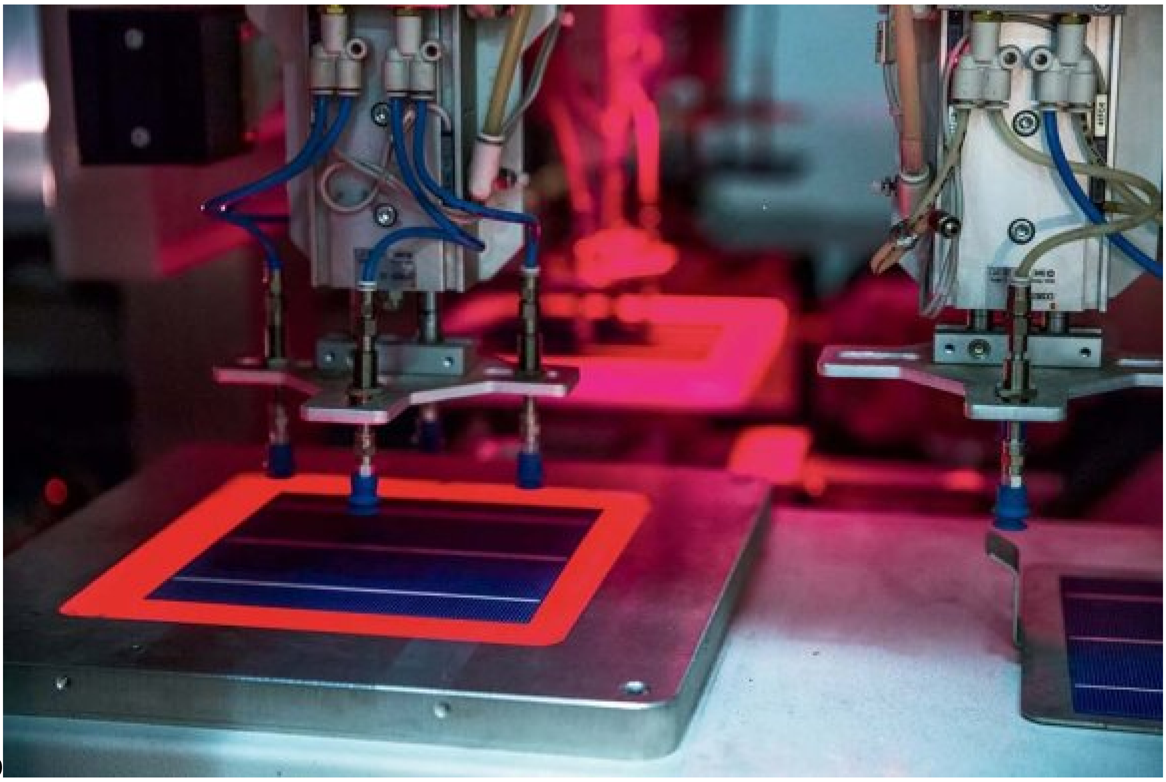
1819 

Figure 17: Fig. 18 :Fig. 19 :

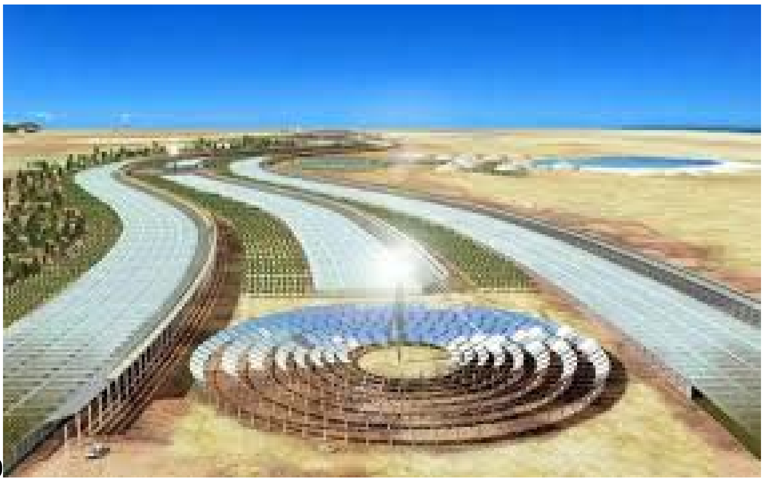
20 

Figure 18: Fig. 20 :

21 

Figure 19: Fig. 21 :

Figure 20:

Figure 21:

Period or year conducted	Location	Description of projects		Application purposes
		Type	Capacity	
1981–1987	Solar Village	PV system	350 kW (2155 MWh)	AC/DC electricity for remote areas
1981–1987	Saudi universities	Solar cooling	–	Developing of solar cooling laboratory
1986–1991	KAU, Jeddah	Solar hydrogen	2 kW (50 kWh)	Testing of different electrode materials for solar hydrogen plant
1986–1994	Solar Village	Solar-thermal dishes	2 pieces, 50 kW	Advanced solar stirling engine
1987–1990	Solar Village	PV test system	3 kW	Demonstration of climatic effects
1987–1993	Solar Village	PV hydrogen production	350 kW (1.6 MWh)	Demonstration plant for solar plant hydrogen production
1988–1993	Dammam	Energy management in buildings	–	Energy conservation
1988–1993	Al-Hassa, Qatif	Solar dryers	–	Food dryers (dates, vegetables, etc.)
1989–1993	Solar Village	Solar hydrogen generator	1 kW (20–30 kWh)	Hydrogen production, testing and measurement (laboratory scale)
Since 1990	Solar Village	Long-term performance of PV	3 kW	Performance evaluation
1993–1995	Solar Village	Internal combustion engine	–	Hydrogen utilization
1993–1997	Solar Village	Solar collectors development	–	Domestic, industrial, agricultural
1993–2000	Solar Village	Fuel cell development	100–1000 W	Hydrogen utilization
1994–1999	Sadous Village	PV water desalination	0.6 m^3	PV/RO interface per hour
1994–2000	12 stations	Solar radiation measurement	–	Saudi solar atlas
1994–2000	5 stations	Wind energy measurement	–	Saudi solar atlas
1996	Southern regions of Saudi Arabia	PV system	4 kW	AC/DC electricity for remote areas
1996	Muzahmia	PV in agriculture	4 kWp	AC/DC grid connected
1996–1997	Solar Village	Solar-thermal desalination	–	Solar distillation of brackish water
1996–1998	Solar Village	PV system	6 kW	PV grid connection
1999–2000	Solar Village	Solar refrigeration	–	Desert application

Figure 22:

Figure 23:

1

Site Name	Site abbreviation	Latitude	Longitude	Elevation (m)
Afif Technical institute	Afif	23.92	42.948	1060
Al Aflaaj Technical Institute	Layla	22.28	46.73	567
Al Dawadmi college of technology	Al Dawadmi	24.55	44.47	955
Al Hanakiyah Technical Institute	Al Hanakiyah	24.856	40.54	873
Al Qunfudhah Technical Institute	Al Qunfudhah	19.11	41.08	20
Al Uyaynah Research Station	Al Uyaynah	24.9	46.39	779
Al Wajh Technical Institute	Al Wajh	26.26	36.44	21
Duba Technical Institute	Duba	27.34	35.7	45
Hafar Albatin Technical College	HafarAlbatin	28.33	45.95	383
K.A.CARE Headquarter Building	HQ Building	24.7	46.67	668
K.A.CARE City Site	K.A.CARE City	24.52	46.45	895
King Abdulaziz University (Ofsan Campus)	Ofsan	21.89	39.25	119
King Abdulaziz University (East Hada Alsham Campus)	HadaAlsham	21.8	39.73	245
King Abdulaziz University Main Campus	KAU main	21.49	39.24	75
King Abdullah University of Science and Technology	KAU ST	22.3	39.1	34
King Fahd University of Petroleum and Minerals	KFPUM	26.3	50.144	75
King Faisal University	Al Ahsa	25.35	49.59	170
Majmaah University	Majmaah	25.86	45.4	722
Qassim University	Qassim	26.35	43.77	688
Saline Water Conversion Corporation (Haql)	Haql	29.29	34.9	36
Saline Water Conversion Corporation (Umluj)	Umluj	25	37.27	10
Saline Water Research institute	Aljubail	26.9	49.76	89
Salman bin Abdulaziz University	Al kharj	24.15	47.27	465
Shaqra University	Shaqra	25.1727	45.14	804
Sharurah Technical Institute	Sharurah	17.47	47.08	760
Tabuk University	Tabuk	28.38	36.48	781
Taif University	Taif	21.43	40.49	1518
Timaa Technical Institute	Timaa	27.61	38.52	844
University of Dammam	Dammam Univ.	26.39	50.19	28
Wadi Addwasir College of Technology	Wadi Addwasir	20.4	44.89	671

Figure 24: Table 1 :

2

	Average daily total GHI WH/m 2	Average daily total DNI WH/m 2	Average daily total DHI WH/m 2	Maximum daily total GHI WH/m 2	Maximum Daily total DNI WH/m 2	Maximum daily total DHI WH/m 2
HafrAlbatin	5919	5673	2193	8599	10382	5203
KFPUM	5781	5409	2113	8474	10079	5334
Al Ahsa	6083	5480	2369	8417	9694	5520
Aljubail	5753	5464	2078	8428	9932	5117
Damam Univ.	5831	5522	2099	8416	10135	5429
Eastern Average	5874	5510	2170	8461	10049	5240
Sharurah	6735	6447	2301	8431	10498	5534
Wadi Addwasir	6559	5946	2437	8501	9168	5222
Southern	6647	6196	2387	8466	9833	5378

Figure 25: Table 2 :

3

Eastern Region

15000
10000
5000
0
Hafr Albatin KFRU Al Ahsa Aljubail Damam

University

Average daily total GHI WH/m2 Average daily totalDNI Wh/m2
Average daily total total DHI Wh/m2 Maximum daily total GHI Wh/m2
Maximum Daily total DNI Wh/m2 Maximum daily toatl DHI Wh/m2

Station Guriat Riyadh	Dhahran Jeddah	Gizan Turaif	Pressure (mb) Mean 1006.7 1007.7 954.8 1007.3 916.9 942.4	Wind speed (m/s) Mean Max 4.38 11.8 3.24 7.7 4.22 16.5
Yanbu			1007.8	3.76 10.3
Abha			794	2.94 14.9
Hail			901.3	3.24 10.8
Aljouf			936.1	4.02 15.9
Al-wajh			1007.9	4.43 11.8
Arar			949.6	3.61 12.9
Bisha			884	2.47 10.3
Gassim			937.6	2.78 9.3

[Note: F Fig. 11: K. A. CARE 9GW wind power locations map]

Figure 26: Table 3 :

Figure 27:

Figure 28:

.1 Acknowledgements

The authors extend their appreciation to the Deanship of Scientific Research at Majmaah University for funding this work under project number No (XXXX-YY).

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