292. Sustainable Energy Measures in Saudi Arabia Based on Renewable Energy Sources: Present Actions and Future Plans

Muhammad Saleem[a]*, and Mehmood Ali [b]

[a] *Department of Civil Engineering, Jubail University College, Jubail Industrial City 31961, Saudi Arabia*
[b]*Department of Environmental Engineering, NED University of Engineering & Technology, Karachi 75270, Pakistan*
**Email Address: saleemm@ucj.edu.sa*

Abstract

Conventional power generation sources are a major cause of environmental pollution and have had a grave impact on public health and safety through greenhouse gas emissions, acid rains, etc. A global transition towards sustainable energy options is underway in order to meet present day demands without jeopardizing the environment and future generations. Even though Saudi Arabia is the top oil producer of the world, it has a se interest in participating in the development and utilization of new environment-friendly technologies that exploit renewable energy sources. It is projected that about US $117 billion will be invested in the country's power sector according to its 25 year strategic energy plan. This plan ensures that the future energy sources should be practically accessible, sustainable, affordable, and costs-optimal to adopt. Despite the current economic constraints, the Kingdom has established a scientific city, 'King Abdullah City for Atomic & Renewable Energy' (KACARE) which is working on the potential of utilizing renewable energy sources in the Kingdom. This paper addresses the current status and future potential of renewable energy applications in the Kingdom. A technical and economic assessment, of major renewable energy sources in this heavily subsidized, oil-rich country, is also discussed.

Keywords: *Sustainable energy, Environmental pollution, Major oil producing country, renuable energy, KACARE*

1. Introduction

Global increase in energy demand and environmental awareness has brought great concern to supply sustainable energy in an environment-friendly manner. Conventionally, oil, coal and natural gas are the chief energy sources being utilized in the major part of world [1]. Mainly the conventional energy sources are responsible in contributing in environmental degradation via greenhouse gases emission and other ways. The renewable clean energy sources appear to be viable substitutes to protect the environment and public health [2].

A large portion of the oil and natural gas reserves is located in the Gulf Cooperative Council (GCC) countries. The GCC countries are rated as in the top 25 countries with the highest CO_2 emissions per capita [3]. The GCC has recently adopted a progressive approach towards environmental reformation, however, to have consistent developments in this direction, lots of work has to be done [4]. The Kyoto protocol in 2005 stressed that the European Union (EU) and GCC broaden their cooperation and that they should take a collaborative approach in the direction of CO_2 reduction. EU and GCC increased their interactions and set realistic goals. They took various innovative measures to accomplish these objectives however; there is still a great need to speed up the resolution of major issues, such as CO_2 emissions and controlled use of energy [5].

The Kingdom of Saudi Arabia (KSA), with an area of about 2.25 million km^2 is the largest country in the Middle East. Oil reserves of the KSA were discovered during the year 1938 and the country started exporting oil from next year. Within a few years the country became the chief oil producer and exporter in the world [6]. Saudi Arabia, with a population of more than 31 million and a rapidly growing

industrial sector, is facing high growth rate in energy demand, with an average of 5% per annum [7]. The domestic electricity use and, ultimately, oil consumption in the KSA is increasing at a very alarming rate compared to the other countries in the world. Therefore, it is important to work out energy conservation measures for the various sectors in the Kingdom as early as possible [8]. It is estimated that the electricity demand in KSA is going to reach more than 60 GW by the year 2020. It is also estimated that by year 2020 a reduction of 1% in the annual electricity consumption could provide saving in electricity bills about $35 billion [9]. Even though Saudi Arabia is the main producer of oil, it has taken a profound interest in participating in the development and utilization of new technologies for exploiting renewable energy sources. The central grid system is supplying the power to roughly 80% users within cities but, it is not practicable to further extend the power supply grid system to sparsely populated remote areas. Therefore, there is still requirement for power source in these areas. Hence, these locations represent a substantial potential for renewable energy applications. It is to be noted that these energy sources may also be connected to the central grid in order to utilize during high demand periods [10]. It is projected that more than US $117 billion will be capitalized in the power production according to the country's 25 year strategic energy plan. The plan ensures that the future energy sources should be practically accessible, sustainable, affordable, and costs-optimal to adopt. Furthermore, despite the current economical constrains the Kingdom has established a scientific city 'King Abdullah City for Atomic & Renewable Energy' (KACARE) which is working on the potential of utilizing renewable energy sources in the Kingdom.

The utilization of renewable energy resources which includes solar, wind, hydro, waste material and geothermal energy seems to be one of the most efficient and effective ways of achieving this goal. Saudi Arabia has plans to develop self-reliance on various power sources including renewable energy. Country aims to invest in its solar and wind power sources utilization programs to fulfill its energy requirement in the future. Various studies in the KSA indicate that, among various renewable resources, the most sustainable and appropriate energy sources for the country are solar and wind energy.

This paper addresses the current status and future potential of renewable energy source applications in the Kingdom. A technical and economical assessment of major renewable energy sources such as solar, wind, hydro, waste-to-energy and other clean energy technologies is discussed. In addition to the present status, environmental and technical evaluation of the sources and their potential in the future is also discussed.

2. Solar Energy Option

The geographic location of Saudi Arabia on the solar belt has endorsed it as one of the most suitable producer of electricity using solar energy. Saudi Arabia has an abundant of solar radiation, which is estimated at about 2200 kilowatt hours per unit area (kW h/m^2). Availability of solar radiation and enormous areas of vacant desert which can be used for installation of solar equipment makes Saudi Arabia an excellent site for solar power generation [10]. This shows that solar energy is one of the valuable renewable energy sources for Saudi Arabia and need further exploration to materialize the plans.

According to Aljarboua [11] the available solar energy is sufficient to produce 12,425 TW-h of electricity that can power the kingdom for more than 70 years. The proximity with the equator and a huge desert area qualifies Saudi Arabia as a well suitable country to utilize solar energy for power production. As reported by Aljarboua it can be seen from figure 1 that the annual average monthly incident radiation for Saudi Arabia is quite promising [11]. Three cities; Jeddah, Riyadh and Dammam are receiving high levels of solar radiation due to their geographic location on the equatorial region. On the local scale (5.78 kW h m^{-2} per day average), all three cities ranked about average. However, on the international scale (1.36 kW h m^{-2} per day average), they are ranked significantly higher [12]. In addition to altitude, Aljarboua pointed out factors such as surface air temperature and the zenith angle are responsible for the small variations between cities [11].

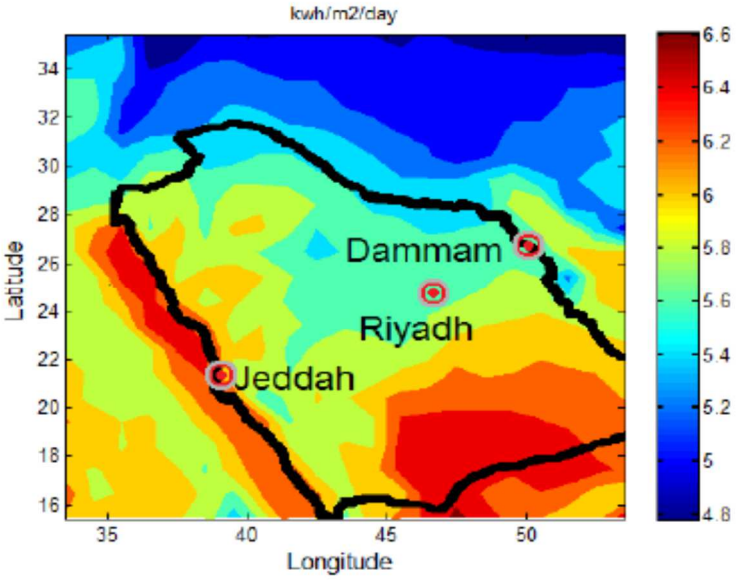

Fig. 1. Annual average monthly incident horizontal radiation for Saudi Arabia [12]

2.1. Progress in solar energy utilization

Although practical implementation of solar energy in the country materialized during 1960, work in this field had started quite earlier [13]. Organized research work on solar energy technology was started after 15 years by 'King Abdul-Aziz City for Science and Technology' (KACST). Several researchers studied the viability of solar radiation in the KSA. For example Baras and co-workers discussed the opportunities and challenges of solar energy in Saudi Arabia which detailed the heating mechanisms as well as solar-thermal processes and desalination prospects [14]. Similarly Pazheri has given an update of the solar energy projects in KSA including the current status and future prospects [15].

The Energy Research Institute at KACST led numerous joint programs at international level in the area of solar energy which includes SOLERAS with the USA. Research activities throughout Saudi Arabia showed that solar radiation has feasibility to produce electrical power in the country [13]. Ibrahim Babelli, the country's deputy minister for economy and planning during a press conference in Dubai emphasized on the use of solar energy as a major energy option for the country [16]. In addition to power generation, options such as Water and Ventilation-Air Preheating systems where solar energy is used to heat water or air are also studied and found promising areas of solar energy utilization.

2.2. Future plans

The cost of installation of solar power plants is tremendously decreasing globally due to increase in manufacturing capability, modified design and reduction in component costs. Saudi Arabia is planning to increase renewable energy production to 9.5 G-Watts, according to new energy plan. Saudi Aramco installed a 10-MW solar powered plant in Dhahran city. Country has planned to spend about $100 billion in producing 41 G-Watts of power by 2030. Chadbourne a US based company involved in installing 4-G-Watts independent power projects (IPP) in Qurayyah said to be the biggest IPP in the world [17]. In order to implement the plans still some hindrances such as dust in the desert area, intermittent availability in addition to availability of subsidized oil need to be further evaluated. However, the available information and obtained experience declaring solar energy option a feasible one.

3. Wind Energy Option

Numerous studies in the past indicated that wind energy is one of the most efficient and promising option of the renewable energy [18]. During 1980's concern for harnessing wind energy augmented enormously in most of the developed countries due to increase in energy demand and persistent issues of environmental degradation [19]. By the end of 1998 the global installed capacity of modern wind

turbines connected to grid was around 10 G-Watts and the annual global progression rates of installation were around 40%. In addition to that during last decade the cost of wind energy decreased by 35%.

Studies in the Kingdom at various locations revealed that country has viable wind energy potential, which is estimated to 5-hour of full-load wind per day on average. In Saudi Arabia the coastal areas along Arabian Gulf and the Red Sea having great potential for wind energy development.

3.1. Progress in wind energy utilization

A Prof of Anderson's College, Glasgow has installed first windmill which was used as a source of electricity production in Scotland in 1987 [20]. Early 5000 B.C, Egyptians have used wind energy to sail their ships in Nile river [21]. During 1940, Vermont hilltop has the largest wind turbine of their time which has the maximum capacity of 1.25 MW which supply electrical power to the local area network [22]. Recent studies have shown that the global projected wind energy potential is 72 TW for the next 10 years [23]. Every 3 years capacity of wind energy is steadily increasing at the average rate of 25.7%. During these days among renewable energy sources, wind energy is the rapidly growing energy source in the world whose installed capacity reached to 14 GW. USA, Spain, Germany and India are considered as the leading countries which has total about 80% of worldwide installation energy power [10].

In Kingdom of Saudi Arabia, various studies of potential of wing energy have been conducted. Martin and Bakhsh during 1985 have studied twenty different locations which are suitable of wind energy potential and having feasibility for wind energy harnessing in Saudi Arabia. It was suggested that the North and coastal region of country has the maximum potential for generation of wind energy [24]. Good potential between 16° to 26° latitudes of Red Sea coast has been found by Khogali and coworkers when they evaluated the wind energy potential in Makkah. However the inland area has the low potential for generation of wind energy [25]. The good potential has been found for coastal and Northern areas of Kingdom of Saudi Arabia by Radhwan when he analyzed the wind pattern in 1994 using weather stations data for 10 years [26]. Different technical details, equipment installation and detailed specifications of sites was provided by Alawaji in various region of Kingdom of Saudi Arabia in 1996.

Economically, for installation of wind parks, Yanbu and Dhahran have been considered as most feasible locations for potential wind energy based on feasibility report by Rehman in 2005 [27]. Haql has been considered as the most potential location for production of maximum wind energy by Khrishna and Thalhi during last year study as it has the wind speed maximum throughout the year [29]. Average wind speed of 5.04 m/sec have been recorded for Al Wajh. Umluj and Duba can be selected for the wind power but Tina and Tabuk do not have wind speed sufficient for wind energy harnessing. Economic and potential viability of wind has been indicated by these studies for conversion of wind energy into electrical energy.

3.2. Future plans

Studies have suggested that Kingdom of Saudi Arabia has promising potential of wind energy utilization. In Yanbu, annual wind speed reported at fifty meters above the ground level is 6.7 meter per second which ranges 7.1 to 8.1 meter per second during summer months. In the nearest future, grid connected wind farms and wind-diesel hybrid systems will be introduce by the authority [30]. The major challenge being faced for utilizing wind energy by KSA is that the wind energy is irregular and without batteries it cannot be stored. Additionally, the location feasible for these grid farms is far from the demand centers. It has been reported that despite of hurdles, KSA will be expected to issue procurements for 13 Giga Watts of geothermal, wind and waste-to-energy plants by year 2032. The release of a white paper by the KACARE, to the renewable energy procurement agency is considered to be the first step for this process [17]. It was found that the possibility of utilizing wind energy in the Kingdom of Saudi Arabia is not fully explored and most of them are funded student projects.

Studies indicated the need of probing more in this area from economic feasibility point of view. Study also revealed that Kingdom of Saudi Arabia has two major regions along the Red sea and Arabian Gulf coasts where wind speed and duration is economically feasible to produce energy from wind power.

Application of previous experience shows a good potential for exploring wind power as one of the renewable energy source in the KSA.

4. Hydro Power

Kingdom of Saudi Arabia is the country which does not have any natural river system but holds few perennial streams [31]. The precipitation value of the world as an average is 1123 mm while Kingdom of Saudi Arabia receives an annual rainfall of 100 mm per year which is considered to be far behind the world [32]. Due to this reason the water bodies like major ponds and lakes are not present. Rain recharge does not replenish available ground water and is depleted rapidly. Water table significant drawdown can be seen in most of the aquifers [33] .There is a massive desalination network which at present is covering up to 70% potable water demand. Some dual-purpose desalination facilities in the country are contributing to fulfill more than 20% of total electricity demand of the country.

There are several dams constructed in the country despite of less rainfall in order to control flood and providing recharge to groundwater aquifers. It has been estimated that there are more than two hundreds of dams which have cumulative reservoir capacity of about 770 Million m^3 [35]. The largest dam in Kingdom of Saudi Arabia is King Fahad Dam (storage capacity of 325 Million m^3) in Bishah which is considered as the 2nd largest dam in the Middle East. It has hypothetical potential energy of about 91.2 Megawatt hour [36]. Kingdom of Saudi Arabia is not been feasible to construct any hydrological structure for generation of electricity because of significant evaporation and excessive sedimentation of dams to achieve the targeted purpose of storage.

5. Geothermal

Saudi Arabia has significant tectonic activity due to its geographical location. Many volcanic ridges are existing along the Red Sea shore. With respect to geothermal resources, there are 10 hot-springs with varying temperatures ranges from 50 to 120°C and different flow rates. In addition to this, there are three major harrats namely Khaybar, Kishb, and Rahat of geothermal concern. The crust thickness in these areas varies between 20 and 40 km and its lower part consists of mafic meta-igneous granulite [37].

In order to promote renewable energy sources during 2008 Ministry of higher education provided huge funds for establishing a centre of research excellence in renewable energy at King Fahd University of Petroleum and Minerals. The research activities in the centre include wind, solar and geothermal power resources to evaluate and utilize [38]. Lashin in early 2014 conducted various research studies in two potential areas Al-lith and Jizan investigating potential of utilizing geothermal energy in those areas. They reported Al-Khouba geothermal resources as an important site for exploiting geothermal energy for power production [39]. In their studies they evaluated thermal parameters heat flow, discharge enthalpy and subsurface temperature and estimated as 144 mW m^{-2}, 318 kJ kg^{-1} and 135°C, respectively. A good geothermal potential of 17.9 MW is estimated for Al Khouba hot spring having estimated volume of 1.125 cubic kilometers. They recommend the site for future technical investigation to explore geothermal energy as a source to obtain electrical energy. [39].

In another study Lashin characterize the reservoir surface area of the volcanic flows, flow rates, heat flow and geothermal grades. They reported that the wet geothermal systems can produce energy up to 23 x 10^9 kWh. Lashin also reported that in the western region a large number of pre and post orogenic highly radioactive granites with very high generating capacity (from 15 to 134 µW m^{-3}) is existing. They reported that this granite can produce about 160 TWh of electricity [40]. Therefore, it seems that geothermal energy is one of the potential sources of renewable energy in the kingdom.

6. Waste To Energy

Rapid increase in global population and living standards promote the generation of more solid waste as well as energy requirement. The trend is with increasing order which is forecasted to reach about 2.2 billion tons per annum in 2025 [41]. The final disposal place for of municipal solid waste (MSW) is landfills or dump sites. In Saudi Arabia few steps have been taken to manage the MSW. Option of

producing energy from waste material has duel benefit controlling the environmental pollution and utilizing waste material to produce valuable energy [42].

In the year 2010 KACARE was established and after 3 years the new regulations stressed the implementation of an integrated MSW management program in the country. KACARE proposed a framework to utilize the MSW for renewable energy production. Plan covers twenty years schedule including production of about 54 GW from nuclear and renewable energy sources. KACARE reported the potential of generating about 2073 MW of electricity by the year 2032. The results show that energy production from waste has great potential in the Kingdom. MSW can be a good source to produce electricity and contribute to electricity supply in the Kingdom [43].

7. Hybrid Energy System

Renewable energy technologies have its inherent limitations and use of a single source is practically not feasible. For example intermittent availability of wind energy and diurnal variation in solar energy limits the use these options for sustainable supply to grid. The use of storage source such as battery bank is required to utilize these technologies. Therefore, use of two or more renewable sources, called as hybrid system is appropriate. Generally, to overcome economy two systems are preferred [44]. the feasibility of combinations such as wind or solar with diesel generator or power bank is essential. Selection should be made based on ease of availability of technology and performance of conversion. One of the criteria is the capital and operational cost of the hybrid system. Study reported that the hybrid system is the best means of providing decentralized power with higher reliability. Typically the selection of one or more of these options mainly depends on the reachable energy, the efficiency of conversion system and the characteristics of the electrical load [45].

In Saudi Arabia related information and data is inadequate and there is a need to further evaluate the hybrid system in detail. The feasibility studies for practical implementation are imperative to decide future plans in the kingdom.

8. Summary and Conclusions

The gradual shift from fossil fuel to renewable sustainable energy sources is imperative for global environmental protection. Among other countries, Saudi Arabia has tremendous potential for renewable energy sources, mainly solar and wind, for electricity production. During the last fifty years, extensive research has been done in the area of solar and wind energy and valuable data and information has been obtained which has acted as the basis for the establishment of renewable energy programs in the KSA. The most promising energy source in the KSA is solar energy, having a wide range of applications, including electricity generation. It has been demonstrated that solar water and ventilation-air preheating have great economic benefits. Wind energy is the second most potential renewable source available in sufficient amounts in various coastal regions of the Kingdom. However, feasibility of wind energy has not been fully explored and experience gained in the field is mainly based on various research projects and installation experience obtained through governmental establishments such as KACST. Other energy sources such as geothermal and waste-to-energy have some potential. However, available data and information on these sources is up to pilot-scale level only. Operation of hydro power has insignificant potential in the region due to the unavailability of it's main components such as rivers or significant water bodies. However, studies show that the use of hybrid systems, such as solar and wind with diesel generators, has great potential to be implemented as they minimize the limitations of these technologies. Therefore, uninterrupted power supply is possible if considering hybrid systems. There is a need for future applications to explore more in this area, in order to make them economical and practical. A generous subsidy from the government is also required, at least for the initial period, to bring these ambitious plans to realization. There is a need to develop a framework, to encourage private sector investments in the renewable energy sector, including financial support incentives to potential developers.

At present, in a country which has huge oil reserves, and where the oil supply is profoundly subsidized, it is very difficult to utilize renewable energy sources as a prime energy source. Today's conventional energy costs, when compared to solar and wind energy, leave no chance for competition in the Saudi

market. Even if the country is eager to shift from conventional to renewable energy sources, a great deal of change in the country's policies is required. The key factors which may bring about this transformation could be the environmental concern and longer sustainability.

It is confirmed that the long-term future of renewable energy is looking quite bright, as a great reduction in greenhouse gas emissions will be achieved when using renewable energy sources instead of conventional fossil fuel. This will result in a reduction in environmental pollution and reduced expenditures on public health care. As the trend shows, the cost of reusable energy is declining steadily, and in the future, its cost will be less than that of conventional energy sources and will make this option even more attractive.

Acknowledgements

Authors are grateful to the Jubail University College, Saudi Arabia for providing help and support in the research and preparation of the paper.

References

[1]. T. Iskander, "Renewable energy in Saudi Arabia: current status and future potentials," *Env. Dev. and Sustainability*, vol. 17, no. 4, pp 859–886, August, 2015
[2]. A.H. Almasoud, H. M. Gandayh, "Future of solar energy in Saudi Arabia,". *J. King Saud Univ. Eng. Sci.* vol. 27, pp. 153–157, 2015.
[3]. M. A. Mujeebu, O. S. Alshamrani, "Prospects of energy conservation and management in buildings – The Saudi Arabian scenario versus global trends," *Renewable and Sustainable Energy Reviews*, vol. 58, pp. 1647–1663, 2016.
[4]. K. D. Patlitzianas, H. Doukas, and J. Psarras, "Enhancing renewable energy in the Arab States of the Gulf: Constraints & efforts," *Energy Policy*, vol. 34, pp. 3719–3726, 2006.
[5]. K. D. Patlitzianas, H. Doukas, and D. T. Askounis, "An assessment of the sustainable energy investments in the framework of the EU–GCC cooperation," *Renew Energy*, vol. 32, pp. 1689–704, 2007.
[6]. H. Jun, "Saudi Arabia's domestic energy situation and policy: focusing on its power sector," *Kyoto Bull Islam Area Stud*, vol. 6, pp. 107–135, 2013.
[7]. F. A. Al-Sulaiman, and F. A. Jamjoum, "Applications of wind power on the East coast of Saudi Arabia" *Renewable Energy*, vol. 2, no.1, pp. 47-55, 1992.
[8]. I. M. Jomoah, S. R. Kumar, A. U. M. Al-Abdulaziz, N. Y. Abdel-Shafi and R. R. Obaid, "*Ethernet TCP/IP based building energy management system in a university campus in Saudi Arabia*," *Int. J Energy Environ*, vol. 4, no. 6, pp. 1033–1040, 2013.
[9]. W. A. Al-Rumaih, "Effective energy conservation programs-key success factors," in *Proceedings of the 7th Saudi Engineering Conference*, KSU. Riyadh; pp. 339–352, 2007.
[10]. S. A. M. Said, I. M. El-Amin, and A. M., & Al-Shehri, "Renewable energy potentials in Saudi Arabia," in *Beirut regional Collaboration Workshop on Energy Efficiency and Renewable Energy Technology*. pp. 76–82, 2004.
[11]. Z. Aljarboua, "The national energy strategy for Saudi Arabia," *World Academy of Sci. Eng. and Technol.*, vol. 57, pp. 501-510, 2009.
[12]. C. Frohlich, "Construction of a Composite Total Solar Irradiance (TSI) Time Series from 1978 to present," *Physikalisch-Meteorologisches Observatorium Davos*, 2006. Available: http://www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant
[13]. F. S. Huraib, S. M. Hasnain and S. H. Alawaji "Lessons learned from solar energy projects in Saudi Arabia," *Renewable Energy* vol. 9, no. 1-4 , pp. 1144-1147, 1996.
[14]. A. Baras, M. Alodan, and J. Engel-Cox. "Opportunities and challenges of solar energy in Saudi Arabia," In *World Renewable Energy Forum", Denver*, vol. 1, pp. 4721. May, 2012.
[15]. F. R. Pazheri, "Solar power potential in Saudi Arabia," *Int. J. Engg. Res. and Applications*, vol 4, no. 9, pp 171 –174, 2014.
[16]. The Gulf Times, (2016, September 18), Avilable http://www.m.**gulf-times**.com/content/pdf/Business/Business**2016**_5_30463302.PDF.
[17]. Chadbourne, "Saudi Arabian Renewable Energy Program: Ready, Set," CHADBOURNE & PARKE, LLP Report. pp.12-230.
[18]. M. A. M. Ramli, S. Twaha, "Analysis of renewable energy feed-in tariffs in selected regions of the globe: lessons for Saudi Arabia,". *Renew Sustain Energy Rev*, vol. 45, pp. 649–661, 2015.
[19]. S. M. Habali, M. Amr, I. Saleh, and R. Ta'ani, "Wind as an Alternative Source of Energy in Jordan," *Energy Conversion and Management*, vol. 42, no. 3, pp. 339-357, 2001.
[20]. T. J. Price, "James Blyth - Britain's First Modern Wind Power Engineer," Wind Eng., vol. 29, no. 3, pp. 191–200, May, 2005.
[21]. *History of Wind Energy* in Cutler J. Cleveland,(ed) *Encyclopaedia of Energy* Vol.6, Elsevier, ISBN 978-1-60119-433-6, 2007, pp. 421–422
[22]. IEA. (2016, September). *Experience of the Danish Transmission System Operator*, Available: (https://www.iea.org/media/workshops/2016/derworkshop1/PARBO.pdf).
[23]. A. Cristina and M. Z. Jacobson, "Evaluation of global wind power," *J. Geophys. Res.*, vol. 110, D12 110, 2005.
[24]. AWEA, "World Wind Capacity Tops 10,000-Megawatt Mark," American Wind Energy Association (AWEA) and European Wind Energy Association (EWEA), Press release on April 22, 1999.

[25]. A. Khogali, O. F. Albar and B. Yousif, "Wind and Solar energy potential in Makkah(Saudi Arabia) – A comparison with red sea coastal sites," *Renewable energy*, vol 1, no. (3/4), pp 435- 440, 1991.
[26]. A. M. Radhwan, "Wind energy applications in remote areas of Saudi Arabia," *Int. J. Ambient Energy*, vol, 15, no. 3, pp 120-130, 1994.
[27]. Y. M. Sulaiman, A. M. Akaak, M. A. Wahab, A. Zakaria, Z. A. Sulaiman and J. Suradi, "Wind Characteristics of Oman," Energy, vol 27, pp 35-46, 2002.
[28]. K. Ramazan, M. Aozgur, O. Erbas and A. Tugcu, "The analysis of wind data and wind energy potential in Kutahya, Turkey," *Renewable and Sustainable Energy Rev*., vol 8, pp 277- 288, 2004.
[29]. L. V. Krishna, and F. A. Al Thalhi, "Solar and Wind Energy Potential in the Tabuk Region, Saudi Arabia," *Int. J. Applied Sci. Techol.*, vol. 5, no. 3, 2015.
[30]. S. Rehman, T. O. Halawani and M. Mohandes, "Wind power cost assessment at twenty locations in the kingdom of Saudi Arabia," *Renewable Energy*, vol. 28, pp. 573–583, 2003.
[31]. C. Napoli and B. Garcia-Tellez, "A framework for understanding energy for water," *Int. J. Water Reso. Dev.*, vol. 32, no. 3, pp. 339-361, 2016.
[32]. D. R. Legates, C.J. Willmontt, "Mean Seasonal and Spatial Variability in Gauge-Corrected, Global Precipitation", *Int. J. of Climatology*, vol. 10, no. 1, pp. 111-127, 2003.
[33]. M. Saleem**,** and M. H. Essa, "Suitability for sustainable reuse of secondary effluent: A case study in Saudi Arabia," *NED Univ. J. Res*., vol. 4, no. 1,, pp. 23-34, 2010.
[34]. N. A. Norton, A. Sadiq, and V. J. Norton, "Desalination as a Water Source for Municipal and Industrial Water Users: The Future is Now," *in 2003 Proc. Georgia Water Resources Conference*. Georgia, April, 2003.
[35]. P. Vincent, "*Saudi Arabia: An Environmental Overview"*, Routledge, 2008, pp. 96.
[36]. A.H. AbuZinada, E.R. Robinson, I.A. Nader and Y.I. Wetaid, "First Saudi Arabian National Report on the Convention on Biological Diversity," National Commission for Wildlife Conservation and Development", 2001.
[37]. S. Rehman and A. Shash, "Geothermal resources of Saudi Arabia – Country update report," in *Proceedings World Geothermal Congress*. Antalya-Turkey, 2005, pp. 7.
[38]. S. Rehman, "Saudi Arabian geothermal energy resources," in *Proceedings World Geothermal Congr*ess. Bali-Indonesia, 2010, pp. 6.
[39]. A. Lashin, D. Chandrasekharam, N. Al Arifi, A. Al Bassam, and C. Varun, "Geothermal energy resources of wadi Al-Lith, Saudi Arabia," *J. African Earth Sci.*, vol. 97, pp. 357–367, 2014.
[40]. A. Lashin, N. Al Arifi, D. Chandrasekharam, A. Al Bassam, S. Rehman, and M. Pipan, "Geothermal energy resources of Saudi Arabia: country update," *World Geothermal Congr*, 2015, pp. 15.
[41]. K. Kawai and T. Tasaki, "Revisiting estimates of municipal solid waste generation per capita and their reliability," *J. of Mat. Cycles and Waste Manag*., vol. 18 no. 1, pp. 1-13, 2016.
[42]. A. M. Omer, "Organic waste treatment for power production and energy supply" *J. of Cell and Animal Biol.*, vol. 1, no. 3, pp. 034-047, 2007.
[43]. O. K. Ouda, H. M. Cekirge and S. A. Raza, "An assessment of the potential contribution from waste-to-energy facilities to electricity demand in Saudi Arabia," *Energy Conversion and Management*, vol. 75, pp. 402-406, 2013.
[44]. M. A. Elhadidy, and S. M. Shaahid, "Feasibility of hybrid (wind + solar) power systems for Dhahran, Saudi Arabia," Renewable Energy, vol. 16, no. 1-4, pp. 970-976, 1999.
[45]. G. Bekele and B. Palm, "Feasibility study for a standalone solar–wind-based hybrid energy system for application in Ethiopia," Applied Energy, vol. 87, no. 2, pp. 487-495, 2010.