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INVESTIGATION OF WIND ENERGY AND ITS IMPACT ON SUSTAINABILITY: JORDAN AS A MODEL

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Abstract

There are interests in renewable energy. Additionally, there is an official promoting and investing in renewable energy like wind energy especially in Jordan. Therefore, it is aimed to assess the renewable energy resources, especially wind energy with a focus on big cities; Amman, Irbid, Ma'an, Aqaba and Mafraq. The latest statistical studies along with wind speed, earth temperature and relative humidity are investigated. It is important to fix a specific method for assessing wind energy status in Jordan through employing local climate data sets for specific locations in Jordan that could affect the stability of static sustainability.

Keywords: Earth temperature; Relative humidity; Wind energy; Wind speed.

1. Introduction

The challenges of growth rate of population and urbanisation cause an increasing of energy consumption. As the fossil fuel is limited and population growth increases, it is necessary to find an alternative source of energy. Therefore, the requirement for producing and investing in renewable energy became necessary and vital, where the generation of electricity has increased to 5.236 GW for 2018 in Jordan [1]. Also, 96% of electricity production in Jordan is generated from imported oil and natural gas [2].

The gas feeder between Jordan and Egypt (Arab Gas Pipeline) to generate 88% of Jordan's electricity has been suffered from terroristic problems for the period 2011-2014 although the government of Jordan has invested Jordanian Dinar 4B in 2012. Therefore, the decision has come to save the national wealth and find a safety resource of energy. Figure 1 illustrates the energy production in Jordan for the period 2013-2020 to show that the majority part of electricity generation is sourced 40% oil, followed by natural gas, oil shale, renewable energy and nuclear as 29%, 14%, 10% and 6%, respectively for the year 2020 [3].

The wind energy is considered in Jordan by the public and private sectors due to the renewable energy includes wind energy, which has positive environmental and economic impacts. Jordan has wind resources and could be a leader for wind energy in the Middle-East to face the population and urbanisation challenges. In addition, due to availability of wind energy, the government has supported the legislation and public service for investing in wind energy.

Jaber [4] has highlighted 85% of greenhouse gas (GHG) emissions in Jordan emanate as a result of fossil fuel combustion. The CO_2 emissions from energy use in manufacturing processes represent 12.1% of total national CO_2 emissions. Carbon dioxide is released as a result of calcining of carbonates during the manufacture of cement and iron. Heavy fuel oil and diesel oil are represented 46% and 7%, respectively, for all energy used by industry. Many viable CO_2 emission mitigation measures have been identified for the industrial sector, and some of these can be considered as attractive opportunities due to low financial investments are required. These mitigation options have been selected on the basis of low GHG emission rates and expert judgement as their viability for wide-scale implementation and economic benefits. However, most of these measures have a negative cost per ton of CO_2 reduced, indicating short pay-back periods for the capital investments needed [5].

Dalabeeh [6] has developed a simple model to assess the capacity factor and predicted costs of wind energy in Jordan. The simulation model is based on calculating the Weibull parameters and annual electrical energy generated using different commercial types of wind turbine generators (WTG). By merging final values of both factors, the best location and most suitable wind turbine could be defined. The estimated cost of electricity produced by wind energy ranged between 0.0259 and 0.0498 US$/kWh. While for other sites and wind turbine models, the cost may reach 0.2220 US$/kWh, which is still far less than those incurred in Jordan during 2013 using conventional thermal power plants firing diesel and/or heavy fuel oil. Dalabeeh [6] has obtained results that could benefited not only for researchers but also for policy makers, developers and investors planning to harness wind energy sources within the Middle East region.

Also, Bataineh and Dalalah [7] have presented a technical assessment of wind power potential in Jordan using statistical analysis to determine the wind characteristic based on measured wind data. Rayleigh distribution is used to model the monthly average data and used to estimate the wind power. Energy calculations, capacity factors and cost of wind energy production are determined with wind machines of different sizes ranging between 1.65 MW and 3 MW. The energy cost analyses show high economic potential with unit cost less than \$0.04/kWh of electricity. The lowest unit cost per kWh is obtained by using GE 2.5 MW.

Ammari et al. [8] have analysed, assessed and evaluated wind power from knowledge of mean monthly wind speeds of a typical year in Jordan. In addition, they have examined the feasibility of using five different wind turbines of different rated power ranging from 100 kW to 3000 kW to be employed in wind farms. The data of wind speeds over five years are fitted to Weibull distribution, which is most frequently used and most appropriate, describing frequency distribution for wind moving over Jordan. The annual mean values of wind speed and frequency distributions are studied [9].

Currently, the significance of this study devotes the investigation of wind energy potential in Jordan with a focus on big cities; Mafraq, Irbid, Amman, Ma'an and Aqaba. To be best of our knowledge, there is no study available in the literature focuses on characterization of wind energy in terms of relative humidity, earth temperature and wind speed to represent a new **significance** could be taken into consideration. The data of meteorology are collected from specific stations of meteorology of Ministry of Energy and Mineral Resources in Jordan [10].

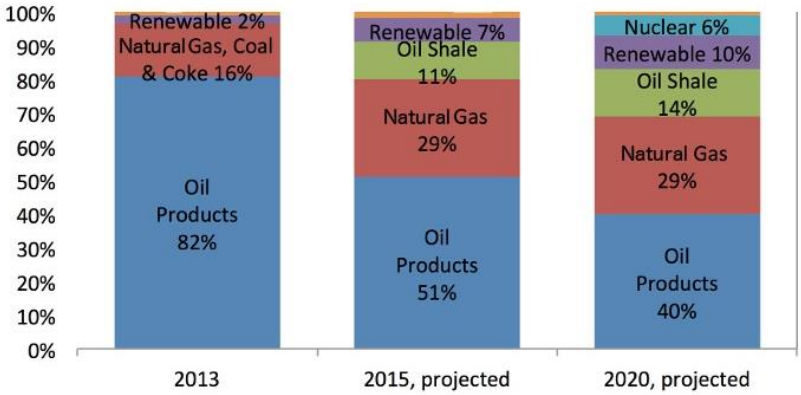

Fig. 1. Energy production in Jordan for 2013-2020 [3].

2. Situation of Renewable Energy in Jordan

Jordan is located in Middle-East region (west part of Asia). The Statistics Department of Jordan has provided fruitful information of total population of Jordan to be 11,285,869 [10]. Due to the growth rapid of population and infrastructure development, Jordan needs to consume more energy. Therefore, there is a huge demand of energy comparing with other countries in Middle-East.

The geographical site of Jordan gives a potential to be a distinguished generator of renewable energy in Middle-East. The importance of renewable energy is to reduce phenomenon of greenhouse gas (GHG) emissions that comes from fossil energy. It is expected to generate electricity of renewable energy by increasing its potential 50 times by 2050 [11], in addition to support the national economy and save USD 12B [12].

The wind energy has the majority of contribution to renewable energy as shown in Fig. 2. Its sharing 65% wind energy compared to 32% solar energy and 3% biomass utilising 15 renewable energy power stations installed in 2015. Furthermore, Jordan has planned to increase renewable energy resources contributed 7% of the total energy supply (9,712 kilo tonnes) in 2018 [13].

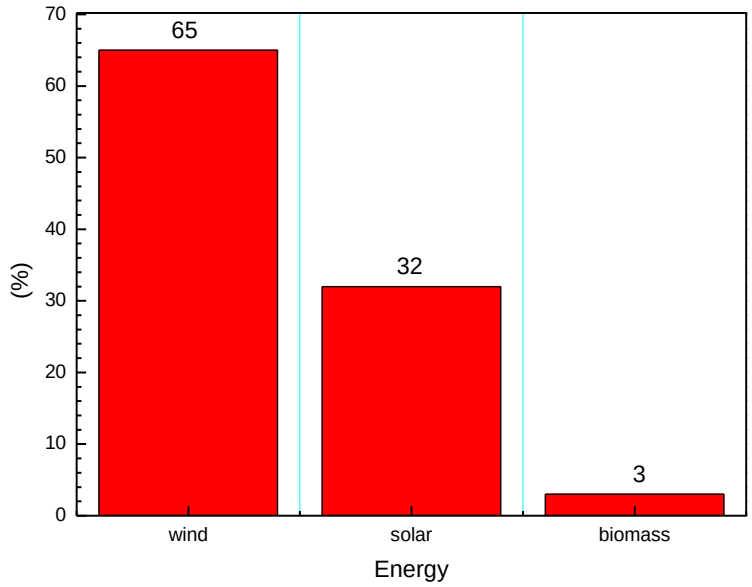

Fig. 2. Renewable energy percentages in Jordan.

3. Situation of wind energy in Jordan

The wind energy has been utilised for few thousands ago to drive water supply to grind crops [4]. As mentioned earlier, wind energy is an important and significant renewable energy for producing electricity. Internationally, electricity production of wind energy is almost 545 GW that increased 46% in comparison with a previous decade as illustrated in Fig. 3 [14]. Where the global electricity generation utilising wind energy for 2022, 2021, 2020, 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012, 2011 and 2010 is 584, 572, 566, 454, 522, 501, 487, 408, 370, 319, 283, 238 and 198 GW, respectively per power stations installed in China, USA, Germany, India, Spain and other part of the world.

The total electricity generation of wind energy in the Middle-East and North Africa (MENA) has reached 3489 MW in 2015 [15]. In Jordan, the annual average wind speed is 4-6.5 m/s and total wind energy is 119 MW provided via three different stations; 117 MW generated wind energy at Altafila, 1.125 MW generated wind energy at Hofa and 320 KW generated wind energy at Al Ibrahimya. Consequently,

the wind energy will gain power in near future to increase wind speed to 10 or 12 m/s at 50 m elevation for attracting revenues estimated USD 90B [16-19].

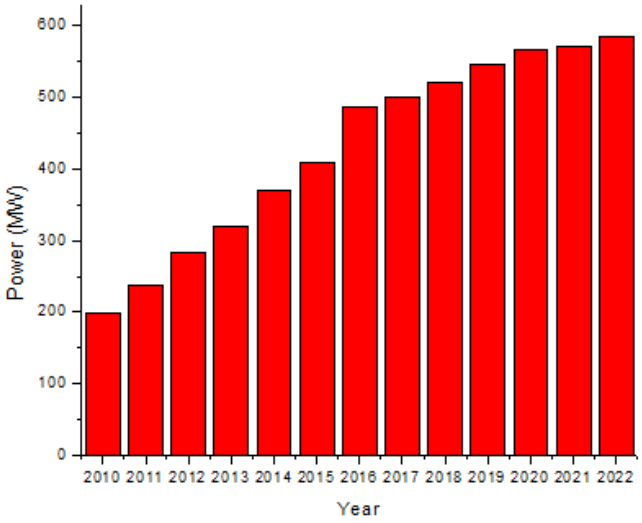

Fig. 3. Production of international wind energy.

4. Results and Discussion

The Jordan has three different zones of climates; Badia (75% covered desert) has 96,000 km^2 of surface area, mountains and Jordan valley. Figure 4 shows the average mean earth temperature annually for specific cities in Jordan. It is cleared that Irbid has the maximum average mean earth temperature, 34.2 °C in summer time. While Mafraq and Ma'an have 30.3 and 30.2 °C, respectively as minimum average at summer time too. Moreover, there is a close rate of temperatures for Mafraq and Irbid aside and Amman, Ma'an and Aqaba another side. So, at winter time, Mafraq has 8.8 °C as minimum average temperature, followed by Irbid and Ma'an have 11.3 and 11.1 °C, respectively along the year from January until December.

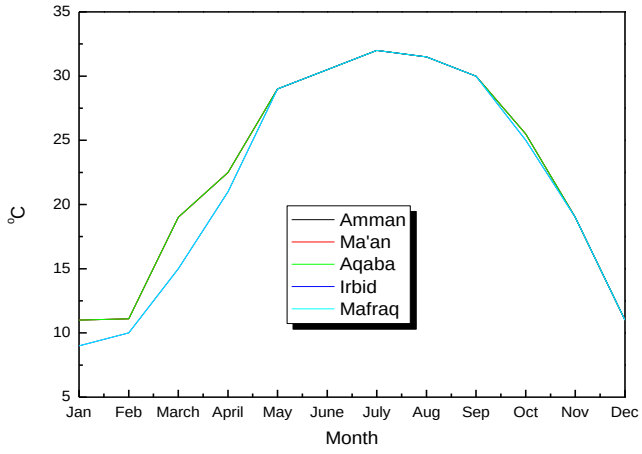

Fig. 4. Earth temperature in Jordan (Amman; black line, Ma'an; red line; Aqaba: green line; Irbid: blue line; Mafraq: light blue line).

The climate in Jordan is dry, which has little humidity. The average humidity annually of specific locations of Jordan is illustrated in Fig. 5. The maximum relative humidity is observed in Amman, 74% in January followed by Irbid, 72%. Additionally, Amman has the lowest relative humidity, 42.5% in July followed by Mafraq. The overall variation is high for Irbid along the year from January until December. Contrarily, the overall variation is low for Mafraq along the year for the same period of months.

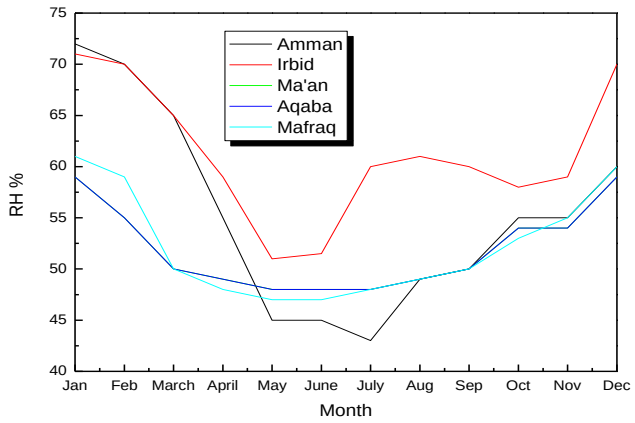

Fig. 5. Relative humidity of Jordan (Amman; black line, Ma'an; red line; Aqaba: green line; Irbid: blue line; Mafraq: light blue line).

It is well known that Jordan average annual wind speed reaches 7 m/s at 10 m elevation. Anyway, the average wind speed annually for those locations are under 5.5 m/s. The highest annual average wind speed in Aqaba, Irbid and Ma'an is 3.54, 3.9 and 4 m/s, respectively at 10 m elevation, followed by Mafraq to be 5.5 m/s at 10 m elevation as shown in Fig. 6. While, the same concept of speed in Mafraq is 5.5 m/s at 10 m elevation at September, then 5 and 5.25 m/s for June and August, respectively for the same elevation.

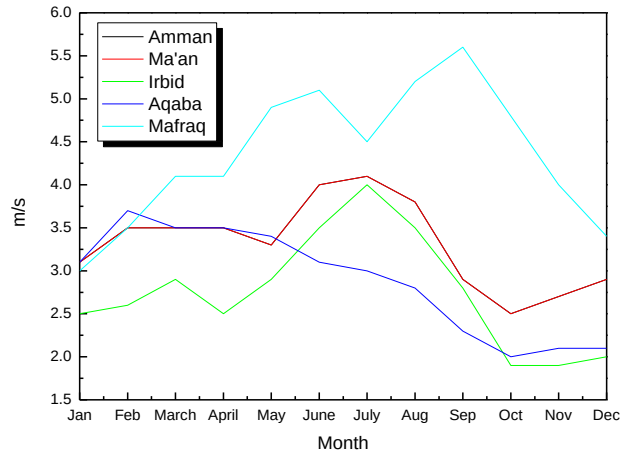

Fig. 6. Wind speed of Jordan (Amman; black line, Ma'an; red line; Aqaba: green line; Irbid: blue line; Mafraq: light blue line).

It is remarked clearly that Jordan has raised its plans and strategies for increasing the awareness and understanding the people about the importance of wind energy as economic and sustainable system. Jordan is a pioneer in the Middle-East countries for utilizing wind energy. Furthermore, Jordan has a lot of issues to perform wide energy technology and employment. Jordan is eager to eliminate all the barriers and obstacles prevent easy use and investment of wind energy. Meanwhile, Jordan has invited all the interests, investors and private sector to work together to consume wind energy perfectly.

The development of wind energy investment is escalating dramatically in Jordan. Moreover, the availability of wind energy, information database and specified wind speed map are allowing for selecting the best-possible site. The wind energy in Jordan is proved to be sustainable and trustworthy, in addition to implementing actual steps of wind energy technologies compared to others in Middle-East region. A report [20] has mentioned accomplished works by the Ministry of Energy and Mineral Resources in Jordan. Jordan encourages public and private sectors to establish projects to disseminate the renewable energy culture, where there is more than 153.5 MW will be generated in Jordan [20]. For future perspective of wind turbine in Jordan [21], the maximum possible output would be the capacity x 8760 hours (there are 8760 hours a year). So, the maximum output at Mafraq (highest speed in Jordan) is 66 kW x 8760 hr/yr = 578,160 kWh/yr (or 578,160 MWh). For the actual output a year is 166,660 kWh, the capacity factor is:

Capacity factor = Actual/Maximum output = 166,666 kWh/578,160 kWh = 28.8%.

5. Conclusions

It was concluded that the highest renewable energy percentage in Jordan was wind energy with 65%, followed by big wind speed to be 5.5 m/s at Mafraq in September, maximum relative humidity in Amman, 74% in January and maximum average mean earth temperature, 34.2 °C in Irbid at summertime. Also, a dissemination of wind energy culture including renewable energy projects for future development and installation was important to develop wind energy for minimizing the GHG and supporting the Jordan's economics that has obvious impact of sustainability.

Data Availability

Data openly available in a public repository that issues datasets with DOIs	The data that support the findings of this study are openly available in figures captions at reference numbers [3].

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Declaration

The authors declare that there is no conflict of interest.

Author Contributions

S.A.W. wrote, edited the draft manuscript. R.A.A organized the draft manuscript. M.F.A.A. validated the draft manuscript. Y. A. wrote, edited, and worked on the formal manuscript, and copyrighted the figures.

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