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The Future of the Renewable Energy in Oman: Case Study of Salalah City

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ABSTRACT

The world-wide energy demand is continuously increasing compounded with global warming. There is an ever-increasing demand in energy accompanied with depletion of fuel stocks, particularly the fossil fuels. The current energy consumption rates are unsustainable and thus have prompted for an active exploration and use of renewable energy sources. In this paper, we shall explore the future of the renewable energy in Oman based on the case study of Salalah city located in Southern Oman. The electricity shortages and the challenges to overcome the increase in electrical demands for the near future are discussed in detail. The climate of any locality is predominantly determined by the amount of sunshine it receives. The duration of sunshine was measured every 1 h using the routine sunshine recorders. Our investigations suggest that solar and wind energy will play an important role in the future of renewable energy in Oman. The paper finishes with some conclusions and recommendations. Based on the basic information of Oman solar radiation data, the application of solar energy has a high opportunity to support Oman's power generating capacity.

Keywords: Renewable Energy, Solar Energy, Wind Energy, Oman
JEL Classifications: Q2, Q3, Q4

1. INTRODUCTION

The world-wide energy demand is continuously increasing compounded with global warming. There is an ever-increasing demand in energy accompanied with depletion of fuel stocks, particularly the fossil fuels. The current energy consumption rates are unsustainable and thus have prompted for an active exploration and use of renewable energy sources. The electricity demand in Oman has more than tripled from 2435MW in 2005 to 7810MW in 2019. It is projected to increase to 8600MW in 2025. Table 1 has the actual electricity demand for the years, 2005-2019 and the projections for the years 2020-2025 (Directorate General of Meteorology and Civil Aviation of Oman 2020 and Ministry of Communication., Sultanate of Oman 2020; Oman Power and Water Procurement Company, 2020).

In this paper, we shall explore the future of the renewable energy in Oman based on the case study of Salalah city located in Southern Oman. We will assess the availability of solar and wind energy. The paper is organized as follows. Section-2 has a brief description of Oman and Salalah in particular. Section-3 describes the "data collection method." Section-4 and Section-5 are on the assessments of solar and wind energy respectively. In these two sections, we shall cover the various aspects such as the Sunshine Hour, Global Radiation, Wind Speed along with their statistical distributions. Section-6 is dedicated to the Weibull Distribution. Section-7 the final section has the concluding remarks.

The Sultanate of Oman is a country on the south-eastern coast of the Arabian Peninsula in Western Asia. Oman has an area of 309,500 km² and a population of about five million. Oman lies between latitudes 16° and 28° N, and longitudes 52° and 60° E. The climate is generally hot, with temperatures going up to 48°C in the summers. Generally, the climate of Oman is dry

with little rainfall. The city of Salalah is the capital of the Dhofar Governorate in southern part of Oman. The coordinates of Salalah are 17°01′11″N 54°05′23″E. The city has a hot desert climate, although summers are cooler than in more northern or inland parts of Oman. The annual rainfall in Salalah is about 120 mm. The city is windy. This makes Salalah an ideal place to exploit the solar energy and wind energy (National Centre for Statistics and Information of Oman, 2020).

2. DATA COLLECTION METHOD

The data used in this paper for the period 2013-2017 was obtained from the Directorate General of Meteorology and Civil Aviation, Ministry of Communication, Government of Oman. There are thirty-two meteorological stations across Oman. These stations are linked to the head office located in the capital Muscat using dedicated communication channels. Since the study is based on the city of Salalah, data was taken from the nearest meteorological station. This data was used to assess the potential of both solar energy and wind energy in the Salalah region. Using the data, we calculated the various vital parameters such as sunshine duration hours, wind speed, rainfall, and solar global radiation. A model of the photovoltaic (PV) system with hybrid type was selected using the HOMER method assessing the complete system of solar energy (American Meteorological Society, 2020 and Duffie et al., 2020). This method can describe the total load, PV system, generator, solar sources, battery, converter, etc.

3. ASSESSMENT OF SOLAR ENERGY POTENTIAL

From the data taken, the global radiation direction, relative humidity, amount of energy production, rainfall, was

Table 1: Electricity Demand in Oman (Years: 2020-2025 are projections)

S. No.	Year	Electricity demand in Oman (Megawatt)
1	2005	2435
2	2006	2544
3	2007	2682
4	2008	3100
5	2009	3581
6	2010	3613
7	2011	4000
8	2012	4455
9	2013	4634
10	2014	5047
11	2015	5565
12	2016	5920
13	2017	6116
14	2018	6168
15	2019	6353
16	2020	6770
17	2021	7160
18	2022	7500
19	2023	7810
20	2024	8190
21	2025	8600

Source: The Oman Power and Water Procurement Company

analysed, and the graph were made to assess their potential. From the previous reported field research, data collection analysis, Oman has the value of monthly extraterrestrial on horizontal ($\overline{H_0}$ varies from 27.42-38.88 MJ/m²), with average (34.54 MJ/m²). The monthly average solar radiation on horizontal surface $\overline{H}$ value varies from (17.02-25.42 MJ/m²), with average (21.02 MJ/m²) as shown in Figure 1 and $\overline{K_T}$ average is (0.61) yearly as shown in Figure 2 for related studies (Al-Malki et al., 1998; Kazem, 2011).

3.1. Sunshine Hour
The climate of a given locality predominantly determined by the amount of sunshine it receives. The duration of sunshine has been measured every one hour using sunshine recorders. Then the hourly measurements were aggregated to hours of bright sunshine on a daily, monthly and yearly basis respectively. From the metrological is obvious that, the highest sunshine occurs the lowest in June, July and August at Salalah city. Refer to the Table 2 along with Figure 3.

The average monthly radiation on surfaces in Salalah, ranging from (3.4 MJ/m²) in August, reach the highest point of (29 MJ/m²) in May, on β = 0⁰. While the value of monthly radiation on slope (β = 0-90) may drop during June to August (during summer), but the decrease is insignificant as shown in Figure 4 below.

Figure 1: Monthly solar radiation extraterrestrial on horizontal surface in Salalah (2013)
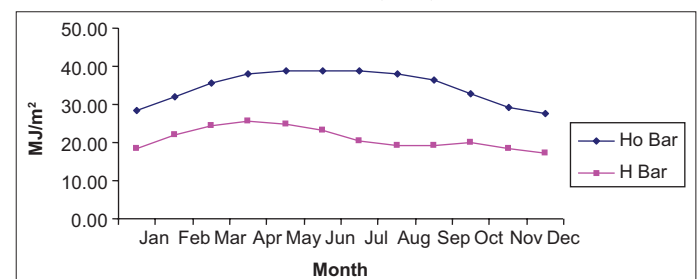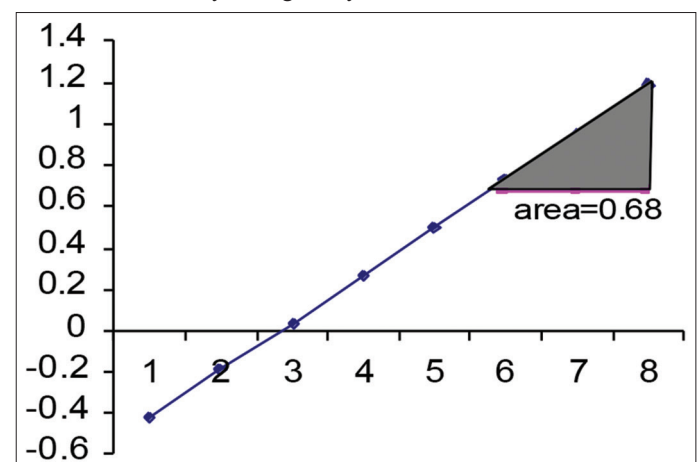

Figure 2: The ratio of daily total radiation on tilted surface and the monthly average daily total on tilted surface

4. ASSESSMENT OF WIND ENERGY POTENTIAL

From the data taken, the wind speed, direction, relative humidity, rainfall, are analysed, and the graph is be made to assess its potential. Table 3 along with Figure 5.

The limitations of single renewable energy systems quantified in terms of power efficiency stability and reliability have been extensively studied when the cost of operation is considered to be minimum. These limitations can be overcome by employing renewable energy hybrid power systems. Such hybrid systems are known to be successful (Al-Alawi and Lawrance 1999, Barley and Winn, 1996; Al-Busaidi et al., 2016).

4.1. Global Radiation (kW/m²/day)

Direct solar radiation and diffuse sky radiation falling together on a unit of horizontal surface constitute the global solar radiation (Stanhill and Achiman, 2017). Diffused solar radiation is the radiation that has been scattered out of the direct beam by molecules, aerosols, and clouds. The total amount of solar energy falling on a horizontal surface is from all parts of the sky apart from the direct sun, as illustrated in Table 4. There should be almost no diffuse sky radiation with the absence of atmosphere. The

Table 2: Accumulation of sunshine hour mean data in Salalah during 2013-2017

S. No.	Month	Year				
		2013	2014	2015	2016	2017
1	January	9.7	9.2	9.6	9.7	9.5
2	February	10.2	10.3	9.7	9.5	8
3	March	10.2	8.4	10.2	10	9.5
4	April	10.8	9.4	9.9	10	10.1
5	May	10.9	11.2	8.9	9.3	9.6
6	June	4.4	6.3	6.2	3.9	6.6
7	July	3.9	1.9	2.8	3.1	3.9
8	August	2.1	2.5	1.3	3.1	1.7
9	September	5.7	8.3	7.2	7.1	6.8
10	October	10.5	10.5	10.3	10.2	9.7
11	November	9.7	10.2	9.9	9.8	10.3
12	December	9.7	9.6	9.3	9.1	9
13	Average	8.1	8.1	7.9	7.9	7.9

Table 3: Accumulation of wind speed mean data in Salalah from year 2013 to 2017

S. No.	Month	Year				
		2013	2014	2015	2016	2017
1	January	5.65	3	3.6	3	3
2	February	5.65	2	3.6	3	3
3	March	2.57	3	2.57	3	3
4	April	3	3.6	3	3	3
5	May	3.6	5.1	3.6	3.6	3.6
6	June	4.6	4.1	3.6	3.6	3.6
7	July	3	3	3.6	3	3.6
8	August	3	3	2.57	3	2.57
9	September	2.57	3	3	3.6	3
10	October	2.57	2	2	2	2.57
11	November	3	3	3	2.57	2.56
12	December	3.6	3	3	3.6	4.1
13	Average	3.5	3.1	3.1	3	3.1

values are usually highest during the cloudy condition and lowest (less than 10%) during clear sky days and overhead sun. Direct solar radiation is the solar radiation that has not been scattered or absorbed and passes through directly to the earth's surface as shown in Figure 6.

5. WEIBULL DISTRIBUTION PLOTTER PROGRAMME

The graph in Figure 6 was obtained by using Weibull distribution plotter programme (Horst, 2008; Weibull Distribution Plotter Programme, 2020), based on the average wind speed in Salalah station (3.55 m/s in the year 2013), Table 5 and Figure 7.

The wind is caused by the natural motion of the air moving parallel to the Earth's surface. Winds are caused by uneven heating and cooling of both the ground and atmosphere, which is significantly

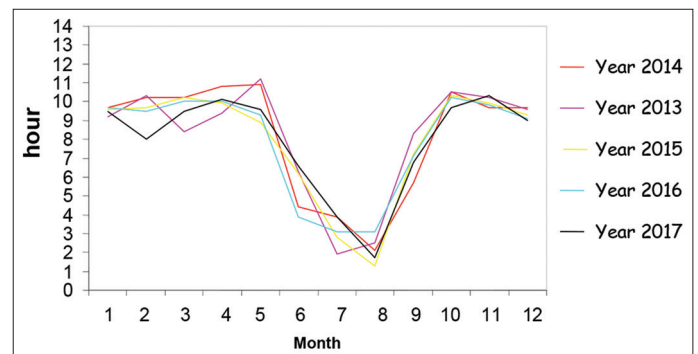**Figure 3:** Sunshine hour from year 2013 to 2017 in Salalah

Figure 4: Variation in estimated average monthly radiation on surfaces of various slope in Salalah
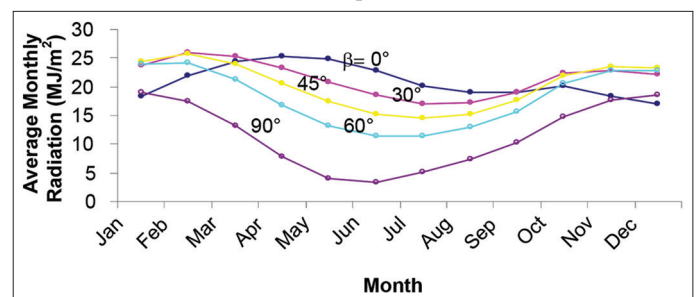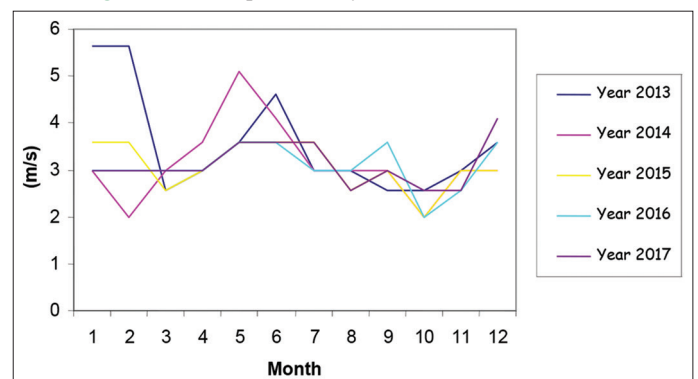

Figure 5: Wind speed from year 2013 to 2017 in Salalah

influenced by the solar radiation as well as the Earth's rotation (http://en.mimi.hu/meteorology/wind.html). As wind cannot be transported, it has to be utilized locally. Hence, the wind turbines must be necessarily located where wind resources are present. The energy content of the wind is proportional to the cube of its speed. So, even a minor change in the wind speed manifests significantly in its energy content. The average wind speed (calculated over a year) at a given location is the prime indicator of the available wind resources. The close relation between the annual mean wind speed and the potential value of the wind energy resources is given in this Table 6. The data for the wind speed showed that Salalah has within the Poor zone.

5.1. Statistical Description of Wind Speeds

The graph in Figure 8 exhibits the probability density distribution normalized to unity. This is evident by the fact that the area under

the curve is exactly one. The wind speeds at the lower end are almost zero.

The median of the distribution occurs at 6.6 m/s and it is indicated by the vertical black line. On either side of this line half of the area under the graph. This clearly indicates that the half of the time the

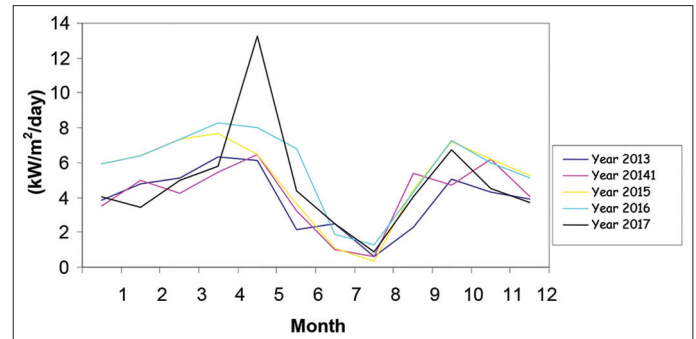**Figure 6:** Global radiation from year 2013 to 2017 in Salalah

Table 4: Accumulation of global radiation mean data in Salalah during 2013-2017

S. No.	Month	Year				
		2013	2014	2015	2016	2017
1	January	3.87	3.48	5.92	5.91	4.06
2	February	4.76	5.01	6.41	6.42	3.42
3	March	5.09	4.21	7.35	7.36	4.98
4	April	6.34	5.48	7.69	8.25	5.76
5	May	6.13	6.47	6.46	7.98	13.24
6	June	2.14	3.21	3.62	6.79	4.38
7	July	2.49	0.99	1.06	1.88	2.49
8	August	0.62	0.63	0.36	1.27	0.9
9	September	2.3	5.4	4.42	4.32	4.06
10	October	5.02	4.71	7.19	7.24	6.72
11	November	4.29	6.21	6.22	6.01	4.5
12	December	3.92	4.01	5.24	5.09	3.7
13	Average	3.9	4.1	5.1	5.7	4.8

Figure 7: Weibull distribution in Salalah year 2017

Table 5: Accumulation of Wind Speed Mean Data in Salalah from year 2013 to 2017

S. No.	Month	Year				
		2013	2014	2015	2016	2017
1	January	5.65	3	3.6	3	3
2	February	5.65	2	3.6	3	3
3	March	2.57	3	2.57	3	3
4	April	3	3.6	3	3	3
5	May	3.6	5.1	3.6	3.6	3.6
6	June	4.6	4.1	3.6	3.6	3.6
7	July	3	3	3.6	3	3.6
8	August	3	3	2.57	3	2.57
9	September	2.57	3	3	3.6	3
10	October	2.45	2	2	2	2.57
11	November	3	3	3	2.75	2.6
12	December	3.6	3	3	3.6	4.1
13	Average	3.55	3.15	3.09	3.09	3.13

Figure 8: Balancing the Weibull distribution

Table 6: Significant of wind energy according to the speed

S. No.	Annual mean wind speed at 10 m	Indicated value of wind resource
1	<4.5 m/s	Poor
2	4.5−5.4 m/s	Marginal
3	5.4−6.7 m/s	Good to very good
4	>6.7	Exceptional
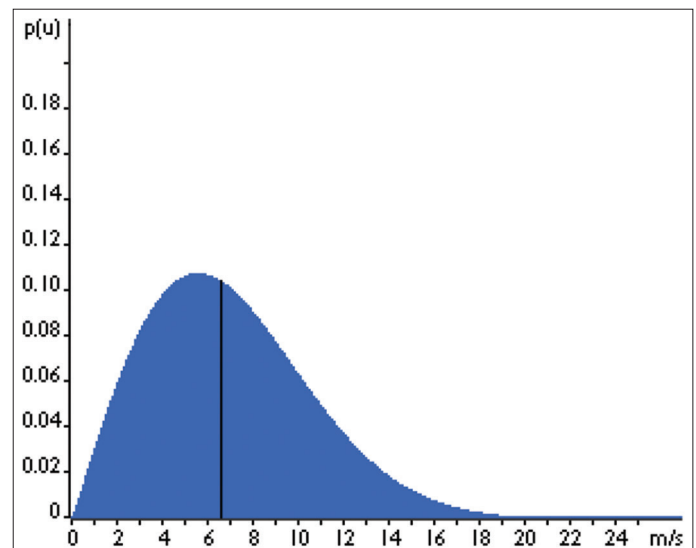
wind speeds are less than 6.6 m/s and more than this value in the remaining half time. In practice, the mean wind speed is closer to 7 m/s. This figure is obtained by direct measurements on this site. The distribution is obviously skewed (i.e. it is not symmetrical about the median line). The high and very high wind speeds are a rarer occurrence. The most common wind speed is 5.5 m/s and is known as the modal value of the wind speed distribution. The mean wind speed can be obtained by summing the average of the products of wind speeds in a given interval with the probability in that interval. The wind speed drastically varies from location to location and consequently the statistical descriptions. The shape of the Weibull distribution is bound to vary significantly from place to place. So, the inferences such as the mean value of the wind speed from the Weibull distribution also vary significantly. The graph in Figure 8 has shape parameter of value 2. Such a graph is known as the Rayleigh distribution. The Rayleigh distribution is frequently used for quantifying and standardizing by the manufacturers of wind turbines. Wind turbine manufacturers often give standard performance figures for their machines using the Rayleigh distribution. The analysis of the statistical description of wind speeds presented here is similar to the approach described at the website: http://ele.aut.ac.ir/~wind/en/tour/wres/weibull.htm.

5.2. Balancing the Weibull Distribution

The Weibull distribution in Figure 8 can be analysed in different ways. One is to balance the areas and that is what we did. This can be done by dividing the graph into small units. Each unit can represent the probability of the wind blowing at that speed for one percent of the time during the complete year. speeds of 1m/s are in the far-left portion of the graph and the far right has the speed of 17 m/s. balance occurs at about 7 m/s.

The average monthly radiation on surfaces in Salalah, ranging from (3.4 MJ/m^2) in August, reach the highest point of (29 MJ/m^2) in May, on $\beta = 0^0$. While the value of monthly radiation on slope ($\beta = 0$-90) may drop during June to August (during summer), but the decrease is insignificant. From the previous reported field research, data collection analysis, Oman has the value of monthly extraterrestial on horizontal ($\overline{H_0}$ varies from 27.42-38.88 MJ/m^2), with average (34.54 MJ/m^2). The monthly average solar radiation on horizontal surface $\overline{H}$ value varies from (17.02 to 25.42 MJ/m^2), with average (21.02 MJ/m^2), $\overline{K_T}$ average is (0.61) yearly.

Based on the basic information of Oman solar radiation data, the application of solar energy has a high opportunity to support Oman's power generating capacity. The application can be in many forms, such as water desalination powered by solar energy, water pumping, irrigation, fishery, and fruit drying, etc.

6. RESULTS

The climate of any locality is predominantly determined by the amount of sunshine it receives. The duration of sunshine was measured every 1 h using the routine sunshine recorders., these measurements were aggregated to hours of bright sunshine on a daily, monthly and yearly basis. the metrological data in Section-6, it is obvious that the lowest at Salalah city Table 5.

From the previous reported field research, data collection analysis, Oman has the value of monthly extraterrestrial on horizontal (varies from 27.42-38.88 MJ/m^2), with average (34.54 MJ/m^2). monthly average solar radiation on horizontal surface value varies from (17.02 to 25.42 MJ/m^2), with average (21.02 MJ/m^2), average is (0.61) yearly. Based on the basic information of Oman solar radiation data, the application of solar energy has a high opportunity to support Oman's power generating capacity. application can be in many forms, such as water desalination powered by solar energy, water pumping, irrigation, fishery, and fruit drying, etc. The yearly average wind speed for the three selected cities was in the range of 3.0-5.6 m/s. However, it is about 3.56 m/s. Applications of renewable energy in Oman nowadays however in a very minimum state, despite several research and field study have been conducted to promote the alternative energy sources. This need a hard and continuous effort to promote the renewable energy in Oman starts from the lowest education level. The curriculum should be revised and edited to include some chapters about the use, and application of renewable energy as a clean and future alternative national source of energy.

7. CONCLUSIONS

It is time to actively implement wind powered electrical generating systems, particularly in the open regions such as deserts which have high wind speeds. In such locations, it is expensive to maintain the traditional electrical power generating systems. Along with the wind energy one can also make use of the hybrid photovoltaic thermal (PV/T) solar collector. Such systems are having demonstrated competence in generating electrical and thermal energies simultaneously (Manwell and McGowan 1993; Othman et al., 2016).

Oman has a long tradition in its efforts to conserve the environment. In order to strengthen international efforts in the field of environmental conservation, late His Majesty Sultan Qaboos Bin Said of Oman declared the establishment of an environment prize during his visit to the UNESCO Headquarters, in Paris, France in 1989. UNESCO established the Statutes of the Prize, adopted by the Executive Board at its 132nd session in November 1989. The inaugural Prize was awarded in 1991 and since then it has been awarded every biennium. The Prize consists of a diploma, a medal and a cash endowment of US$100,000 (Khan, 2016a; Khan, 2018a; Khan, 2018b; Khan, 2018c; Khan, 2018d; Khan, 2020). The award ceremony is held on the 1st day of the World Science Forum, under the auspices of UNESCO (Khan, 2021). The other notable science prizes established in the Middle East are the Mustafa Prize for Science from Iran (Khan, 2016b) and the King Faisal International Prize from Saudi Arabia (Khan, 2018e; Khan, 2021).

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