Solar Resource Mapping of AL Duqm Industrial Area

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Abstract: The Sultanate of Oman has one of the highest percentages of potential solar radiation in the world, which puts it in an outstanding position to horde electricity generation plants through photovoltaic solar systems. Oman consists of 11 governorates, and each governorate is divided into many Willyiah, which are made up of small villages. Willyiah of Al Duqm is located in Al Wusta Governorate (19°39'42" N 57°42'17" E) in central-eastern Oman. This paper proposes the use of a monthly average hourly diffuse illuminance from meteorological data and from a Geographic Information System (GIS) to identify the best plots suitable for installing photovoltaic solar farms in the Al Duqm Industrial Area. Solar data collected in this study shows that the highest average annual solar radiation data recorded is 5,764 Wh/m² in the Al Duqm area. Solar radiation data from 2000 to 2012 has been collected for further analysis. The Annual Energy Production (AEP) simulated using ArcGIS ranges between 6,028 Wh/m² and 3,668 Wh/m². This shows a very close estimation between simulation results and the data collected from the meteorological department in Oman.

Keywords: Solar, Resource Mapping, ArcGIS, Duqm, Oman

1. Introduction

Oman government has started to build a Special Economic Zone (SEZ) in the Al Duqm region, which is predicted to need around 1 GWh of electricity in 2020. The Al Duqm SEZ comprises a seaport industrial area, a new town, a fishing harbour, a tourist zone and a logistics centre, which are supported by a multimodal transport system connecting to the Arabian Gulf countries, Middle East, East Africa and South East Asia. However, these rapid developments may face the challenge of providing the sufficient electricity required in this SEZ that is environmentally clean. On other hand, Oman Vision 2020 seeks to reduce Oman’s dependence on oil, diversify the economy and create new employment opportunities for all Oman citizens. Vision 2020 stresses the promotion of technology transfer and the increased use of natural and renewable energy resources, with due regard to the social and natural environments [1].

The demand for electricity energy has been continuously increasing in Oman. As projected in the Oman Power and Water Procurement (OPWP) 7-year statement (2012–2018) for long-term planning [2], it is estimated that the electricity demand will increase from 19 TWh to 31.2 TWh between 2011 and 2018, with an increase in the annual average growth rate of 8%.

Among the renewable energy resources, solar energy is becoming one of the most promising forms of power generation in Oman. Many studies have been conducted to determine PV locations in Oman considering their geographical locations. Charabi and Gastli [3,4,5] studied solar power prospects for Al Duqm in the Sultanate of Oman based on the master development plan and GIS solar radiation map. This solar mapping will help the government policy leaders to be more pro-active in the development of solar energy and to create a viable solar energy market in the region. The solar mapping was conducted using ArcMap tools embedded in ArcGIS software. They found a very high potential of solar energy and solar electricity generation in Al Duqm throughout the year because of the high ratio of ‘sky clearness’ and the geographical location, which is located within a country with a very high potential of solar electricity generation that can easily rise up to 1 GW.
The main gaps of the above research include a lack of consideration of populated areas, roads, rivers and sensitive areas in the maps as well as future planning and developments of the country. Moreover, few studies combined solar energy with other energy sources or implementation of solar energy (pilot projects). Filling these gaps will give a more accurate prediction of the actual situation of the area and should be considered when studying the Al Duqm regions. Moreover, implementing pilot projects allows the researchers to obtain complete pictures of the surrounding effects of the renewable energy in that location. Furthermore, spatial analysis gives clear pictures of resource potential in the area of study.

2. Methodology
In this paper, two approaches will be applied to analyse the solar radiation in the area of Al Duqm. First, meteorological data derived from the monitoring station at an elevation of 2 m above mean sea level (MSL) on the coordinates of latitude 19°037’ N and longitude 57°038’E are collected. The data obtained are assumed to represent a circumference of up to 150 km around this point, relying on single data points, and will be used to validate the data in the second approach.

The second approach will complement the first approach by providing the grid points results based on a numerical model using ArcGIS. The ArcGIS system provides solar radiation modelling analysis tools that calculate insolation across a landscape or for specific locations, based on methods from the hemispherical view shed algorithm developed by Rich et al. [6]. The solar radiation analysis tool, which is a part of the spatial analyst extension, enables users to map and analyse the effects of the sun over a geographic area for specific periods. The tool takes into consideration the atmospheric effects, site latitude elevation, steepness (slope) and compass direction (aspect), daily and seasonal shifts of the sun angle, and effects of shadows cast by surrounding topography. However, reflected radiation is not considered in the calculations of the total radiation; therefore, the total radiation is the sum of direct and diffuse radiation.

3. Resource Assessment
3.1 Observation method
The solar radiation data of the Al Duqm area were collected from the meteorology department over a 13-year period from 2000 to 2012. The data were checked, evaluated and treated to the final arrangement for use in this study. The sunshine period from November until the end of March was 11 hours and from April until the end of October was 12 hours. The annual average solar radiation of 13 years is 5,764.394 Wh/m².

Figure 1: Hourly average solar radiation 2000-2012
Figure 2: Monthly average solar radiation 2000-2012
Figure 3: Hourly average solar radiation profile over 24 hours
Figure 1 shows the average hourly solar radiation from 2000 to 2012 is between 427 W/m² and 465 W/m², proving mostly stable over the 13-year period; thus, future solar radiation is expected to fall into an equivalent range. Figure 2 shows the monthly average solar radiation from 2000 to 2012. The peak solar radiation occurred in July (464.86 W/m²) and the lowest solar radiation occurred in January (417.45 W/m²). Diurnal variation of irradiation is important for the daily operation of any solar based electricity generation system. The hourly average solar radiation for a 24-hour profile is shown in Figure 3, where a peak irradiation of 1,005.56 W/m² occurred at 13:00 hrs.

3.2 ArcGIS method
Total monthly and annual global radiation is calculated using the DEM over the land of Duqm. Notice that the highest solar radiation per day (6,028 Wh/m²) is occurred during July (summer solstice) and the lowest (3,668 Wh/m²) is occurred in December (winter solstice); the solar potential is high throughout the year. Figure 5 shows the annual global solar radiation (GSR) over Duqm and the border of the SEZ of Duqm SEZAD.

Figure 4: Global annual average solar radiation
Figure 5: Direct annual average solar radiation
Figure 6: Diffuse annual average solar radiation

As it can be seen that the inland areas of Duqm receive significantly more solar radiation than the coastal areas. On the other hand, the west side of SEZAD has the highest solar radiation values. In this study, the main components of global radiation are direct and diffuse radiations, as shown in Figure 4, 5 and 6, respectively.

Figure 7: Simulated global monthly solar radiation using ArcGIS model

Direct radiation is intercepted unimpeded in a direct line from the sun, while diffuse radiation is scattered by atmospheric constituents, such as clouds and dust. About 75% of the GSR is direct radiation. In addition to
measuring the annual solar radiation, it is very useful to analyse the monthly solar radiation for any resource assessment. Figure 7 shows the monthly GSR. The amount of solar radiation over Duqm increases gradually at the beginning of the year until it reaches its maximum during July and then starts decreasing until reaching its minimum in December, as shown in Figure 8

![Figure 8: Average monthly variability of maximum and minimum GSR](image)

4. Analysis of Results

Solar energy is a continuing and prevalent source of energy that is perfect for remote electrification in the recent circumstance. Previous studies have confirmed that acceptable production costs of solar electricity occur where radiation levels exceed about 1700 kWh/m²-yr. However, for utilisation of solar energy, it is necessary to know how much the received solar radiation is weakened by the atmosphere. For clear sky conditions, 9% of direct solar radiation is exhausted by atmospheric scattering, 6% by surface reflection and 3% by other gases, smoke and dust. Moreover, the relative air mass, which is defined as the path length relative to that at the zenith at sea level, is an important parameter to consider when studying solar energy in such a selected location, and it increases as the angle between the source and the zenith increases.

In this study, the observation and ArcGIS methods were used to assess the energy resources in the Al Duqm industrial area in Oman. This study found that the annual average solar radiation over 13 years was 5,764.394 Wh/m². No significant difference was found between the results of the two methods. That is, the ArcGIS method recorded the highest daily solar radiation of 6,028 Wh/m² in July and the lowest of 3,668 Wh/m² in December, while the observation method found the highest daily solar radiation of 6,043 Wh/m² in July and the lowest of 5426 Wh/m² in December. However, Charabi and Gastli [5] reported a yearly solar radiation of 2357 Wh/m² for the Al Duqm area, which is low compared with the results of this study.

5. Conclusion

This paper shows the availability of solar energy resources for the Al Duqm industrial area in the Sultanate of Oman based on observations and analysis of meteorological weather data and the ArcGIS solar radiation map. The observation data set was used to validate the ArcGIS solar radiation map. The outcomes of the results show very high potential of solar energy and solar electricity generation in the Al Duqm over a year. The solar radiation varies between 6,028 Wh/m²/day and 3,668 Wh/m²/day at 1:00 pm and 6:00 pm, respectively. The annual average of solar radiation in the Al Duqm area is 5,764 Wh/m²/day with an average annual duration of sunshine of 11.5 hours.

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