A Review of Conventional and Renewable Energy Resources in Oman

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Abstract:

Energy has become an important sector in Omani vision 2020. Renewable energy (RE) sources form a vital and strategic solution for the provision of electric power in the Sultanate; few studies have indicated that Oman is rich in solar and wind energy. However, this sector faces many challenges, and the development of RE is at a slow pace. This paper provides a comprehensive review of Oman conventional and possible renewable energy resources. Although Oman in not currently utilizing its renewable energy resources however this study reveals that renewable energy resources such as wind, solar, waves and biogas are having enough potential which can be directly utilized for electricity generation. The study further discuss that geothermal energy would not be suitable for direct generation of electricity.

Key Words: renewable energy, conventional energy, Omani vision 2020, geothermal energy

1. Introduction:

Energy is essential to economic and social development and improved quality of life in all countries. Much of the world's energy, however, is currently produced and consumed in ways that could not be sustained if technology were to remain constant and if overall quantities were to increase substantially. The need to control atmospheric emissions of greenhouse and other gases and substances will increasingly need to be based on efficiency in energy production, transmission, distribution and consumption in the country. On the other hand, electricity supply infrastructures in many developing countries are being rapidly expanded as policymakers and investors around the world increasingly recognize electricity's pivotal role in improving living standards and sustaining economic growth [1–3].
Climate change is one of the most difficult challenges facing the world today and preventing will necessitate profound changes in the way we produce, distribute and consume energy. Burning fossil fuels such as coal, oil and gas provides about three quarters of the world's energy. However, when these same fuels are burned, they emit greenhouse gases (GHGs) that are now recognized as being responsible for climate change [4–6]. These fuels are ubiquitous. Fossil energy has fuelled industrial development, and continues to fuel the global economy. We each use energy in many forms every day: heating, cooking, lighting, TV, commuting, working, shopping etc., and almost every activity requires energy. Beyond daily individual use, modern societies use even more energy for agriculture, industrial processes and freight transport. The primary GHG emitted through fuel combustion is carbon dioxide (CO2). Land-use and land-use changes, notably deforestation, also involve emissions of carbon dioxide. Other GHGs are also
emitted during energy use, the most significant of which are methane (CH4) and nitrous oxide (N2O) [7,8].
Oman, like other Arab gulf countries, depends on oil and gas to produce electricity. However, these resources are not guaranteed to last forever, and are one of the energy security issues in the country. Some of the gulf countries have diversified their energy resources—for example, the United Arab Emirates has considered the nuclear and Renewable Energy (RE) as part of their electric generation and Qatar aims to generate 20% of its energy from renewable by 2024 with 1800MW of installed green capacity by 2020 — As for Oman, the progress of RE development is at a slow pace as currently the electricity generation is still depending on the oil and gas. Omani Vision 2020 seeks to reduce dependence on oil, diversify the economy and create new employment opportunities for all Omani citizens. The Vision 2020 also stresses on the promotion of technology transfer and the increased use of natural and renewable resources, with due regard to the social and natural environment, which gives priority to the main key aspects [9].

2. Background Oman Conventional Energy

Oman's economy is heavily reliant on oil and gas revenues, which account for about 84.2% in 2005 of the country's export earnings and 48.8% of its gross domestic product (GDP). All of Oman's domestic energy consumption is supplied by natural gas and oil, reflecting the country's relative abundance of oil and natural gas reserves. In 2011, oil accounted for 71% of Oman's total primary energy consumption, and natural gas made up the remaining 29%. With the exception of 2009, Oman's petroleum consumption rose steadily over the past decade, reaching 154,000 bbl/d in 2013. This further has a significant contribution towards greenhouses gases.

2.1 Oil sector

According to the *Oil & Gas Journal*, Oman had 5.5 billion barrels of estimated proved oil reserves as of January 2014 [10]. Oman's 5.5 billion barrels of proved oil reserves rank 7th in the Middle East, and 23rd in the world. A report published by the U.S. Geological Survey in 2012 stated that the estimated mean undiscovered energy resources in the South Oman Salt Basin–located in the southern part of the country–

totaled more than 370 million barrels of oil, 315 billion cubic feet (Bcf) of natural gas, and more than 40 million barrels of natural gas liquids (NGL)[11] With rising production levels, a growing petrochemical sector–which relies on liquefied petroleum gases (LPG) and NGL–and additional potential resources, the country is unlikely to significantly alter its dependence on hydrocarbons in the short term [12]. Oman's petroleum deposits were discovered in 1962, decades after those of its neighbours. Moreover, Oman's oil fields are generally smaller, more widely scattered, less productive, and pose higher production costs than in other Arabian Gulf countries. The average well in Oman produces only around 400 barrels per day (bbl/d), about one-tenth the volume per well of those in neighbouring countries. To compensate, Oman uses a variety of enhanced oil recovery (EOR) techniques. The oil reserves in Oman are shown in Fig. 1.

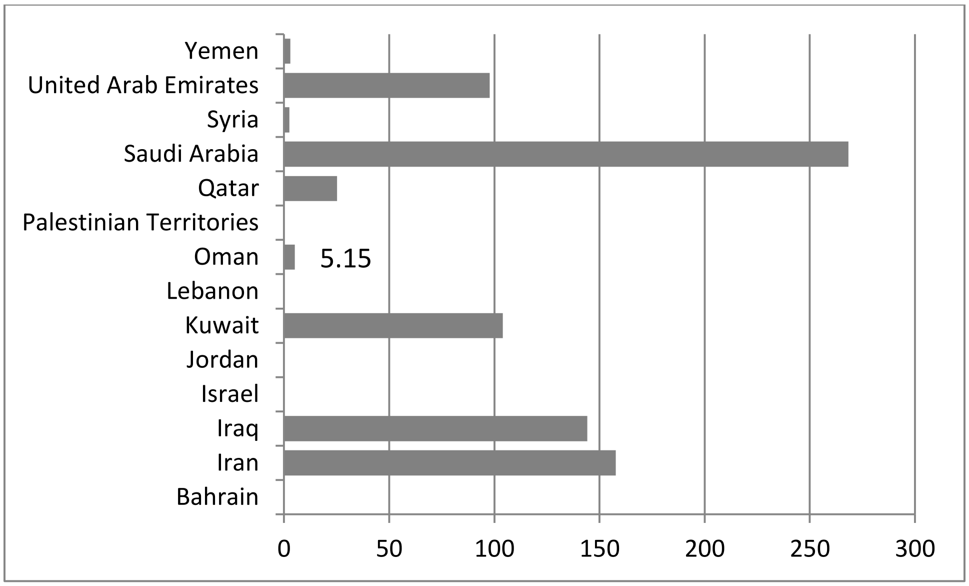

Figure. 1 Selected Middle East Proven Oil Reserves in Billion Barrels (2015)
(Source: U.S. energy Information Administration, International Energy Statistics)

During 2006, Oman consumed an estimated 64,000 bbl/d of oil, with net exports of 679,000 bbl/d. Oman is not a member of the Organization of the Petroleum Exporting Countries (OPEC), though it is a significant exporter of oil. Most of Oman's crude oil exports go to Asian countries, with China, India, Japan, South Korea, and Thailand the largest importers. Table 1. Shows Oman crudes oil exports by quantity to different countries.

Country	**Amount (thousand bbl/d)**
China	495
Japan	80
Taiwan	75
Thailand	47
India	44
Singapore 37	37
South Korea 14	14
Sri Lanka	13
Oman Oil Refineries and Petroleum Industries (ORPIC) and Other	28

Total	833

Table 1. 2013 Oman crude oil and condensate exports, by country

Source: US. Energy and Information Administration, International Energy Data and Analysis (Oman) dated 5th December, 2014.

2.1.2 Exploration and Production

To help offset declining oil output, Oman's Minister of Oil and Gas announced in April 2006 that the country planned to invest $10 billion in upstream oil and natural gas projects during the next five years. Much of this effort will focus on enhanced oil recovery (EOR) initiatives to improve recovery rates at several of the country's oil fields. Oman also plans to increase exploration and production (E&P) activities, although the natural gas sector will receive much of this investment. The oil production and oil consumption in Oman is shown in Fig. 2.

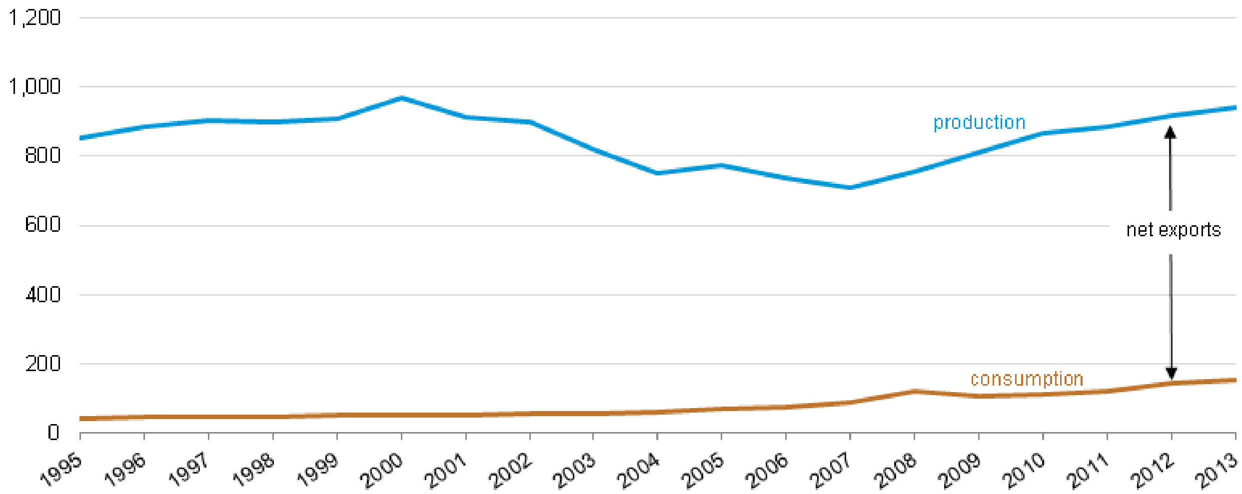

Figure 2. Oman Crude Oil and Lease Condensate Production, Consumption and net Export, 1995-2013 (sources: U.S energy Information Administration)

2.2 Natural Gas

According to OGJ, Oman's proven natural gas reserves stood at 30 trillion cubic feet (Tcf) as of January 2007. Expanding natural gas production has become a chief focus of Oman's strategy to diversify its economy away from the oil sector. Rising natural gas production over the last several years has resulted in the expansion of natural gas-based industries, such as petrochemicals, power generation, and the use of natural gas as a feedstock for enhanced oil recovery projects. However, despite the recent rise in production, additional natural gas reserves have not been located as quickly as the government had hoped. Some industry sources have speculated that, given the country's long-term liquefied natural gas (LNG) export obligations, natural gas supplies may be overcommitted in Oman. Natural gas production in Oman stood at 607 billion cubic feet (Bcf) in 2004, up more than threefold since 1999. Oman consumed 239 Bcf of natural gas in 2004 with LNG exports of 324 Bcf. Nearly two-thirds of Oman's LNG exports went to South Korea, while the remainder went to Japan, Taiwan, Spain, France, and the United States. Oman also pipes some natural gas exports to the United Arab Emirates (UAE), although it has plans to import natural gas in the future. The estimated natural gas reserves in the Middle East countries for 2007 are shown in Fig. 3.

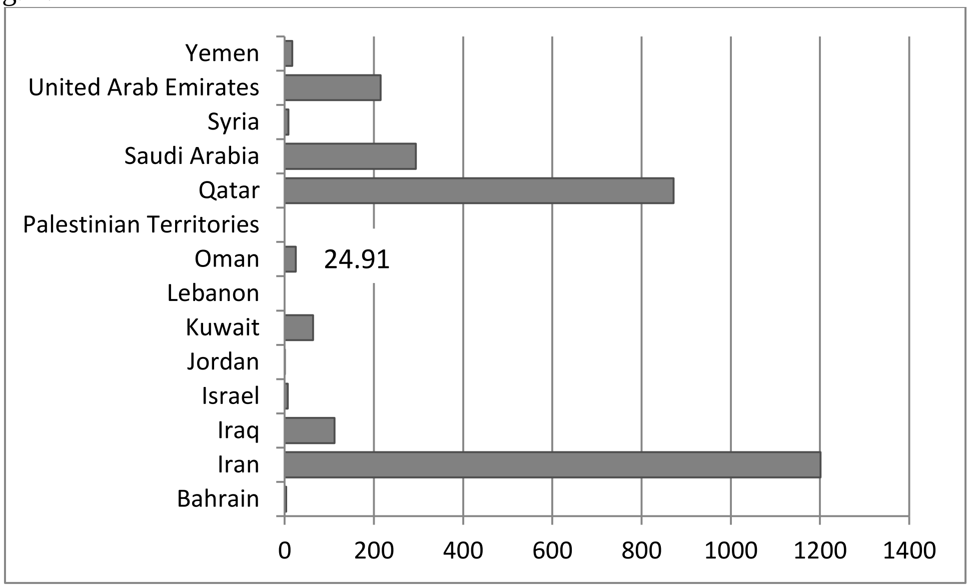

Figure 3. Selected Middle East Proven Natural Gas Reserves in Trillion Cubic Feet (2015)
(Source: U.S. energy Information Administration, International Energy Statistics)

2.2.1 Exploration and Production

Natural gas production has risen significantly since 1999, although increases in production have tapered off during the last two years. The Omani government has intensified its efforts to locate additional natural gas supplies to help meet rising domestic natural gas requirements as well as the country's LNG export commitments. Fig. 4. indicates Oman Natural Gas Flows and net Exports, 2000-2012.

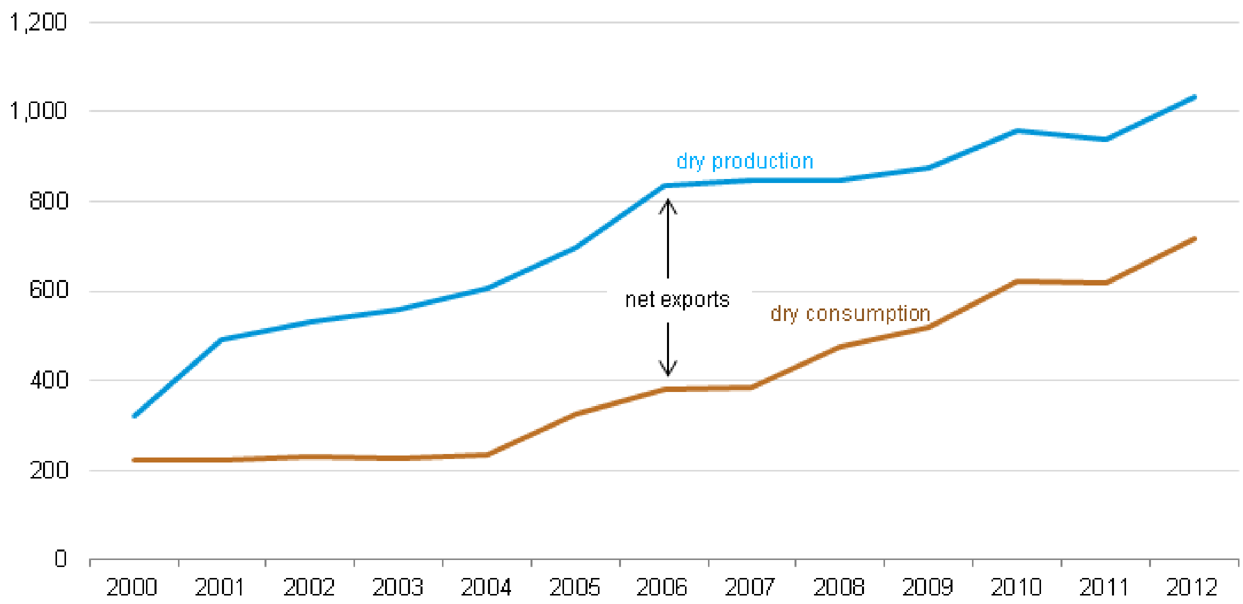

Figure 4. Oman Natural Gas Flows and net Exports, 2000-2012
(Source: BP statistical Review of World Energy 2014, US energy Information Administration)

3. Renewable energy resources in Oman

The Oman Authority of Electricity Regulation complied a study report on the renewable resources in Oman (2008). The study finds significant potential sources of renewable energy in the Sultanate of Oman which covers solar energy, wind energy, biogas, wave energy and geothermal energy.

3.1 Wind energy

The assessment of the wind energy resources is based on the wind data measured at twenty one stations in Oman under the responsibility of Directorate General of Civil Aviation and Meteorology. The wind data is measured at 10 m above ground level. The data indicate that five stations are having high wind speed (in 2005). For these stations the hourly wind speed data for 2006 was obtained from Directorate General of Civil Aviation and Meteorology. From these data the annual mean wind speed in 2005 and in 2006 was calculated. The wind conditions at 80 m above ground level were estimated which is equal is to the hub height of a modern large wind turbine, having a capacity in the order of 2-3 MW. The high wind speeds are found along the coast from Masirah to Salalah. The highest wind speeds are in the Dhofar Mountain Chain north of Salalah. The low wind speed areas are in the north and western part of Oman. The measured annual mean wind speed at 10 m and the estimated annual mean wind speed at 80 m above ground level at each of the five selected met station is shown in Fig. 5.

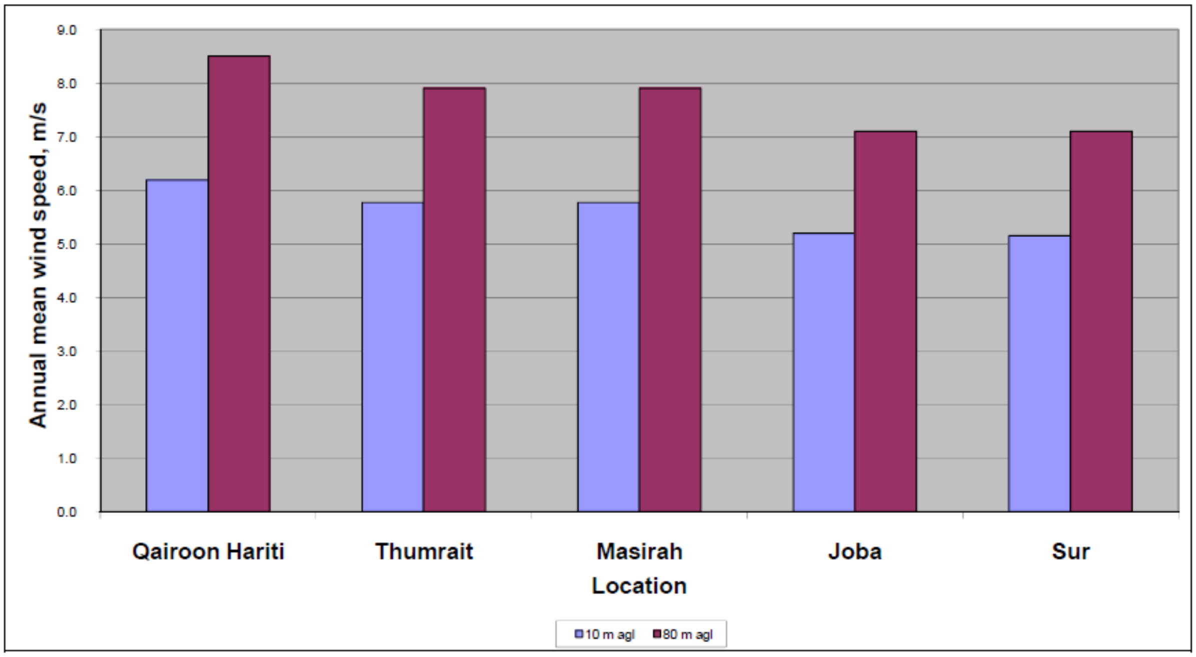

Figure5. Annual mean wind speed at 10 m and at 80 m above ground level at five meteorological stations.

The highest wind energy speeds are observed during the summer period. The summer period is also the period with the highest electricity demand in Oman. The wind monitoring masts at Thumrait and Qairoon Hariti were inspected as part of the study in order to evaluate the measuring conditions. The measuring conditions have been evaluated as acceptable but due to some complexity of the terrain around the masts more detailed wind analysis are required in order to determine the wind energy resources more accurately. A rough estimate of the wind energy content at 80 m above ground level has been made at each of the five selected met stations based on the hourly mean wind speed data for 2006 received from Directorate General of Civil Aviation and Meteorology. The annual wind energy content at each met mast is indicated on Fig. 6. The energy is specified as kWh per year through a vertical area of one m2, kWh/year/m2.

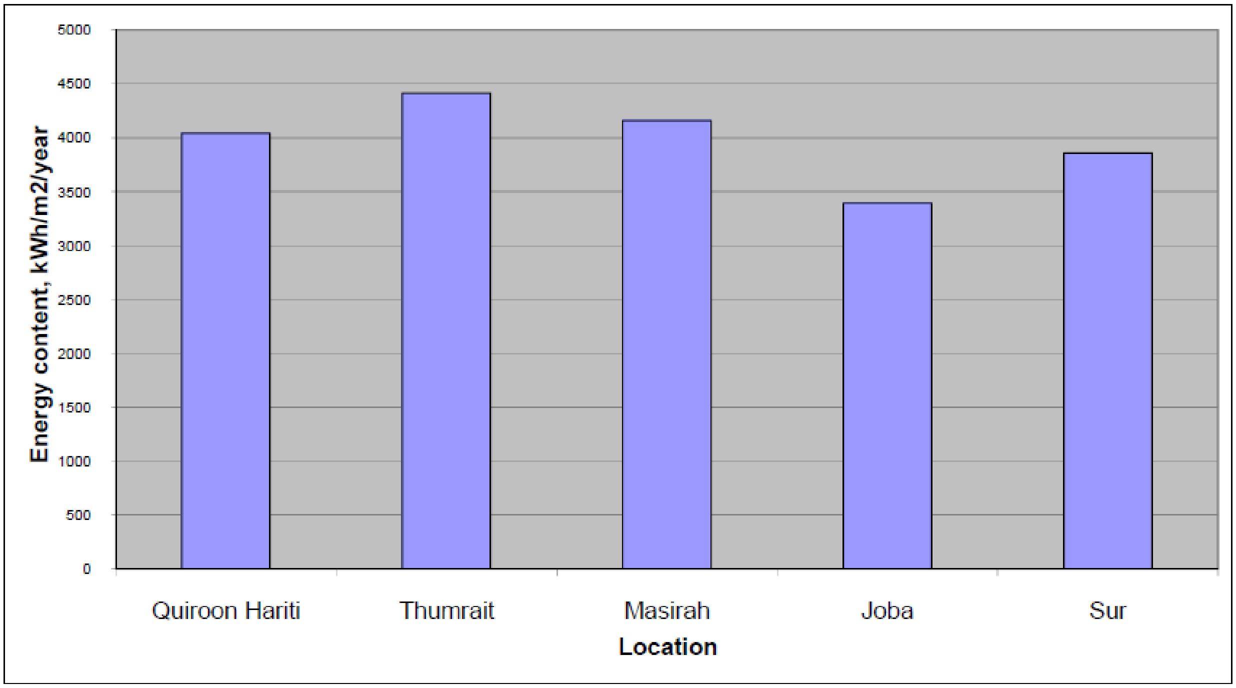

Figure 6 Energy content in the wind at 80 m above ground level at five meteorological stations.

3.2 Solar energy

The solar insolation varies from year to year. It is therefore important to use data covering several years in order to estimate the long term average solar energy resources.

Data from 1987 to 1992 for six different locations in Oman has been identified and used for this study in order to base the analyses on long term data. These data are global insolation data which is the sum of direct and diffuse radiation on a horizontal plane measured with a pyranograph. The location of the sites where the solar insolation data is measured is shown in Fig. 7.

Figure 7 Locations of the stations for Collection of Solar Data

3.2.1 Solar energy resources

The solar resources at various locations and the monthly variations are presented in Fig. 8 and Fig. 9.

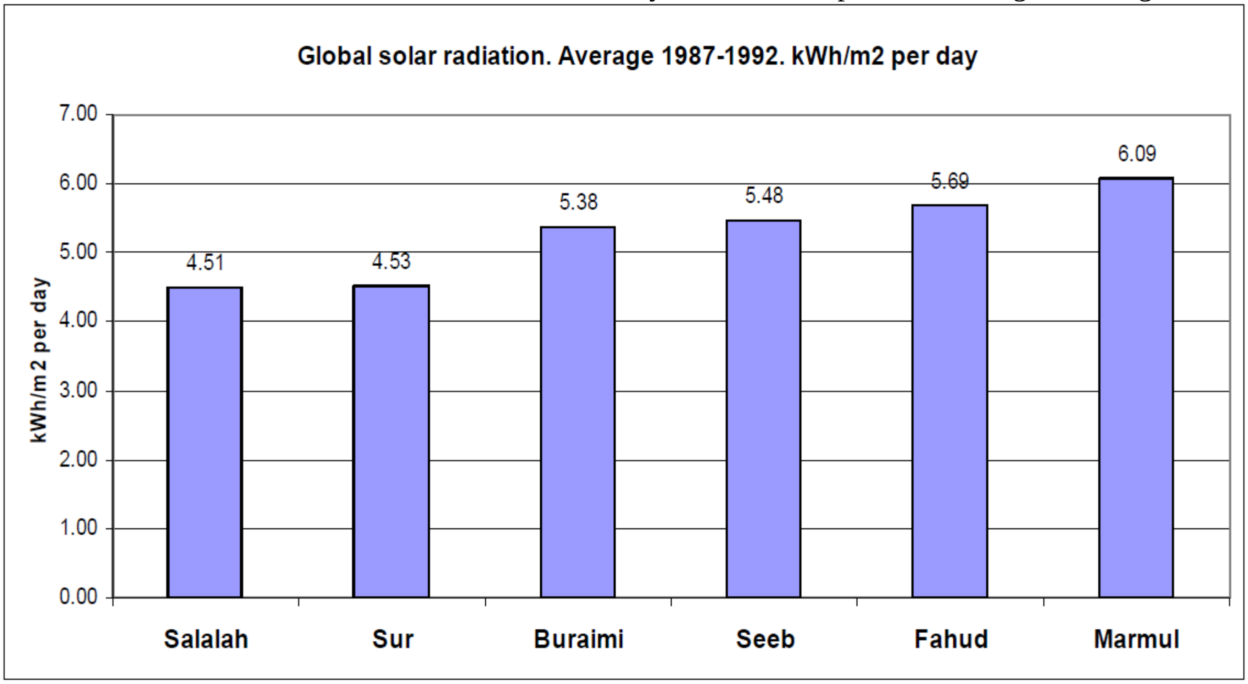

Fig. 8 Global insolation average for 1987-1992 for the stations included in this study.

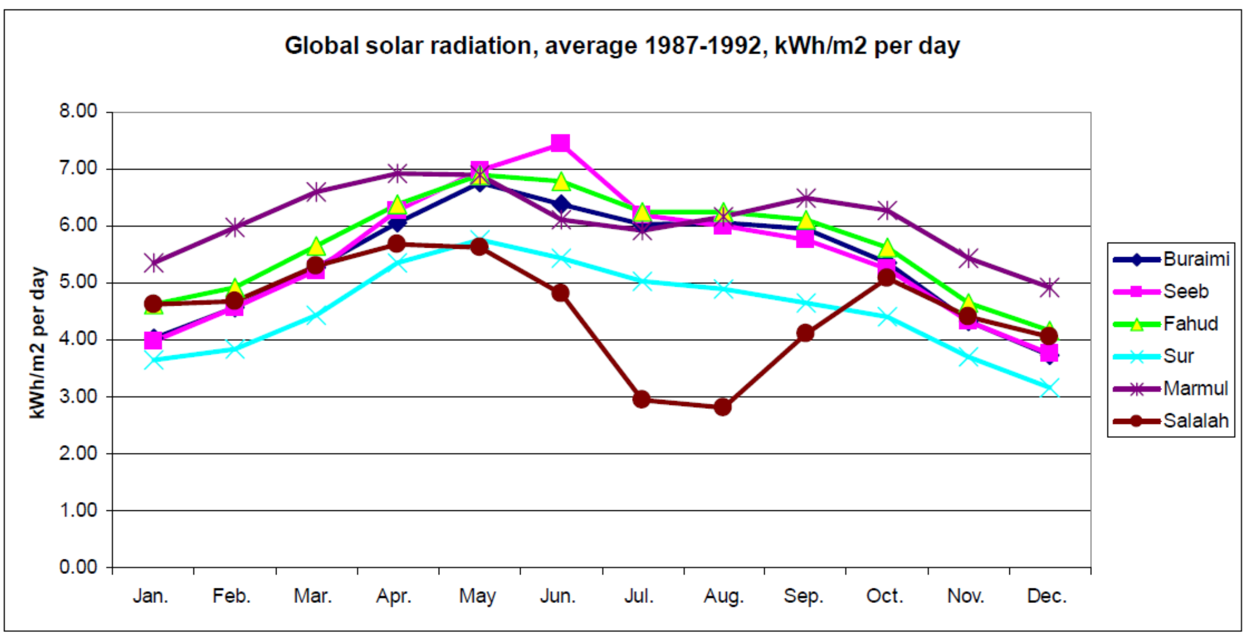

Fig. 9 Global solar insolation (on horizontal) average 1987-1992 for the 6 Stations.

The seasonal variation on a sloped surface will be smaller than on fig 9 for horizontal radiation.

4. Biogas

4.1 Waste water sludge

Oman Wastewater Services Company (OWWC) and Salalah Wastewater Services Company are currently the only commercial entities granted exclusive concession rights to build and operate waste water systems in Muscat and Salalah, respectively. The Ministry of Regional Municipalities and Water Resources operates several sewer networks and treatment plants in the rest of the country. In Muscat approximately 15% of the population is connected to the company network and the daily average waste water treatment is 43.000 m3. The waste amounts 8000 m3 which is composted for fertilising. The amount of waste water treated is rapidly increasing according to information given by the OWSC company.

Year	**2007**	**2010**	**2015**	**2020**	**2025**
Waste water m3/day	43,544	72,757	151.128	197,560	218,840
Sludge 20% TS kg/day	54,430	90,946	188,910	246,950	272,550

Table 2 Amount of waste water

The amount of organic matter is about 50-70% of total solids (TS). Thus the organic matter collected in the sludge is presently 5-7 ton/day which will increase 5 fold before year 2025. 7 ton organic matter per day corresponds to about 2500 tons per year from which it is theoretically possible to produce about 1 mill Nm3 CH4 (methane) per year, equivalent to 11,000 MWh.

4.2 Solid waste (dung)

An overview of the type and number of farm animals is presented in Table 3.

Types of Animal	**Cows 250 kg**	**Camels 250 kg**	**Sheep 30 kg**	**Goats 25 kg**
Estimated Population No.	301,600	117,300	351,000	1,55,700
Manure Total solids (TS) tonnes/year per animal	1.98	1.5	0.18	0.15
Total TS tonnes/year	597,168	175,950	63,180	233,355
VS (Volatile Solids = organic matters) tonnes/year at VS/TS = 0.75	447,876	131,962	47,385	175,016
Percent of Total	56	16	6	22

Table 3 Overview of Total Resource by 2005 (Source: Ministry of Agriculture Year Book 2006)

4.3 Biogas energy resources

The theoretic potential biogas production at 100% conversion rate can be estimated as follows:

Cows, cattle, sheep and goats 9%TS: 0.21 Nm3 CH4 per kg VS
Waste water sludge 0.25% / 20% TS: 0.4 Nm3 CH4 per kg VS
Sorted organic household waste: 0.35 Nm3 CH4 per kg VS
Vegetable, fruit and grass waste: 0.5 Nm3 CH4 per kg VS
Cereals: 0.22 Nm3 CH4 per kg VS
Vegetable oil e.g. from palm or animal fats: 1.44 Nm3 CH4 per kg VS

It is seen that it is very valuable for the gas production to add a certain amount of fatty wastes. The practical utilisation rate in the process can vary from 40% to 90% of the potential gas production, depending on residence time, pre-treatment, material mix, process temperature, reactor load etc. The total biogas production for the animals is about 150,000,000 Nm3 CH4 per year or 1,650,000 MWh. Poultry production is rapidly growing and poultry waste can to a certain extent be added to biogas plants. Biogas plants on poultry waste alone is however not possible due to ammonia inhibition of the process. Waste from vegetables, fruits and field crops from sorted household waste and waste from abattoirs and fish industry can with advantage be added to biogas plants. The amount of added material to the process should not be more than 25% of the base material (i.e. manure or sludge) in order to avoid process inhibition. There is not sufficient data available to estimate the amounts available but it is considered plenty to fulfil the 25% limit. The practical utilisation of biogas is limited by several factors, such as collection of material to the plant, organisation of the plant if dependent on individual farmers, possible use of the biogas produced both for heat and power. Biogas plants can be located at wastewater treatment plants at food industries and at big farms. As a rule of thump there should be at least 100-200 milk cows or camels on stable before a biogas plant is worth considering. Major farms are mostly located in Batinah region. There are to the less extent in Dhofar. It is estimated that there are about 50 farms with more than 500 animals of different species. The largest farms have about 4000 cattle. The rest of the animals are spread amongst minor farmers and shepherds which makes the resource practically unreachable. If we estimate that there is 50 farms with 500 animals corresponding to an equivalent of 300 milk cows / camel, then the yearly production of biogas can be estimated to approximately 4,200,000 Nm3 CH4 per year or approximately 46,000 MWh. The potential biogas production can be increased by say 50% by adding other material as described above, but the total practical reachable resource is still very small in the total energy balance of Oman. It will probably be realistic that no more than 5 big farms, 2 sewerage treatment plants and 3 industries establish a biogas plant over the next 15-20 years.

5. Wave energy

Measurements of wave data along the Oman coast have not been performed and data on wave height, wave length and wave period from Oman was not available for this study. Instead information on wave energy along the Omani coast has been obtained from the European Directory of Renewable Energy, 1991.

5.1 Wave energy resources

An estimation of the wave energy in the world oceans indicate that the wave energy flux in the world oceans varies from approximately 10 kW per m wave length and up to approximately 100 kW/m [13]. A map showing the wave resources are presented in Fig. 10. The wave energy potential in the Arabian Sea is among the lowest in the world. The wave energy flux in the open sea is in the order of 17 kW per m wave length, corresponding to 150,000 kWh/m/year- Along the coast to the Arabian Sea the wave energy flux is lower than at the open sea. Compared to the world wide wave energy resources the wave energy resources at the coast of Oman are relatively small and it is assumed that wave energy can not contribute significantly to the energy generation in Oman.

Figure 10 Wave energy potential worldwide (source: European Directory of Renewable Energy, 1991)

6. Geothermal energy

People in at least 64 countries around the world are enjoying the use of geothermal resources in variable forms. The scale of use is, however, very variable. The country with the most extensive use of geothermal energy is Iceland which obtains 50% of the total primary energy use from geothermal, the remainder comes from hydropower 18%, oil 30% and coal 2%. About 68% of the primary energy of Iceland are thus produced by renewable energy sources. The average figure for the countries of the European Union (EU) is slightly over 5%. The only EU countries with over 8% of their gross inland consumption coming from renewables are Austria and Sweden with about 22% as well as Portugal and Finland with about 19% [14]. The study report compiled by Authority for Electricity Regulation, Oman in 2008 indicates the temperature of boreholes of 500 m and 1500 m depths at different locations. . The number of the boreholes having a temperature above 100 C is 55. The highest observed temperatures are located in the northern part of Oman in the Omani mountains. The highest observed borehole temperature is 174 C. This temperature is below the temperature required for directly use of the hot water for steam power plants.

7. Conclusion

There is an great opportunity for Oman to utilize renewable energy for commercial advantage, as solar and wind energy technologies in particular can achieve more competitive costs. The effective use of these technologies would require the development of a suitable skills base and provide the opportunity to develop a local level of manufacturing, each involving an increase in the level of skilled employment. It would contribute to the extension and diversification of both the economy and energy sources. It would be in line with the objectives of Oman Vision 2020. It would also help Oman establish a world position in this energy sector by providing a professional demonstration and monitoring capability for technology providers, as well as helping to carry forward the development of relevant technologies.

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