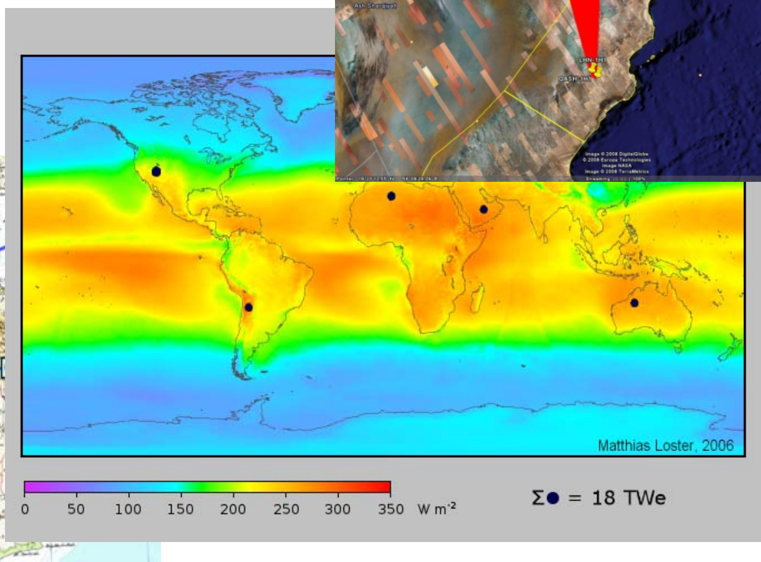
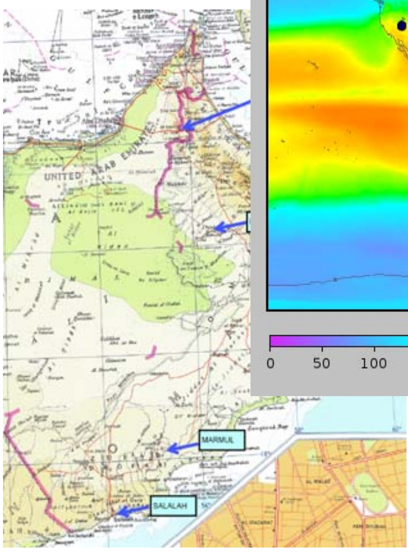
Authority for Electricity Regulation, Oman

Study on Renewable Energy Resources, Oman

Final Report

May 2008





Authority for Electricity Regulation, Oman

Study on Renewable Energy Resources, Oman

Final Report

May 2008

COWI and Partners LLC

P.O.Box 2115
RUWI Postal Code 112
Sultanate of Oman

Tel +968 2460 4200
Fax +968 2460 4788

Report no.	66847-1-1
Issue no.	Rev. 0
Date of issue	12.05.2008
Prepared	SEM/NBP/KF/SAJ
Checked	JHA/DEM
Approved	SAJ

Table of Contents

Appendix 1 Summary of meetings

Appendix 2 Site visits

Appendix 3 Analysis of wind data

Appendix 4 Analysis of solar data

Appendix 5 Geothermal data

Appendix 6 Solar technology

Appendix 7 Calculation of wind farm output

Appendix 8 Details on electricity cost calculations

Appendix 9 List of R&D projects in Oman related to renewable energy

Appendix 10 Average production costs RAECO diesel generator stations

Appendix 11 Examples of tax credit schemes

Appendix 12 Details on 20 kW grid connected solar PV pilot project

Appendix 13 Details on 10 kW PV/10kW diesel stand alone pilot project

1 Introduction

1.1 Background to the Study

The Authority for Electricity Regulation, Oman (the Authority), is responsible for regulating the electricity and related water sector in Oman. The Authority has a range of statutory duties including:

- a duty to secure the provision of electricity in all parts of the Sultanate of Oman (Article (22) para (1)[1]; and

- a duty to secure and develop the safe, effective and economic operation of the electricity sector, (Article (22) para (3)) and a duty to afford due consideration to the protection of the environment (Article (22) para (11))

The Authority commissioned COWI/SCO (the Consultant) to identify sources of renewable energy in Oman and undertake initial technical and economic assessments of the potential use of renewable sources of energy for electricity production. The scope of work required the Consultant to prepare renewable energy technology profiles that would include, but not be limited to:

- Assessments of available renewable resources;
- Technology descriptions;
- Potential electricity production (including efficiencies, capacity factor);
- Cost of energy (including equipment, installation, operating and maintenance and capital costs);
- Life-cycle economics;
- Advantages and disadvantages of technology
- Non-energy benefits of technology in particular the potential reduction in greenhouse gas emissions;
- Technical, economic, and market potential (next 3, 5, 10, and 20 years)
- Market drivers;
- Barriers to renewable energy (regulatory, market, information, infrastructure, technology, financial, economic); and
- Recommendations to address barriers.

The Consultant was also asked to review mechanisms used by governments in other jurisdictions to provide financial support for renewable energy and advise the Authority on possible support mechanisms suitable for Oman.

[1] references are to Articles in law promulgated by Royal Decree 78/2004

1.2 Study Methodology

The study was conducted in three phases. Each phase included the tasks described below.

Phase 1:	Inception and initiation collection of data and information
Task 1	Mobilisation and planning data/information collection
Task 2	Data collection and visits to sites and authorities
Phase 2:	Analysis of data and review of previous RE studies in Oman
Task 3	Technology analysis
Task 4	Economic analysis
Task 5	Technology evaluation
Task 6	Market analysis
Task 7	Barriers
Phase 3:	Final analysis and reporting
Task 8	Outline cost effective options for use of renewable energy
Task 9	Appraisal of the possible financial mechanisms that could be introduced to encourage use of renewable energy
Task 10	Final reporting

1.3 Collection of data and information

The study utilises information and data provided by various Ministries, companies within the electricity sector, waste water companies, Sultan Qaboos University and the Research Council, meteorological department, Petroleum Development Oman and the Royal Oman Police. Meetings with these authorities were based on questionnaires prepared prior to the meetings. Almost all the requested data and information was received except for data on wave energy which we understand is not available. To overcome this, the Consultants undertook preliminarily analysis using research data derived from the literature. We recommend steps are taken to fill this information gap by collecting wave energy data to assist further studies and research.

During the data collection process the Consultant team was afforded the full cooperation and support of the entities we visited, all of whom expressed strong support for the utilisation of renewable energy in Oman.

1.4 Report Structure

The report is presented in three parts.

- An Executive Summary presents the key results of the study including our assessment of renewable energy potential in Oman and our principal recommendations;
- The Study analysis starting from Section 3; and
- Appendices to the report that provide background information, detailed data, analysis and other documentation.

1.5 Acknowledgements

The Consultants would like to express their gratitude to all the officials and individuals who they met during the course of the study, for the kindness, support and valuable information given to the team during its stay in Oman and which has greatly assisted our work.

1.6 Abbreviations and conversion factors

List of abbreviations

AEO	Annual Energy Output
Authority	Authority for Electricity Regulation, Oman
AGL	Above ground level
Bcf	Billion Cubic Feet
BST	Bulk Supply Tariff
Btu	British Thermal Unit (1 kWh = 3,413 Btu)
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CO_2	Carbon Dioxide
CSP	Concentrating Solar Power
CCGT	Combined Cycle Gas Turbine
DPC	Dhofar Power Company
DGCAM	Directorate General of Civil Aviation & Meteorology
EU	European Union
E&P	Exploration and Production
EOR	Enhanced Oil Recovery
FIT	Feed in tariff
ETS	Emission Trade Scheme
FTZ	Free Trade Zone
GJ	Giga Joules
GT	Gas Turbine
GDP	Gross Domestic Product
GHG	Green House Gas
GWh	Giga Watt hours
HFO	Heavy Fuel Oil
IEA	International Energy Agency
IPP	Independent Power Producer
IRR	Internal Rate of Return
kV	kilo Volt
kW_p	Kilowatt-Peak
kWh	kilo Watt hours
LCV	Low Caloric Value
LNG	Liquid Natural Gas
LRMC	Long run marginal cost
MAR	Maximum Allowed Revenue
MIS	Main Interconnected System
MWh	Mega Watt hours
NPV	Net Present Value
OGJ	Oil & Gas Journal
ORC	Oman Refinery Company
O&M	Operation and Maintenance
OECD	Organisation for Economic Co-Operation and Development
OETC	Oman Electricity Transmission Company
OPEC	Organisation of the Petroleum Exporting Countries
OPWP	Oman Power and Water Procurement
OWWC	Oman Wastewater Services Company
PV	Photovoltaic

PDO	Petroleum Development Oman
PPP	Purchasing Power Parity
RO	Rial Omani = 2.6 USD
RES	Renewable Energy Systems
RET	Renewable Energy Technology
ROP	Royal Oman Police
RAECO	Rural Areas Electricity Company
ST	Steam Turbine
SEI	Socio-Economic Impact
SPA	Sales and Purchase Agreement
TS	Total Solids
Tcf	Trillion Cubic Feet
TGC	Tradable Green Certificate
USD	US Dollar
VS	Volatile Solids
VAT	Value Added Tax
W	Watt
WTO	World Trade Organisation
WTP	Willingness to Pay

Conversion factors

1 barrel	158.9 litre
1 barrel crude oil	Equivalent to 1325 MWh
1 barrel crude oil	equivalent to 4770 MJ
1 kWh	1055 MJ
1 l crude oil	equivalent to 30 MJ
1 cubic feet	0.0283168466 m3
1 m3 gas	equivalent to 10.8 kWh

2 Executive Summary

2.1 Purpose of the Study

The Authority commissioned this study to provide an overview of renewable sources of energy in Oman, and the potential use of such resources for electricity production. The government of Oman is formulating policies to promote the application of renewable energy technologies. The Authority hopes the results of this study will assist the process of developing renewable energy policies for Oman.

In terms of scope:

- the study covers solar energy, wind energy, biogas, wave energy and geothermal energy;
- the study compares estimates of the cost of electricity produced from renewable energy and the present cost of fossil fuel (primarily natural gas) based electricity generated in Oman;
- the study presents an assessment of available renewable energy technologies and the Consultant's view of their technical suitability for use in Oman considering the available renewable energy resources, environmental conditions, and cost; and
- the study considers mechanisms used to provide financial incentives for promoting renewable energy projects, and identifies mechanisms which could be applied in Oman.

The technological development of renewable energy technologies is an ongoing process and technologies which are not economically viable today may very soon become relevant for Oman due to the present rapid technological development of renewable energy technologies. The study identifies Concentration Solar Power systems as a technology that may be relevant for future large scale implementation in Oman.

2.2 Conclusions

2.2.1 Renewable energy resources in Oman

The study finds significant potential sources of renewable energy in the Sultanate of Oman. The findings for each type of renewable energy are as follows:

Solar Energy: The level of solar **energy density in Oman is among the highest in the world**. There is significant scope for developing solar energy resources throughout Oman and solar energy has the potential to provide sufficient electricity to meet all of Oman's domestic electricity requirements and provide some electricity for export. High solar energy density is available in all regions of Oman: areas of highest density are dessert areas. Areas of lowest density are coastal areas in the southern part of Oman;

Wind Energy: The study has **identified significant wind energy potential in coastal areas in the southern part of Oman and in the mountains north of Salalah**. Wind speeds in these areas are comparable to recorded wind speeds at inland sites in Europe where large numbers of wind turbines are installed and operational. Wind speeds are observed to be highest in summer months which coincide with peak periods of electricity demand in Oman;

Biogas: Material from waste water and agricultural waste is available in northern parts of Oman. In the south, biogas material is available from waste water, agricultural waste and animal dung. However, a large amount of waste material is presently used as fertiliser. Animal waste is spread over large areas making collection of sufficient quantities of animal waste difficult and expensive. For these reasons **the study finds only limited potential for biogas electricity production;**

Geothermal Energy: The study reviewed borehole temperature data and found temperatures to be below that required to allow the direct use of water for steam plants. On the basis of the data reviewed, **the study finds the potential for utilising geothermal energy for electricity production to be limited;**

Wave Energy: Is available along the Arabian Sea coast but the energy density is relatively low compared to other locations world wide. **The potential use of wave energy is considered marginal compared to solar and wind energy resources.**

2.2.2 Renewable energy technologies relevant for Oman

Solar energy, photovoltaic (PV) systems

Two main types of solar cells are used to make solar modules. The first generation are silicon wafer-based with silicone cells which has been dominating the market. The price of this type of cell has reduced considerably over the years. The advantages of the crystalline solar cells are that they are efficient, reliable with long lifetime and a long record of proven durability. Therefore, they are often the preferred solution for solar based electricity production on buildings.

Thin film solar panels are less efficient and have a shorter lifetime. Thin film is increasingly used in small applications. It is generally expected that in the long term thin film technology with multi layer cells will be widely used and attain efficiencies beyond 25%. The major advantage of thin film is that they use less material and are therefore potentially less expensive than conventional PV technology.

The solar photovoltaic (PV) technology is a well proven technology for producing electricity. PV systems are either grid connected (with electricity fed directly into the grid system) or PV systems used in off-grid applications in small power systems in combination with diesel power gen-sets. Both types of solar PV system are relevant for Oman.

The solar PV technology is suitable for use in northern parts of Oman for producing electricity for the Main Interconnected System. The solar PV technology is also suitable for electricity generation in off-grid power plants in rural desert areas where the solar energy can reduce diesel fuel use. Solar energy resources are highest in northern parts of Oman and in desert areas.

The efficiency of PV cells is influenced by high air temperature and dust contamination. We estimate the environmental conditions in Oman would reduce the efficiency of PV cells by approximately 10 % compared to standard conditions (this does not affect our recommendations for the use of this technology in Oman).

Solar energy, solar thermal plants

Solar energy can also be used to sustain solar thermal plants in what are referred to as, Concentration Solar Power (CSP) systems. In CSP systems the solar insolation is concentrated and used to produce steam which is converted into electricity as in conventional power plant. CSP systems store heat recovered during the day for use at night thereby enabling continuous electricity production. CSP technology is expected to be fully developed within the next decade and may provide capacity ranging from a few MW up to several hundred MW. We believe CSP is very well suited to conditions in Oman.

Wind energy, grid connected wind turbines

Modern grid connected wind turbine technology has been developed over the last twenty years. The typical capacity of a modern grid connected wind turbine is in the range of one to five MW. Wind turbine designs can accommodate high wind or low wind conditions.

Wind turbines designed for low wind conditions are characterised by a large swept rotor area in relation to the capacity, and an increased hub height. Low wind turbines are suitable for wind conditions in Oman.

Modern wind turbines are equipped with cooling systems enabling operation under extreme environmental conditions such as the high air temperatures which occur in Oman.

Utilisation of the wind energy resources in the southern part of Oman should be further investigated. We recommend a detailed wind resource survey and further analysis of the potential connection of wind turbines to the Salalah Power System.

Other renewable energy technologies

The study finds only limited potential for producing electricity using other renewable energy resources such as geothermal energy, wave energy and biomass. Consequently, we are not recommending the implementation of large scale electricity production based on these energy resources at this time.

2.2.3 Technical potential of renewable energy

Solar energy, photovoltaic systems

The theoretical potential for electricity production in Oman using solar energy is significant.

The technical potential for electricity generation by grid connected PV systems is determined by the area available for installation of PV cells (e.g. on buildings, parking areas etc). Assuming that 50% of the houses in Oman are suitable for installation of PV cells and the area available at each house is 20 m^2 the total potential area would provide space for an installed capacity in the order of 420 MW, and a potential annual electricity production of 750 GWh/year which corresponds to 5 % - 6 % of the present annual electricity demand (13,900 GWh in 2007). PV systems can also be located in the desert. Typical capacity per m^2 of land is about 30 Wp (Watt peak) corresponding to 30 MWp per km^2.

The technical potential for electricity generation by PV systems operating with diesel gen-sets and battery storage capacity in isolated off-grid power systems is assumed to be 20% of the present electricity generation. This corresponds to 70 GWh/year and a solar PV capacity of 40 MW. By using a fraction of 20% a major part of the generated electricity can be used directly and only a minor part has to be stored.

The potential for utilising PV cells as power supply for small equipment and lighting is large. Presently the oil industry has PV cell capacity available for operation of small equipment in remote areas. Due to the small capacity of this type of power supply the contribution to the total electricity generation by solar power is relatively small, but should not be overlooked.

The potential for producing electricity using PV systems is highest during the summer which coincides with the period of peak electricity demand in Oman.

Solar energy, solar thermal plants

From a long term perspective the theoretical potential for producing electricity using Concentrating Solar Power (CSP) systems in Oman is significant. CSP plants with storage for continuous supply of electricity as conventional power plants require 1 km^2 of land use for 10 MW capacity. Theoretically it would be possible to supply all of Oman's present electricity consumption of 13,900 GWh by utilising about 280 km^2 of desert area for solar collectors, corresponding to around 0.1 % of the Sultanate's land area.

Wind energy, grid connected wind turbines

The use of wind turbine capacity in a grid system is generally limited by technical considerations. If wind turbines account for a high percentage of total generating capacity, fluctuations in the energy output of wind turbines may adversely affect power quality in terms of frequency and voltage fluctuations, unless special measures are implemented to regulate wind turbine output.

The present technical potential for grid connected wind turbines in Oman is approximately up to 50 MW, corresponding to 20 % of the present installed capacity of the Salalah Power System (251 MW). In 2014 commissioning of the new Salalah IWPP will increase the amount of generating capacity connected to the Salalah Power System to 580 MW and the potential wind turbine capacity will increase to around 120 MW. The interconnection of the Main Interconnected System and the Salalah Power System would further increase the potential for wind turbine capacity to at least 750 MW. This corresponds to an estimated net annual energy output of at least 2300 GWh/year.

The potential for grid connected wind turbines would be even higher if the interconnected system had the capacity to transmit electricity to all load centres in Oman from the southern part of the country where wind energy resources appear to be abundant.

Wind energy resources are highest during the summer period which coincides with the period of peak electricity demand.

Wind energy, off-grid wind turbines

The study finds the potential for off grid wind turbine applications to be limited. These types of applications may be relevant for electricity supply to consumers in rural areas where wind speeds are high e.g. along the coast in the southern part of Oman and where no grid connection is possible.

2.2.4 Electricity production costs

In this section we present an analysis of production costs of natural gas fired plant, diesel plant and new coal fired power stations. We also present estimates of the electricity production costs of renewable energy technologies proposed for Oman.

Table 2.1 Production Costs of Conventional Fossil Fuel Plants

Natural Gas Fired Production Costs: (average costs including capital, operating and fuel costs):		
	USD/MWh	**RO/MWh**
existing MIS connected gas fired production facilities (average 2006 costs)	31	11.9
new Combined Cycle Gas Turbines	18	7.1
new Open Cycle Gas Turbines	24	9.1

These costs are long run marginal costs based on a gas price of 1.5 USD /MMBtu.

Diesel Fired Production Costs: (average costs including capital, operating and fuel costs):		
	USD/MWh	**RO/MWh**
existing RAEC facilities (average 2006 costs)	210	80.8
new Diesel plant	161	61.9

These production costs are based on a fuel price of 146 Baiza per Litre diesel fuel.

New Coal Fired Production Costs: (average costs including capital, operating and fuel costs):		
	USD/MWh	**RO/MWh**
production cost based on 62 USD/tonne	41	15.8
production cost based on 100 USD/tonne	53	20.5
production cost based on 150 USD/tonne	69	26.7

Coal prices have risen sharply in recent months due to problems in major supply markets and increasing demand. As a sensitivity we present the total production cost of a coal facility assuming coal costs of 62 US$/tonne, 100 US$/tonne, and 150 US$/tonne.

The production costs today of electricity generated by renewable energy technologies using renewable energy resources in Oman are shown in Table 2.2.

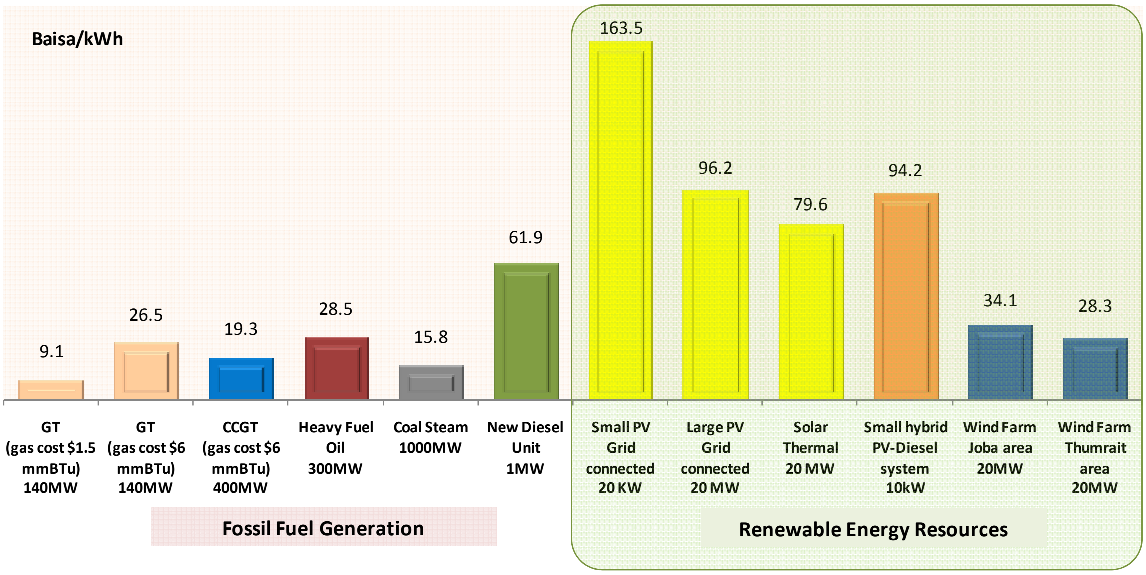
Table 2.2 Production Costs of Renewable Energy Technologies

Renewable Energy Production Costs: (average costs including capital and operating costs):		
	USD/MWh	RO/MWh
solar PV, small grid connected	425	163.5
PV/diesel hybrid system, 10% solar energy	245	94.2
solar PV, large grid connected	250	96.2
solar thermal plant	207	79.6
grid connected wind farm (Thumrait)	74	28.3

Comparison of fossil fuel and renewable energy production costs

Figure 2.1 compares the production cost of electricity produced using conventional fossil fuel technology and renewable energy resources.

Fig. 2.1 Long Run Production Costs: Fossil Fuel & Renewable resources [1].



[1] **Assumptions:**

1) Fuel costs: Natural gas low gas price 1.5 USD/MMBtu, high gas price 6 USD/MMBtu
Diesel Oil 0.38 USD/Litre Coal 62.45 USD/ton, HFO 50 USD/barrel

2) Station life (in cost calculations): Gas (GT & CCGT) 25 years, HFO, Coal & new Diesel 30 years, PV 25 yrs Wind >20 years

3) Operating hours: GT, CCGT, HFO & Coal 7500 hours, New Diesel 5000

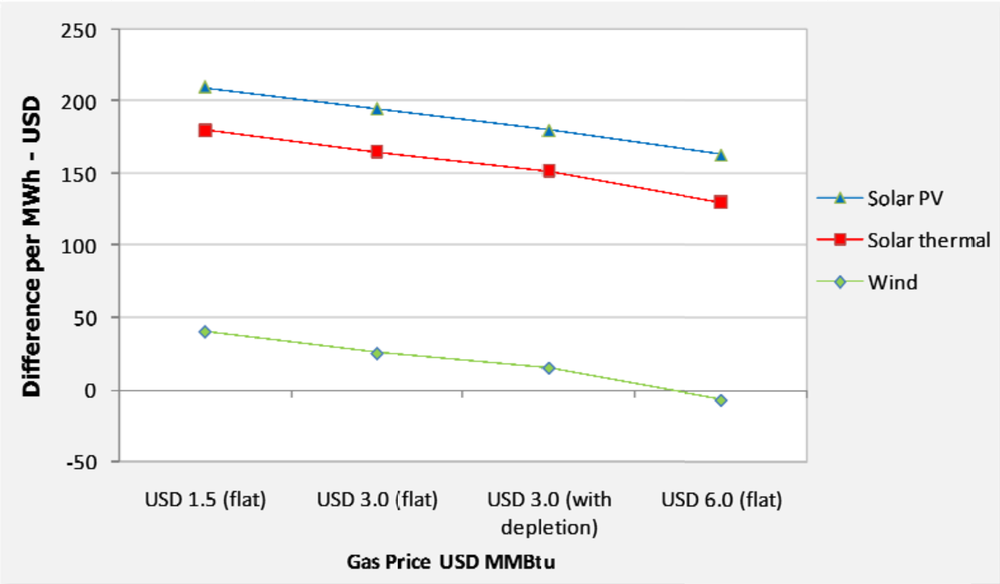
4) Discount rate: 7.55%

Our analysis indicates that the cost of electricity generation using fossil fuel technology, at present fuel prices, is lower than the cost of electricity produced using renewable energy technologies. There are however several factors that might reduce the observed differences in fossil fuel and renewable energy costs:

- increases in the cost of fossil fuels;
- reductions in the capital cost of renewable technologies resulting from more widespread application (economics of sale) and advances in technical progress (noting that technical progress might also reduce the cost of fossil fuel technology); and
- adjusting the cost of fossil fuel generation to reflect the 'environmental damage' of emissions (these costs could be directly ascribed as a benefit to renewable energy technologies).

Fig 2.2 presents differentials in the cost natural gas and renewable (wind, solar thermal and solar PV) based electricity production at a range of gas prices.

Fig. 2.2 Differences in gas costs and solar & wind energy production costs

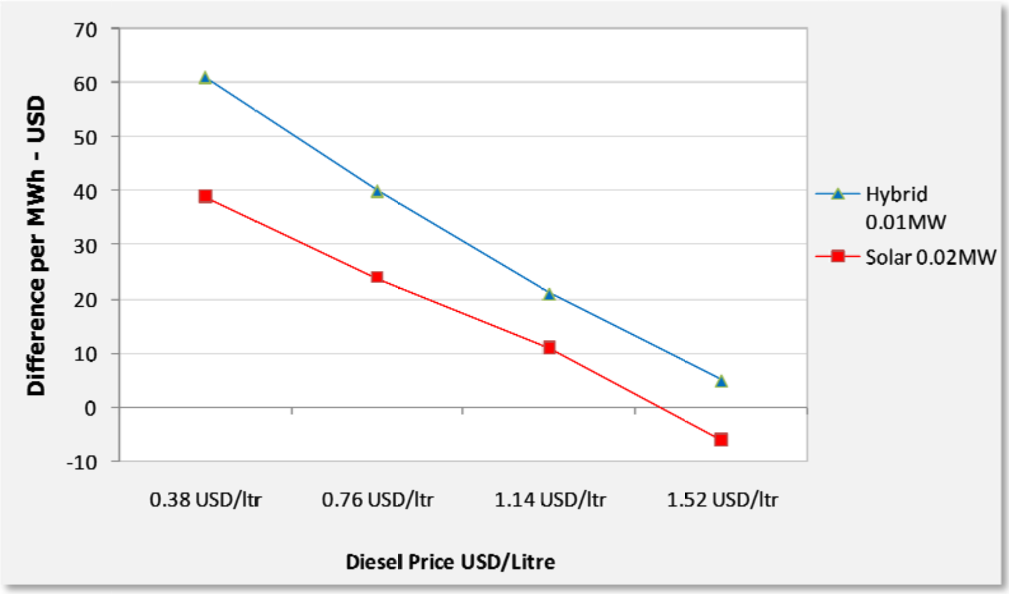


At the present gas price in Oman of 1.5 USD/MMBtu electricity produced using renewable resources is considerably more costly than gas based electricity, Solar PV and Solar Thermal is significantly more costly.

At a gas price of 6 USD/MMBtu the cost of electricity from wind turbines is marginally lower than that of electricity generated using natural gas. If we assume the opportunity cost of natural gas is 3.0 USD/MMBtu and add a depletion premium of 3% p.a., the cost of electricity produced by wind turbines and gas plant is broadly similar.

The cost of electricity produced using solar energy resources is significantly higher than gas based electricity at all gas prices.

Fig. 2.3 Difference in production costs between diesel power plant and solar PV and hybrid plants



At the present diesel price in Oman of 0.38 USD/Litre the production costs of Solar PV and hybrid (PV and diesel) systems are considerably higher than diesel based generation. At a diesel price of around 1.30 USD/Litre, the cost of Solar PV systems and new diesel generation is broadly equivalent.

The cost of diesel fuel would have to rise to around 1.55 USD/Litre, to equate the production costs of a hybrid system and diesel generation.

2.2.5 Non energy benefits

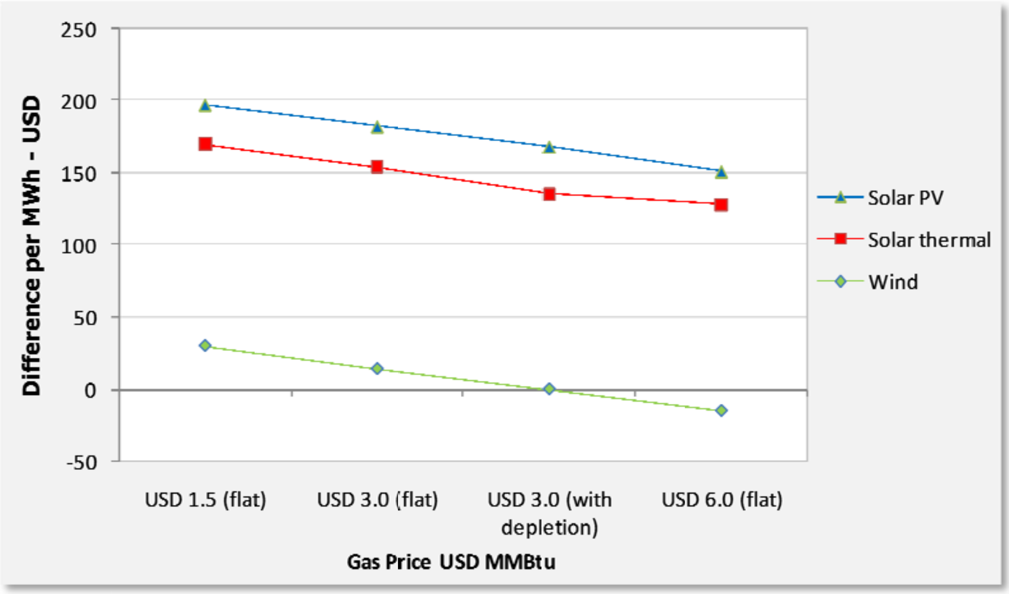
Renewable energy used to produce electricity emits zero Green House Gas (GHG). Using renewable energy technologies in place of conventional fossil fuel plant would therefore reduce Green House Gas emissions in the Sultanate, including CO_2.

The reduction in GHG emissions (carbon) would be approximately 175 kg/MWh where renewable energy replaces natural gas and 212 kg/MWh when diesel fuel is replaced.

Total savings in GHG emissions will depend on the contribution of renewable energy technologies to total electricity supply.

The carbon damage cost in Oman is not known. Based on the average damage cost in some industrialised countries of around 20 USD/ton CO_2, the following diagram illustrates the effect on renewable energy costs taking the cost of environmental damage into consideration.

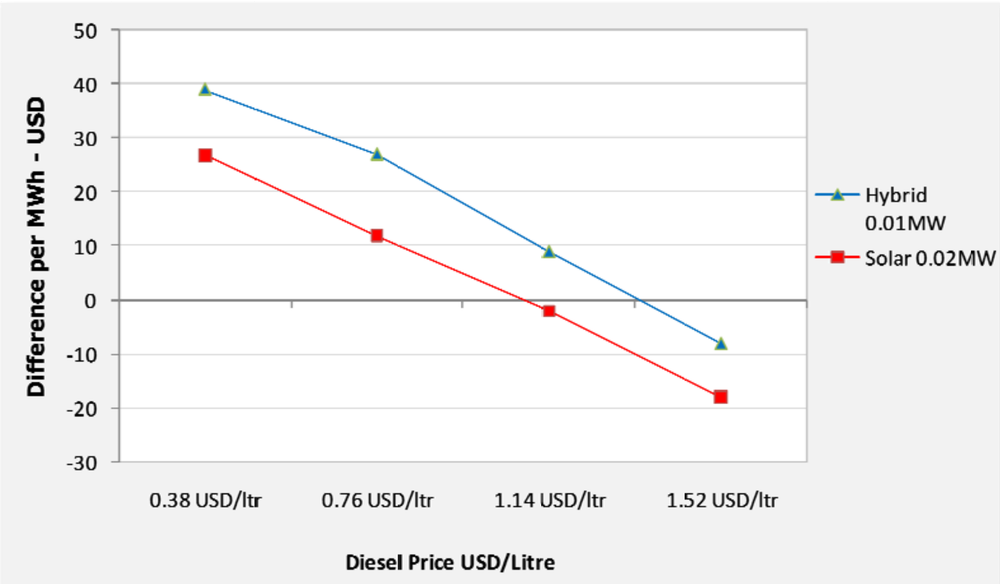
Fig. 2.4 Differences in gas costs and solar and wind energy production costs taking carbon damage into consideration



As can be seen wind energy becomes viable at a natural gas price of app. 3.0 USD mMBtu including depletion when the cost of environmental impacts (only CO_2 emissions) is included in the assessment.

For renewable technologies replacing diesel the cost difference is illustrated in the figure below.

Fig. 2.5 Difference in production costs between diesel power plant and solar PV and hybrid plants taking carbon damage into consideration



Solar PV becomes cost effective for RAEC when the cost of diesel reaches 1.14 USD/Litre, and environmental costs are taken into consideration.

2.2.6 Future scenario for utilisation of renewable energy in Oman

Our analysis clearly indicates that at present the cost of fossil fuel based electricity is below that of electricity produced using renewable energy. In the long term the cost of fossil fuel based electricity generation may increase and the production costs of renewable energy technologies decrease due to increased efficiency and construction optimisation. The development costs of renewable energy technologies cannot be foreseen in detail and it is not therefore possible to make a precise plan for the economically optimum transition from fossil fuel based electricity generation to production using renewable energy resources.

An approach to this challenge might be to integrate wind energy and solar PV into the power system gradually and thereby build up a local capacity to deal with renewable energy. Other advantages of this approach would be that although solar PV and wind energy would not fully replace conventional capacity they would a capacity value to the system and may be constructed in shorter timescales than conventional plants. These are important advantages in the context of Oman's requirement for new generating capacity, something in the region of 2,758 MW within the next seven years.

If one were to construct a long term (20 – 30 year) scenario for Oman, one could envisage a power system with CSP plants (with heat storage for night production) supplemented by grid connected wind turbines and PV. From a resource point of view this could be provided using a few hundred km2 of desert and may provided sufficient electricity production to meet conventional demands and electricity for electric cars.

This would be a zero carbon electricity supply, and some scientists indicate that this could also be the cheapest option from a traditional cost calculation point of view at that time.

The important issue is finding an appropriate starting point and development scenario for the use of renewable energy in Oman that may lead to the zero carbon scenario described above.

The forecast of electricity generation capacity is 5691 MW in 2014. A scenario where 5% of the capacity (285 MW) is covered by renewable energy could e.g. consist of a combination of 125 MW wind turbine capacity, 100 MW solar thermal power capacity and the remaining capacity of 50 MW large and 10 MW small solar PV. The investment costs for this scenario would be in the order of 900 Mill USD based on the present market price of renewable energy technologies and corresponds to 3 USD/MW. In comparison the specific investment costs for a gas turbine plant is 0.3 USD/MW and for a coal steam plant 1.6 USD/MW.

2.3 Recommendations

2.3.1 Renewable energy activities

The analysis and research undertaken in the course of the study provides support for various recommendations that we outline in this section. We recommend the immediate implementation of certain types of renewable pilot projects, the development of policies to support and encourage renewable energy, and that the Authority and other entities undertake further research and maintain a watching brief on developing renewable technologies. Our recommendations are presented in three categories in the expected sequence of implementation:

1 Recommendations: Small Projects & Further Feasibility Studies

Our analysis supports the immediate implementation of small scale renewable energy projects, particularly in rural areas (we provide details of recommended projects below). These initial renewable energy projects would help demonstrate the technical and economic performance of renewable energy technologies under local conditions, and would, if implemented appropriately, facilitate the transfer of knowledge and know how to relevant institutions and entities in Oman.

Projects A and B below are the type of renewable energy projects we believe the Authority could approve for immediate implementation by the Rural Areas Electricity Company SAOC.

Project A: 10 kW off-grid Solar PV/Diesel Hybrid System

Purposes:	To demonstrate the technology and compare the performance of hybrid systems with combinations of solar and diesel capacity. Obtain experience of the design to support the subsequent implementation of large PV projects under Omani conditions.
Technology:	(i) One plant comprising 10 kWp PV/10 kW diesel engine and battery storage, (ii) One plant comprising 5 kWp PV /10 kW diesel engine and without battery storage.
Location:	Rural area, off grid location.
Annual energy output:	7 - 8 MWh/year (solar PV cells)
Budget:	USD 135,000 (tentative)
Energy production cost:	250 - 300 USD/MWh.

Project B: 20 kW Grid Connected Solar PV

Purposes:	To demonstrate the technology and obtain experiences with the operation under Omani conditions. The results of this project could be used as a basis for the design of larger PV projects. We recommend undertaking a number of small scale projects for different types of applications: on buildings, parking areas etc.
Technology:	20 kW system consisting of 20 kWp solar PV panels (app. 200 m^2) and a 20 kW power converter.
Location:	Rural area, connected to local grid/power system.
Annual energy output :	34 MWh/year
Budget:	USD 150,000 (tentative)
Energy production cost:	425 USD/MWh

Before implementing these types of projects, we recommend further detailed technical and economic analysis is undertaken to verify assumptions in this report and confirm the suitability of individual project locations.

We also recommend the implementation of a wind monitoring programme in south Oman along the coast and in the mountains north of Salalah to verify and map wind energy resources. This programme should also include detailed grid analysis to determine the amount of wind turbine capacity that could be connected to the Salalah Power System (noting that for technical reasons wind turbine capacity should normally not exceed 15% to 20% of total system capacity). We expect the wind monitoring programme to support the early implementation of a wind turbine project such as Project C.

Project C: 10 MW Grid Connected Wind Farm

Purposes:	Demonstrate the technology and obtain experience of operating the technology under Omani conditions.
Technology:	10 MW Wind farm consisting of 5 x 2 MW wind turbines.
Location:	Dhofar, Thumrait/Quiroon Hariti area.
Annual energy output:	25-30 GWh/year.
Budget:	USD 20 - 22 mill. (tentative)
Energy production cost:	65 USD/MWh.

This project is potentially very significant, as it could provide the basis for a larger scale wind farm of between 500 to 750 MW (assuming interconnection of the Main Interconnected System and the Salalah Power System).

Other Recommendations for immediate implementation

We offer two further recommendations:

1. Interest in CSP technology has increased considerably in recent years and we expect there to be significant growth in the utilisation of this technology in areas with high solar energy potential. In order to evaluate the present potential for this technology in Oman we recommend an immediate feasibility study to clarify the present and future technical and economic viability of CSP technology in local conditions. The study should make specific recommendations with regard to timing and location for the introduction of CSP technology in Oman; and

2. We see significant scope for introducing solar thermal collectors in public buildings to produce hot tap water. This measure could be implemented easily and quickly and consideration should be given to stipulating this as a mandatory requirement in all new buildings that have characteristics to support the technology.

2 Recommendations: Policies to support Large Scale Projects

The study has identified significant potential sources of renewable energy in the Sultanate of Oman. However, if solar and wind energy resources are to be utilised on a large scale, as we believe they could, new policies and funding mechanisms will be needed to support and encourage renewable energy investment.

Policy Development Recommendations – Financial issues

Table 2.3 summarises policy instruments used in other jurisdictions to facilitate renewable energy projects, and indicates in the final column the suitability of each policy instrument for Oman.

Table 2.3 Policy Instruments to Promote Renewable Energy

Instrument	PROs	CONs	Suitable for Oman?
Environmental Taxes	Creates even playing field for renewable energy	Difficult to estimate objectively the optimum level of tax.	Tax would increase supply costs and subsidy but not induce change in consumer consumption. **Limited Applicability**
Tax Credits	Creates incentives for investors	May distort market prices	**Applicable**
Green Marketing	Based on willingness to pay (WTP) and optional schemes	Difficult to control and limited information on consumer WTP	Probably very little impact in Oman. **Limited Applicability**
Investment subsidies	Increase incentives to establish and invest in renewable energy generation	May result in over-investment	May create new subsidy flow in the system to investors. **Applicable**
Feed in Tariffs	Efficient in promoting RE if monitored carefully and changed in accordance with technological developments	Investor risk if removed for political reasons	**Applicable**
Renewable Energy Quotas	Effective way to promote renewable energy projects	New tendering procedures required but simple to administer. Tends to promote established technologies	Easily accommodated in OPWP and RAEC tendering systems. **Applicable**

The implementation of **Tax Credits** and **Investment Subsidies** would be a matter for the tax authorities in Oman and the Ministry of Finance. However, we recommend the Authority in conjunction with relevant government authorities take steps to implement the following measures:

- **Renewable energy quotas**: the government might require, for example, renewable energy projects to account for X% of total system capacity by 2015. The Authority would then have to ensure that PWP and RAEC complied with the quotas in a cost effective and efficient manner having regard to security of supply considerations and other relevant licence conditions; and

- **Feed in tariffs**: for large scale projects we recommend the Authority develop feed in tariffs to support projects over several stages of development (in the expectation that tariffs in the latter stages of a project would be lower than in the initial stage due to the technology being proven, economies of scale and so on);

These measures would, we believe, help stimulate interest and investment in renewable energy projects in Oman. If these measures were implemented in conjunction with existing requirements (competition in tendering, economic purchase obligations and so on) we believe renewable energy projects could provide significant long term benefits to Oman.

Feasibility Studies for Large Scale Projects

In conjunction with the policy initiatives outlined above, we recommend further feasibility studies for the large scale utilisation of solar and wind energy resources in Oman. In addition to providing further technological and economic justification for large scale projects, these studies would also inform the specification of targets for renewable energy contributions to system capacity.

Policy Development Recommendations – Legal issues

The study finds that the present market structure and statutory framework of licensing and regulation can, in several limited respects, facilitate small scale renewable energy projects. However, we believe certain changes to the regulatory framework would facilitate renewable energy investment on a wider scale. For example, we recommend that:

1. the Authority review and proposes changes to the existing market rules to **allow licensed distribution and supply companies to connect renewable energy projects to their systems and contract for the purchase of capacity and output of such systems**. This is not permitted at present (OPWP and RAEC is responsible for the procurement of all connected capacity and output). The Authority would need to ensure economic purchase and security of supply obligations continued to apply. Widespread application of 'distributed generation' is a feature of electricity markets in other jurisdictions and has been shown to have a range of benefits in addition to environments benefits; and

2. we recommend the Authority take immediate steps to specify procedures, technical regulations and standards needed to facilitate the design, planning, connection and operation of small scale and large scale renewable energy projects. This would reduce uncertainty about the scope for implementing renewable energy technologies in Oman, and stimulate interest on the part of potential investors and renewable energy technology providers.

In summary, we recommend that the Authority act to remove barriers to the utilisation of renewable energy, whether technical, economic or legal barriers, so as not to hinder policy initiatives that aim to facilitate and promote renewable energy projects.

Clean Development Mechanisms

We recommend that Oman establish a Designated National Authority (DNA) to facilitate and administer incentives for Clean Development Mechanisms (CDM).

This would allow investors promoting renewable energy projects to benefit from cost savings gained through a carbon credit trading scheme. A wind farm, for example, implemented as a CDM project that contributed to reduced carbon emissions by replacing gas consumption would be able to secure a financial benefit equal to the value of reduced carbon emissions (calculated assuming a shadow price of carbon of 25.5 USD/ton). Any such benefit would help to reduce the cost of the wind farm.

Arrangements such as these have been successfully introduced in other jurisdictions.

Table 2.4 Average cost of renewable energy and potential cost savings from Carbon Trading assuming 25.5 USD/ton CO_2

Renewable Sources of energy: average costs including capital and operating costs			**Potential cost savings per MWh supplied from Carbon Trading (25.5 USD/ton CO_2)**
	USD/MWh	RO/MWh	RO/MWh
Solar PV, small grid connected	425	163.5	5.16
Solar PV, large grid connected	250	96.2	5.16
Solar thermal plant	207	79.6	5.16
PV/diesel hybrid system, 10% solar energy	245	94.2	5.49
Grid connected wind farm	74	28.3	5.16

3 Recommendations for Further Research

We recommend that Oman undertakes further research into the development of emerging renewable energy technologies such as CSP. The Authority might consider seeking advice from international consultants from time to time on the potential utilisation of new technologies in Oman. It would be sensible also to educate local staff in installations about the operation and maintenance of renewable energy systems. We also advise support of R&D activities within the renewable energy sector and promoting the local development and manufacture of renewable energy technology.

Energy Efficiency

Renewable energy should always be seen together with efficient use of energy. Energy efficiency should be afforded a high priority. Requirements for buildings regarding insulation, improved windows, shading and recovery of cold air on ventilation systems for cooling should be strengthen and enforced.

3 Key information for Oman

3.1 Demography

3.1.1 Population

The total population of Oman is 2.6 mill including 0.7 mill non-nationals, Ref./1/. The country is divided into nine administrative districts. Table 3.1 shows the variation of the population for each district.

Table 3.1. Population in different Governorates and Regions.

Administrative District	Population	Population, %
Muscat Governorate	719,000	**28%**
Musandam Governorate	31,000	**1%**
Dhofar Governorate	241,000	**9%**
Al Buraimi Governorate	88,000	**3%**
Al Batinah Region	704,000	**27%**
Adh Dhahirah Region	142,000	**6%**
Ad Dakhliyah Region	287,000	**11%**
Ash Sharqiyah Region	338,000	**14%**
Al Wusta Region	26,000	**1%**
Total	**2,576,000**	**100%**

3.1.2 Housing

The total number of housing in Oman is in the order of 425,000, Ref /2/. This number includes apartments in building and individual houses.

3.2 Industry

Industrial development in Oman has traditionally focused on relatively small-scale manufacturing. However, with the discovery in the early 1990s of large deposits of non-associated natural gas, the focus of government efforts has shifted to attracting large investment in capital-intensive gas-based industries.

3.2.1 Industrial Estates

Manufacturing industry has generally been located on the country's industrial estates.

Established in 1983, Rusayl is Oman's flagship industrial estate. From its initial 12 factories, Rusayl is now a bustling estate with over 130 factories in operation, a further five in construction and 40 under consideration.

Factories in operation produce a wide spectrum of consumer as well as industry orientated products, ranging from:

- Chemicals
- Batteries
- Electrical
- Building materials
- Fibre optic cables
- Foodstuff
- Textiles
- Garments
- Stationery
- Paints

Other industrial estates include the Raysut Industrial Estate in Dhofar, as well as those at Sohar, Nizwa, Sur and Buraimi. There is also a free-trade zone (FTZ) in Al Mazunah, near the border with Yemen, and Oman is finally proceeding with plans to create an FTZ in Salalah. However, the Salalah Free Zone will still face stiff regional competition from well-established, successful free-trade zones such as Jebel Ali in Dubai.

Sohar Industrial Estate covers an area of 334 hectares, of which 130 hectares have been developed and subdivided into 226 plots. Established in November 1992, and ideally located mid-way between Muscat (200 kilometres) and Dubai (180 Kilometres) Sohar – Oman's garden city – offers tenants easy access to domestic as well as international markets. The estate is home to 60 businesses, 18 units under construction and a further 44 are expected to come on stream in the near future.

On the estate's doorstep is Sohar Port, a large three-phase project which began late-1999. Indeed, the Port has helped to generate considerable international interest in Sohar Industrial Estate.

Production on the estate includes:

- Marble
- Paper recycling
- Foodstuffs
- Detergents
- Leather
- Furniture
- Toothpaste
- Beverages
- Ice cream
- Resins
- Glass
- Steel bars
- Engine oil

3.2.2 Liquid Natural Gas (LNG)

The discovery of large reserves of natural gas in the late 1980s and early 1990s paved the way for development of gas-based industry in Oman. The success story has been the LNG facility in Sur, which began exporting in April 2000, driving a sharp rise in the otherwise sedate average growth rate for the manufacturing sector. Oman LNG is a joint venture between the Omani government (51%), Royal Dutch/Shell (30%), Total (5.54%), Korea LNG (5%), Mitsubishi (2.77%) and Mitsui (2.77%) of Japan, Partex (2%) and Itochu (0.92%, also of Japan). Long-term sale and purchase agreements (SPA) with Korea Gas Corporation, Osaka Gas of Japan and Dabhol Power of India account in theory for most of the facility's output.

In 2002 the Omani government announced that it had decided to construct a third LNG train to operate alongside the existing two at Sur, ultimately lifting total production to slightly over 10m tonnes/year (t/y). The Qalhat LNG facility, which was formally commissioned in March 2006, is a single train with capacity of 3.7m t/y. The owners of Qalhat LNG are the Omani government (55.8%), Oman LNG (36.8%) and Union Fenosa of Spain (7.4%). Given the government's 51% stake in Oman LNG, this means that the state (directly and indirectly) owns 78% of shares in Qalhat LNG. Union Fenosa has a 20-year sales and purchase agreement (SPA) for some 1.65m t/y of LNG, or 50% of planned output.

3.2.3 Other gas-based industry

Gas-based industrial development is central to Oman's diversification plans. Much of it will be based in Sohar, where there is a new industrial port with dedicated container-handling facilities, and gas is supplied by pipeline from central Omani fields. In 2004 the US Dow Chemical Company agreed to take a 50% stake in a USD 2.6bn polyethylene plant to be constructed in Sohar. OOC and the Omani government jointly took the remaining 50% stake in the Oman Petrochemical Industries Company, which intends to produce between 800,000 and 1m t/y of polyethylene.

In 2005, Sohar Aluminium Company signed an engineering, procurement and construction contract with Bechtel Corporation of the US for its USD 2.2bn project to build an aluminium smelter. It will have an initial capacity of 325,000 MT/y and is expected to begin commercial production in 2008. OOC and the Abu Dhabi Water and Electricity Authority each hold a 40% stake in Sohar Aluminium Company, with Alcan Corporation of Canada holding the remaining 20%.

Implementation also continues in Sohar of, among other projects, a USD 320m polypropylene plant and a USD 400m methanol plant.

In 2007 a USD 650m fertiliser plant run by Sohar International Urea and Chemicals Industries is scheduled to start producing 3,500 MT/d of urea and 2,000 MT/d of ammonia. In the same year, the first USD 350m phase should be completed on the Shadeed Iron and Steel plant, owned by a UAE-based company, Al Ghaith Holdings, which should have an output of 720,000 MT/y of steel alloys and iron.

Finally, in mid-2008, the Liwa Petrochemical Company's new USD 300m plant should begin producing 300,000 MT/y of ethylene dichloride and 240,000 MT/y of caustic soda. Liwa Petrochemical is a joint venture between OOC, LG International of South Korea and the Iranian National Petrochemical Company. LG International also has a 20% stake in Aromatics Oman (with OOC holding 60% and the Oman Refinery Company the remaining 20%), which in 2005 announced plans for a USD 1.1bn aromatics complex at Sohar, to produce 800,000 MT/y of paraxylene and 210,000 MT/y of benzene.

Away from Sohar, a methanol plant is also planned for the free-trade zone in Salalah, while other gas-based industries are being located at Oman's second emerging industrial city, Sur site of the country's LNG facilities. In 2005 the Oman India Fertiliser Company (Omifco) completed its new USD 1bn plant in Sur and began production and export. Omifco is a joint venture between OOC (50%) and two Indian companies, Krishak Bharati Co-operative Limited (25%) and Indian Farmers Fertiliser Co-operative (Iffco, 25%). The Indian government has agreed to purchase the plant's 5,060 MT/d urea output, and the Indian Agriculture Fertilisers Company will buy the 3,500 MT/d of ammonia.

3.2.4 Oil refining

The Oman Refinery Company (ORC) was established in 1982 with the aim of serving the local market. The refinery, which is in Muscat, currently has a processing capacity of more than 106,000 b/d (late 2006). The refinery's product mix includes petrol, kerosene, gas oil and butane.

In addition to running the existing Muscat facility, ORC is overseeing the construction of the new USD 1.3bn refinery in Sohar, which was completed in 2006/7. The project is being financed through government equity and a syndicated loan. When operational, the new refinery will produce gasoline, propylene, liquefied petroleum gas, naphtha, fuel oil, kerosene, and gas oil.

3.2.5 Economic Sectors' Contribution to GDP

Mining & Quarrying: The contribution of this sector was very insignificant in 1980 with a share of just RO one million. However, by 1990, the sector's contribution to GDP reached RO 12 million, constituting 0.26%. In 2001, the figure rose to RO 17.8 million. In 2005, the Mining & Quarrying sector's share in the GDP reached 0.2%.

Agriculture & Fisheries: The fact that around 40% of the national manpower is engaged in agriculture and fisheries sectors make them the most promising sectors for diversifying the manufacturing base and raising people's income and living standards. This sector's contribution is still low with rates ranging from 2.6% to 2.7% during the last two decades, despite the fact that the prices at current rates were steadily shooting up, starting with RO 116.2 million in 1990 to RO 154.6 million RO in 2001. In 2005, the Agriculture & Fisheries sector's share in the GDP reached 1.4%.

Converting Industries (manufacturing): In the year 1990, around 3% of the GDP came from this important sector with a share of around RO 131.7 million. The rate increased to 5.7% with a value of RO 640.2 million by the year 2001. In 2005, the Converting Industries sector's share in the GDP reached 8.3%.

Electricity & Water: This sector did achieve a growth in its share in GDP during the period from 1991 to 2001. The contribution steadily grew from 0.9% in 1991 (RO 39.3m) to 1.6% in 2001 (RO 79.7m). In 2005, the Electricity & Water sector's share in the GDP reached 1.2%.

Building & Construction: This is a vital sector that plays a significant role in Oman's developments. This sector's share in GDP in 1991 was around 2.9%. However, by 2001 it dropped to 2.8%. In 2005, the Building & Construction sector's share in the GDP is only 2.5%.

Oil & Gas Sectors: Crude oil is still the major source of Oman's economy. Its share along with natural gas stands at around 78.4% of the Government's gross revenue. However, its share GDP rose from 41.9% in 1991 to 42.6% in 2001. In 2005, the Oil & Gas sector's share in the GDP reached 48.8% (Oil 45.2%; Gas 3.6%). This shows a continued rise in the contributions of oil sectors to GDP.

Services Activities & Foreign Trade: The Sultanate enjoys full freedom of import from and export to the international markets and the degree of openness of the Omani economy reflects the philosophy of the country's economic policy and the extent of its relations with the outer world. This also underscores the Sultanate's decision to join the World Trade Organisation (WTO). In 2005, the Services Activities & Foreign Trade sector's share in the GDP reached 39.0%.

3.3 Electricity sector in Oman

3.3.1 Electricity companies

In Royal Decree 78/2004 promulgated on 1 August 2004 the current sector and market structure was implemented. The main principles are privatisation of electricity companies and establishment of a regulator (the Authority). Former structures were transferred to the following government owned companies:

- Electricity Holding Company
- Oman Power and Water Procurement Company (OPWP)
- Oman Electricity Transmission Company
- Wadi Al Jizzi Power Company
- Al Ghubrah Power and Desalination Company
- Mazoon Electricity Company
- Majan Electricity Company
- Muscat Electricity Distribution Company
- Rural Areas Electricity Company (RAECO)

In terms of ownership the companies represent a mix of Government and private ownership - the above mentioned are wholly Government owned. The privately owned companies are:

- AES Barka
- SMN Barka
- Al Kamil Power Company
- United Power Company
- Dhofar Power Company
- Sohar Power Company
- Rusail Power Company

These companies have a majority of private shareholders. Further electricity privatisation will be implemented through the sale of the government interest in some of the successor companies listed above. However there are no plans to privatise Electricity Holding Company, OPWP and RAECO

The Governments approach to privatisation has been to allow 100% private ownership for an initial period, with an obligation to make public offerings of stipulated shareholdings through the Muscat Securities Market. This has been a successful strategy and one that is likely to be adopted for the privatisation of successor companies.

Since 1 May 2005 the Authority has assumed full responsibility for the regulation of electricity and related water sector. The following activities in the sector are regulated:

- Generation, Transmission, Distribution, Export, Import or Supply of electricity
- Generation of electricity combined with Desalination of Water
- Generation of electricity co-located with Desalination of Water
- Central dispatching
- Development and/or operation of international interconnections
- Functions of OPWP Company

The regulation is pursued through licensing by the Authority.

The Government approves Permitted Tariffs, further privatisation plans, and liberalisation of the sector and approval of interconnections.

The sector law includes provisions to safeguard interest of investors, for instance international arbitration. The sector law also provides that key electricity assets will remain available to service the needs of citizens irrespective of public private sector ownership. There is no provision for tax exemption for (foreign) investments in the renewable energy activities.

3.3.2 Market Structure

The sector comprises three separate and distinct markets: Main Interconnected System (MIS), the Rural Systems (RAECO) and the Salalah Power System.

Main Interconnected system (MIS)

Production

MIS has the generation facilities shown in Table 3.2.

Table 3.2 Generation facilities in the MIS system, Ref /3/.

Name	No. of Units/ Technology	Capacity MW	Fuel	Production 2005 GWh	Production 2006 GWh
Al Kamil	3 GT	290	Nat. gas	1 210	1,151
Barka*	2 CCGT / 1 ST	427	Nat. gas	2 747	2,624
Ghubrah*	4 ST/13 GT	523	Nat. gas	2 382	2,341
Manah Phase 1 + 2	5 GT	267	Nat. gas	1 046	1,188
Rusail	8 GT	688	Nat. gas	2 170	2,369
Wadi Al Jizzi	11 GT	295	Nat. gas	1 390	1,044
Sohar*	3 GT / 1 ST	585	Nat. gas		1,036
Other			Nat. gas	97	29
Total		**2865**		**11, 041**	**11, 782**

*combined desalinated water and power production

OPWP is the single buyer of electricity and power from the licensed production facilities. In 2005 OPWP purchased 10.8 TWh of electricity.

MIS contracted capacity increased to 2,865 MW in April 2006 with the commissioning of a new Integrated Water and Power Production facility in Sohar. Sohar has been operating at its full capacity of 585 MW from 2007.

OPWP will contract for a further 700 MW (IWPP) by 2009 from a plant located at Barka which will provide 350 MW of early power in 2008.

Transmission

The Oman Electricity Transmission Company (OETC) is monopoly provider of transmission services to the MIS. OETC own and operate the 220 kV and 132 kV interconnected transmission system in the north of Oman and as system operator is responsible for the central dispatch of generating and desalination facilities connected to the MIS. OETC manages its system operator functions from a recently commissioned load dispatch centre in Al Mawalleh. Information about the transmission system is provided in Table 3.3.

Table 3.3 Transmission System Data - 2006, Ref /4/

Item	Value
Service areas	129,334 km^2
220 kV Transmission lines	576 km
123 kV Transmission lines	2,631 km
Sub stations	34
Peak demand	2,639 MW
Units transmitted	10,821 GWh
System Avaliability	98%

Distribution

Three licensed distribution and supply companies have monopoly rights to distribute electricity within Authorised Areas as provided for in the following licenses:

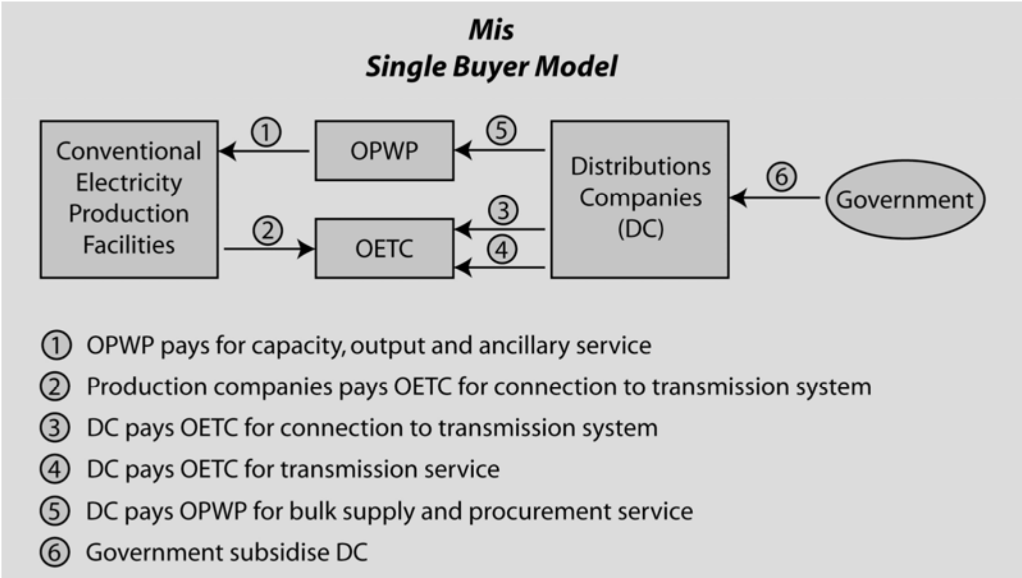
- Muscat, corresponding to Muscat Governorate
- Majan, corresponding to North Batinah, Dhahirah and al Buraimi regions
- Mazoon, corresponding to Sharqiyah, Dakhliah and South Batinah regions

Muscat is supplying the most densely populated area of the three

Regulation of the Sector - MIS

The MIS is organised according the Single Buyer Model with OPWP as the single buyer. The Fig.3.1 summarises the principal regulated transactions in MIS:

Fig. 3.1 Regulatory overview MIS

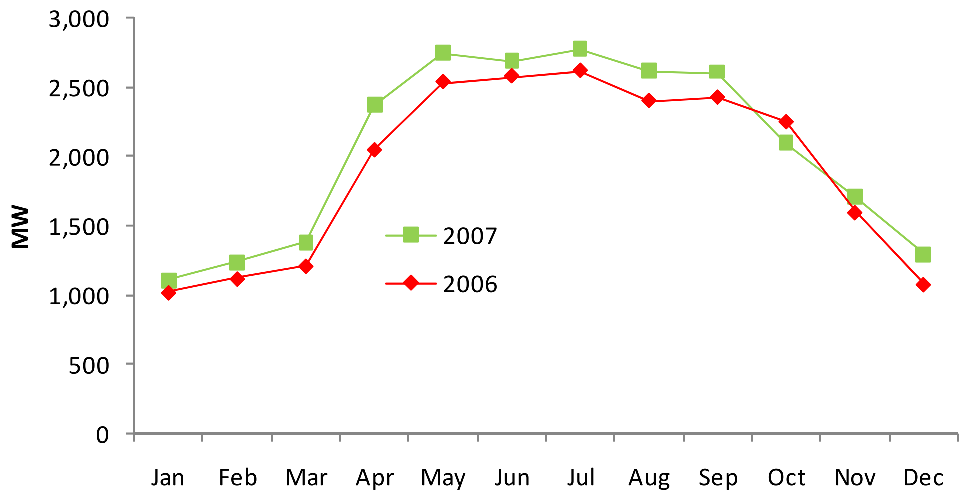


The OPWP purchases capacity and output from the licensed production facilities in accordance with the payment terms of power purchase agreements. These payment terms are established during competitions for market entry, and are not directly regulated by the Authority. The Authority has a duty to ensure the OPWP conducts competitions for new contracted capacity and output in a fair and transparent manner.

OPWP provides bulk supplies of electricity to the distribution companies. These transactions are implemented through cost reflective electricity tariff approved by the Authority. The electricity Bulk Supply Tariff (BST) allows OPWP to recover its purchase costs and the direct costs of its procurement functions.

Electricity is purchased by the OPWP at licensed production facility exit points and transported across the transmission system of OETC. The DC purchase electricity from OPWP and are responsible for the cost of transporting electricity across to the customers. The DC pays connection and use of system charges approved by the Authority for connection and use of the system.

Fig. 3.2 Main Interconnected System monthly peak Demand, Ref /3/



MIS electricity demand has a distinct seasonal shape - demand in summer months is significantly higher than in winter. Air condition loads in summer rise in response to higher temperatures resulting in the strong positive correlation of monthly peak demand and maximum monthly ambient temperature.

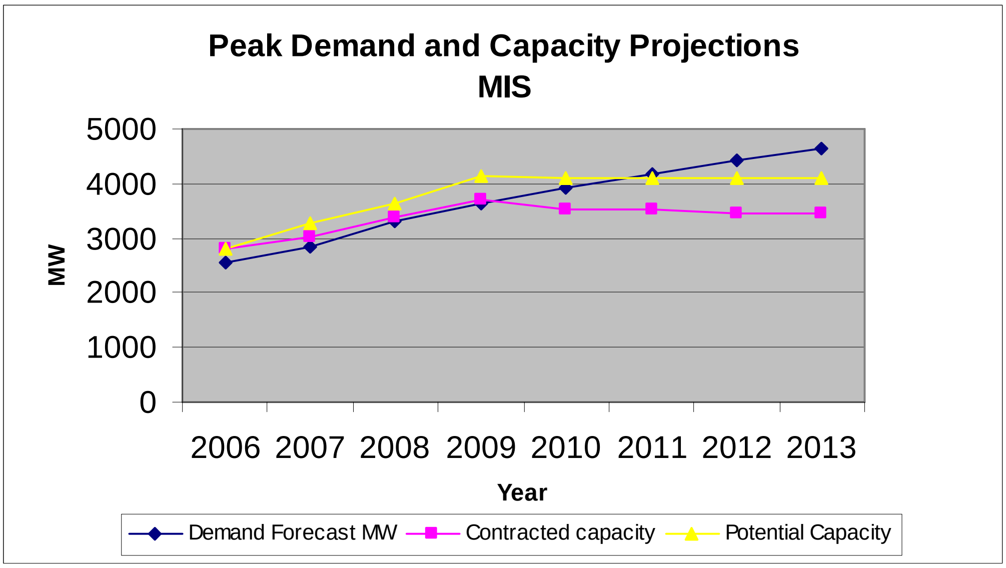
2006 peak demand was 2,614 MW, and increased to 2,773 MW in 2007.

Daily load profile is also distinct. Daily loads in June, with the highest loads, are almost double of February having the lowest loads. Peak hours are between 3 pm and 5 pm, and again between 11 pm and 4 am in the summer. In the winter there is a small peak hour at 8 pm.

MIS electricity Demand Forecast

MIS Peak demand will increase from 2,773 MW in 2007 to an expected 4,634 MW in 2013. The annual growth rate is app. 9%. Peak demand is envisaged to continue increasing due to the accelerated growth in Oman.

Fig. 3.3 Capacity Projections for the MIS, Ref /5/



OPWP projection of the peak for the coming 7 years is shown above. The principal drivers behind the increase are population growth, industrial sector growth and growth in the tourism sector.

The figure show the capacity forecast, the already contracted capacity and the potential known capacity that can be contracted. It shows that already from 2010 or earlier OPWP must contract new capacity.

The forecast for electricity generation in 2014 is 24.0 TWh.

Rural Systems

RAECO is generating, transmitting and distributing power in its areas. RAECO is also responsible for electrification of rural areas and funds this through a special mechanism in the Sector law.

Most of the electricity in RAECO is generated in diesel fuelled facilities. The total capacity is 447 MW. The electricity supply was 246 GWh in 2006, Ref /3/.

Demand for electricity in RAECO areas will increase considerably when the development projects in the Duqum area and Masirah Island take off.

The forecast for RAECO area is approximately 350 GWh in 2012.

Salalah Power System

The Dhofar Power Company (DPC) has a concession agreement to generate, transmission, distribution and supply of electricity in its concession area until 2021.

The generation facilities are listed in Table 3.4.

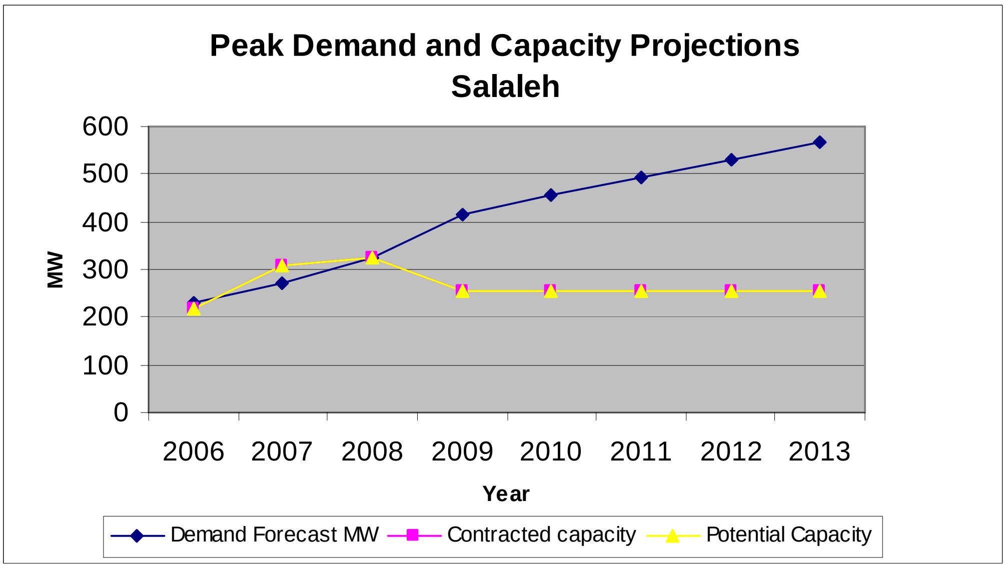
Table 3.4 Generation Capacity Salalah Power System, Ref / 3/

Name	Technology/ No. of Units	Capacity MW	Fuel	Production 2005 GWh
DPC	GT / 6	195	Nat. gas	1,057
Frame 6	GT / 1	30	Nat. gas	0
LM 2500	GT / 1	17	Nat. gas	0
RAECO gen		70	Diesel	1
Total		**312**		**1,058**

The vertically integrated nature of the Salalah Concession Agreement is in contract. OPWP is counterpart in the concession agreement and its activities are regulated by the Authority.

Demand and capacity projections are shown in the diagram below. The diagram shows that Salalah Power Systems is in need of new capacity already from 2007. The RAECO generation capacity is not available after 2008, leaving a short fall in capacity of 70 MW. The strong demand growth is the result of increasing population, new industrial projects in the new Salalah Free Zone, development of tourism and expansion of the system to new areas.

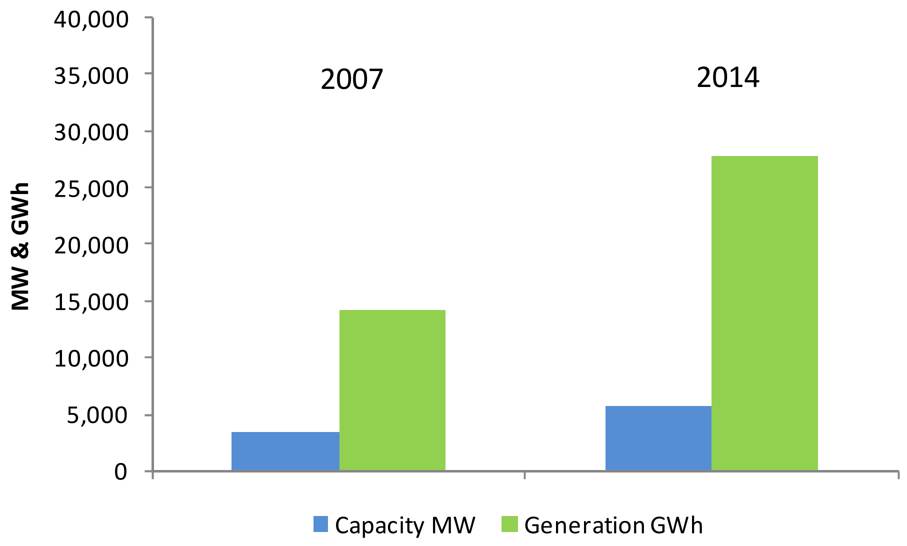
Fig. 3.4 Capacity Projections for the Salalah, Ref /5/



The forecast for electricity generation for Salalah is 3.5 TWh in 2014.

The total power capacity and the total electricity generation in Oman in 2007 and respective forecasts for 2014 are shown in Fig. 3.5.

Fig .3.5 Capacity and electricity generation, 2007 and 2014 forecast, Ref /23/



The total additional power capacity required in order to meet the demand in 2014 is 2,758 MW.

3.3.3 Interconnection Projects

A 220 kV interconnection between MIS and UAE (Abu Dhabi) was completed in early 2007. This is the first step in an interconnection system linking all GCC members.

Currently the MIS is linked to RAECO through Petroleum Development of Oman systems. The plan is to link the PDO system to the Dhofar areas also.

On a longer term it is likely that a system linking MIS and Dhofar via Duqm will be established.

3.3.4 Current Energy Sector Policy

The current sector law for electricity and water implements the Government policies for the electricity sector. The most important elements of the law include:

- A comprehensive **restructuring** of the electricity sector, whereby operational responsibility for the sector will pass from MHEW to newly created successor entities that will for a time, be wholly owned by the Government.

- Further **privatisation** of the electricity sector, in accordance with a timetable of the Governments choosing, the Government shareholding in certain successor companies will be offered to local and international investors thereby extending private sector participation;

- **Public interest regulation** of the electricity sector. The sector law established an Authority to regulate the electricity sector, and a licensing regime through which the Authority can authorize persons wishing to undertake activities stipulated in the sector law as regulated activities.

- The sector law also ensures that the Government remains responsible for all matters relating to customer tariffs, for the approval of interconnections with neighbouring countries, and for the approval of any further changes to the structure of the electricity market.

Article 18 of the Sector Law implements a mechanism through which the Ministry of Finance provides electricity subsidies, calculated by the Authority to licensed suppliers (Muscat, Majan, Mazoon and RAECO) on an annual basis. The Authority undertakes two separate subsidy calculations: the first calculates the subsidy to Muscat, Majan and Mazoon distribution companies and the second calculates the subsidy to RAECO.

The subsidy is defined as the difference between the economic cost of supply (including financing costs) and Permitted tariff (and other) revenue. Economic supply cost are derived from OPWP, OETC and Muscat, Majan, and Mazoon price control Maximum Allowed Revenue (MAR). Subtracting customer tariff revenue (and other sources of income) from the MAR identifies the electricity subsidy required in a particular year.

The maximum tariff (permitted tariff) is approved by the Council of Ministers and shown in Table 3.5. No new permitted tariff was implemented in 2006.

Table 3.5 Permitted Tariff for Electricity Supply - 2006, Ref /3/

A: **Permitted Tariffs for Electricity Supply**

Permitted Tariff Category	Tariff Structure				
Industrial[1]	All Regions except Dhofar			Dhofar Region	
	September to April: 12 Baiza per kWh			August to March: 12 Baiza perkWh	
	May to August: 24 Baiza per kWh			April to July: 24 Baiza per kWh	
Commercial	Flat rate @ 20 Baiza per KWh				
Ministry of Defence	Flat rate @ 20 Baiza per KWh				
Residential	0-3000 kWh	3001-5000 kWh	5001-7000 kWh	7001-10000 kWh	above 10000 kWh
	10 Bz / kWh	15 Bz / kWh	20 Bz / kWh	25 Bz / kWh	30 Bz / kWh
Government	0-3000 kWh	3001-5000 kWh	5001-7000 kWh	7001-10000 kWh	above 10000 kWh
	10 Bz / kWh	15 Bz / kWh	20 Bz / kWh	25 Bz / kWh	30 Bz / kWh
Agriculture & Fisheries	0-7000 kWh			7001 kWh & above	
	10 Baiza per kWh			20 Baiza per kWh	
Tourism[2]	0-3000 kWh	3001-5000 kWh	5001-7000 kWh	above 7001 kWh	
	10 Bz / kWh	15 Bz / kWh	20 Bz / kWh	20 Bz / kWh	

1 Customers require a MOCI letter of recommendation and must maintain a power factor of least 0.9
2 Subject to Ministry of Tourism regulations and approval

B: **Permitted Tariff fees for Disconnection & Reconnection of accounts**

Disconnection fee (all types of metered accounts): 7.500 Rial Omani
Reconnection fee (all types of metered accounts): 7.500 Rial Omani

The level of subsidy is high and differs from region to region and by company. The subsidies in 2006 are shown in Table 3.6.

Table 3.6 Revenue, Subsidies & Economic Costs in 2006 - Baiza/kWh, Ref /3/

Item	Muscat	Majan	Mazoon	MIS Total	RAECO
Customer Revenue	17.5	13.8	13.4	15.6	14.3
Subsidy	4.2	11.8	17.6	9.6	68.0
Economic Cost	21.7	25.6	31.0	25.1	82.3
Subsidy as % Economic Cost	19%	46%	56%	38%	83%

The actual revenue corresponds to around 15 Baiza/kWh, while the economic cost varies from 22 to 82 Baiza/kWh. The difference reflects the differences in customer base and especially customer density.

3.3.5 Connection Charging Principles

During 2006 the Authority approved new connection charging principles proposed by distribution companies. The new principles provide for the application of 'shallow connection charges', whereby most customers only pay for connecting to a network and do not contribute to the cost of network extensions or reinforcement.

The new charging principles reduce the financial burden of consumers and will allow network operators more scope to plan and design integrated and optimised distribution networks.

3.3.6 Economic Regulation of the Electricity Sector

The Authority is responsible for the economic regulation of the electricity and related water sector, including monitoring RPI-X price controls under which companies with monopoly power operate, and approving electricity bulk supply tariffs. The 2007 PWP electricity bulk supply tariffs are presented in Table 3.7.

Table 3.7 Cost reflective Bulk Tariffs - BST Baiza/kWh, Ref /3/

Baiza per kWh	Off peak	Night Peak	Weekday Day-peak	Thursday Day-peak	Friday Day-peak
Jan-Mar	7.0	7.0	7.0	7.0	7.0
Apr	8.0	8.0	8.0	8.0	8.0
May-Aug	8.0	15.0	40.0	25.0	20.0
Sep.	8.0	8.0	8.0	8.0	8.0
Oct-Dec	7.0	7.0	7.0	7.0	7.0
Off-peak	All days: 02 to 13 and 17 - 22				
Night Peak	All days: 22-02 (following day)				
Week Day-peak	Saturday to Wednesday: 13 - 17				
Thursday Day-peak	Thursday 13 - 17				
Friday Day-peak	Friday 13 -17				

A basic principle of the market structure is a single point of subsidy injection, i.e. the Government provides subsidies to the licensed suppliers - all other entities are self-sustaining in economic terms and charge fully cost reflective tariffs for the services they provide.

3.3.7 Energy costs in Oman

The current natural gas price provided by the Ministry of Oil and Gas Resources is 1.5 USD/MMBtu for all power generators. This is below the current economic opportunity cost of natural gas, assumed to be 3 USD/MMBtu with a 3% depletion premium. In combination with the end-user subsidy provided by the Government to the DC's, the level of subsidization is quite large.

Cost of Diesel is 146 Baiza per Litre.

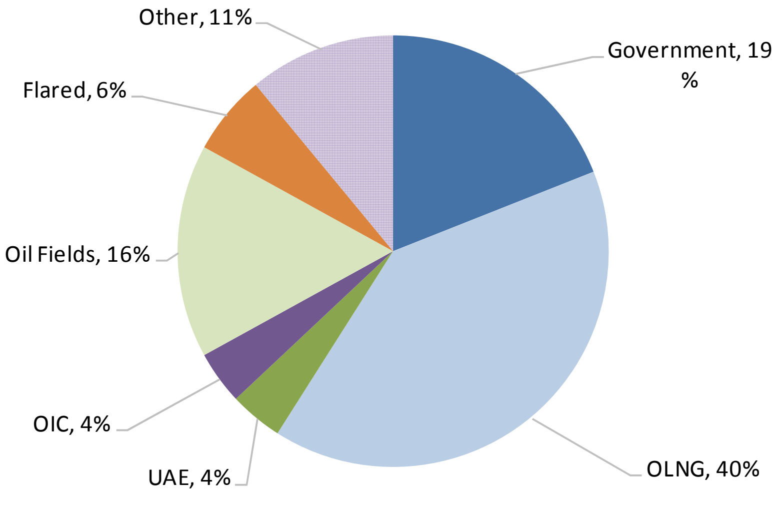
3.3.8 Energy supply and consumption

Present

The annual crude oil production is nearly 300 MN BBL per year and has been slightly declining between 2003 and 2006. Approximately 90% is exported and the remaining used domestically.

The annual natural gas production is approximately 900 000 MNSCF per year and has been increasing over the last years. In 2005 the natural gas production was 918 000 MNSCF. The usage of the natural gas in 2006 is shown in Fig. 3.6.

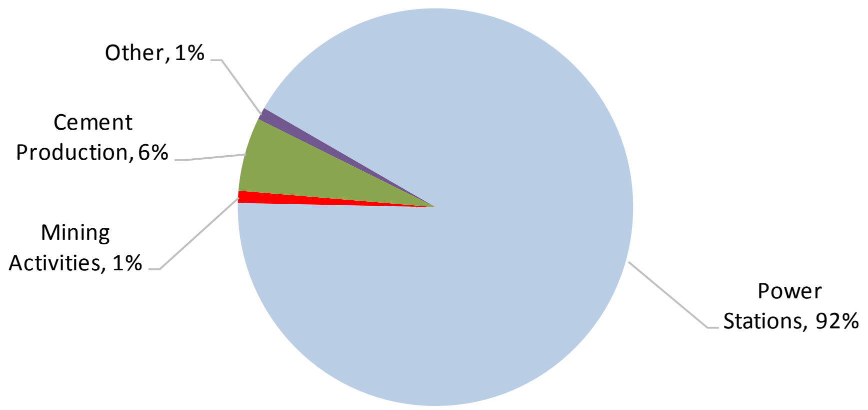
Fig. 3.6 Usage of natural gas in 2006, Ref /6/



The Government accounts for 19% of total gas, while the remainder is used in oil-production and for export. The largest share (40%) is used for LNG and exported. Oman natural gas resources are constrained due to long-term commitments to export LNG to Korea and Japan, and due to the usage in local industry and power stations. The low price of gas charged for local use has been considered important to stimulate and attract of industrial development.

The use of natural gas by the Government is shown in Fig. 3.7.

Fig. 3.7 Government of Oman -use of natural gas, Ref /6/



92% of natural gas used domestically is used for power production.

Coal production and usage in Oman is insignificant.

3.4 Renewable energy activities in Oman

3.4.1 Existing RE systems

Solar energy is the sole renewable energy resource which presently is utilised in Oman.

Solar energy is primarily used for house hold water heating by heating water in tanks located on the roofs at private houses.

Solar energy is also utilised by the oil production industry (PDO). Electricity generation by Photovoltaic cells is used for powering small remote located equipment and solar energy is used for steam production which is used for extraction of oil from the oil fields in the dessert.

3.4.2 Ongoing initiatives on RE systems

Presently there are some discussions and planning activities regarding implementation of renewable energy systems in Oman.

Private initiatives are ongoing regarding distributed power production by small wind turbines. Also small PV systems are considered as power supply for remote areas.

In connection with planning of the development of new industrial and settlement areas in Oman, considerations on large scale utilisation of solar thermal systems for power supply are under consideration.

3.4.3 Research and Development

Research and development (R&D) activities within renewable energy have been carried out at Sultan Qaboos University by the Renewable and Sustainable Energies Research Group.

The R&D activities have included theoretical studies as well as experimental studies within the areas PV systems, non PV solar systems, Wind Energy Systems and Energy Planning and Management. Reference list of R&D activities is enclosed in Appendix 9.

3.5 Conventional energy resources in Oman

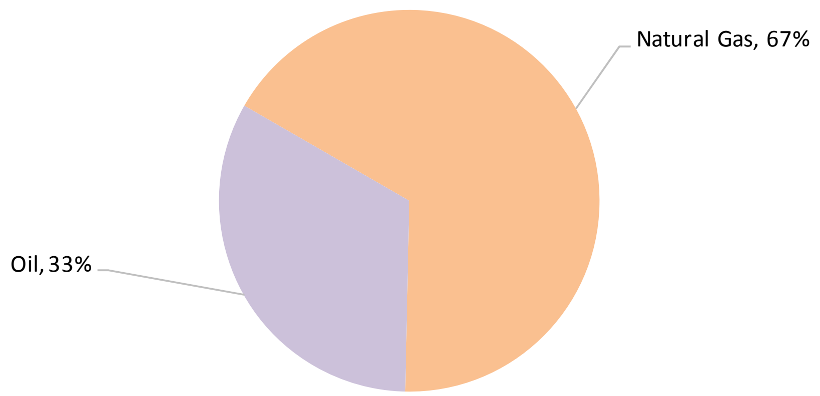
Conventional (non-renewable) resources are as follows:

- Natural Gas (relevant for Oman)
- Petroleum (relevant for Oman)
- Gasoline (relevant for Oman)
- Fossil Fuels (relevant for Oman)
- Coal (not relevant for Oman)
- Nuclear Energy (not relevant for Oman)

3.5.1 Background

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. Refer to Fig. 3.8 for split in 2004.

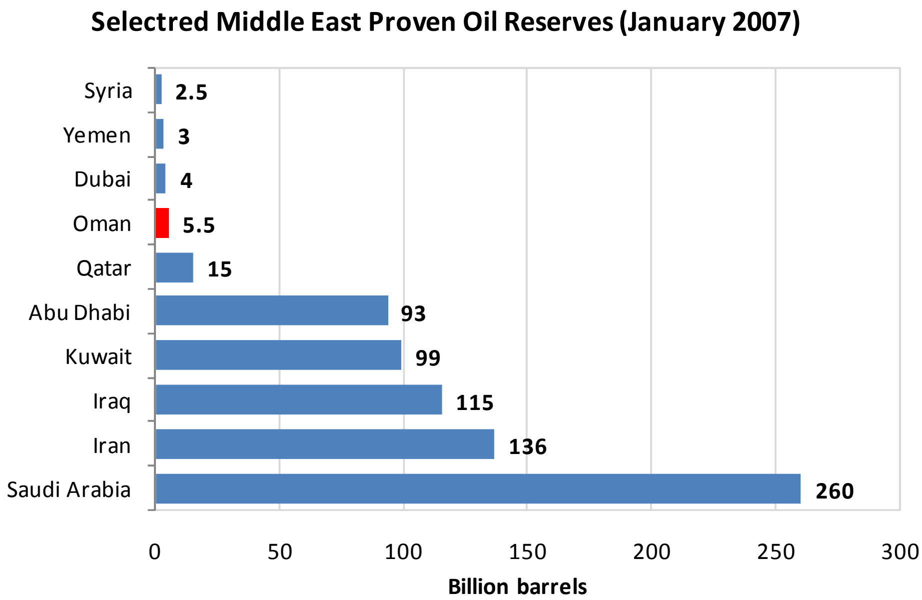
Fig. 3.8 Total energy consumption in Oman.



3.5.2 Oil sector

According to Oil & Gas Journal (OGJ), proven oil reserves in Oman stood at 5.5 billion barrels as of January 2007. 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. 3.9.

Fig. 3.9 Oil reserves in Oman



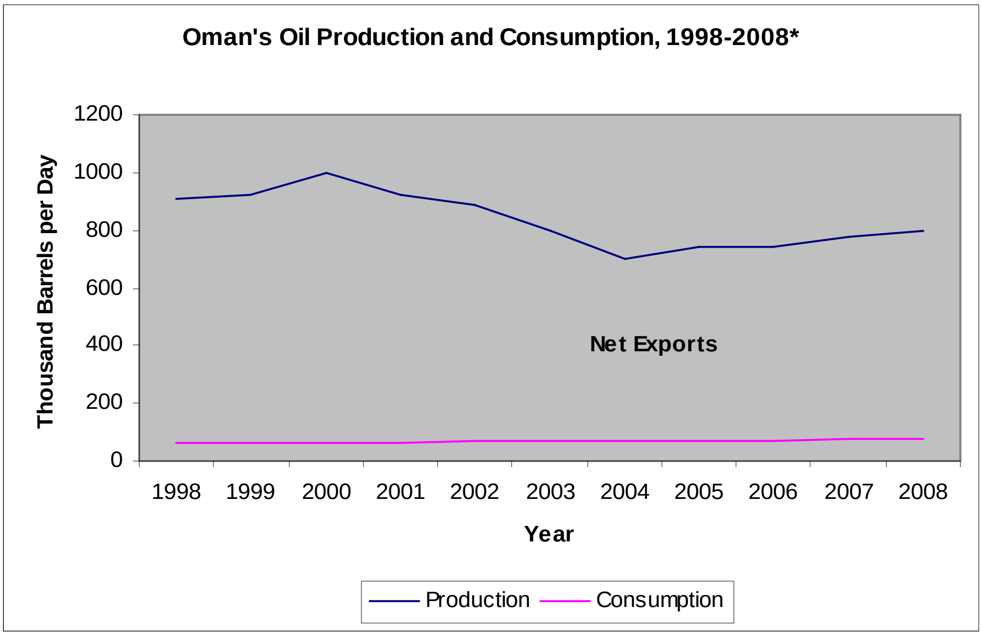
During 2006, Oman consumed an estimated 64,000 bbl/d of oil, with net exports of 679,000 bbl/d. Oman is not a member of the Organisation of the Petroleum Exporting Countries (OPEC), though it is a significant exporter of oil. Most of Oman's crude oil exports go to Asian countries, with China, India,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

3.5.3 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. 3.10.

Fig. 3.10 Oil production in Oman



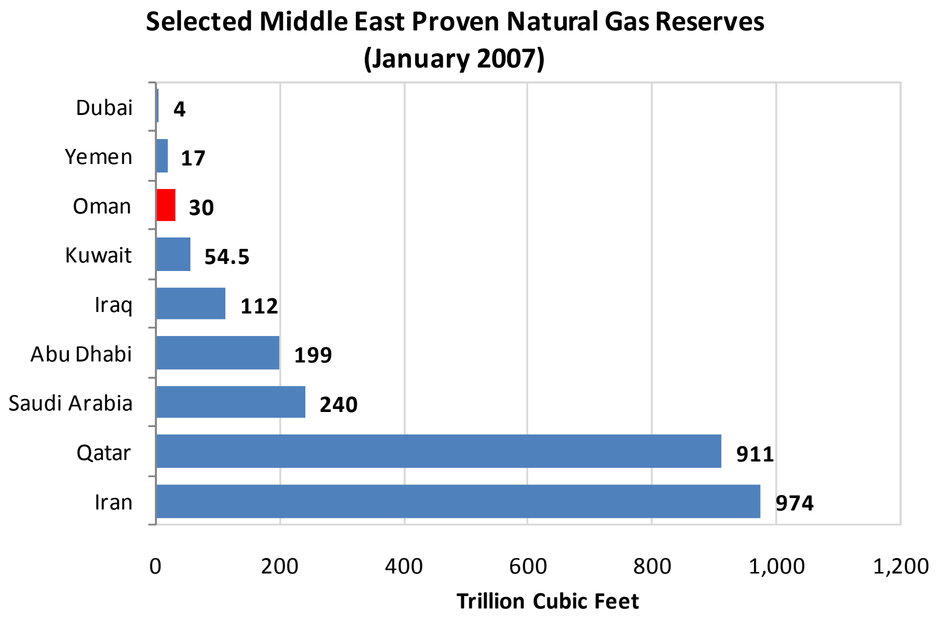
3.5.4 Natural Gas

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. 3.11.

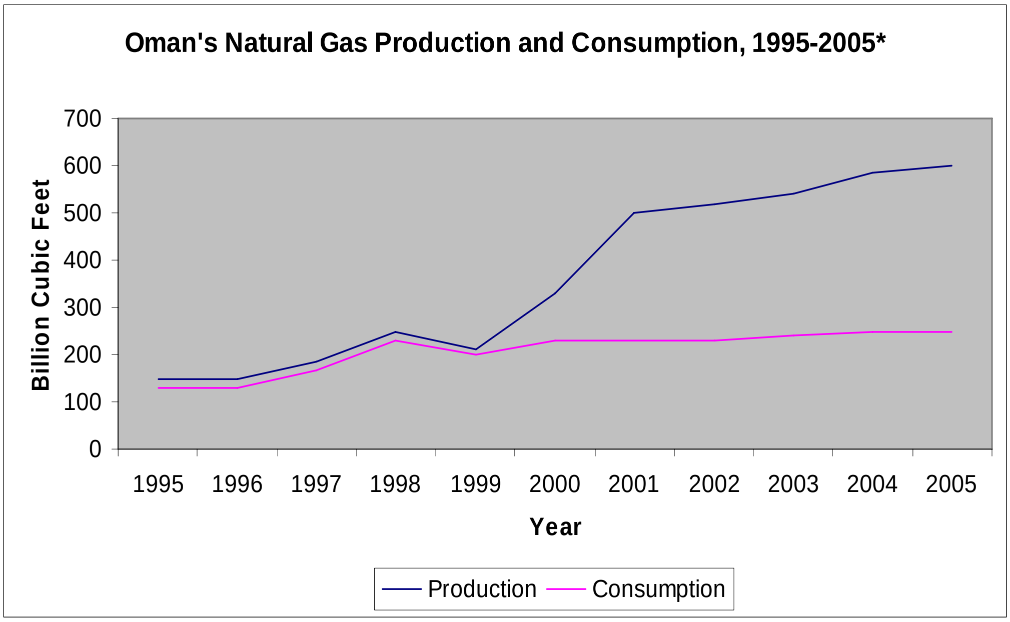
Fig. 3.11 Natural gas reserves



3.5.5 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. 3.12 Natural gas production and consumption in Oman



4 Renewable energy resources in Oman

Renewable energy resources are as follows:

- Solar energy
- Wind energy
- Wave, tidel energy
- Thermal energy
- Bio mass, biogas
- Hydro power

This study includes solar-, wind-, thermal-, wave- and biogas resources. The basis for the estimation of these resources in Oman is data and information collected during visits to a number of authorities. The summaries of the meetings held with the authorities and lists of received information are enclosed in Appendix 1.

4.1 Wind energy

4.1.1 Wind data

The assessment of the wind energy resources is based on the wind data measured at twenty one stations in Oman under the responsibility of DGCAM. The wind data is measured at 10 m above ground level. The details of the stations including their locations are included in Appendix 3.

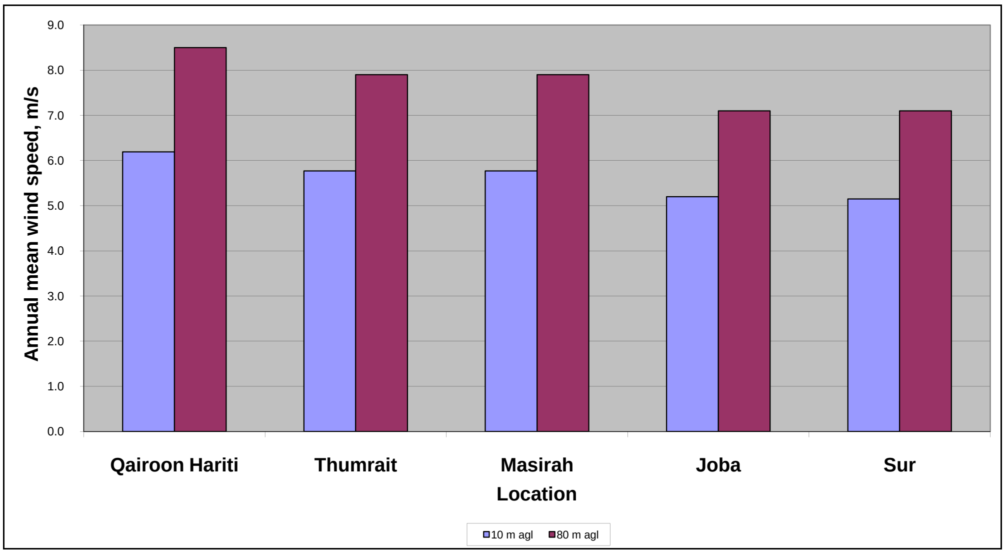
Five stations with the highest wind speeds (in 2005) were identified based on the data from Ref /7/. For these stations the hourly wind speed data for 2006 was received from DGCAM. The annual mean wind speed in 2005 and in 2006 was almost identical.

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 calculation is based on the hourly wind speed data for 2006 received from DGCAM.

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. 4.1. Details on the calculation of the monthly mean wind speed and the wind rose at each of the five selected stations are included in Appendix 3.

Fig. 4.1 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 monthly wind speed variation at each of the five stations is included in Appendix 3.

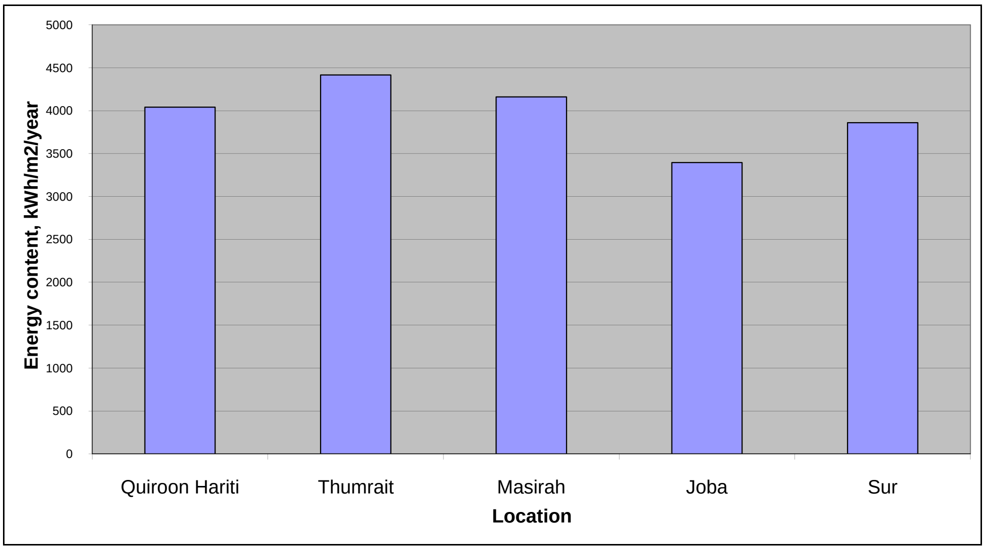
The wind monitoring masts at Thumrait and Qairoon Hariti were inspected as part of the study in order to evaluate the measuring conditions. The measuring conditions have been evaluated as acceptable but due to some complexity of the terrain around the masts more detailed wind analysis are required in order to determine the wind energy resources more accurately. Photos of the meteorological stations at Thumrait and Qairoon Hariti and the surrounding landscape are included in Appendix 2.

4.1.2 Wind energy resources

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 DGCAM. The calculation sheet is enclosed in Appendix 7.

The annual wind energy content at each met mast is indicated on Fig. 4.2. The energy is specified as kWh per year through a vertical area of one m^2, $kWh/year/m^2$.

Fig. 4.2 Energy content in the wind at 80 m above ground level at five meteorological stations.



4.1.3 Potential capacity for grid connected wind turbines

As a general rule based on experiences the maximum wind power capacity should not exceed approximately 15 % - 20 % of the existing conventional power capacity of the system in order to avoid disturbances in the power quality due to the fluctuating power generation by the wind turbines. In case of sufficient grid capacity a higher percentage of wind turbine capacity can be connected to the grid.

In Oman the future power system will have a total capacity of 5000 MW (2015) and the power system in the north and in the south will be interconnected. The technical future potential for installation of wind turbine capacity in Oman will be at least 750 MW.

Another technical limitation for installation of wind power capacity is the availability of open land without obstacles for erection of the turbines.

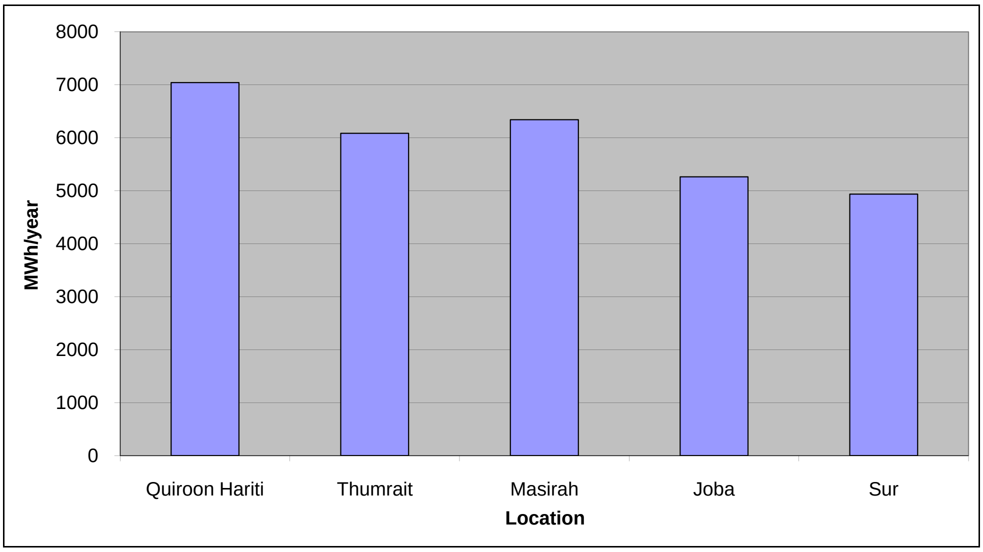
The space required for installation of wind farms with a total capacity of 750 MW is available in the mountains north of Salalah where the highest wind speeds in Oman are measured. Another possibility for installation of wind turbines is at Sur where the third highest wind energy resources are observed. The estimated required land area for a 750 MW wind farm is in the order of 100 km^2 assuming 375 turbines with a capacity of 2 MW each. A photo of the landscape in the Dhofar Mountains is included in Appendix 2.

4.1.4 Potential electricity generation

At different locations

A tentative estimate of the energy output by a 2 MW wind turbine erected in the five high wind areas in Oman is shown in Fig. 4.3. The reference wind turbine has a hub height of 80 m and a rotor diameter of 90 m.

Fig. 4.3 Estimated annual energy output by a 2 MW wind turbine at different locations



Total electricity generation

The wind conditions at Thumrait and at Quiroon Hariti and a 2MW reference wind turbine with a hub height of 80 m has been used as a n example for estimation of the technical potential for electricity generation by wind turbines. The location at Masirah is not considered suitable for installation of large scale wind power capacity as the present power system is an isolated system and the energy consumption on the island is relatively small. In the power system connects to the main system via sea cables Masirah may be relevant for installation of wind turbines. Joba and Sur could be potential sites for wind turbines, however the annual output at these locations is more than 25 % lower than at Quiroon Hariti.

The tentative estimated annual net energy output from a 2 MW wind turbine at Thumrait is 5820 MWh/year and at Quiroon Hariti the net output is 6470 MWh/year. If half of the capacity equal to 375 MW is installed at wind conditions corresponding to the wind conditions at Thumrait and the other half of the capacity is installed at wind conditions similar to the conditions at Quiroon Hariti the total annual net output of 750 MW wind turbine capacity will be in the order of 2300 GWh/year. This corresponds to 20 % of the total electricity generation in Oman in 2005.

4.2 Solar energy

4.2.1 Solar data

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, Ref./8 /. These data are global insolation data which is the sum of direct and diffuse radiation on a horizontal plane measured with a pyranograph. Only one year data was available from DGCAM, Ref /7/.

The locations of the sites where the solar insolation data is measured is shown in Fig. 4.4.

Fig.4.4 Locations of the stations from where the long term solar data used in this study have been measured, Ref /8/.

4.2.2 Solar energy resources

The solar resources at various locations and the monthly variations are presented in Fig. 4.5 and Fig. 4.6.

Fig. 4.5 Global insolation average for 1987-1992 for the stations included in this study.

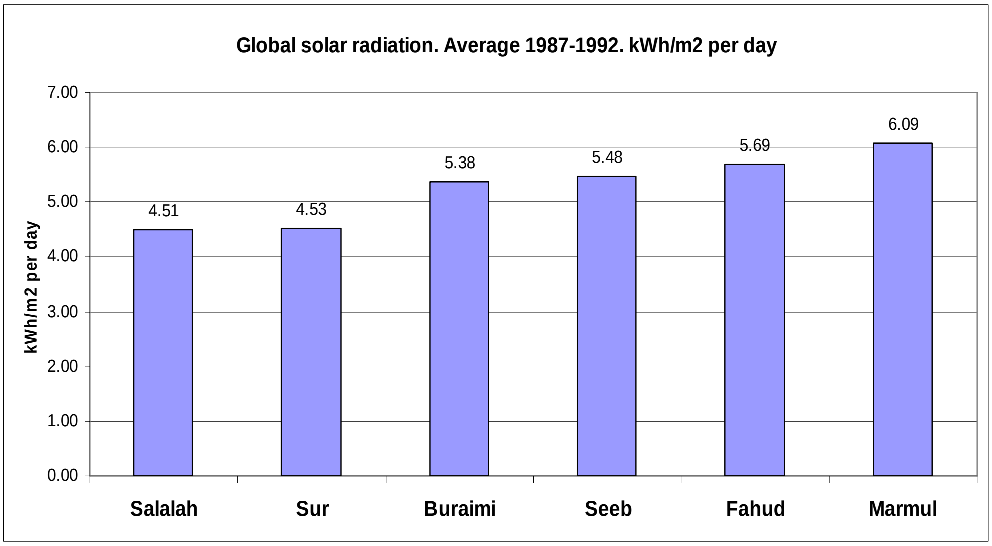
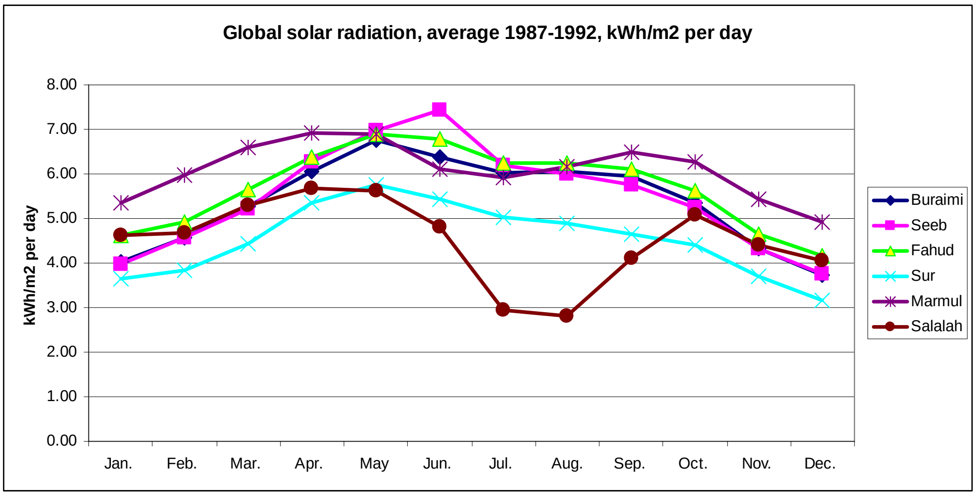


Fig. 4.6 Global solar insolation (on horizontal) average 1987-1992 for the 6 stations.



The seasonal variation on a sloped surface will be smaller than on fig 4.6 for horizontal radiation.

The monthly average solar insolation for each of the six stations is enclosed in Appendix 4.

General evaluation of the data.

The solar insolation varies from 4.5 to 6.1 kWh/m^2 per day, corresponding to 1,640 to 2,200 kWh per year.

The difference between the highest and the lowest daily mean insolation within a month is shown in Appendix 4. The difference is significant when the insolation is low. For a good location like Fahud the global insolation vary from 2 to 5 kWh per day in January, while the variation in July to September is only from 5 to 7 kWh per day. The yearly variation in average amounts to about 4 kWh/m^2 per day for January to about 6.5 kWh/m^2 per day for May in which the solar insolation is highest.

Salalah and Sur have a significantly lower insolation than other stations. In Salalah it is due to the summer rain period from July to September(Khareef season). For Sur the reason may be due to frequent periods with fog. The insulation in Seeb is high even though it is near the coast.

For all stations there is a significant difference between the minimum and maximum values, indicating that on all locations there will be days with little insulation and with a need for backup for systems based on solar energy.

Generally the highest potential is in the dessert areas and the lowest potential is at the coastal area in the southern part of Oman. The solar resources in Oman are among the highest in the world.

The highest solar irradiation occurs during the summer period where the electricity demand is highest. However, the seasonal variation in the demand is much higher than the variation in the solar radiation. A system based on 100 % solar energy in the summer time will therefore give a surplus of power in the winter. The surplus could be exported if possible. Seasonal storage in that magnitude is not available.

The total solar energy resources in Oman are huge and can theoretically cover all energy demands and could provide for an export as well. High solar energy density is available in all regions of Oman. The highest density is found in the dessert areas and the lowest density is in the coastal areas in the southern part of Oman. The level of the solar energy density in Oman is among the highest in the world.

4.3 Biogas

4.3.1 Data

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 m^3. The waste amounts 8000 m^3 which is composted for fertilising. The amount of waste water treated is rapidly increasing according to information given by the OWSC company, Ref /9/.

Table 4.1 Amount of waste water

Year		2007	2010	2015	2020	2025
Waste water	**m^3/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

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 Nm^3 CH_4 (methane) per year, equivalent to 11,000 MWh.

Solid waste (dung)

An overview of the type and number of farm animals is presented in Table 4.2.

Table 4.2 Overview of total resource by 2005. Ref /10 /.

Type of Animal	Cows 250 kg	Camels 250 kg	Sheep 30 kg	Goats 25 kg
Estimated population no	301,600	117,300	351,000	1,555,700
Manure Total Solids (TS) tonnes/year per animal	1.98	1.50	0.18	0.15
Total TS tonnes/year	597,168	175,950	63,180	233,355
VS (Volatile Solids = organic matter) tonnes/year at VS/TS = 0.75	447,876	131,962	47,385	175,016
Percent of total	56	16	6	22

4.3.2 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 Nm^3 CH_4 per kg VS
Waste water sludge 0.25% / 20% TS:	0.4 Nm^3 CH_4 per kg VS
Sorted organic household waste:	0.35 Nm^3 CH_4 per kg VS
Vegetable, fruit and grass waste:	0.5 Nm^3 CH_4 per kg VS
Cereals:	0.22 Nm^3 CH_4 per kg VS
Vegetable oil e.g. from palm or animal fats:	1.44 Nm^3 CH_4 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 listed in section 5.3.1 is about 150,000,000 Nm^3 CH_4 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 Nm^3 CH_4 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.

4.3.3 Electricity generation

By use of biogas in large gen-sets it is possible to convert about 35-40% of the energy content in the biogas to electric power hereof 10-20% is consumed by the process itself.

It is not unrealistic to estimate a biogas production of 100.000 MWh at year 2020. From this about 35,000 MWh net power can be produced corresponding to a continuous power of about 4 MW.

Summary: Biogas resources material for generation is primarily available in the northern part of Oman in the forms of waste water and agriculture waste and in the southern part of Oman in the forms of waste water, animal dung and agriculture waste.

The theoretical potential for biogas generation from waste water is 1,000,000 Nm3 equivalent to 11,000 MWh and from animal dung 150,000,000 Nm^3 equivalent to 1,650,000 MWh.

The total technical potential for electricity generation by biogas in Oman is 35,000 MWh/year corresponding to a continuous power capacity of 4 MW.

4.4 Wave energy

4.4.1 Wave data

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, Ref /11/.

4.4.2 Wave energy resources

An estimation of the wave energy in the world oceans has been made and presented in Ref /3/. According to this reference the wave energy flux in the world oceans varies from approximately 10 kW per m wave length and up to approximately 100 kW/m. A map showing the wave resources are presented in Fig. 4.7.

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.

Fig. 4.7 Wave energy potential world wide, Ref /11/

4.5 Geothermal energy

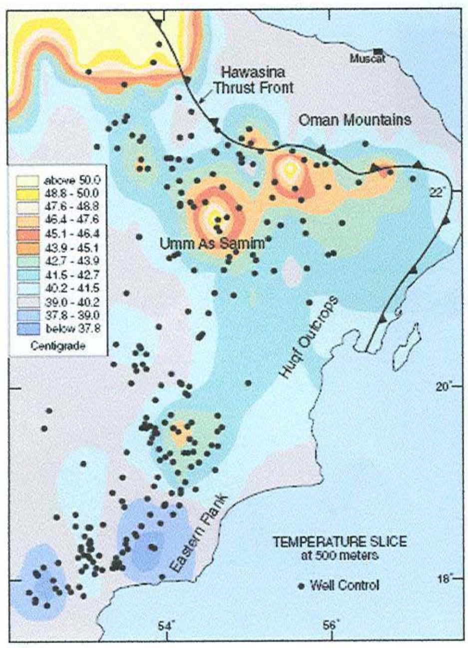
4.5.1 Data

Two types of data have been available for this study and were provided by the Ministry of Oil & Gas., Ref /13 /.

Temperature maps for 500 m and 1500 m depths and locations of boreholes within the Petroleum Development Oman (PDO) concession area are shown on the maps in Fig. 4.8. These data is based on Ref /12/.

The locations, the depths and the temperatures for the boreholes having tempera-ture above 100 ^{o}C are listed in Appendix 5. The number of the boreholes having a temperature above 100 ^{o}C is 55. These boreholes are located within the area shown on the map in Fig. 4.9.

Fig. 4.8 Soil temperature at 500 m and 1500 m depts, Ref. /12/



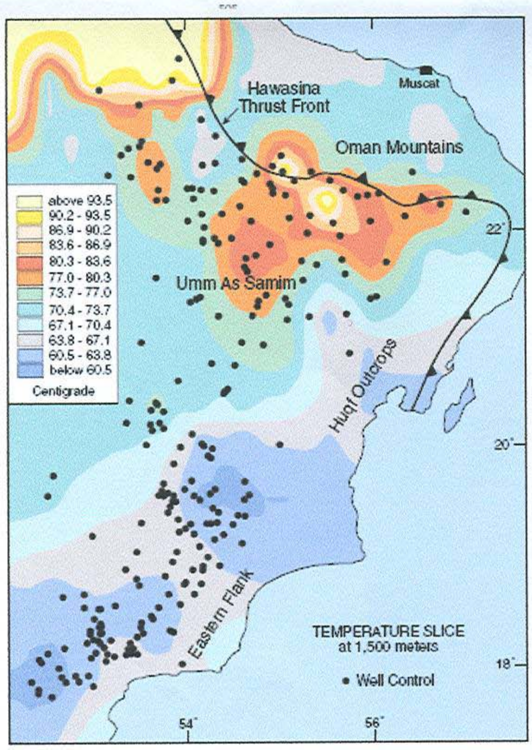
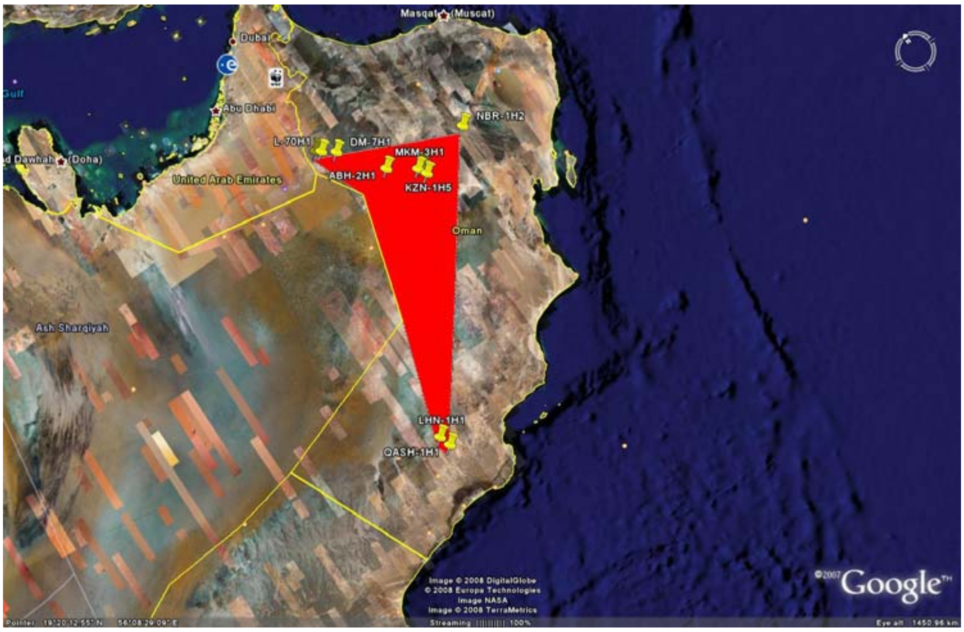


Figure 7b: Temperature slice at 1,500 m (approx. depth of Paleozoic strata) indicates lower temperature to the south where water recharge occurs along the Dhofar Mountains.

Fig. 4.9 Area with boreholes with temperature above 100 deg C.



4.5.2 Electricity generation

The highest observed temperatures are located in the northern part of Oman in the Omani mountains.

The highest observed borehole temperature is 174 ^{o} C. This temperature is below the temperature required for directly use of the hot water for steam power plants.

5 Renewable energy technologies

5.1 Wind turbines

Energy conversion principle

A wind turbine utilises the kinetic energy of the air flow. The power content in the wind is proportional to the cube of the wind speed and the air density.

The energy in the wind is converted into rotational energy by the wind turbine rotor. The conversion can be made either by aerodynamic forces acting on the rotor blades or by the air pressure acting on the rotor blades.

The rotational energy can be converted into electrical energy via a generator be utilised for mechanical work.

Technology

Grid connected wind turbines

The technology for grid connected wind turbines is well proven and wind turbines have been commercially available for more than twenty years. The capacity of the first commercially available wind turbines in the 1980'es was in the range 15 -55 kW. The capacity has gradually increased and to day the wind turbine capacity is in the range between 1 and 5 MW.

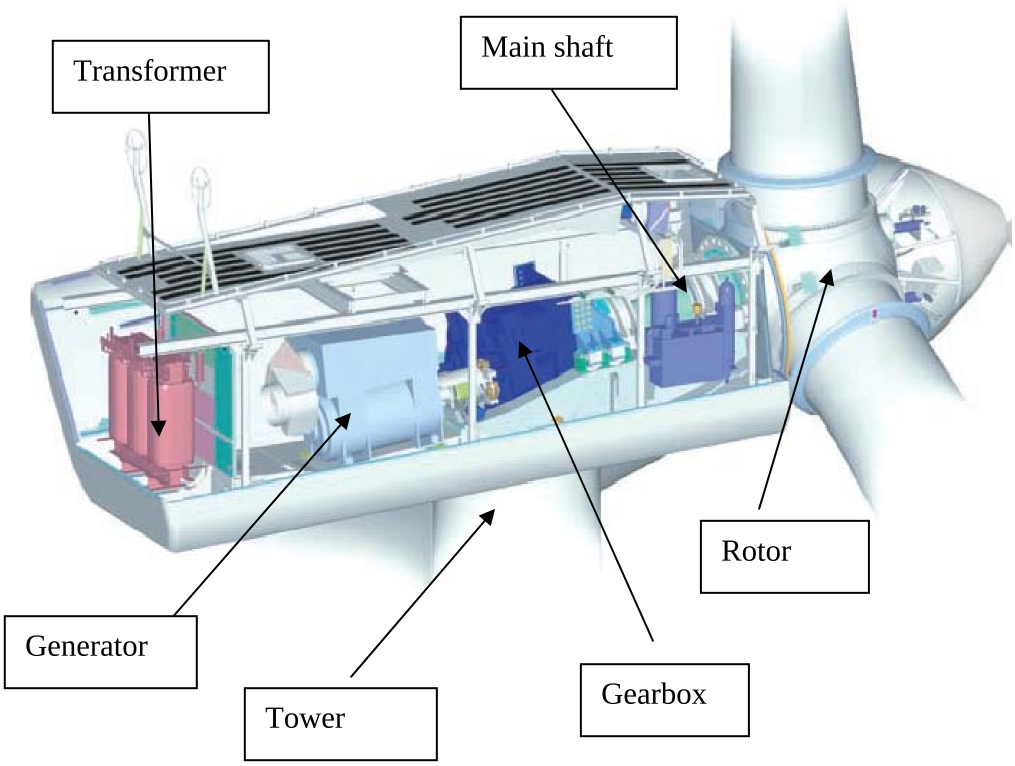
The wind turbine industry invests large amount in R&D activities in order to improve the cost effectiveness of wind turbines. This is done in order to optimise the design to reduce the use of material and to improve the reliability of the technology in order to reduce the O&M costs.

The modern grid connected wind turbine is a three bladed, pitch regulated turbine with the nacelle mounted on the top of a tubular tower.

The hub height of a modern wind turbine is in the order of 60 to 90 m and the rotor diameter is between 60 and 90 m depending on the capacity of the wind turbine.

Fig.5.1.Modern grid connected wind turbine.

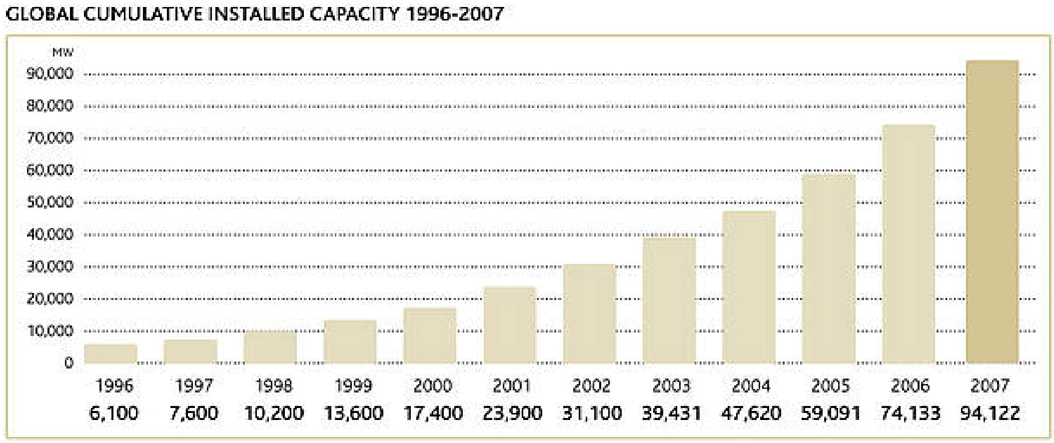
Fig. 5.2   Nacelle of a grid connected wind turbine.



The total energy conversion system for a grid connected wind turbine is installed in the nacelle. The main components are the rotor connected to the gearbox via a main shaft and the generator connected to the gearbox via a high speed shaft. The power generated by the generator is transmitted to the grid eventually through a step up transformer.

In 2006 the total installed wind power capacity worldwide was 75 GW of which 15 GW was installed in 2006. In some countries the wind turbines contribute up to 20 % of the total electricity production. The development of the global wind power capacity is shown in Fig. 5.3, Ref /14 /.

Fig. 5.3. Development of global wind power capacity, Ref /14/



An annual increase in wind turbine capacity world wide is expected to be 15-20 %. In 2020 the world wide installed wind turbine capacity is expected to reach approximately 1000 GW.

Off shore located wind turbines have been erected during recent years. This is relevant for countries where land availability is limited.

Stand alone wind turbines

Stand alone wind turbines for electricity generation can be divided into three categories:

Micro systems: 100 W or less.

Mini systems: 100 W - 10 kW

Small systems: 10 kW to 50 kW.

Stand alone wind turbines can been used as an inexpensive water pumping source, either as a mechanical pump or as power source for an electrical pump system.

Fig. 5.4 Wind turbine for mechanical water pumping

Fig. 5.5 Stand alone wind turbine for electricity genera-

Applications

The electricity generating wind turbines can be either grid connected or non-grid connected.

For the grid connected wind turbines the generated electricity is fed into the grid system. As a general rule wind turbine capacity up to approximately 15 % - 20 % of the conventional power capacity in a grid system can be connected to the grid without requirements of special measures in order to maintain stable grid conditions. Otherwise the fluctuating power generated by the wind turbines would have an impact on the power quality of the grid system. Detailed grid analysis are required in order to determine the accurate maximum wind power capacity which can be connected to a specific grid system.

The planned future interconnection of the northern and the southern grid systems will improve the technology preconditions for large scale utilisation of wind energy in Oman. Up to 15 % of the total capacity within a power system can be wind power. For Oman this corresponds to maximum wind power capacity up to 750 MW.

Stand alone systems

Small off grid wind turbines are relevant for remote areas and villages for power supply of small electrical equipment and lighting in connection with battery charging/backup.

The micro systems are typically used for power supply for small equipment and energy supply for lighting. Mini systems are suitable for off grid application as power supply for house holds radios and small appliances. Small systems are suitable as off grid application as stand alone power system or as integrated system in a hybrid power systems where the wind energy replaces fuel oil in isolated diesel power systems.

Wind turbines providing mechanical output are typically used for water pumping purposes or for mill of corn. The capacity of this type of wind turbines is few kWs.

Electricity generation

The power output generated by a wind turbine is a function of the wind speed at the location where the turbine is erected.

The electricity generation starts at a wind speed of approximately 4 m/s at hub height and at 12-13 m/s the output is equal to the rated power. At wind speeds between 13 m/s and 25 m/s the output is almost equal to the rated power. At 25 m/s the wind turbine is stopped in order to limit the loads on the wind turbine.

Economic key figures

The price for grid connected wind power plants on land is in the order of 1.9 mill USD/MW installed capacity. This includes the wind turbine costs as well as other project costs but excluding costs for land. For off shore wind turbines the price is approximately 40 % higher.

The annual operation and maintenance costs are typically 2% of the construction costs of the wind turbine.

The cost per kW installed capacity for stand alone systems is in general relatively higher compared to grid connected turbines.

Advantage/disadvantage

The advantages by utilising wind energy are:

- short implementation period compared to conventional power plants
- less dependant on fossil fuel
- pollution free electricity generation

The disadvantages are:

- Possible visual impact on the landscape as they are visible in the open areas where the wind speed is high
- In case wind turbines are erected close to settlements the noise emission may have a negative impact. Siting of wind turbines shall be made carefully to avoid noise nuisance.
- The rotating rotor blades cause shade effects due to the interaction with the sunrays. The flicker can be reduced or eliminated by carefully siting of the turbines

5.2 Solar PV panels and heaters

Technology

Solar photovoltaic

There are two main types of solar cells used to make solar modules. The first generation are the silicon wafer-based with silicone cells (mono and multi crystalline) which has been dominating and take up 93% of the market in 2005. The price of these has been reduced considerably over the years. The other type is the thin film cells, which today cover the last 7 % of the market. The thin film solar cells exist in many different types and are under constant development. As the technology stay today, the advantages with the crystalline solar cells are that they are more efficient, more reliable with longer lifetime and a longer record of proven durability. Therefore, they are often the preferred solution for power production on buildings.

The thin film solar panels are less efficient today and have a shorter lifetime and stability. The thin film is dominating as a power source for small appliances'. Very advanced thin film panels with high efficiency is used in space today but not commercially. It is generally accepted that on the longer term (beyond 2020) thin film technology with multi layer cells will dominate. These will have efficiency beyond 25%. The major advantage with the thin film is that they use less material and can therefore potentially be very cheap

Photovoltaic systems (PV) are commercially available and are based on reliable and tested technology. PV systems are suitable for use in rural areas in hybrid applications in combination with diesel power units and for electricity generation to the main grid, either as small building integrated systems or large grid connected systems located in the desert. The capacity will typically be in the order from few kW to 20-50 MW.

PV systems are best suited to feed electricity into the grid in the same way as wind energy with a certain percentage without storage. This possible percentage seems to be in the range of 20 % for Oman with the present load pattern. A higher percentage will give surplus production in the winter time. The percentage can be increased if the load pattern is changing, for example as a result of savings on cooling demand and use of excess heat for cooling purposes. The PV capacity can be achieved by a large number of smaller PV systems on buildings or it can be larger systems in the desert. That depends on the cost considering that PV on buildings or parking places also serves other purposes, shadow, architectural ideas as well as roofing and façade covering.

Solar PV has since it was introduced in space technology developed rapidly with increasing production and decreasing costs. It is, however, still marginal for power production as compared to other energy sources, including wind energy - mainly due to the cost.

Solar PV

- Typical max capacity per m2 of panel, today, 100 Wp per m2.
- Typical max capacity per m2 of panel, future, 300 Wp per m2.

Solar Thermal Power system

Solar Thermal Power, also called Concentrating Solar Power (CSP) produces steam which can be used either directly for electricity generation or the heat can be stored for continued operation during the night. CSP plants can therefore supply electricity as a conventional power plant, all the time, except for regular maintenance etc. Excess heat from the steam cycle can be utilized for heat driven cooling and desalination and this can make CSP a very attractive technology for Oman on the longer term.

CSP is not a fully developed technology. Plants without storage have been in operation for many years, development of systems with storage are ongoing and efficiency increase and cost reductions is expected that will eventually make such plants more attractive than conventional power plants from a commercial point of view.

It is important to notice that the size or capacity of a solar electricity plant is indicated as electricity capacity. For photovoltaic the capacity is called kWp (kW peak) to avoid misunderstandings. A 100 kWp PV plant means that the plant will deliver 100 kW at the standard conditions with 25^{o} C cell temperature and an insolation of 1000 W/m2 corresponding to the maximum during the day. On a yearly basis such plant will in Oman deliver about 1800 kWh for each kW installed PV.

A 20 MW CSP plant delivers 20 MW electricity from the generator. The capacity of the solar collectors are much higher as more than half of the heat is lost in the steam cycle. A 20 MW CSP plant with storage for night operation will deliver 20 MW (almost) constantly and the solar capacity will be even higher as some of the heat produced during the day will be stored for night operation.

CSP was in a period in the last part of last century almost a forgotten technology and the development had stopped. This has changed dramatically over the recent years in which the technology and marked development in certain countries (Spain and others) has been very positive.

Solar thermal power

- Typical max capacity per m2 of panel, today, 150 W per m2.
- Typical max capacity per m2 of panel, future, 200 W per m2.

An advantage of solar thermal power, as compared with PV, is that a solar thermal power plant can be made to provide electricity constantly. This can be done in two ways. The first is that the heat (high temperature) can be stored for shorter periods (for the night) to produce electricity after sunset. Another way is to use gas (or other) to heat the steam when the sun is not available. The first option, the storage, is still on the experimental stage while the use of gas as the backup is widely used.

Solar heating

Electricity is often used to heat water for domestic use and/or for use by the industry. Solar thermal collectors can replace part of the electricity consumption, especially in sunny climates like in Oman. In this way solar thermal produces electricity indirectly. See Appendix 5 for more information on solar thermal.

Solar heat

- Typical max capacity per m2 of panel, today, 600 W per m2.
- Typical max capacity per m2 of panel, future, 600 W per m2.

Electricity generation

PV cells

Today's PV module converts from 5-15 percent of the solar energy directly to DC electricity. This DC electricity can be stored in batteries and converted to AC electricity in a converter to be used in conventional appliances. With a typical maximum solar insolation of 800 W/m2 a PV module produces maximum about 100 W per m2 of collector.

The efficiency of a solar PV module depends on the environmental impact such as the surrounding air temperature and the dust contamination of the surface of the PV cells. The reduction of the efficiency of a solar PV cell due to high air temperature is estimated to 8% for Omani conditions and the reduction in efficiency due to dust contamination is assumed to be 2%. Details on the influence of air temperature on the PV cell efficiency is enclosed in Appendix 6.

Fig. 5.6 Solar PV panel.

Solar thermal plants

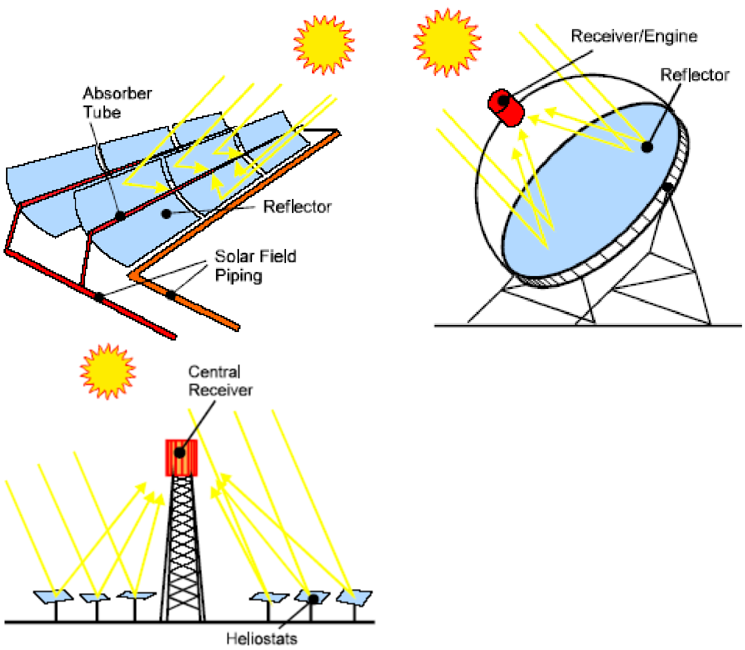
In a solar thermal plant the solar energy is used to produce high temperature steam which is used in turbines to generate electricity.

The efficiency of a solar thermal power plant depends on the concentration ratio of the collector as higher temperatures give higher conversion efficiency in a steam turbine. Three different concepts of solar thermal plant exist:

- Parabolic trough system (one dimensional concentration, 400 ^{o} C)
- Dish system (two dimensional concentration)
- Solar tower with mirrors directing solar radiation to a tower, representing the highest concentration ratios giving up to 1000 ^{o} C.

The parabolic trough has been dominating but the solar tower is under rapid development and may be dominating in the long term. The dish system is typically made with a stirling engine and generator in the focal point of the dish to produce power directly.

Fig. 5.7 Solar thermal concepts: parabolic trough, dish system and solar tower for production of high temperatures for solar thermal power.



Solar thermal power or Concentrating Solar Power (CSP) produces heat which is easier to store than electricity and therefore the system can be made to supply electricity as a conventional power plant. With the storage the power supply can be varied over the day according to the need. The CSP can be made with or without conventional fuel (gas) as backup.

For Oman an interesting option is a CSP where the heat from the condenser in the steam cycle is utilized for desalination. Systems with storage are being demonstrated today but the combination with desalination has not been made.

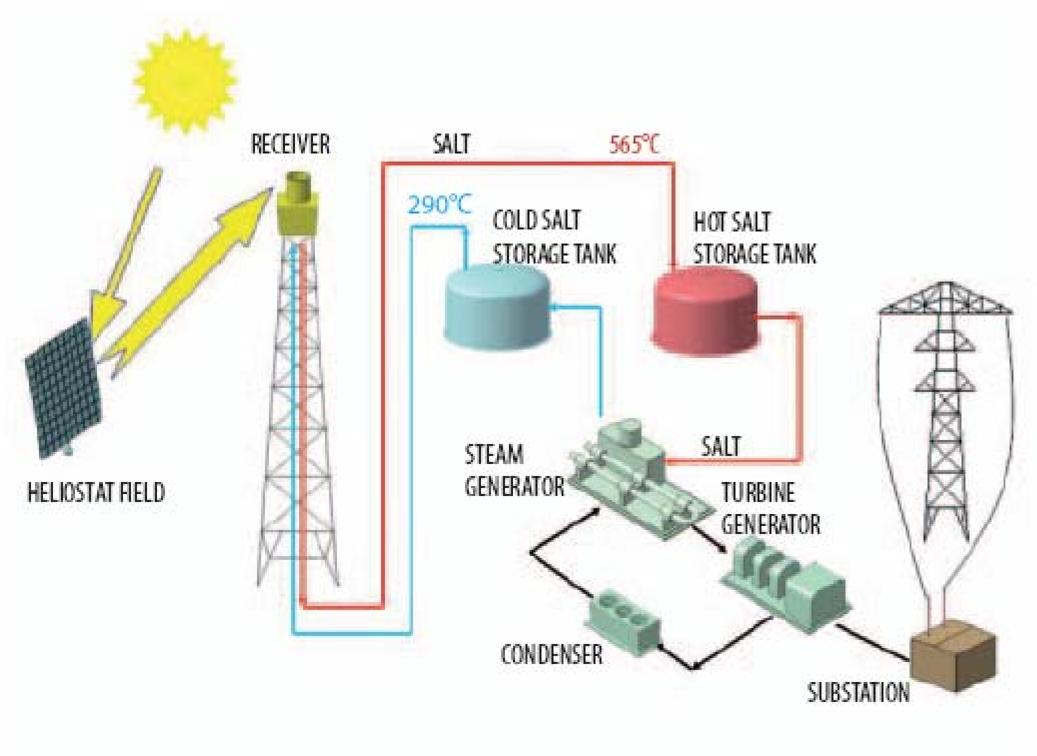
As mentioned this technology can together with PV develop to be the main technology for electricity in Oman and even give the basis for export. The potential for production of solar energy is more or less independent on the season in Oman with a slight decrease in winter time. The consumption is higher in summer due the need for air condition. It is too costly to oversize renewable energy systems to be able to supply 100 % renewable energy. It is therefore feasible to export the surplus production in the winter to Europe where the need is highest in winter. Seasonal storage can only be considered on the very long term.

Demonstration projects under construction today with this technology is about 10 to 50 MW but it is expected that the future optimum size will be much higher, perhaps 200 or 300 MW.

A Concentrating Solar Power plant should be located in the desert not too far from the coast and sufficient main grid. Water is needed for cooling and for desalination as well as for cleaning of panels. Another important aspects is to consider the delivery of the desalinated water which need to be piped.

The SOLAR TRES plant under development in Spain is interesting for Oman. It is a system with central receiver (tower) and heat storage in molten salt with a cold and hot tank. The storage is for 15 hours of operation and the system can also be supplemented with a gas boiler. See Fig. 5.8.

Fig. 5.8 The SOLAR TRES concentrating Solar Power plant under development in Spain. Ref /15 /.



SOLAR TRES – DESIGN FEATURES	
Location	Ecija, Spain
Receiver thermal power	120 MW
Turbine electrical power	17 MW
Tower height	120 m
Heliostats	2,480
Surface of heliostats	285,200 m^2
Ground area covered by heliostats	142.31 ha
Storage size	15 hr
Natural gas boiler thermal capacity	16 MW
Annual electricity production (min.)	96,400 MWh
CO_2 mitigation (best available technology)	23,000 ton/year
CO_2 mitigation (coal power plant)	85,000 ton/year

Fig. 5.9 Main data for the SOLAR TRES concentrating Solar Power plant under development in Spain.

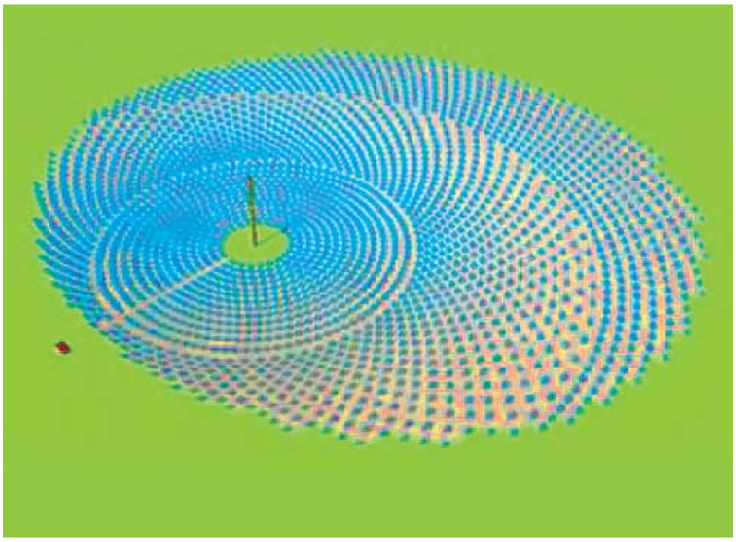
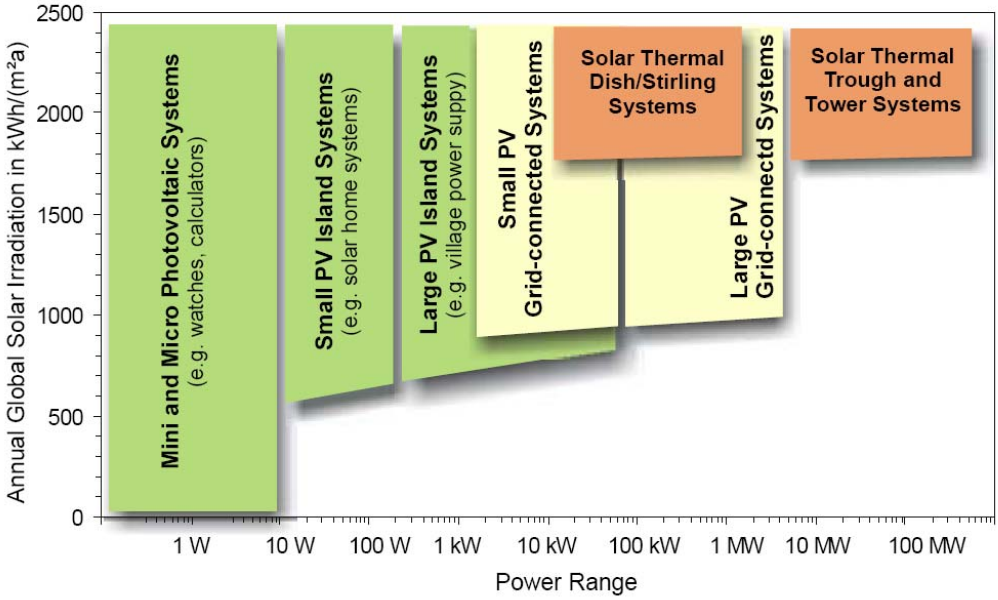


Fig. 5.10 The SOLAR TRES concentrating Solar Power plant under development in Spain. View of the mirrors. Ref /15/.

Applications

The typical applications of solar energy systems are illustrated in Fig. 5.11. Off grid PV systems are typically in the range between few W and up to 100 kW. Grid connected PV systems are typically in the range between few kW and up to 10-20 MW. Solar thermal power plants are only relevant where the solar insolation is high. According the Fig. 6.11 solar thermal power is applicable in Oman having a solar insolation of about 2200 kWh/m2 per year. It also appears that solar thermal plants are preferred for large capacity.

Fig. 5.11 Application of solar thermal power plants and photovoltaic systems as function of the installed capacity and the annual global solar insolation, Ref /16/.



Examples of applications in

- large cities connected to national grid
- in rural off grid large cities with a number of diesel units for production of electricity
- in rural small villages and in isolated settlements
- in desert areas

Solar energy can in principle be used for desalination in two ways, with PV electricity for a reverse osmosis process and in a number of ways where heat is used to evaporate the water in a distillation process. Another heat source can be used in this respect for example from conventional power production, a steam cycle or a diesel engine. Further data is needed to analyse this.

Electricity generation

The technical potential for electricity generation by grid connected PV systems is determined by the area suitable for installation of PV cells (e.g. on buildings, parking areas etc). Assuming that 50% of the houses in Oman are suitable for installation of PV cells and the area available at each house is 20 m^2 in average the total potential area for installation of PV cells on houses is 4,250,000 m^2. This area of PV cells corresponds to a potential annual electricity generation of 750 GWh/year and an installed capacity of 420 MW, or about 15% of the total capacity today. On top of that PV can be located in the desert. Typical capacity per m^2 of land is about 30 Wp (Watt peak) corresponding to 30 MWp per km^2.

In the long term perspective the theoretical potential for electricity generation by Concentrating Solar Power (CSP) systems in Oman is huge. CSP plants with storage for supply of electricity as conventional power plants will require 1 km^2 of land use for 10 MW capacity. Theoretically it is possible to supply Oman's present consumption of 13,100 GWh by utilising about 280 km^2 of the desert for solar collectors, corresponding to 0.1 % of the area of the country.

The technical potential for electricity generation by PV systems operating with diesel gen-sets and battery storage capacity in isolated off-grid power systems is assumed to be 20% of the present electricity generation. This corresponds to 70 GWh/year and a solar PV capacity of 40 MW. By using a fraction of 20% a major part of the generated electricity can be used directly and only a minor part has to be stored.

The potential for utilising PV cells as power supply for small equipment and lighting is large. Presently the oil industry has PV cell capacity available for operation of small equipment in remote areas. Due to the small capacity of this type of power supply the total potential for this type of solar power supply is relatively small.

Economic key figures

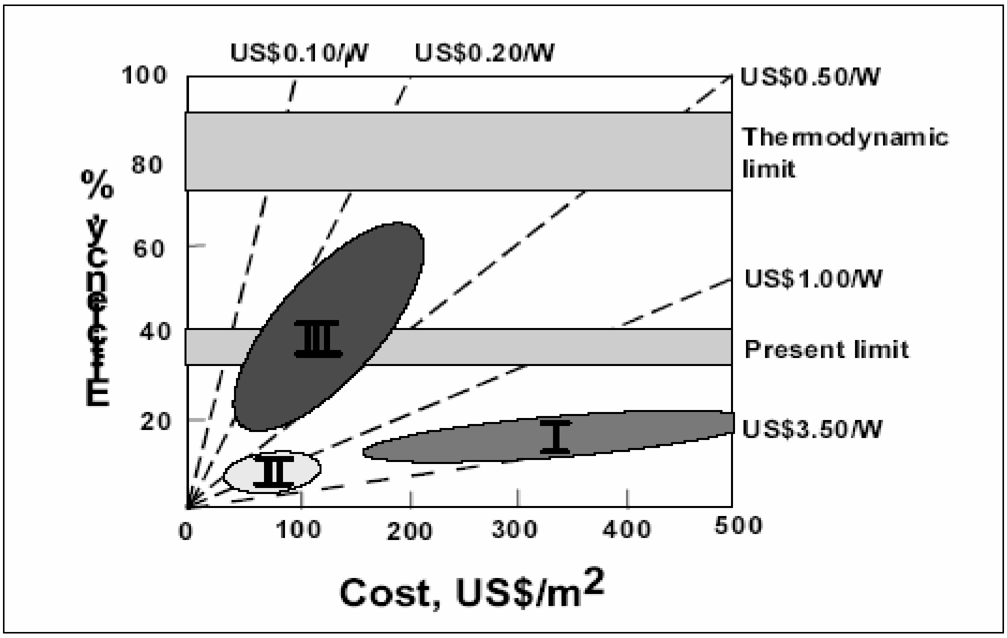
Solar PV

A typical way of showing cost projections for solar PV has three generations of solar PV, see below Fig. 5.12. The present stage of development is stage II, the second generation, where the cost is reduced considerably compared to first generation. The efficiency has also dropped due to introduction of thin film PV. During this decade, up to 2010 it is expected that the cost will decrease further and thin film PV will take over. In the next decade, up to 2020, it is expected that III generation PV cells with much higher efficiency will be further developed and commercialised. This generation is based on multilayer cells, the higher efficiency is important in order to reduce cost of material for the panel as well as for support structures.

The life time of solar PV panels is 25 years. Other minor component in a solar PV system such as converter, batteries etc. have shorter life time approximately between 5 - 15 years.

This development will bring the cost below 0.5 USD per installed W which will make PV directly competitive on the grid making PV the first choice for roof cover material worldwide.

Fig. 5.12 Efficiency and cost of the three generations of solar cells. I is wafers. II is thin-films and III is advanced thin-films. Cost in 2007 USD. Ref /17/.

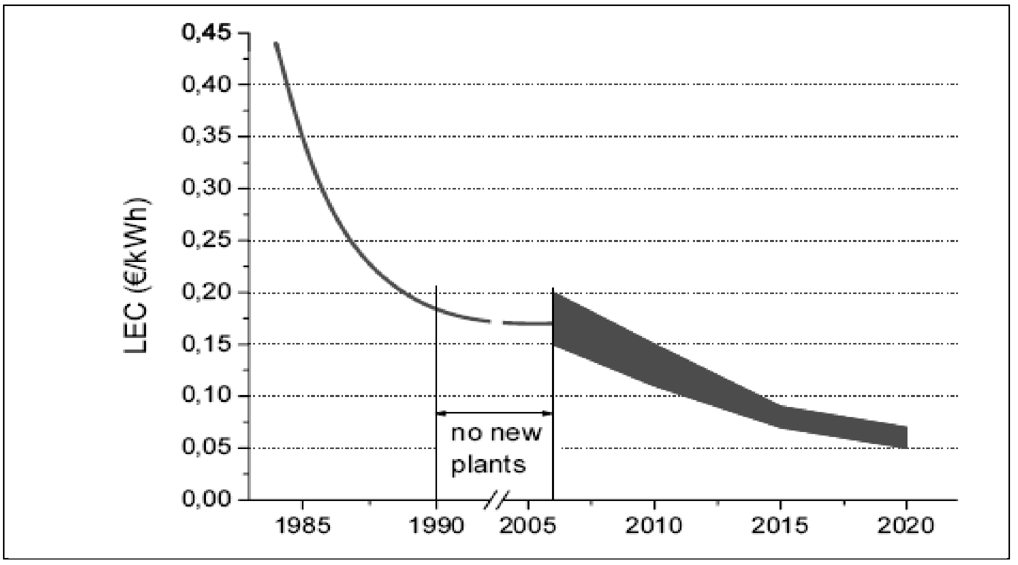


- Typical installation cost 5000 to 10000 USD/kW
- Current energy cost 0.25 to 1.60 USD/kWh (for Oman the low value)
- Future energy cost, down to 0.05 USD/MWh

Solar thermal plant

Fig. 5.13 shows a typical learning curve for CSP solar thermal power plants in Euro per kWh, Ref /17/. Today the levelized cost is about 0.15 Euro per kWh corresponding to about 210 USD per MWh.

Fig. 5.13 Learning curve for expected levelized cost of solar thermal power. Cost in Euro per kWh. Ref /18/.



- Typical installation cost 2500 to 6000 USD/kW
- Current energy cost 0.12 to 0.34 USD/kWh
- Future energy cost, down to 0.04 USD/kWh

At present the levelized cost of CSP power varies from 120 to about 210 USD per MWh for a location like Oman. The low cost is for combined plants where most of the power is by gas and the high cost for those with solar only. As it appears from the above learning curve a significant cost reduction is expected over the coming decade, bringing the cost down to well below 100 USD per MWh.

Solar heating collectors

Solar thermal energy, solar collectors for heating of water, is a fairly developed technology. At present China is developing the production capacity for the vacuum collectors rapidly and has established effective production lines. But solar thermal collectors are still not mass produced in the same way as consumer goods and there is still space for large cost reductions.

- Typical installation cost 300 to 1700 USD/kW
- Current energy cost 0.02 to 0.25 USD/kWh (Oman in the low end)
- Future energy cost 0.02 to 0.01 USD/kWh

It is important to notice that already today the cost of producing heat by solar is much lower than the cost of producing electricity and use this for heating of water.

Advantages/disadvantages

The advantages and disadvantages for solar thermal power plants and large PV plants are compared in below Table 5.1.

Table 5.1 Advantages and disadvantages for solar PV and CSP

Solar PV		CSP - Concentrating Solar Power	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Low or no pollution	The high cost at present.	Low or no pollution	The high cost at present
Very flexible from small to very large plants.	Only produce electricity when the sun is shining.	Can be made with heat storage to supply electricity constantly as a base load plant.	Only for larger plants, in the future more than 100 MW or perhaps 200 MW.
Cost reductions expected to make PV directly competitive to conventional power sometimes with in the next few decades.	Electricity is produced directly and electricity is difficult (expensive) to store.	Cost reductions in the same magnitude as for PV expected or possible.	Certain parts (storage and heat transfer media) still under development.
Used off grid as well as on-grid.		Suitable for desert location.	Longer implementation time than PV.
Can serve other purposes if integrated into buildings, shading, roofing etc.		Excess heat from power production can be used for desalination.	Uses only direct radiation. Potential converted percentage of solar insolation lower than with PV. But excess heat can be used.
Feed into the grid in urban areas give less losses.			
Proven technology with long life time			
Low maintenance and simple to apply.			

5.3 Biogas production

Energy conversion principle

Organic matter in effluent water from sewage treatment plants and other biomass (e.g. organic household waste or waste from food industry or manure/dung from animals etc) is converted biological to biogas by bacteria under anaerobic conditions i.e. without presence of oxygen. Ideally the substance processed should have an organic content of about 8-10% weight VS (volatile solids) which is max. for pumping, but plants are seen with operation up to 30% VS (dry process) and down to 2-3% VS (biofilter plants).

The degassed material can be used as fertiliser and soil conditioner, provided that it does not contain to high content of environmental harm full substances.

The biogas produced consists of 60-70% CH_4 (Methane) and 30-40% CO_2 (Carbon Dioxide) plus traces of other gasses hereunder H_2S (Hydrogen Sulphide) typically 300-3000 PPM, which smells and is poisonous. The process temperature is typically 35^oC or 52-55 ^{o}C. At high temperature the process is faster but also more sensitive and less reliable.

Biogas can also be extracted from old landfills with large depths and more than 200,000 tonnes tipped. But the production of landfill gas is very dependent on the composition of waste and age of the landfill and the principles of operation.

Applications

The production and utilisation of biogas can be based both on small and large plants.

Maximum size is in the range of 30,000 Nm^3 biogas per day delivered at a constant level. The size of plant possible is normally limited by the amount of organic waste available. Gas production is normally in the range of 25-60 Nm^3 per m^3 raw material.

The biogas with 65% CH_4 has a lower calorific value (LCV) of about 23 MJ per m^3. Landfill gas has normally only 40-60% CH_4 due to some 10% mixture with air.

Parasitic energy demand is about 2.8 MJ per m^3 and 0.14 kWh electricity per m^3 biogas produced.

The gas can be used directly for heating purpose e.g. production of hot water or steam for industry. The gas can also be cleaned and compressed for use in vehicles, e.g. waste lorries, taxies, busses, normal cars etc. Finally the gas can also be fed into gas distribution pipes and used several kilometres from site of production.

Technology

Biogas technology is considered well proven and fully commercial and developed technology for the wet processes, but for semidry and dry processes used for processing organic household waste, the experience is mixed with room for improvements.

Most reliable and economical plants are anaerobic sewage treatment plants where additional organic matter can be added.

If a landfill is considered for extraction of gas, then drills and test pumping is needed to evaluate the potential of construction.

Electricity generation

Gas can after little cleaning be used in a gas-engine to produce electric power preferably in combination with utilisation of the surplus heat i.e. in a CHP combined heat and power plant.

In a gen-set utilising biogas about 40% electricity can be gained from the energy content in the gas. Overall efficiency for heat and power depends on the cooling of the flue gasses, but can be up to about 90%.

Economic key figures

Biogas plants are expensive and are normally only built for solving an environmental problem.

The investment costs is about 315 - 940 USD per m^3 biogas produced per day and the yearly O&M cost is about 62 USD per m^3 biogas produced per day (1995 cost level). Technical lifespan is about 20 years.

Advantages/disadvantages

Advantages

- caption of biogas containing CH_4 (CH_4 has a high impact on climate change)

Disadvantages

- Biogas smells, is toxic and is highly explosive (Traditional proper precautions must be taken in order to avoid hazards in the operation).
- Risks for emissions of TOC, CH_4, CO and NO_x

5.4 Wave energy absorption units

Energy conversion principle

A wave energy absorption unit utilises the kinetic and the potential energy of the sea waves. The power content in the waves is proportional with the square of the wave height multiplied by the wave length. In principles there are three different types of utilising the wave energy.

One type utilises the vertical movement of the water surface. A floating device absorb the vertical movement and transform this movement into a rotation.

Another type is based on sluicing the water. By this mechanism the potential energy of water is collected and stored. By letting the stored water fall through a turbine the potential energy is converted into rotational energy.

Third type is based on oscillating of an air column. The variation of the water level due to the waves actuate an air column in a chamber. The fluctuating air column acts on a rotor which absorbs the kinetic energy in the air and transform this into a rotational movement.

In all the types the movement of the rotational movement is converted into electricity by a generator.

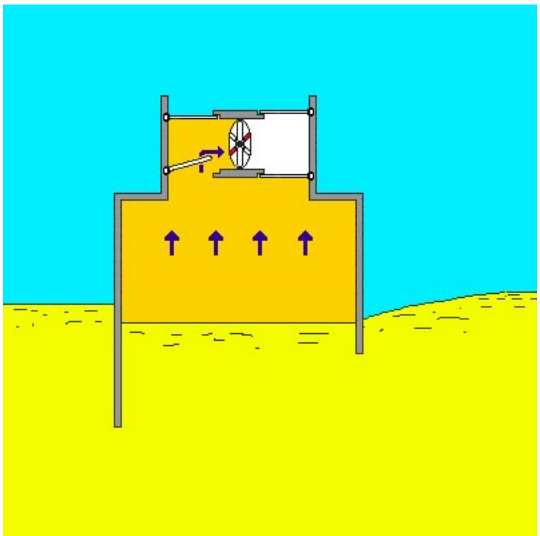
Technology

A number of different wave energy absorption concepts have been designed and tested as prototypes. Examples of tested concepts representing each of the three types are illustrated below.

Fig. 5.14 System utilising vertical movement of the water.

Fig. 5.15 System based on sluicing water

Fig. 5.16 System utilising fluctuating air column



Test results regarding the reliability of such systems in operation under real ocean environmental conditions are still collected. According to achieved experiences the main challenge is to design the wave energy units to withstand the environmental impact in the sea water.

Commercially available systems with documented successful long term track records are not yet available on the market. Thus this technology is still considered as being at the development stage even recent performance test results are promising.

Applications
The rotational energy generated by a wave energy absorption unit is used for electricity generation. The generator is installed as an integrated part of the wave energy absorption unit. The generated electricity is transmitted to the shore via a sea cable.

The power is fed to the main grid on land.

Electricity generation
The test results of prototype systems indicate that the efficiency of wave energy absorption systems is approximately 10 %, Ref/10/. The efficiency of the conversion to electricity is in the order of 80 %. Thus the total net overall efficiency is in the order of 8 %

The wave energy flux in the Arabian Sea is 17 kW/m. At this energy flux the net annual energy production by a wave energy system in the Arabien Sea is 15 MW/m/year. The production by a system installed closer to the Omani coast will generate less energy.

Economic key figures
According to the example in Ref /19/ the installation cost per kW installed capacity is approximately 2,800 USD/kW.

Advantages/disadvantages
Advantages

- no land requirement for installation of the plant
- no visual impact in the landscape

Disadvantages

- difficult environment to perform maintenance

5.5 Geothermal power plants

Energy conversion principle

Geothermal heat originates from weak radioactive activity of volcanic activity in the underground. The temperature in the ground normally raise with 30^{o} C per kilometres depth meaning that a borehole normally need to be more than 3 km in order to be able produce steam or superheated water, that can be used to drive a low pressure steam turbine or other equipment.

If volcanic activity is present usable heat at higher temperature and less depth will be available.

Technology

The water from geothermal wells is normally extreme saline and contains many salts solutions, particles and compounds. Clogging and corrosion problems are therefore often seen and need to be considered. Used water from the geothermal well can be drained off or re-infiltrated in the ground, which also can create problems with clogging of re-infiltration wells.

Applications

Geothermal is used in different applications depending on the temperature of the soil water.

In a temperature range between 60^{o} C and 100^{o} C the energy can be used for district heating. Via a heat exchanger the energy content in the hot water from the well is transferred to the circulated water in the district heating system.

In a temperature range between 100^{o} C and 170^{o} C the energy can be utilised for electricity generation. The heat from the hot water is transferred through a heat exchanger to another liquid with a low boiling point and is used for electricity generation in a power plant.

At temperatures above 170^{o} C the hot water can be utilised directly in steam plants after the water is cleaned. When the hot water is pumped up from the underground the pressure decreases and the water is transferred into steam.

The hot water could also be used to desalinate seawater in thermally driven desalination systems based on vapour compression cycles. This implies that the well is located close to the coast line.

Electricity generation

If steam is generated from the well, it can be used to drive a low pressure condensing steam cycle to generate electricity at low efficiency depending

An alternative is to use an ORC plant (Organic Rankine Cycle), which would be able to produce electricity based on superheated water of around 120^{o}C with an electricity production of typically 8-12% electricity of the incoming energy before subtraction of pumping energy for the wells. Pumping energy has to be considered from case to case. It is not unusual that electricity consumption for pumping energy amounts to 5-10% of the usable heat in the well water.

Economic key figures

The cost of pre-investigations is high unless needed data are already available from the oil industry.

If clogging or corrosion problems occur then the O&M costs can be considerable. Size of plants is typical around 15 MW thermal and above. Investment costs for a 15 MW thermal plant is about 50 mill USD.

If the used well water is re-infiltrated at same depth as the filter of the production well, then the environmental impact is very little.

Advantages/disadvantages

Advantages

- steady power supply

Disadvantages

- saline hot water may have negative impact on the environment

5.6 Non energy benefits

The potential renewable energy (at least wind and solar) technologies analysed in this report will all replace natural gas (in MIS and Salalah) or diesel (in RAECO) as fuels. Renewable energy projects have zero green house gas emissions so the replacement will result in a reduction of the emissions of CO_2.

Key to the carbon emission reduction is the properties of the various fuels analysed. The table below summarizes these properties as defined by the UN's International Governmental Panel on Climate Change (IPCC).

Table 5.2 shows the assumed fuel properties and the carbon content per unit. The top four rows shows 'clean' contents of the fuels, while the last four shows the carbon content in electricity production assuming 10% T&D losses and the efficiencies indicated.

The column Carbon Content per MWh shows the carbon emission per MWh electricity replaced by carbon neutral renewable energy production. The most interest in the Oman context is mainly natural gas and to a smaller extent diesel. As the table shows carbon emission the emissions from natural gas are comparable smaller than for HFO, diesel and coal. These values are used latter in the study to calculate the potential carbon emission reductions.

Table 5.2 Assumed Fuel Properties and carbon emissions

Fuel type	Heat Content	IPCC Carbon Content	Carbon emission per MWh consumed	Efficiency in use
Coal, high-grade*	28 MJ/kg	25.8 tC/TJ		
Fuel oil	40.3 and 42 MJ/L	21.1 tC/TJ		
Natural gas	40 MJ/Nm^3	15.3 tC/TJ		
Diesel	50 MJ/L	20. tC/TJ		
Electricity - Gas fired	3.6 MJ/kWh	48.7 tc/TJ	175 kg/MWh	34%
Electricity - Fuel Oil Fired	3.6/kWh	61.7 tC/TJ	222 kg/MWh	38%
Electricity - Coal fired	3.6 MJ/kWh	86.9 tC/TJ*	312 kg/MWh	33%
Electricity - Diesel	3.6 MJ/kWh	59.0 tC/TJ	212 kg /MWh	38%

5.7 Energy efficiency

Renewable energy should always be seen together with efficient use of energy as the cost of supply is expensive and efficient use therefore important. Ideally energy efficiency should have a priority until the cost of saving equals the cost of producing. For Oman probably the most important in this respect is standards and requirements related to cooling, insulation of flat roofs and walls, improved windows and shading is essential. It also includes labelling, requirements for periodic mandatory check, standards etc. The European Unions actions in this respect can be used as an inspiration. These aspects is not included into the present study but should always be kept in mind.

6 Cost of electricity generation in Oman

In this section we compare the cost of electricity generation using conventional fossil fuel generation technologies to the cost of electricity produced using renewable energy technologies.

The methodology used is levelised cost and the comparison focuses on Long Run Marginal Costs (capital, fixed and variable o&m, fuel costs and financing costs).

6.1 Generation based on conventional fuels

6.1.1 Investments in new power capacity

Investments in the power market/sector are typically connected with the following characteristics:

- Investments require much capital;
- Investments are long-term investments;
- The time from plant decision until the plant is ready for operation is long (particularly for major thermal power plants);
- The market/sector is heavily influenced by political conditions (taxes, regulation etc.) which normally change over time.

This means that calculations on new investments are often connected with large uncertainties. During a 20-30 year period, which is a typical investment horizon for a power plant, substantial changes may occur in the market/sector. The main risks for generators are the uncertainty about fuel and electricity prices, and the risks of increased environmental restrictions or other restrictions from the regulators. The higher risk there is in the market/sector, the higher risk premium the investors or project developers will take, and the higher electricity prices the consumers will have to pay (assuming that the electricity prices are based on market prices).

In order to estimate the feasibility of investments in new power capacity, it is necessary to have an overview of the expected annual income and costs. The main income comes from sale of electricity, whereas a supplementary income may come from sale of system services (e.g. voltage regulation) or from sale of by-products (e.g. gypsum from de-sulphuring equipment). These supplementary income source are not considered here.

The main costs include the following elements:

- Fuel costs;
- Environmental costs, e.g. taxes;
- Variable O&M costs;
- Fixed O&M costs;
- Investment costs.

In order to evaluate an investment, the investor or project developer has to set up requirements to the investment horizon and to the rate of return. A typical investment horizon in the power sector is 20-30 years, which in some cases is shorter than the actual life time of a new plant. The cost estimates in the following sections are the levelised cost of the total life of the investment. A typical required rate of return including risk premium is 10%. In this study a discount factor of 7.55% p.a. is used as agreed with the Authority. In some cases sensitivity calculations with discount rates from 5 to 13% p.a. have been made.

6.1.2 Short- and long-term marginal costs

When estimating costs, it is relevant to differ between short- and long-run marginal costs. The short-run marginal costs include only variable costs such as fuel costs and variable O&M costs (including environmental taxes, if any). In addition to this, the long-run marginal costs include capital/investment costs and fixed O&M costs.

In this section, the short- and long-term marginal costs for new generation capacity based on fossil fuel are estimated: for two different gas technologies, one HFO technology, and one coal technology. This comparison is the most relevant in terms of deciding if renewable energy should be included in the future fuel mix. However, in order to determine the financial impact on the subsidy expenditure in Oman current average cost in the power production of Oman is also considered at the end of this section.

The long-term marginal costs are estimated assuming an annual number of full load hours of thermal power plants of 5000 and 7500 hours, respectively. Table 6.1 below shows the main assumptions and the calculated marginal short- and long-run costs for the four different plants/technologies.

The assumed price used is 1.5 USD MMBtu (595 USc/Gcal), the crude oil price 50 USD/barrel and the coal price 62.45 USD per ton.

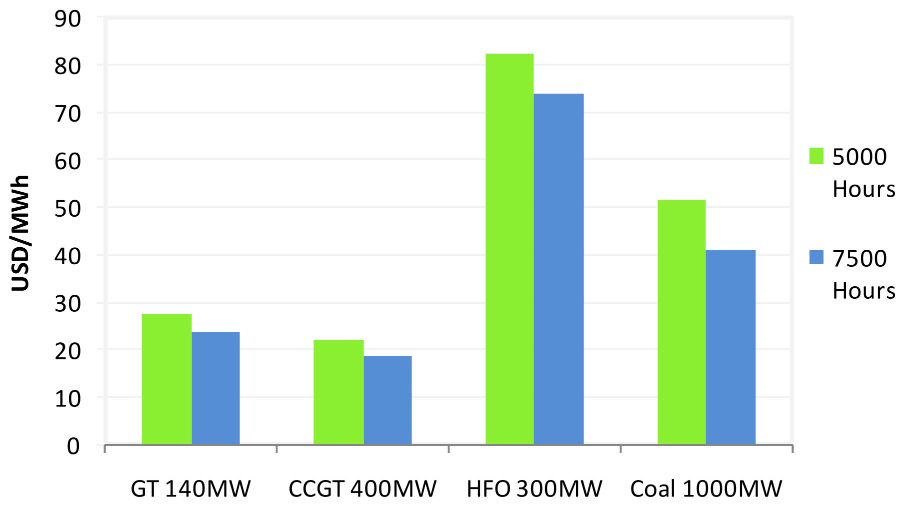
Table 6.1 Assumptions and calculation of short- and long-term marginal costs, USD /MWh -low gas price (595 US c/Gcal)

	Gas turbine, 140 MW	Combined Cycle, 400 MW	HFO Steam, 300 MW	Coal Steam, 1000 MW
Power capacity, MW	140	400	300	1000
Economic Lifetime, years	25	25	30	30
Investment costs, million USD	45	184	289	1640
Specific investment costs, million USD/MW	0.32	0.46	0.96	1.64
Fuel efficiency, %	33.9%	48.4%	38.2%	38.0%
Fuel costs, US c/Gcal	595	595	2519	880
Variable O&M costs, USD/MWh	0.55	0.70	0.80	0.05
Short run marginal costs, USD/MWh	15.64	11.28	57.50	19.97
Fixed annual O&M costs, USD Mill	4.26	5.04	12.65	18.60
Annual capital/investment costs, USD Mill	4.09	16.58	24.59	139.54
Long run marginal costs, USD/MWh (5.000 h)	27.57	22.09	82.33	51.59
Long run marginal costs, USD/MWh (7.500 h)	23.59	18.49	74.05	41.05

It appears from the table that short-run marginal costs at the conventional gas plants differ from around 11 USD/MWh to 16 USD/MWh. The short-run marginal costs are lowest for the combined cycle plants because these plants have larger fuel efficiencies than the gas turbines. With the assumed oil and coal prices conventional gas plants have the lowest economic cost.

The results with respect to long-run costs are shown in Fig. 6.1.

Fig. 6.1 Long-run marginal costs for conventional technologies (two annual full load hours scenarios) - Low Gas Price



The assumed number of annual full load hours influences long-run marginal costs. Increasing the assumed number of full load hours per year from 5000 to 7500, acts to reduce the long-run marginal cost per unit.

The long-run costs of the gas turbine are least sensitive towards number of full load hours because this technology has the lowest specific investment costs. If the annual number of full load hours was decreased to below approximately 2000 hours, the long-run costs for the gas turbines would be lower than for the combined cycle plants. This is one reason why gas turbines are suitable as peak load units with only few operational hours per year.

The tables 6.2 and 6.3 below show the short- and long-run marginal costs, if fuel prices were 3 USD per MMBtu and 6 USD per MMBtu. The low gas price (1.5 USD per MMBtu) corresponds to the price currently charged the power plants, i.e. actual cost, not economic costs. Economic costs are assumed to be 3 USD/MMBtu with a depletion premium of 3% p.a. Table 6.2 shows the marginal cost with a natural gas price of 3 USD/MMBtu and Table 6.3 the cost with a natural gas price of 6 USD/MMBtu.

Table 6.2 Assumptions and calculation of short- and long-term marginal costs, USD /MWh -(medium gas price 1190 US c/Gcal)

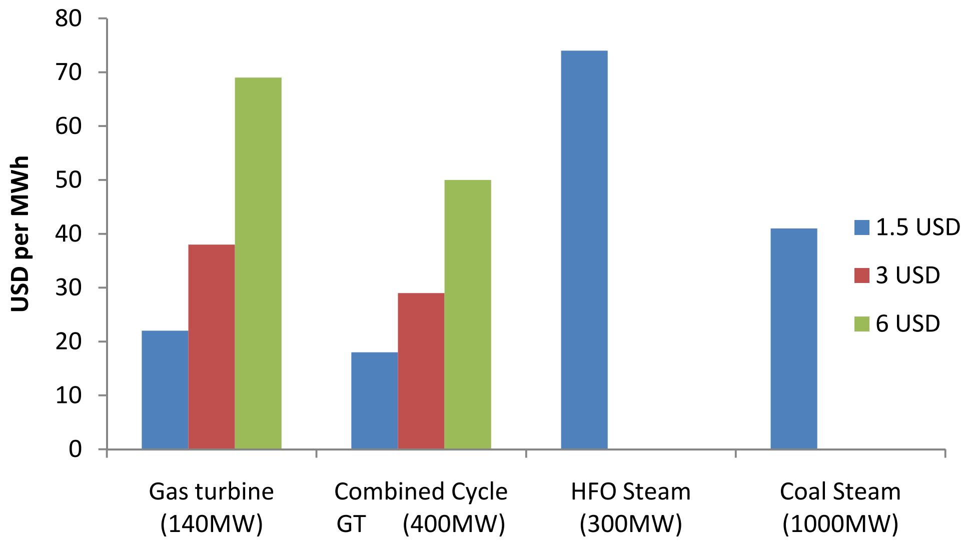
	Gas turbine, 140 MW	Combined Cycle, 400 MW	HFO Steam, 300 MW	Coal Steam, 1000 MW
Fuel costs, US c/Gcal	1190	1190	2519	880
Short run marginal costs, USD/MWh	30.73	21.86	57.50	19.97
Long run marginal costs, USD/MWh (5.000 h)	42.66	32.67	82.33	51.59
Long run marginal costs, USD/MWh (7.500 h)	38.68	29.06	74.05	41.05

Table 6.3 Assumptions and calculation of short- and long term marginal costs, USD /MWh - (high gas price (2380 US c/Gcal)

	Gas turbine, 140 MW	Combined Cycle, 400 MW	HFO Steam, 300 MW	Coal Steam, 1000 MW
Fuel costs, US c/Gcal	2380	2380	2519	880
Short run marginal costs, USD/MWh	60.91	43.02	57.50	19.97
Long run marginal costs, USD/MWh (5.000 h)	72.84	53.83	82.33	51.59
Long run marginal costs, USD/MWh (7.500 h)	68.86	50.22	74.05	41.05

The results are summarised in comparing the long run marginal cost of the two conventional gas technologies, and different gas prices, with conventional HFO and coal technology.

Fig. 6.2 Long run marginal cost of generation with conventional gas technology and varying gas price.



Note: All technologies 7500 annual full load hours

Average Generation Cost in Oman

The current average generation cost for MIS and Salalah can been found in Ref /20/, Oman Power and Water Procurement, annual Report 2006.

Fig. 6.3 Average cost of generation in Oman by plant 2006

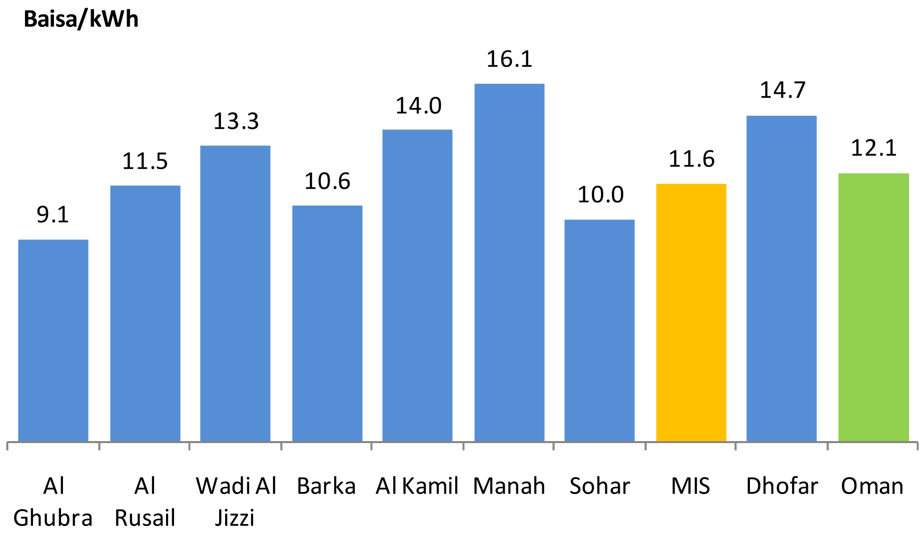


Figure 6.3 shows the average cost in 2006 by power plant. There are large variations between the plants with Manah and Dhofar as the most expensive and Al Ghubra and Barka having the lowest cost. The average for the country, excluding RAECO, is 0.031 USD/kWh. 50% of the average costs are fuel cost, and natural gas is currently supplied at the price of 1.5 USD/MMBtu to the power plants on long term contracts with duration of 15 years.

6.1.3 Diesel power plants

Method and assumptions

Power generation in RAECO' s are is mainly diesel based. The price of diesel is 146 Baiza/Litre, corresponding to 0.38 USD per Litre.

Production cost of existing capacity

The average generation costs in RAECO have been calculated by The Authority to 0.21 USD/kWh in 2006. The cost variation is large and the highest recorded costs were 0.67 USD/kWh and even higher at some locations with little production, as can be seen in Appendix 10.

Because of the dispersed population in the rural areas the production cost per unit are significantly higher than those of the MIS and Salalah systems. The higher cost improves the competitive position of renewable energy, and in order to find suitable candidates a list of the cost at various plants is provided in Appendix 10. The data is based on information for Jan to June 2006 and full year 2006.

Production cost of new diesel capacity

The calculation of the production cost for a new diesel capacity has been based on the assumed that the capacity is 1 MW and the operation hours is 5000. Costs of generation in diesel plants are very dependent on the number of operating hour, due to the high fuel and other variable cost.

It has further been assumed that the efficiency is 38%. The data for this calculation is based on World Bank Energy Unit Discussion Paper: 'Technical and Economic Assessment: Off-grid, Mini-Grid and Grid Electrification Technologies' from November 2005, Ref /21/. Prices are updated to 2007 level with adding 6.09%.

Table 6.4 Assumptions for calculation of new diesel capacity, Ref /21/

Item	Value		Comment
Capacity	1.0 MW	1.0 MW	
Capital Cost	0.6 Mill USD	0.6 Mill USD	
O&M Cost Fixed	0.1 Mill USD	0.1 Mill USD	
O& M Cost Variable	30 USD/MWh	30 USD/MWh	
Fuel cost	4450 USc/Gcal	4450 USc/Gcal	146 Baiza/Litre diesel
Operating hours	5000 hours	3000 hours	
Power Production (Useful)	5000 MWh	3000 MWh	
Efficiency	38%	38%	
Lifetime	30 years	30 years	
Discount Factor	7.55%	7.55%	
Short Run Marginal Cost	130.7 USD/MWh	130.7 USD/MWh	
Long Run Marginal Cost	160.9 USD MWh	181.1USD MWh	

Table 6.4 shows the results of this calculation. Long Run Marginal Cost of new diesel capacity is estimated to 160.9 USD/MWh at 5000 operating hours and 181.1 USD/MWh at 3000 operating hours.

6.2 Generation based on renewable energy

The production cost of electricity based on the solar and wind energy resources in Oman has been calculated for four specific types of plant:

- 20 kW grid connected solar PV plant
- 20 MW grid connected solar PV plant,
- 20 MW grid connected solar thermal plant
- 10kW off grid PV-diesel plant
- 20 MW grid connected wind farm

6.2.1 Small grid connected solar PV plant, 20kW

Description of the technology and the solar insolation assumptions regarding a small grid connected solar PV is described in Appendix 12. This application is foreseen to be implemented in an urban environment and comprises 200 m^2 conventional panels. It is an end-user application and replace electricity from the grid at the customer level. In terms of comparison of cost it should therefore be compared with the end-user tariff (Permitted Tariff). The result of the cost calculation is shown below in Table 6.5. The costing and optimisation of the application is made in HOMER -Version 2.19 and summarised in Appendix 12.

Table 6.5 Cost data for Solar PV plant - 20 kW

Item	Value
Capacity	0.02 MW
Capital Cost	0.15 Mill USD
O&M Cost	0.001 Mill USD per year
Power Production (Useful)	34 MWh
Lifetime	25 years
Discount Factor	7.5%
Short Run Marginal Cost	0
Long Run Marginal Cost	425 USD/MWh

The Long Run Marginal Costs are estimated to 425 USD/MWh.

6.2.2 Large grid connected solar PV plant, 20 MW

Description of the technology and the solar insolation assumptions regarding a large grid connected solar PV is described in Appendix 8, including detailed cost estimate.

This application is in principle identical to the previous, except for the capacity scale. The panels will cover an area of about 200 000 m^2 and be among the largest in world. The application will supply the grid and is the result of the cost calculation is shown below in Table 6.6. The cost calculation is made in HOMER-version 2.19.

Table 6.6 Cost data for a new grid connected PV plant - 20 MW

Item	Value
Capacity	20 MW
Capital Cost	89 Mill USD
O&M Cost	0.5 mill USD per year kWh
Power Production (Useful)	36 GWh/year
Lifetime	25 years
Discount Factor	7.5%
Short Run Marginal Cost	0
Long Run Marginal Cost	250 USD/MWh

The Long Run Marginal Costs are estimated to 250 USD/MWh for this application.

6.2.3 Solar thermal plant, 20 MW

The economic calculation for the Solar Thermal plant in below table 6.7 is valid for a plant without storage and with data from Ref /15/ and Ref /22/. There are a number of plants under construction which includes storage of up 15 hours capacity. The solar TRES plant mentioned in chapter 5 (fig 5.9) is planned to generate 96 GWh of electricity per year with an investment cost not much higher than in the example below.

Table 6.7 Solar Thermal Plant - 20 MW

Item	Value	Comment
Capacity	20 MW	
Collector Area	130 000 m^2	
Capital Cost	72.5 Mill USD	3.6 USD/W, includes connection cost to transmission system
O&M Cost	0.8 mill USD per year	
Solar insolation	2 200 kWh/m^2	
Power Production (Useful)	35 GWh/year	
Lifetime	25 years	
Discount Factor	7.5%	
Long Run Marginal Cost	207 USD/MWh	

The economic result depends on the lifetime of the plant, which is estimated to 25 year. Assuming a life time of 40 years, and a discount rate of 4% the economic cost of Solar Thermal Plane is 126 USD/MWh.

6.2.4 Small off-grid solar PV -diesel system, 10 kW

The system is configured with one10 kW diesel engine, 2 kW PV and 50 batteries with a storage capacity of about 25 kWh. The key figures in the cost calculation are shown below in Table 6.8.

Table 6.8 10 kW off grid solar PV system

Item	Value	Comment
Capacity	0.01 MW	
Capital Cost	32 800 USD	
Capital Replacement Cost	1900 USD per year	Lifetime varies per item
O&M Cost	4 600 USD per year	
Power Production (Useful)	78 MWh year	
Lifetime	15 - 25 years	Varies by item in the system
Diesel Price	146 Baiza per Litre	
Discount Factor	7.5%	
Short Run Marginal Cost	127 USD/MWh	
Long Run Marginal Cost	245 USD/MWh	

The Long Run Marginal Costs are estimated to 245 USD/MWh. Approximately 5% of the electricity produced by the system will be solar.

6.2.5 Grid connected 20 MW wind farm

Method and Assumptions

The following Table 6.9 shows the assumptions regarding the construction costs for a 20 MW wind farm in Oman. It has been assumed that the construction costs are independent of the wind farm site.

Table 6.9 Construction cost of a 20 MW wind farm in Oman

	Mill USD		USD
Item	Unit price	Quantity	Amount
WIND TURBINE			
Wind turbine, 2.0 MW	3.00	10	30.0
Monitoring system	0.20	1	0.2
CIVIL WORKS			
Wind turbine foundation	0.15	10	1.5
Access roads (5 km)	0.30	1	0.3
Control room, facilities	0.50	1	0.5
ELECTRCAL WORKS			
Main substation	1.00	1	1.0
Feeder	0.05	4	0.2
Transformer	0.30	15	4.5
Distribution net work	0.50	1	0.5
OTHER COSTS			
Insurance	0.10	1	0.1
Shipment	0.10	1	0.1
Design, supervision	0.20	1	0.2
TOTAL, 20 MW wind farm			38.6
TOTAL per MW installed			1.9

The lifetime is assumed to be 20 years and the O&M cost 0.5 Mill USD per year. Like for the other plants the used discount rate is 7.5% p.a.

Annual energy output

The annual energy output depends on the wind resource at the site. The annual energy output of the five selected stations is shown in table 6.10.

Table 6.10 Annual Energy Output 20 MW wind farm by station

Station	Wind speed 10 m agl	Capacity factor	Annual Energy Output 20 MW wind farm
	m/s	%	MWh/year
Quiroon Hariti	6.2	0.39	67,595
Thumrait	5.8	0.33	58,416
Masirah	5.8	0.35	60,870
Joba	5.2	0.29	50,528
Sur	5.2	0.27	47,387

Production cost

Table 6.11 Wind energy - levelised cost per MWh by site

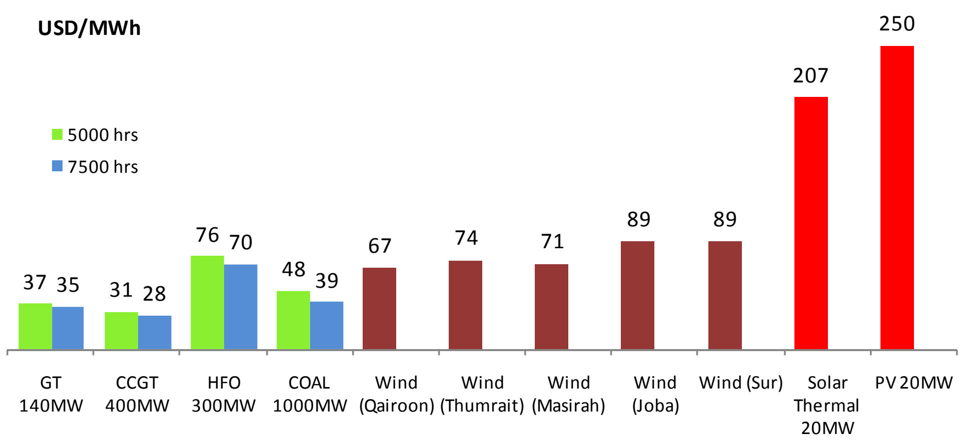
Station	USD/MWh	USD/MWh	USD/MWh	USD/MWh
Discount Factor	(Base Case) 7.5%	5%	10%	13%
Quiroon Hariti	67.2	56.4	79.0	94.0
Thumrait	73.5	61.7	86.3	102.8
Masirah	70.6	59.3	82.9	98.7
Joba	88.7	77.0	101.3	117.5
Sur	88.5	74.3	103.9	123.8

Wind Energy cost varies according the wind speed at the site. The most efficient production site is Qairoon with average cost of 67.2 USD/MWh, while Joba is the most expensive production site with 88.7 USD/MWh.

6.3 Overview of generation costs in Oman

Fig. 6.4 shows the relation between the cost of generation for conventional plants, wind turbines at five specific sites, a 20 MW solar thermal plant and the grid connected 20 MW PV plant. The figure also shows the current average cost of 0.31 USD/kWh, excl. RAECO areas. The assumed gas price is 1.5 USD/MMBtu also for new generation capacity.

Fig. 6.4 Overview of generation cost for new capacity in Oman USD/MWh



The figure indicates that Gas Turbines or Combined Cycles plants have the lowest average production cost. However the table also shows that based on the present costs of solar systems wind power is the most competitive of the renewable energy sources. It has significantly lower cost than CSP and PV power plants.

6.3.1 Impact of Wind Farm on Generation Expansion

In OPWP's 7 year statement for 2007-13, Ref /5/ a number of scenarios has been analysed. Common for all scenarios is that the new generation units will be gas turbines and combined cycle units.

The economic effects by replacing a minor part of the planned capacity by wind turbine capacity are illustrated by the following example. It is assumed that 40 MW wind power plant replaces 40 MW gas power plant.

The establishment of 40 MW wind farm will have the following main effects on the Omani power system:

- The electricity generation from the wind farm will reduce electricity generation (GWh) at other plants in the system, and thereby lead to decreased fuel costs, variable O&M costs, and emissions

- The wind farm will contribute to the installed capacity in the system (MW). Due to wind speed variation the net capacity contribution by wind turbines is less than the installed capacity.

The system effects by a wind farm connected to a power system can be analysed by a system modelling tool (e.g. WASP), which can estimate the effects in the form of substituted electricity (MWh), and in the form of substituted capacity (MW) assuming that the level of security of supply is the same as in the base-case situation. The system effects can also be estimated from the base-case situation by doing some assumptions/considerations on what conventional units that may be substituted. The second approach is used for an evaluation of the system effect of establishing the wind farm in the power system.

Economic effects

It is assumed that the 40 MW installed wind power capacity can substitute 40 MW gas turbine capacity. In the calculation it is assumed that a 140 MW GT (natural gas fired) is replaced by a 100 MW GT and a 40 MW Wind Farm erected in the Quiroon and Thumrait areas. It is assumed that the wind farm can be ready for operation in 2011 and one of the 140 MW gas turbines in 2009 will be replaced by a 100 MW gas turbine and 40 MW wind farm.

It is furthermore assumed that the electricity generation from the wind farm substitutes the electricity generation from the planned gas turbine corresponding to the production by 40 MW. By this assumption the annual savings in fuel cost and variable O&M costs can be calculated.

Table 6.12 below shows the net present value of the wind farm costs and the saved costs at conventional plants, assuming that the wind farm substitutes gas turbine capacity both with respect to the capacity and the generation. The costs are calculated for the four different gas prices previously used. Furthermore, the NPV's are calculated, assuming a real discount rate of 7.5% and a lifetime of 25 years for conventional technologies and 20 year for the wind farm.

Table 6.12 Discounted economic net costs of wind farms, million USD, compared to Gas Turbines

	Low gas price	Medium gas price,	Gas Opportunity Cost plus depletion premium	High Gas price
	1.5 USD/MMBtu	3.0 USD/MMBtu	3.0 USD/MMBtu	6.0 USD/MMBtu
Costs of wind farm	69	69	69	69
- capital costs	61	61	61	61
- O&M costs	8	8	8	8
Saved costs at conventional power	24	39	54	69
- saved capital costs	8	8	8	8
- save fuel costs	15	30	45	60
- saved O&M costs	1	1	1	1
Net costs	**45**	**30**	**15**	**0**

Concerning the wind farm capital costs, it is assumed that half of the investment is made in 2009 and the other half in 2010. In order to assess what requirements it takes for wind power to become completely competitive with natural gas, the break even price for natural gas has been calculated below in Fig. 6.5.

Fig. 6.5   Break- even Natural Gas price compared to 40 MW Wind Farm

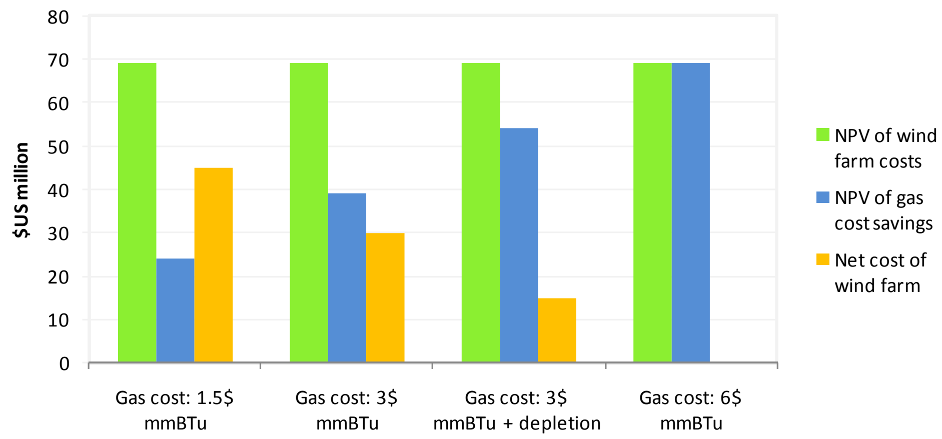
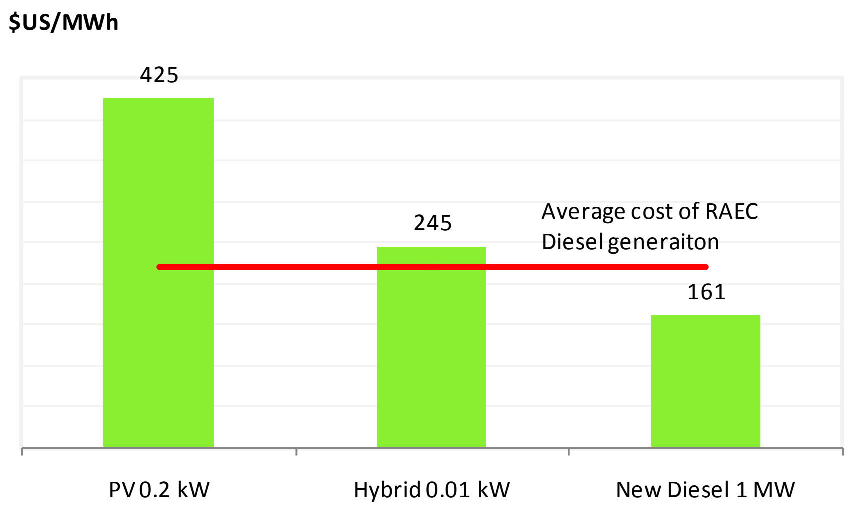


Fig. 6.5 shows that a gas price of 6 USD/MMBtu balances the net costs of wind energy. The opportunity cost of gas which is assumed to 3 USD/MMBtu with a depletion premium of 3% p.a. returns discount ed net wind farm costs of USD 15 Mill in this case. If a wind farm can be implemented as a CDM project, and the avoided carbon emissions from gas consumption sold, the price obtained for the Certified Emission Reductions (CER) can be calculated based on the shadow price of CER of 25.5 USD/ton. This is considerably higher than current level obtained on the European markets which is between 3 - 5 EUR/ton. However, it is expected that the carbon prices will increase when the market becomes more mature and organised over the coming years and a future price of 12 -15 EUR/ton is not considered unlikely.

6.3.2 Small Electricity Generation

Fig. 6.6 shows a comparison of the production cost of PV, PV-diesel and diesel generation systems. The cost of diesel generation is based on the current Oman diesel price. It can be seen that the diesel generation has the lowest cost, followed by the PV-Diesel hybrid.

Fig. 6.6   Cost of Small Applications - New Capacity



7 Financing mechanisms

7.1 Revenue by Renewable Energy production

The costs of most renewable energy technologies are higher than conventional power generation. This is also the case in Oman, as demonstrated in the previous chapter. The cost difference is however decreasing and will further decrease in the future. Due to this, renewable energy should receive special attention and support in order to find a place in the power production portfolio.

The objective of this section is to introduce commonly used economic incentives tools to introduce and develop renewable energy production. There are a number of models that have been introduced in different countries and in this section the mechanism and the experience with these models are summarised.

Many of these models are designed to work in a liberalised power sector and attempts to make use of the market mechanism to select the most efficient technology and producer of renewable energy. However none of them are perfect in this respect - all of them have their advantages and drawbacks. This chapter will try to identify these.

This section will also make an attempt of relating these models to an Omani context where the power sector is unbundled, not liberalised and the network organised in three (nearly) independent supply systems with limited interconnections and limited international interconnection.

7.2 Environmental Taxes

7.2.1 External Costs

No electricity generation technology exists that is completely devoid of pollution or negative environmental impacts. Energy supply has impacts on the environment, e.g. from emissions of chemical pollutants into air, water and soil both at construction and during operation. Many of these emissions cause accountable damage, such as to human health, natural ecosystems and the built environment. This is termed external effects and is not paid by owners of the energy system, and not passed on to the consumers.

However there is true expenditure involved in these impacts, which has to be paid by those affected. Such costs represent a cost to society that are not paid for by the polluter that causes the emissions. If the polluter does pay adequately for the damage caused, then this is referred to as 'internalisation of external cost'. As long as the external costs are not internalised the market mechanism cannot secure an optimal allocation of resources. The prices of goods with high associated external costs, are less than if such costs were internalised, so there is overconsumption of these goods, as compared to the optimal consumption for the welfare of the society.

The fossil fuels that represent the largest specific costs are: coal, HFO, diesel oil, and natural gas; of which gas has the lowest environmental costs. Electricity generated from renewable energy has less specific external cost compared to natural gas generation.

The external cost imposed on society differs from country to country, and they must be specifically evaluated in a national context. The following external cost estimates are from industrialised countries and China and provided by the World Bank.

- Average abatement cost in the industrialised countries is 20 USD per tonne CO_2
- Abatement cost of SO_2 emissions are estimated to 100 USD per tonne
- Abatement cost Particles emissions are estimated to 35 USD per tonne
- NOx emission abatement costs are 240 USD per tonne, but emission is very plant specific and difficult to generalise

7.2.2 Environmental Tax

An environmental tax is a tax on electricity production that reflects the environmental impact of the various fuels and technologies; it can be imposed on the producers or the purchasers of the electricity. It will in any case have to be brought forward to the end-users, who will pay the tax at the end of the day.

Based on emission factors for the various fuels a levy corresponding to the abatement cost per unit of fuel is imposed.

Adding the levy will improve the competitive position of the renewable energy sources in the market place. Environmental Tax makes the 'shadow price' of competing energy sources visible for the users and thereby provides incentives to optimise the energy consumption fuel mix.

Environmental taxes are currently in use in many European countries, including Denmark, Netherlands, Germany, Sweden and Norway.

Environmental taxes are a meaningful way to level the playing field in the electricity markets, but they are (politically) difficult to agree on the level (abatement costs are difficult to estimate) and often they, over time, provide a fiscal revenue for the Government and can be difficult to change, as the abatement cost changes due to technological changes.

7.2.3 Application in Oman

Oman could apply an environmental tax related to abatement cost on electricity production based on the emissions of CO_2, SO_2, NO_x, and particulates, either at the production level (Generating facilities) or at the purchase level (OPWP). In both cases it would - ceteris paribus - increase the producer's and/or the purchaser's incentive to produce more renewable energy or purchase more renewable energy, due the reduced cost difference between natural gas based production and renewable energy production.

Auto-generators would also get incentives to include renewable energy in their production, like other end-users would get an incentive to apply small solar application and purchase less electricity from the Distribution Companies.

However, it would require that cost of the environmental tax could be passed on to the end-users. In the present set-up, the Permitted Tariff is determined without taking the cost basis into consideration, this will not happen. As long as the Permitted Tariff is applied without consideration of the actual cost of electricity production, it will not be possible to apply an environmental tax efficiently.

7.3 Tax Credits

Tax credits are preferential taxations schemes for investments in renewable energy or renewable energy production facilities. They are aimed at providing incentives for investments, normally by lowering taxation in the first years after the investment either in the form of deductions in taxable income and/or accelerated depreciation schemes. In many countries the VAT is also lower than the general level.

The mechanism is basically the same as a direct subsidy to the renewable energy producers. Whether an incentive is a credit or a cash payment makes no difference from the investor perspective. However, politically it can be important whether an incentive is paid by the consumer as a levy or by the taxpayer within the general taxation.

The schemes are parallel to the tax credits provided in a number of countries to foreign investors in order to attract foreign investments.

Tax credits are very common world wide. Examples of countries using credits are: Netherlands, Portugal, US, Greece, Spain, Ireland and Germany. Examples of tax credit schemes in the EU are presented in Appendix 11. The schemes typically comprise a maximum reduction in the taxable income, either of the income earned from investments or fractions of the investment made in renewable energy production. The schemes are typically effective during the first years after investment.

The United States also have a very comprehensive tax credit system, the so-called federal Production Tax Credit (PTC), which currently have a value of approximately 2 USc per kWh produced.

Tax credits provides incentives for investment, but also have the general disadvantages that they distort competition and pricing and they can end being provided to investments that would has taken place anyway.

7.3.1 Application in Oman

Oman does not have tax credit schemes in the energy sector today. It is a measure that Oman could pursue in order to attract investments in renewable energy facilities. Tax incentives for wind energy producers could close the current gap between wind energy production cost and gas turbines that will be the choices in the future expansion of electricity production in Oman and if applied also for production of renewable energy equipment, it would also support development of a local industry.

The exact design must be adapted to the current company and tax regulations. Financing of the credits is provided by the Government.

7.4 Green Marketing

Green Marketing is based on the assumption that consumers Willingness to Pay (WTP) is higher for environmentally friendly produced electricity than traditionally produced. Therefore green energy can obtain a premium price at the market, even if the product is identical to the consumer in all other respects. In combination with other measures - green electricity - has proved to be a success especially in the Netherlands, where the first and most comprehensive schemes have been implemented. Ireland is another example of a successful Green Marketing scheme.

Currently Green electricity is also marketed in Denmark and Germany at a surcharge.

Green marketing requires a concerted marketing effort to promote the products, either from power companies or from specialised authorities. Surveys in Europe confirm that there is a market for green electricity, i.e. some consumers are willing to pay the surcharge, in Europe, it is - however- limited in size. Surveys in Denmark show that nearly 60% of the population is willing to pay 5-10% more for documented green electricity. Surveys and experience in the US show similar results. However, actually only 0.5% of the customers having access actually purchased this product in Denmark. There seems to be a large discrepancy between attitude and actual demand of these products.

The 'sustainability' of the production method is documented through certificates of origin.

The disadvantage with Green Marketing is seen from a resource allocation point of view, suggesting that green energy that would have been produced anyway can obtain the premium price. One example of this is hydropower produced in Norway and Sweden at very low cost, way below thermal and nuclear production, has been put on the market as green electricity and sold at a surcharge. This production would have taken place anyway and the surcharge does not reflect increased production cost. Similar experiences have been obtained in the Netherlands with wind energy production replacing traditional electricity production on cost terms in some instances.

The consumer WTP is also uncertain and unstable over time. Whether green marketing has proven to be a successful concept in US and Europe is very difficult to say, because they are often backed by a politically determined framework for investment in renewable energy.

7.4.1 Application in Oman

Green marketing of electricity probably requires a mature market for sustainable products and standard of living in order to generate any impact of magnitude and can probably not stand alone. Therefore green marketing is not recommended as the first measure that should be taken to increase use of renewable energy resources in Oman.

7.5 Investment Subsidies

Investment subsidies are very often used as an incentive to investors in renewable energy production. We will here use wind energy as an example, but investment subsidies can be applied to all types of renewable energy production.

Investment subsidies directly to producers are normally based on the rated power production capacity (in kW) of the wind farm. The subsidy decreases cost and makes the investment more feasible. An investor in a wind farm will automatically receive a subsidy corresponding to capacity established. The power produced is sold directly to suppliers or directly to the customer at the commercial rate.

They have been widely used in India and Great Britain, but have been abandoned as the only means in an incentive system. In Great Britain it is still in use in combination with other incentives. The reason for abandoning the investment subsidies is because it encourages the establishment of less efficient wind turbines. The experience with investment subsidies in Great Britain and India was that they resulted in:

- poor siting, less efficient sites were used;
- disproportionately large generators. These large generators improved project viability but produced less kWh than could have been obtained from an optimal generator size;
- they attracted manufactures with dubious products;

These experiences have lead to the general understanding that efficient production depends on a number of factors and that efficient provision of subsidies should be related to the production (kWh) rather than rated capacity. At least for wind energy the trend is to reject investment subsidies as the only incentive, because it is considered economically inefficient.

In combination with feed-in-tariffs it is still in used in Great Britain, but now only for off-shore wind mills. The British government offers investment subsidies to off-shore wind farm only as a (small) supplement to the renewable energy quota system that is in place.

7.5.1 Application in Oman

Investment subsidies could be applied in Oman, the source of the subsidy could be the Government already providing subsidies to the power sector through the DC's in MIS and to RAECO. Taking the current set-up at least in the MIS into consideration, investment subsidies would open a new subsidy stream to the sector at least in MIS. This subsidy flow should either be directed to the investors in generation capacity, the IPP's, or through OPWP.

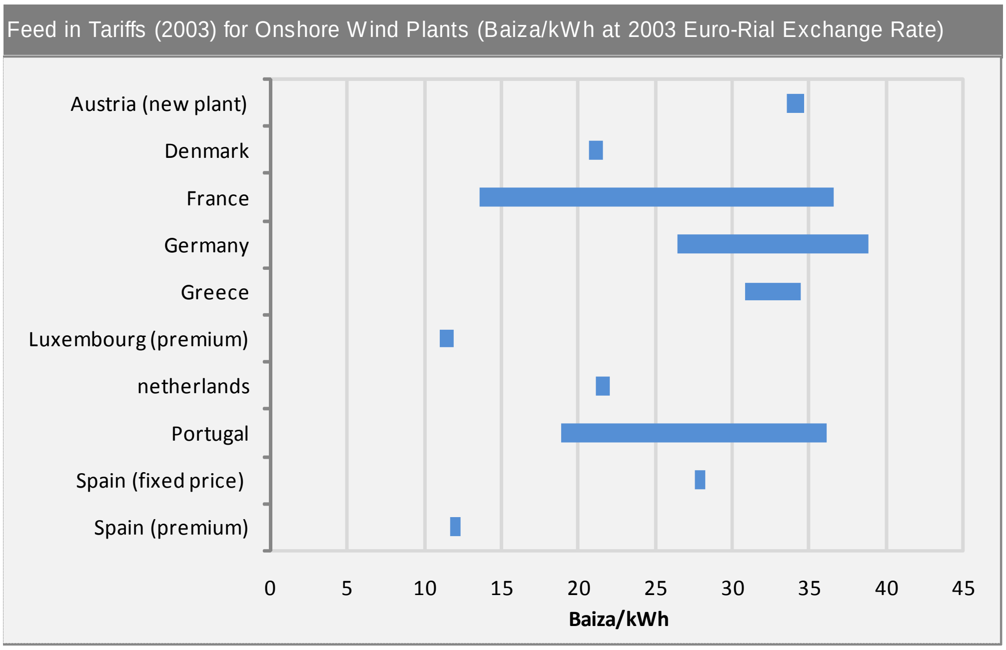
7.6 Fixed Prices - Feed in Tariffs

FIT are fixed and guaranteed prices for energy sales from renewable sources. The prices are fixed by legislation. This system is widespread in Europe. The extra cost of this mechanism - the difference between the feed-in-tariff and the market price - is borne by Government (taxpayers) or the electricity consumers.

Currently FIT is used in Denmark, Austria, France, Greece, Spain, Luxembourg, Portugal and other countries. FIT is the preferred means of the EU Commission in its new plan to increase renewable energy consumption and reduce carbon emissions in the coming years.

The precise mechanism depends, in some cases the FIT is a fixed premium over the current market price, and the total price obtained by the producers varies. In other cases it is the total price per kWh supplied that is fixed. Fig. 7.1 below shows some examples of the FIT for wind energy in EU countries.

Fig. 7.1 Examples of Feed in Tariffs for Onshore Wind Plants



Source: Wind Energy – The Facts: Volume 5 Market Developments

FIT optimal level defined as the level that will attract the production that is defined politically or from power system considerations. Due to technology changes this FIT is highly dynamic and needs to be monitored and adjusted continuously in order not to over subsidise or attract excessive production.

FIT is simple as there are no Power Purchase Agreements to be concluded and no possibility of defaulting counterparts. There are however political risks for the investors by way of lowering or removing the FIT.

7.6.1 Application in Oman

Application of an FIT in Oman could be an option. The FIT should compensate the renewable energy generator for the additional cost he has. The tariff could be paid either directly to the producers or to the purchaser OPWP. It will require that the renewable energy production capacity established is given priority.

7.7 Renewable Quotas - Portfolio Standards

In fixed quantity systems or 'Obligated Renewable Quota' system - in US Renewable Portfolio Standards', the government sets a quota for the amount of renewable energy that should be produced or traded. It is then up to the market to determine the price. Where the Government under FIT determines the price and the markets subsequently determine the produced quantities, it is the opposite under the Quota system: quantities are fixed and the market determines the price.

Two types of mechanisms have been used to control the uptake of capacity to meet the aims of the renewable quota systems: Tendering and Green Certificates

7.7.1 Tendering

Tendering or competitive bidding is used to promote renewable energy in Ireland, France and was previously used in Great Britain. Authorities tender renewable energy capacity according to the quota it has been politically decided to pursue.

Developers submit their project proposals with a wholesale price for electricity for a given period. The companies that bid to supply electricity at the lowest price win contracts to do so and can start construction and production. Usually 15-20 years power purchase agreements are entered into. The difference between the contracted price and the wholesale price of conventional power is paid to the developers/owners from a levy, which represents the additional cost of producing green electricity.

In Great Britain, the system was abandoned because of some drawbacks: Contract winner in some cases delayed their projects considerably in order to apply new and cheaper technology or the winning projects did not materialise at all. In other cases the system resulted in very bad siting in terms of environment, especially of wind farms. The targets for renewable energy production were therefore no met.

7.7.2 Tradable Green Certificates (TGC)

TGC is a mechanism that in some ways resembles the tendering system. As in the tendering system a target for the share of renewable energy to be produced is politically formulated and the corresponding amount of TGC's is issued by the authorities.

The main difference compared to the tendering system is that the price of power and TGC's are settled on a daily basis on the electricity market and on a separate market for tradable certificates, while tendering is based on long-term PPA's. With daily setting of the prices it is more risky for the investor than tendering, as the selling price will be volatile.

A tradable green certificate market working effectively will reflect the difference between market cost of electricity and the generating cost of new renewable production facilities. The value of the certificate represents the additional costs of producing renewable electricity compared to conventional sources.

The TGC market works as follows:

1 The Government sets a specific gradually increasing quantity for the amount of renewable energy in the supply portfolio.

2 An obligation to hold certificates is placed on either the electricity suppliers or the end-users of electricity.

3 The generators, wholesalers, retailers or consumers are obliged to consume a certain percentage of electricity from renewable energy sources.

4 At the settlement date, the operators have to submit the required number of certificates to demonstrate compliance.

Certificates can be obtained the following ways:

- from production of renewable energy at his own plants;
- purchasing certificates from other renewable energy producers;
- purchasing from other actors in the market with an obligation to hold certificates.

The gradually increasing obligation creates a demand for TGCs. It is left to the market to deliver the supply of certificates. TGC's are issued to producers of renewable electricity in proportion to the volume of green electricity they generate. A TGC serves as evidence that a specific amount of green power has been produced and fed into the grid. The equilibrium price of the TGC corresponds to the level that satisfies investors return requirements and new capacity will be installed to meet the quota. There are a number of different certificate models.

The complexity of the TGC models gives it some problems for renewable generation owners and the fact that the market is not perfect also provides some challenges for the operators. The main deficiency being that it is only the most efficient technologies that are promoted, i.e. there is a barrier for emerging technologies with higher cost to enter the market.

7.7.3 Application

A renewable energy quota model could be applied in Oman, based on the tendering system. The political system defines the renewable energy targets and in the MIS the OPWP has an obligation to ensure that the quota is purchased for renewable energy purchased is fulfilled either by the existing generator supplementing their existing facilities with renewable energy or establishment of IPP's using renewable energy. The additional cost OPWP pays for the renewable energy will be passed on the DC's and through the existing subsidy mechanism based on the Permitted Tariff be refunded by the Government. This would be a very simple mechanism that could fit into the existing system.

7.8 Evaluation of the various schemes

A comparison and evaluation of the various schemes in relation to renewable energy is summarised in Table 7.1. It lists the general advantages and disadvantages of the various models. It also summarises the discussion of each measure in relation to application in Oman.

Table 7.1 Overview of Renewable Energy subsidy measures

Instrument	PROs	CONs	Suitable for Oman?
Environmental Taxes	Creates even playing field for renewable energy	Difficult to estimate objectively the optimum level of tax.	Tax would increase supply costs and subsidy but not induce change in consumer consumption. **Limited Applicability**
Tax Credits	Creates incentives for investors	May distort market prices	**Applicable**
Green Marketing	Based on willingness to pay (WTP) and optional schemes	Difficult to control and limited information on consumer WTP	Probably very little impact in Oman. **Limited Applicability**
Investment subsidies	Increase incentives to establish and invest in renewable energy generation	May result in over-investment	May create new subsidy flow in the system to investors. **Applicable**
Feed in Tariffs	Efficient in promoting RE if monitored carefully and changed in accordance with technological developments	Investor risk if removed for political reasons	**Applicable**
Renewable Energy Quotas	Effective way to promote renewable energy projects	New tendering procedures required but simple to administer. Tends to promote established technologies	Easily accommodated in OPWP and RAEC tendering systems. **Applicable**

7.9 Model suitable for Oman

In this section a proposed suitable financial mechanism for Oman is described.

Secondly the required support of different forms of renewable energy (wind and solar) in terms of the cost is estimated.

7.9.1 Large Applications

In Oman electricity usage is subsidised at the end-user level. Licensed suppliers receive subsidy from the Government corresponding to the difference between their actual costs and revenue generated from Permitted Tariffs. In other words the end-user tariffs do not reflect actual electricity production costs, but have been set at levels to achieve political objectives. Oman already uses a payment mechanism to disperse subsidies, which can be exploited in promoting renewable energy, if there is political support to a more sustainable development.

Generation, transmission, supply and distribution are at least in MIS unbundled. Generation is already privatised and the production purchased from IPP's. New capacity is tendered directly by OPWP, when required.

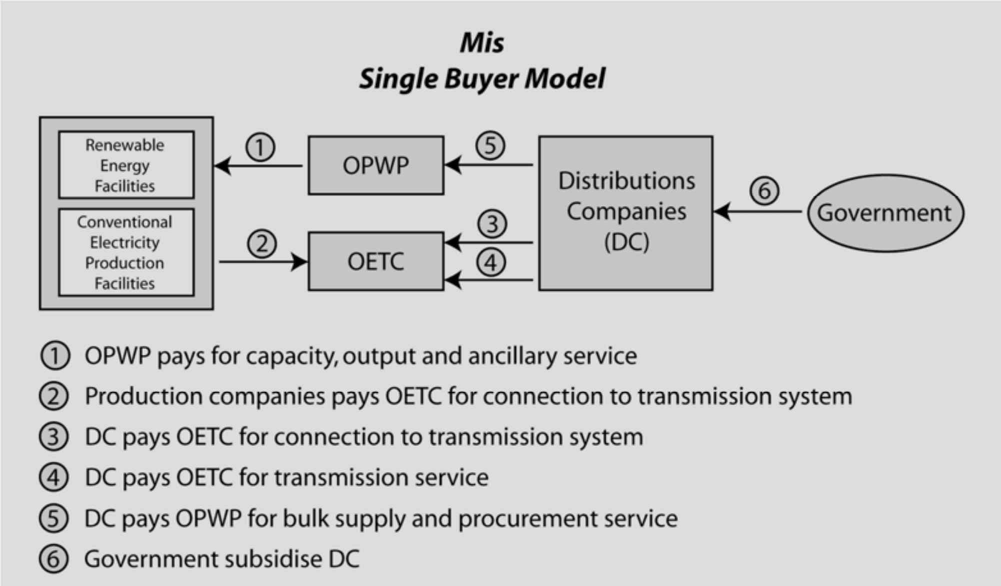
In MIS, a model for application of larger wind and solar system that are feeding the transmission grid could provide OPWP with the obligation to purchase certain amounts, or to establish certain capacities for demand of renewable energy.

The purchase process should be the competitive international tendering of a wind farm or alternatively a renewable energy capacity/production of a certain size, where the bidders decide the technology and the OPWP select the tender with the lowest cost per unit. Not much different from the current process for purchase of new capacity.

OPWP purchases the production at the full cost from the successful bidder on terms defined in a PPA. The additional cost of renewable energy will be passed on to licensed suppliers, who would receive subsidy corresponding to the difference between their Maximum Allowed Revenue and Permitted Tariff revenue. All elements in the current regulation can be maintained under this framework, as shown in Figure *7*.2, where renewable energy production facilities are added to the existing model.

A similar model can be applied in Salalah, it will, however, require a revision of the concession agreement with DPC. When the concession agreement terminates, it is expected that the Salalah system will be regulated under the same model as MIS, and a similar model can be implemented.

Fig. 7.2 Sector overview, including renewable energy facilities, MIS



Other measures that could be used by the Government of Oman to reduce the cost for renewable energy installation are:

- Long Term power purchase agreement, including priority to renewable energy production;
- Free provision of land for wind farms and solar applications;
- Grid connection free of charge;
- Preferential loans for investments from Oman Development Bank;
- Exemptions of local taxes, customs and import duties for a period.

7.9.2 RAECO - Rural Areas

RAECO is a fully integrated vertically integrated company covering generation, transmission and distribution. The production and consumption in RAECO is small compared to the other areas. The cost of supplying the rural areas is very high with large variations. There is probably room for inclusion of small scale renewable energy at some of the locations. Experience shows, however, that there is also a need for a mechanism ensuring efficient operations in general and also of possible renewable energy sources.

Given its cost structure, RAECO should be motivated to identify opportunities to substitute or combine diesel generation with solar applications. It must be expected that there are systems/locations where it is viable with current cost levels to use hybrid applications instead of diesel generation. The cost level in some of the system indicates that there might be economic benefits from using PV or hybrid applications in this system and it should be considered using stand alone solar systems to supply the most remote customers instead of extending grid structures.

It is concluded that a financial mechanism is not required in RAECO as there seems to be economicaly viable opportunities to utilises renewable energy without subsidization. It is recommended to initiate a process that identifies the systems with highest cost and investigate the reasons why. It is also recommended that RAECO introduce a standard procedure when designing new systems and purchasing new capacity to make a comparison between diesel and a hybrid system to ensure that the consideration it always done.

7.10 Level of Subsidy Required

In order to asses the cost of exploiting the renewable resources in Oman with today cost structures, this section combine the resource assessment from Chapter 5 with the cost evaluation in Chapter 6.

The methodology is to compare the LRMC of the cheapest power generation technology, i.e. natural gas fuelled GT, with the LRMC of wind power and solar thermal. The cost difference is the required subsidy per MWh, which must be provided to the system in order to attract investments. In Table 7.2 this calculation has been made depending on the gas price and with a discount factor of 7.5% p.a. The table shows the subsidy required to equalise the return for an investor in a gas turbine and in a 20 MW wind farm, respectively.

Table 7.2 Subsidy scenario for wind power

Natural Gas Price USD/MMBtu	Generation Cost per MWh Gas Turbine USD	Generation Cost per MWh Wind Power USD	Difference Subsidy per MWh USD	Annual subsidy required to support 750 MW Mill USD
1.5	28	67	39	90
3.0	43	67	24	55
3.0 with depletion premium	56	67	11	25
6 .0	73	67	-6	-14

Total costs are sensitive to actual installed capacity. It is assumed that 750 MW of wind power capacity could be established with an annual production of 2300 GWh. The annual subsidy to support this capacity is shown in the right hand column. It varies between USD 25 Mill and USD 90 Mill depending on the natural gas price, used in the calculation. If the natural gas price is above 6 USD per MMBtu, electricity based on gas is more expensive than the proposed wind energy scenario.

Table 7.3 below shows the similar calculation for Solar Thermal Power (CSP).

Table 7.3 Subsidy scenario for Solar Thermal Power

Natural Gas Price USD/MMBtu	Generation Cost per MWh Gas Turbine USD	Generation Cost per MWh Solar USD	Difference Subsidy per MWh USD	Annual subsidy required to support 1450 MW Mill USD
1.5	28	207	179	453
3.0	43	207	164	415
3.0 with depletion premium	56	207	151	382
6.0	73	207	134	339

Total costs are sensitive to actual installed capacity. It is assumed that 1450 MW of solar thermal power capacity can be established with an annual production of 2,530 GWh. The annual subsidy to support this capacity is shown in the right hand column. It varies between USD 339 Mill and USD 453 Mill per year depending on the natural gas price.

In comparison the annual subsidy to MIS licensed suppliers in 2006 was around USD 250 Mill. This subsidy is the difference between the economic cost of the companies and Permitted Tariff Revenue.

8 Market for renewable energy in Oman

8.1 Barriers

Developers of renewable energy projects face a number of barriers. These concern several factors, some of which relate to the underlying technology and associated cost structures others relate to the structure of the power market where their outputs is sold.

The barriers include among others:

- Cost competitiveness and cost structures
- Intermittency
- Scale
- Legal Framework

For each of these potential barriers the key issues are identified and commented in the following section.

8.1.1 Cost competitiveness

Cost competitiveness is a barrier for widespread use of renewable energy in Oman. It has been demonstrated in the previous section, that all the renewable energy technologies analysed have higher cost than conventional power production in Oman with prevailing prices of natural gas of 1.5 USD/MMBtu.

In the following paragraphs the cost competitiveness is analysed at two levels: production and end-user level.

Cost at generation level

Currently conventional generators are provided with gas at a low price from the Ministry of Oil and Gas. The price is low in economic terms, because it does not include all the external cost of production of power based on gas, i.e. the cost of emissions, as previously explained. The revenue is also lower than the alternative revenue that could be obtained from export of the gas. The spot LNG price is and has been much higher than the 1.5 USD/MMBtu for a long time and represents higher revenue for the society, which should be taken into consideration when comparing cost of conventional production and renewable production.

In practical terms the natural gas provision price for the power plants is determined in long term contracts. However through indexation of the price it is possible to transfer to the international LNG price to the natural gas contracts. The economic price is somewhere between the production costs in Oman and the spot LNG price. As mentioned earlier a gas price 3 USD/MMBtu with 3% annual escalation, would make wind power competitive provided carbon emission reductions can be sold at 25 USD/ton.

Using a price of natural gas, reflecting the cost of economic use of the gas, would increase the room for renewable energy in the planning of new power production. It might also provide current producer with incentives to consider renewable energy as a supplement in the production operations with a cost reducing impact.

The changes in cost of energy production are in a well functioning market, transferred to the end-users thus impacting their behaviour in terms of energy use. However, in Oman this mechanism is not operating because the Permitted Tariff currently is settled below cost.

Price at End-user level

End-user electricity tariffs are settled in a political process and are below the economic cost of power as an average, due to the subsidy provided to the distribution companies. From economic theory it is well known that the consequences are: consumption of energy is not efficient, over investments in production capacity/depletion of the natural gas resources quicker than optimal for the society. In the longer term this will lead to the requirement import of natural gas / oil, at market costs and a lower security of supply.

It is also directly a barrier to the introduction of renewable energy applications at the end user level. Introduction of renewable energy applications in an industry or in a household are costly and require investments. The return of investing in e.g. a solar application will be lower and the payback time will be longer if electricity is priced below its real cost. This will therefore have an adverse impact on investment in production and installation of renewable energy in the country. Cost reflective end-user prices are necessary to encourage the end-users to make the decision regarding energy use and invest in renewable energy applications.

The Authority is presently recommending an introduction of Cost Reflective end-user tariffs. Steps in this direction, would also assist in removing an important barrier for renewable energy and other improvements in the use of energy.

Possible increases of the power tariff should must take place gradually in order to mitigate the impacts on the poorest household.

8.1.2 Scale

Conventional power plants can be very large - thousand of MW in size. Renewable generators are much smaller in size. The smaller size of renewable energy technologies has advantages and disadvantages.

The principal disadvantage is that the cost of participating in the market (transaction costs) are high per unit produced. This accounts for the whole project cycle.

A number of cost items in the project cycle are to some extent independent of the size of the project: investigations, pre-feasibility studies, feasibility studies, siting considerations, land purchase, detailed design, creating access to the site plant, establishing connection to the grid, insurances, negotiating of power sales agreements, obtaining licenses and permits and the tendering process. This cost can't be avoided and in some countries special programmes with support measures are established to assist investors overcoming this barrier.

Further during operation, unless a developer of renewable energy project has a diversified portfolio of generators, renewable energy operators are unable to net off imbalances with the company. For instance when operating a wind farm supplying the grid, the transmission company - or organisation responsible for balancing the system - can obtain difficulties in ensuring the balance because of the volatility of the wind farm production. For the system operator, this might result in additional purchase or cancellation of already purchased power, which means additional costs that in principle are transferrable to the wind energy producer. These situations are less costly to handle if you operate a diversified portfolio of facilities. There needs to be a set of market regulations that the markets access for renewable energy producers, before investors will consider investing.

In more mature renewable energy set-up special services and facilities have been developed to deal with these issues. In Oman, where renewable energy is emerging these programmes and rules have to be defined before a development on a commercial scale can be expected.

8.1.3 Power Sector Set-up and Legal Framework

The present legal framework for the power sector is formulated in the Law for the Regulation and Privatisation of the Electricity and Related Water Sector and described in Section 4.3 of this report.

The legislation lack formal arrangements and statuary mechanisms to accommodate renewable energy or facilitate its introduction, some examples are discussed below. These examples do not mean that isolated renewable energy project cannot be undertaken, but should be seen as barriers for the broader market to take off. In the energy legislation in most countries, you will find specific regulations regarding inclusion of renewable in the power supply in order to have a basis for the practical arrangements and in order to support the process.

The lack of a strong interconnection, between MIS, RAECO and Salalah makes introduction of renewable energy less economic than in an interconnected system. The intermittency of say wind energy adds system imbalances easier to cope with in a system with strong interconnections and of some size. Wind resources are located mainly in the Southern part of Oman, but the Northern part of the country cannot benefit from wind energy production from the South in situation of overproduction. This goes of course for all production resources, but is especially important with a volatile resource such as wind.

The current legislation stipulates that the DC's in MIS must purchase all their power from OPWP. They are not allowed to establish their own 'embedded' production facilities - local power generation inside their own distribution areas - based on for instance small scale renewable resources, if found to be cost effective compared to purchase from OPWP.

A parallel issue is generation at the end-user, for instance an industry, which decides to establish renewable auto-generation and might have capacity to export to the grid during some parts of the day. This industry cannot sell the surplus production to the local DC or to OPWP under the current legislation. There is no mechanism defined in the legislation to make the transaction and no tariff/price regulation defined for such a transaction. In many countries there exist an established buy-back system (net-banking), where auto-generators buy and sell at the (same) prevailing price/tariff, instead of buying at the prevailing tariff and selling at a much lower rate. This mechanism has been effective in supporting small scale local renewable energy production.

Finally, the usage of the permitted tariff - where it is below economic cost - is discouraging end-users to use solar applications and similar, as supplement to their purchases from the grid, because the pay back time of the investment becomes too long, as previously mentioned.

8.2 Renewable energy industry, Market players

A few companies in Oman working with renewable energy (solar) related activities have been identified. Their characteristics are:

Growth International LLC

- **Business type:** manufacturer, retail sales, wholesale supplier, importer
- **Product types:** solar street lighting, photovoltaic modules, solar traffic lighting systems, solar water pumping systems, photovoltaic systems.
- **Service types:** consulting, design, installation, construction, engineering, education and training services, maintenance and repair services

Oman Solar Systems Co. LLC

- **Business type:** Projects and Retail sales
- **Product types:** Solar Photovoltaic Power Systems for Oil & Gas and Telecom Applications, Solar PV Industrial Systems, Solar-Wind Hybrid Systems, Solar Grid connected Systems, Total Renewable Energy Solutions, Solar Water Heating Systems, Solar Home Systems, Passive Cooled Enclosures, UPS, Rectifier Systems, Voltage Stabilisers etc.
- **Service types:** design, installation and commissioning

OMASY Co., LTD

- **Business type:** retail sales, wholesale supplier, importer
- **Product types:** solar electric power systems, solar water pumping systems, wind energy systems (small), solar water heating systems, photovoltaic systems, solar outdoor lighting systems.
- **Service types:** consulting, design, installation, construction, engineering, research services, site survey and assessment services, contractor services, maintenance and repair services, recycling services

8.3 Awareness

Presently solar energy is used for water heating purposes in households and for power supply of remote located equipment, primarily within the oil and gas industry. The awareness of other types of renewable energy resources is limited in Oman and large scale utilisation of renewable energy resources has not yet been considered as a serious supplement to the use of conventional energy resources.

Research and development activities related to utilisation of renewable energy are carried out at the Sultan Qaboos University in Muscat. However the allocation of financial resources for these activities is limited.

Several initiatives can be implemented in order to increase the awareness of renewable energy:

- implementation of demonstration projects for testing of the most promising renewable energy technologies for Oman
- increase the R&D activities related to renewable energy utilisation
- integration of renewable energy systems (primarily solar PV) in public buildings where the technology can be presented for many people (i.e. power supply at public buildings and for lighting)
- education of renewable energy in the schools

The awareness by decision makers and the public regarding the potential of renewable energy resources in Oman is important for the development of the utilisation of these domestic energy resources.

9 Renewable energy pilot projects

9.1 Criteria for recommendation of pilot projects

The technologies for utilisation of solar and wind energy resources for electricity generation are commercially available and have demonstrated technical reliability in many countries.

In order to demonstrate the technical and economical performance of renewable energy plants in Oman it is recommended to establish a number of pilot projects. One or several of the following types of projects are recommended as pilot projects.

The criteria for selection of the recommended type pilot projects include:

- demand for the type of project is expected in the future
- the type of project is expected to be economically viable in the future assuming high conventional fuel prices in the future
- the project shall contribute to the awareness of renewable energy in Oman
- the project shall be based on well proven and reliable technology

9.2 Solar pilot projects

Two types of solar energy systems are recommended as pilot projects. A 20 kW system for installation on a building in an urban environment and a 10 kW solar PV / diesel hybrid system.

9.2.1 PV pilot project, grid connected 20 kWp system

Outline design and technology

The 20 kW system consists of the following components:

- 20 kWp solar PV panels (approximately 200 m2 conventional panels) mounted in an urban environment.
- A 20 kW power converter to convert the DC from the panels to AC voltage for the grid.
- A connection to the grid including a power meter.

Budget
The following budget represents the market cost for the technology and does not include design, project management, monitoring, evaluation, reporting and campaigning etc. which should be a part of a pilot project.

Break down of construction costs:

Component	Initial Capital USD
PV Array including mounting	136,000
Converter and connections	14,000
Totals	150,000

Action plan
Realisation of the pilot project will have the following steps:

- Prepare a total budget including project expenses for the following steps.
- Ensure financing.
- Project planning
- Identification of host for project
- Design of installations
- Procurement, installation, commissioning and testing
- Monitoring of results
- Evaluation, reporting and presentation of results and conclusions.

For the pilot project the monitoring could incorporate hourly data collection which could be utilized by researchers and for demonstration. A display with indication of production could also be included.

9.2.2 10 kW stand alone system

Location
The capacity corresponds to the capacity need of a small off grid settlement with few houses, perhaps with small service function, restaurant, shop or gasoline station.

This type of energy supply is typically made by diesel engines. This will be compared with alternative supply with hybrid systems including solar energy, diesel and battery storage.

At a first phase it is suggested to make a pilot project including two different concepts.

Concept 1 - One system with 10 kW solar PV, 10 kW diesel and battery storage.

Concept 2 - One system with 5 kW solar PV, 10 kW diesel and without battery.

The second one can not give a 100 percent cover of the demand as defined above. There will be periods with low level in batteries where people will have to make priorities, for example reduce the air conditioning in order to have power for lighting and cooking.

Break down of construction costs:

Concept 1

Component	Initial Capital USD
PV Array including mounting	68,000
Generator	7,800
Battery	8,000
Converter and connections	7,000
Totals	90,800

Concept 2

Component	Initial Capital USD
PV Array including mounting	34,000
Generator	7,800
Converter and connections	3,500
Totals	45,300

9.3 Wind Power Project

It is recommended to implement a small pilot wind farm project in order to give demonstration the performance of the modern wind turbine technology under Omani conditions and to evaluate the interaction between the turbines and the grid.

Technology

The wind farm should consist of five 2 MW wind turbines with hub height of approximately 80 m and rotor diameter of 90 m.

Wind turbine specifications:

Description	Unit	
WT Capacity	MW	2.0
Tower height	m	80 - 85
Rotor diameter	m	90
Generator		Asynchronous
Type of power regulation		pitch
Rated generator voltage	Volt	690

Wind farm specifications:

Description	Unit	
Plant Capacity	MW	10
Number of Wind Turbines		5
Layout wind farm		Micro siting
Wake losses	%	2 -5 %
Life time	Years	20

The wind farm should be connected to the high voltage grid system in Dhofar. The total power capacity of the Salalah system is 350 MW. The 10 MW wind farm capacity will be 3 % of the total power capacity in the Salalah power system.

Location

The project should be implemented in the Thumrait/Quiroon Hariti area where the highest wind energy potential in Oman is observed. Exact locations of the individual turbines should be made based on detailed micro siting.

The landscape in this area is suitable for erection of wind turbines. There are no vegetation or obstacles.

Fig. 9.1 Representative landscape in the Quiroon Hariti area

Budget

Based on the present market price the cost per MW installed capacity for on shore wind farms is in the order of 2 mill USD. For the proposed pilot project the total construction cost will be USD 20 - 22 mill.

Break down of the construction costs:

	Mill USD		USD
Item	Unit price	Quantity	Amount
WIND TURBINE			
Wind turbine, 2.0 MW	3.00	5	15.0
Monitoring system	0.20	1	0.2
CIVIL WORKS			
Wind turbine foundation	0.15	5	0.65
Access roads (5 km)	0.30	1	0.3
Control room, facilities	0.50	1	0.5
ELECTRCAL WORKS			
Main substation	1.00	1	1.0
Feeder	0.05	2	0.1
Transformer	0.30	5	1.5
Distribution net work	0.50	1	0.5
OTHER COSTS			
Insurance	0.10	1	0.1
Shipment	0.10	1	0.1
Design, supervision	0.20	1	0.2
TOTAL, 10 MW wind farm			20.2
TOTAL per MW installed			2.0

Action plan

The following activities should be made for implementation of the project:

Planning phase

- Set up project organisation
- Power purchase agreement
- Determine financing sources

Design

- Detailed wind analysis for the area, including possible wind measurements
- Site selection based on land and grid availability
- Micrositing of the wind turbines for optimum location
- Conceptual design of the wind farm
- Design of power system on site
- Design grid connection, incl. transform and sub station
- Design civil works (roads, facility buiildings)

Implementation

- Tendering
- Supervision
- testing

Operation

- training of operation and maintenance staff
- performance monitoring

REFERENCES

Ref. no.	Title
/1/	Ministry of National Economy, 2006
/2/	Ministry of National Economy, Socio-Economic Atlas, September 2006
/3/	Authority for Electricity Regulation, Annual Report 2006
/4/	Oman Electricity Transmission Corporation, Annual Report 2006
/5/	Oman Power and Water procurement, Seven Years Statement, 2007-2013
/6/	Ministry of National Economy, Statistical Yearbook, October 2006
/7/	Directorate General of Civil Aviation & Meteorology, Dept. of Meteorology, Annual Climate Summary 2005
/8/	"Typical Solar Radiation Data for Oman", H.A. Al-Hinai og S. M. Al-Alawi, Department of Mechanical Engineering, Sultan Qaboos University. Published in Applied Energy 52, (1995), page 153-163.
/9/	Oman Wastewater Service Company. Letter dated 03 November 2007, Ref.no.OWSC/PE/SA/014/2007
/10/	Ministry of Agriculture, Yearbook 2006
/11/	European Directory of Renewable Energy, 1991
/12/	"The role of Hydrogeology in Petroleum Development Oman" by Al Lamki, M. and Terken, Jos, GeoArabia, Vol.I, no.4, 1996
/13/	Ministry of Oil & Gas, letter dated 13 February 2008, Ref. 478
/14/	Global Wind Energy Council, 15 Februiary 2007
/15/	"Concentrating Solar Power, From Research to Implementation", European Commission, 2007.
/16/	From Volker Quaschning, VGB Congress Power Plants 2001 · Brussels · October 2001
/17/	"THE FUTURE OF THIN FILM SOLAR CELLS", Martin A. Green, ARC Photovoltaic Centre of Excellence, University of New South Wales, Sydney Australia 2052
/18/	"INTERNATIONAL MARKET INTRODUCTION OF CONCENTRATED SOLAR POWER-POLICIES AND BENEFITS", Michael Geyer, IEA Solar PACES Implementing Agreement
/19/	International Energy Agency (IEA), Ocean energy systems, 2003
/20/	Oman Power and Water Procurement, Annual Report 2006
/21/	"Technical and Economic Assessment: Off-grid, Mini-grid and grid Electrification Technologies", World Bank Energy Unit, November 2005
/22/	"life-cycle Analysis of Energy Systems", Bernd Kuemmel, Stefan Krüger Nielse, Bent Sørensen, 1997
/23/	Oman Power and Procurement, 7-Year Statement (2008 - 2014), Dec. 2007

Appendix 1 Summary of meetings

1. Ministry of Fisheries

H.E. Hamed Said Al-Oufi, Undersecretary
Date: 24.09.07 at 13:00 hrs

A. Basis for the meeting

***Subject*: Biogas**

1. Location of major fish industry in Oman
2. Present mode of handling waste management
3. Fuels from waste, especially on dried waste
4. Main fishing season in Oman (region)
5. Type and amount of available wastes from fish industry
6. Attitude to renewable energy supply

B. Comments received

Waste from fishing industry is nearly 100% which is transferred to the Fish Meal Company in Muscat. The large part of it is used for agriculture and cattle breeding.
Renewable energy supply could be investigated for the Shrimps Fabrication, close to Al Duqm which is actually powered by diesel generator now.

Two other projects have been suggested:

1. Algae farming in the sea for biogas production
2. Algae farming based on well water production of oil drilling

C. Documents received

No documents received

2. Mazoon Electricity Company

Eng. Abdullah Al-Badri, General Manager
Date: 24.09.07 at 09:00 h

A. Basis for the meeting

***Subject*: General information**

1. Location and capacity for existing power stations, main transmission and distribution lines
2. Location and capacity for present isolated grid system.
3. Load centres including min., max. and average electricity demand. Information for main grid and for isolated grid systems
4. Number of present and future consumers in main grid and isolated grids
5. Plans for extension of power system, including capacity of plants, transmission and distribution lines
6. Information, e.g. annual reports. historic data (technology, efficiency, fuel consumption and age), maps and production cost (split in fuel, fixed and variable cost) of generation, transmission and distribution facilities.
7. Generation and transmission system expansion plans. Current and foreseen bottlenecks in the system. Load curves and factors.
8. Attitude to include renewable energy supply in the plans

B. Comments received

The questionnaire was discussed in detail. Answers will be prepared in writing. There are several unconnected villages in the area of Mazoon's district. One of them is SALMAH close to Muscat in the mountains (about 30 inhabitants). The Company, Bahwan Group installed there a PV system for a common room. The electrical power is used for ventilators and refrigerator.
Mazoon Electricity mentioned a special report regarding rural areas in the district that will be handed over with the annual reports and the answers to the questionnaire.

C. Documents received

- Answers on questions
- Annual report 2005 and 2006
- Report on rural areas

3. Oman Power&Water Procurement Company

Eng. Saleh Al-Rasdi, CEO
Date: 25.09.07 at 10:00 h

A. Basis for the meeting

***Subject*: Biogas**

1. Plan for new power generation of electricity (MW)
2. Types and amount of fuel of existing and future power generation plants
3. Efficiency of existing and future power generation plants
4. Cost for generation of electricity
5. Cost of fuel at present and forecast (next 20 years)
6. Annual reports
7. Attitude to include renewable energy supply in the plans

B. Comments received

Actually there are 7 gas fired power generation plants in Oman. All of them are backed-up by diesel power generation. The installed capacity amounts to 3600 MW. New capacity is planned for Salalah with 400 MW for Dhofar Power Company.

Regarding the development of Al Duqm, the connection to the main grid is under planning and shall be finalized end of 2009 till 2010. Along with the growing demand of electric power in Al Duqm a local power generation plant will probably be implemented. Future plans are to connect Dhofar grid with MIS via the existing mini-grid of PDO.

Eng. Saleh Al-Rasdi mentioned about potential for renewable energy in Salalah with wind energy and on other locations with hydropower plants. Due to the relatively low electrical power consumption in the winter period the balance capacity of the installed power generation plants could be used to pump water up in dams. Power consumption in winter period decreases to 1/3 of the peaks in summer period. The stowed water could thus power hydropower turbines in the hot season.

For detailed meeting it was decided to meet with Mr. Alan Davis (Planning & Pricing Manager).

C. Documents received

- Annual report 2006
- Strategy report 2007 – 2013 (available on homepage)

4. Oman Waste Water Company

Eng, Omar Khalfan Al-Wahibi, CEO
Date: 25.09.07 at 13:00 h

A. Basis for the meeting

<u>Subject</u>: Biogas

1. Waste management structure
2. Waste management documents
3. Current waste accumulation, quantity development and composition
4. Which type of industry/consumers produce the waste water
5. Present mode of handling of waste water: how is the waste water transported to the waste water plant, what is it used for?
6. What are the expenditures for handling the waste water?
7. Have there been any considerations for utilizing waste water for biogas production?
8. Attitude to include renewable energy supply in the plans

B. Comments received

OWWC is only responsible for waste water in the area of Muscat. All the rural areas are under the responsibility of the Ministry of Regional Municipalities. A third company is responsible for Salalah. Solid waste is managed by other authorities. The infrastructure of waste water management is under development. It is targeted to reach 80% coverage in 2013. The today's yearly amount of waste water is around 43,000 m3. The activities are actually concentrated on the higher populated areas.

There is no biogas production due to small amount of waste. Waste is partly used for fertilizer production. A new composting facility shall start operation in 2010. The capacity was not communicated. The yearly operational cost of OWWC amounts to 2.6 m USD.

The attitude to renewables was very positive. The shortage of gas should especially taken into consideration when talking about renewables.

C. Documents received

- Annual report 2006

5. Royal Oman Police (ROP)

Colonel Ahmed Darwsh Al-Zadjali
Khalid Al-Shabibi, Director of Projects
Ahmed Mohd. Hatim Al-Balushi, Project Maintenance
Eng. Bashir Al-Farsi, Electrical Engineer
Date: 26.09.07 at 10:00 h

A. Basis for the meeting

<u>Subject</u>: Wind, Solar, Geothermal

1. Type of renewable energy technology, date of installation and capacity
2. Operation and performance experience (generated output, technical availability, type of problems)
3. Local operation and maintenance skills for this type of renewable energy technology
4. Implementation and operation costs for the systems
5. Attitude to include renewable energy supply in the plans

B. Comments received

ROP is very interested to implement renewables in their power supply concept. BOT projects are the most favourable projects in this regard. They mentioned that solar could be still too expensive for feed-in solutions compared to the gas generated electrical power in Oman which is subsidised. ROP purchases electric power on a basis of 50% of the official tariffs in Oman. They are interested to investigate more on the feasibility of wind power generation (for example for the island of Masirah).

ROP is only looking to supply power for there own buildings like prisons, academies etc. The average power demand of these buildings lies between 500 and 1000 kW. The new prison next to Nizwa (name???) is planned to have 1.8 MW. ROP is ready to invest in renewables even if the power production is more cost intensive than comparable gas fired power generation. The amortisation period can be up to 20 years.

ROP asked for the delivery time of one 5 MW wind power station and of smaller systems with around 600 kW.

ROP operates one solar power unit on Daymaniyat Islands for radio base and radar stations with installed capacity of 2.0 kW.

C. Documents received

- Wind date (measurements in 50 m height)

6. Ministry of Regional Municipalities

Eng. Abdul Hakim Al-Zadjani, Director General Technical affairs
Date: 26.09.07 at 12:00 h

A. Basis for the meeting

Subject*: *Biogas

Questions related to biogas

1. Information on landfills: locations, size, depth, age, type of content
2. Locations of industries generating waste water (e.g. food industry, palm oil and slaughter houses)
3. Locations of major farms and number/type of animals
4. Data on waste water from the industries with effluents with high organic content (solid organic material after vaporisation)
5. Locations waste water treatment plants and amount of flow of biological waste water
6. Legislation regarding handling of waste water
7. Previous reports on the landfills and biogas potential in Oman

General

1. Attitude to include renewable energy supply in the plans

B. Comments received

MRM operates around 300 trop-off sites for domestic waste. A new landfill is planned for Sur with the local Municipality of Sur. A similar project will be established in Adan area in 2009 (Dakhla region). 8 major locations with 7000 m3/day are: Sur, Ibra, Sumail, Nizwa, Ibri, Saham, Rustakh, Khasab and Barka.

The waste treatment plants in all other cities (approximately 75) are very small and have capacity between 120 and 200 m3/day.

Data about the food industry, slaughter houses etc. have to be collected from the Ministry of Industry and Commerce. Further information about waste of farms, numbers of animals and so on can be collected from the Ministry of Agriculture. Industrial waste is not under the responsibility of MRM.

Regarding the handling of waste, the legislation for OWWC and MRM are identical.
Regarding landfill no reports are available and no studies are done right now.

Positivity about renewables. Eng. Abdul Hakim Al-Zadjani mentioned to visit the oldest wind powered water pump in Oman in Matrah (Muscat) which was installed between 50 to 60 years ago.

C. Documents received - No documents received

7. Sultan Qaboos University

Dr. Ali Salim Al-Alawi, Dr. Hilal Al-Ismaily, Dr. Nabeel Al-Rawahi
Dept. of Mechanical & Industrial Engineering
Date: 29.09.07 at 09:00 h

A. Basis for the meeting

***Subject*: R&D, studies**

1. Overview of existing renewable energy systems in Oman including date of installation, owners, locations and types
   - types
   - year of installation
   - owners, energy generation
2. Information on performance of existing renewable energy systems including energy output and operation reliability
3. Types of R&D activities within renewable energy and R&D budget for this sector
4. Are there any plans for new, future R&D activities regarding renewable energy in Oman? If any, within which area and why are these areas prioritized
5. Which type of renewable energy technology is most suitable for Oman
6. Are there any norms and standards regarding installation of renewable energy (e.g. documentation solar panel efficiency, installation requirements)
7. Norms, standards regarding renewable energy (e.g. documentation solar panel efficiency)
8. Attitude to renewable energy supply

B. Comments received

Several student projects in wind, solar (PV and thermal) identified, such as a PV solar car; research activities in combined solar thermal and seawater desalination. Wind study on the island of Masirah. PDO utilises hot steam for processing; Possibility for concentrator thermal systems for hot steam generation. Further information could eventually be collected from the Solar Conference at SQU in 2001. Data are available at the library.

Project hot water systems for remote areas powered by wind energy. The following steps are focused:

1. Data collection
2. WASP and installation of measurement device
3. Search of sponsors for wind turbine installation

Step 1 and 2 together requires approx. 10,000 to 20,000 OMR

Wind conditions at the coastal line between Sur and Salalah during summer season (mid of June till mid of September) very strong. Inhabitants are leaving the coastal villages and are moving inside Oman at this time. Fishing is to dangerous due to high waves like in Ras Al-Hadd.
For more reliable data higher measurement masts need to be installed.

According to SQU studies, wind and solar power are the only feasible options in Oman subject to the location.

Important to meet also Dr. Adel from the electrotechnical department.

Research program together with Electricity Technology Japan since approx. 9 years which will be determined next year.
The subject: Impact on PV cells under the specific environmental conditions in Oman.

The following internet link was recommended for more data about solar radiation and wind of Oman: www.sciencedirect.com

Dr. Al-Alawi made its doctoral thesis in "An integrated PV-Diesel Hybrid Water and Power Supply System for Remote Arid Regions".

Dr. Saleh Suleimani published a paper on wind turbine for water pumping in Hayma (located close to Thumrait).

C. Documents received

- Published articles about renewable energy
- Viability of Hybrid Wind-Diesel Power Generation in Fossil Fuel Rich Countries : A Case Study of Masirah Island, Oman

8. Ministry of Transport & Telecommunication

Directorate for Transport and Ports
Eng. Hamed Saud Al-Ramdani
Date: 29.09.07 at 12:00 h

A. Basis for the meeting

Subject*: *Wave, Wind

Wave energy related questions

1. Positions where wave data has been measured
2. Measured wave characteristics at the sea of Oman: wave length, wave height, wave directions (frequency), since the measuring started. Estimated max wave height (50 year wave)
3. Average water depth along Oman coast, preferably indicated on sea map.
4. Restrictions for installation of wave power stations in the sea

Wind energy related questions

1. Locations of off shore/on shore wind monitoring stations, specified by coordinates and shown on map
2. Height above sea level of the wind speed and wind direction sensors at each station
3. Measurement period since Gov. started measuring (start date - end date (if any) for each mast.
4. By which frequency is the wind data measured (each second, each 10 minutes, each hour)
5. In which format are the raw data for wind speed, wind direction and temperature available (manual registration or digital registration)
6. Results of data analyses:
   - Hourly mean wind speed variation during a day
   - Monthly mean wind speed variation during a year
   - Annual mean speed variation (year to year variations)
   - Annual wind direction frequency (wind rose)
   - Annual wind speed frequency distribution (histogram)
   - Hourly, monthly and annual mean air temperature
7. Restriction for installation of wind power plants at harbours/on shore/off shore

General

1. Attitude to include renewable energy supply in the plans

B. Comments received

Directorate General for Transport and Ports doesn’t have any marine data. It was proposed to meet with Royal Oman Navy (RON).

**C. Documents received - ** No documents received

9. Ministry of Transport and Telecommunications

Directorate General of Civil Aviation & Meteorology (DGCAM)
Ahmed Hamoud Mohammed Al-Harthy, Director of Meteorology
Dr. Juma Al-Maskari (Ass. DG for Meteorological Affairs)
Date: 30.09.07 at 11:30 h

A. Basis for the meeting

<u>Subject</u>: Wind

1. Locations of met. stations/wind monitoring masts - shown on map and specified by coordinates and by height above sea level
2. Height above ground level of the wind speed and wind direction sensors at each mast
3. Measurement period since Gov. started measuring (start date - end date (if any)) for each mast.
4. Type of terrain surrounding the masts (open flat area, mountain and hills, built-up area)
5. By which frequency is the wind data measured (each second, each 10 minutes, each hour)
6. In which format are the raw data for wind speed, wind direction and temperature available (manual registration or digital registration)
7. Results of data analyses:
   - Hourly mean wind speed variation during a day
   - Monthly mean wind speed variation during a year
   - Annual mean speed variation (year to year variations)
   - Annual wind direction frequency (wind rose)
   - Annual wind speed frequency distribution (histogram)
   - Hourly, monthly and annual mean air temperature
8. Restriction for installation of wind power plants at harbours/on shore/off shore
9. Reports on wind energy studies and surveys in Oman

General

1. Attitude to include renewable energy supply in the plans

B. Comments received

Wind and solar data are available hourly since 1942 for some masts.
Fees for data collection from DGCAM (Civil Aviation) as follows:

- Hourly data basis: 30 OMR per parameter per station per month
- Daily data basis: 20 OMR per parameter per station per month
- Monthly data basis: 60 OMR per parameter per station per year

C. Documents received

- Map with locations of measurement station in Oman (approx. 30 stations)
- Parameter and criteria of stations

10. Ministry of Environment and Climate Affairs

Eng. Naeem Salim Al-Musharroti, Section Environmental Impact (EIA)
Dr. Barry P. Jupp, Marine Ecologist
Date: 30.09.07 at 10:15 h and 15:00 h

A. Basis for the meeting

Subject*: *Wind, Solar

Wind related questions

1. Locations of met stations/wind monitoring masts - shown on map and specified by coordinates and by height above sea level
2. Height above ground level of the wind speed and wind direction sensors at each mast
3. Type of terrain surrounding the masts (open flat area, mountain and hills, built-up area)
4. Measurement period for each mast (start date - end date (if any))
5. By which frequency is the wind data measured (each second, each 10 minutes, each hour)
6. In which format are the raw data for wind speed, wind direction and temperature available (manual registration or digital registration)
7. Results of data analyses:
   - Hourly mean wind speed variation during a day
   - Monthly mean wind speed variation during a year
   - Annual mean speed variation (year to year variations)
   - Annual wind direction frequency (wind rose)
   - Annual wind speed frequency distribution (histogram)
   - Hourly, monthly and annual mean air temperature
8. Reports on wind energy studies and surveys in Oman

Solar related questions

1. Available climatic data : solar radiation, air temperature, air humidity from Jan. to Dec. 2005, 2006, 2007
2. Reports on solar energy studies and surveys in Oman

General

1. Attitude to include renewable energy supply in the plans

B. Comments received

Discussion about renewables in Oman, potentials of wind and solar. Regarding marine data, Eng. Naeem provided link to Dr. Barry Jupp.

C. Documents received

- Several excerpts of environmental law and procedures

11. Supreme Committee for Town Planning,

H.E. Muneer Baker Al-Musawi, Secretary General
Contact: Eng. Fahad Mohammed A. Nabi Macki (D.G. of Technical Developments)
Consultant: Klaus Friedl, V.R.Prasad
Date: 22.10.07

A. Basis for the meeting

***Subject*: General information**

1. Development plans for existing and new towns: locations population
2. What type and amount of energy supply is planned for the new towns
3. Building density and residential area
4. Attitude to include renewable energy supply in the plans

B. Comments received

Major town planning project located in Duqm. The development of Duqm is being overseen by the Ministry of National Economy and the Ministry of Transport and Communications.

The development of Duqm and surround area will create a major new city in the Al Wusta region that will serve as an administrative, industrial and commercial centre. The government is developing the necessary infrastructure and facilities required (e.g. schools, hospital, airport, telecom) plus the amenities necessary to attract companies, service providers and people to what will be an important centre for continuing the development and diversification of our economy. This major new city will bring employment and increased prosperity to Oman in general and to the Al Wusta region in particular.

It is very difficult to provide an accurate assessment, but in the medium to long term it is expected that private and government expenditure will be in the billions of Omani rials. Duqm is expected to grow into a town of more than 50,000 people and almost everything is yet to be built – by government, companies and the public. The cost of the development of the town and infrastructure can be expected to be very significant. The development of the city of Duqm is a major undertaking and it will be the first time in Oman's recent history that a completely new city has been created.

Energy projects are planned by the Authority of Electricity Regulation Oman and the Rural Area Electricity Company. A coal fired power generation plant with a capacity of 1000 MW is under consideration but also the opportunity of implementing 50 MW of solar thermal or photovoltaic energy.

Connection Duqm with MIS planned until 2010/2011.

C. Documents received

- Map of Master Town Planning Duqm
- View of coastal highway Muscat to UAE incl. street lighting

12. Ministry of Agriculture

H.E. Eng. Khalfan bin Saleh Al Naebi, Undersecretary
Date: 30.09.07 at 09:30 h

A. Basis for the meeting

***Subject*: Biogas**

1. Location of major farms and number/type of animals (visits of big farms in Dhofar, Batinah, Sharkya, Dakhlia)
2. Present handling of waste
3. Fuels from waste, respectively dried waste
4. Approximately amount of available waste from agriculture activities (bagasse, citrus fruit peels, straw)
5. Main crops in Oman (region, harvest time)
6. Type and amount of available waste from fish industry
7. Attitude to include renewable energy supply in the plans

B. Comments received

The questionnaire was discussed and hand out. The questionnaire and the introduction letter will be forwarded internally to the technical department. They will provide reply by next week. In case of open questions a further meeting with the technical department should take place.

Positivity about renewables. Offered support to arrange visits with big farms in the north and the south of Oman.

C. Documents received

- Bulletin of Agriculture and Fisheries 2004
- Bulletin of Agriculture and Fisheries 2005
- Bulletin of Agriculture and Fisheries 2006

13. Ministry of National Economy

H.E. Sheik / Al Fadil bin Mohammad bin Ahmed Al-Harthy, Undersecretary
Consultant: Niels Bisgaard Petersen, V.R.Prasad
Date: 11.11.07

A. Basis for the meeting

Subject*: *General information, Census and Social Statistics

1. Demographic information: the population, distribution on cities, villages and in rural areas
2. Population on a communal level
3. Employment
4. Social-economical structure
5. Household (national data or data from target areas)
6. Poverty, livelihoods and well-being
7. Location of cities and villages
8. Building density and residential area
9. Maps of Oman (digital, hardcopy)
10. Statistics on income, average on each location/region
11. Attitude to include renewable energy supply in the plans

B. Comments received

A number of statistical demographic and economic information relevant for the study was received.

C. Documents received

- Year book 2006 of Oman

14. Ministry of Oil and Gas

H.E. Nasser bin Khamis Al Jashmi, Undersecretary
Date: 29.09.07 at 13:00 h

A. Basis for the meeting

<u>Subject</u>: Geothermal energy

Questions related to geothermal energy

1. Locations of bore holes:
   - along the northen coast (from Khasab to Quriyat) (appr. within a 20 km belt along the coastline)
   - along the southern coast (from Dalkut to Sadah)
   - (appr. within a 20 km belt along the coastline)
   - on the island Masirah
   - at Ibri, Hayma and Thumrayt
2. Data form the boreholes:
   - depth
   - temperature gradient
   - presence of water/steam
   - temperature of water/steam
3. Seismic activities in Oman
4. Domestic fuel Subject: oil, coal and gas.
5. Attitude to include renewable energy supply in the plans

B. Comments received

Positivity about renewables. Oman has to take into consideration alternatives to fossil fuel due to limited gas reserves. All power generation plants in Oman are gas fired. The gas is sold for 1.5 USD per million BTU to the Omani power generation plants. The export prices are situated between 3 and 10 USD per million BTU depending on the product specifications. For the renewable energy study he suggested to generate different scenarios of future gas prices or equivalent gas prices for coal.

Regarding specific data about oil field operations the Undersecretary suggested to meet with PDO. He offered support to provide additional introduction letter for data collection if required.

C. Documents received

- Reply on questionnaire received

15. Petrol Development Oman (PDO)

Corporate Planning
Steve J. Van Rossem, Corporate Planning Manager (UCPM)
Richard R. Terres Ph.D, Corporate Strategy & Portfolio Manager (UCS)
Date: 29.09.07 at 14:15 h

A. Basis for the meeting

Subject*: *Wind, Solar, Geothermal

General questions

1. Type of renewable energy technology, date of installation and capacity
2. Operation and performance experiences (generated output, technical availability, type of problems)
3. Local operation and maintenance skills for this type of renewable energy technology
4. Implementation and operation costs for the systems
5. Basis for determination of fuel cost for domestic users and for export
6. Actual costs of fuel and their forecasts

Questions related to geothermal energy

1. Locations of bore holes:
   - along the northern coast (from Khasab to Qurayyat) (app. within a 20 km belt along the coastline)
   - along the southern coast (from Dalkut to Sadah)
   - (app. within a 20 km belt along the coastline)
   - on the island Masirah
   - at Ibri, Hayma and Thumrait
2. Data form the boreholes:
   - depth
   - temperature gradient
   - presence of water/steam
   - temperature of water/steam
3. Seismic surveys in Oman
4. Domestic fuel subject: oil, coal and gas.
5. Attitude to include renewable energy supply in the plans

B. Comments received

Both managers pointed out that the right of property of all data belong to PDO and its shareholders and are subject to approval.
PDO operates over 5000 well drillings in more than 120 oil fields in Oman. All oil fields are located in block 6. Some of them pump less than 500 bpd.
PDO operates actually app. 600 MW installed electric power generation plants. Till end 2007 the capacity will be extended up to 900 MW (One power plant with more than 100MW; the others are smaller power stations with 30 to 50MW). These power plants are fired by non-associated gas (natural gas). This capacity is nearly exclusive used by PDO.

The power grid of PDO grew along with the development of the drilling activities. Therefore the grid is actually not adapted for high load.

PDO is producing 7 barrels of well water per barrel of crude oil (5 to 6 million barrels of water a day). Most of the produced well water is re-injected in the same or new wells. The average temperature of the well water was estimated to 86C°. Regarding geothermal power it was mentioned that hot springs in the mountain region and around Muscat could be more suitable. On some locations in a depth of 5000 m the temperature of the well water was only 10K hotter than the outside temperature with around 55C°.

In order to analyse the geothermal potentials and the data available with PDO it was recommended to plan a meeting between a geothermal expert of COWI and a geologist of PDO.

The existing implementations of solar energy systems are minor. PDO uses hot steam for production process which is generated by gas firing. If solar thermal systems are competitive a combined solution (gas/solar) could be possible.

PDO is interested in wind power generation and in the results of our study. Under certain conditions PDO would be a co-investor in a wind power generations station.

C. Documents received

- Facts sheet as of July 2007

16. Scientific Research Council

H.E. Dr. Hilal bin Ali Al Hinai
Date: 26.09.07 at 13:00 h

A. Basis for the meeting

<u>Subject</u>: R&D, strategy in Renewables

1. Overview of previous and existing renewable energy systems in Oman:
   - types
   - year of installation
   - owners, energy generation
2. Types of present R&D activities within renewable energy and R&D budget for this sector
3. Are there any plans for new, future R&D activities regarding renewable energy in Oman? If any within which area and why are these areas prioritized
4. Which type of renewable energy technology is most suitable for Oman
5. Are there any policy regarding involvement of industry in developing renewable energy sector
6. Are there and norms and standards regarding installation of renewable energy (e.g. documentation solar panel efficiency, installation requirements)
7. Attitude to renewable energy supply

B. Comments received

The policy of the research council is to provide fund mechanism for R&D projects. Two main sections are targeted; the section of Energy and of Education & Culture. The official strategy and program of the research council will be declared in October/November 2007.

Subsidies in power supply are considerably higher in other AGCC countries than in Oman. The question for Oman is, if renewables are able to supply enough energy and in a cost efficient way.

Dr. Hilal recommended solar energy prior for remote areas or combined with water desalination or treatment. The cost of desalinated water in urban areas lies around 1.5 USD / m3, but in remote areas over 25 USD / m3.

Wind energy is most suitable for the coast line in the south, from Sur to Salalah.

The RE study should take into consideration the today's greenhouse gas emission of Oman and the potential of RE/solar energy export, Dr. Hilal said.

Dr. Hilal discussed his paper about solar chimney for power generation and water desalination. Referring to this he mentioned the lower impact of dust on solar thermal systems as on photovoltaic systems.
He also mentioned to study the possibility of "Ocean Thermal Conversion". The necessary temperature difference and depth of the sea seems to be sufficient in Salalah.

C. Documents received

- A high efficiency Solar Chimney for Power Generation and Water Desalination

17. Authority for Electricity Regulation Oman

Eng. Hilal Al-Ghaithi
Date: 09.09.07 at 10:00 h

A. Basis for the meeting

***Subject*: Power Industry Oman, Subsidy system in Oman**

Questions related to the energy sector

1. Energy related legislation and regulations, i.e. energy law, electricity law, renewable energy law, energy efficiency law and similar.
2. Energy policy documents regarding electricity sectors, oil and gas sectors, energy and environment, targets for renewable energy share and energy policy tools under consideration, status in relation to Kyoto and climate change (energy taxes, environmental taxation (CO2), subsidies to renewable energy etc).
3. Energy sector structure and possible plans to privatise restructure and unbundle, especially electricity supply.
4. Information, i.e. annual reports, from energy/electricity suppliers. Historic data (technology, efficiency, fuel consumption and age), maps and production cost (split in fuel, fixed and variable cost) of generation, transmission and distribution facilities. Generation and transmission system expansion plans. Current and foreseen bottlenecks in the system. Load curves and factors.
5. Information about and annual report from Regulation Authority. Regulations regarding renewable energy production and licensing of electricity producers.
6. Information material and annual report from Ministry of Energy including annual energy statistics like Energy balance, Energy trade, Demand and Supply forecasts.
7. Survey and reports on the knowledge, attitude and acceptance of renewable energy among consumers and in industry.
8. Current retail and bulk prices for electricity by tariff, HFO, diesel, kerosene and LPG.
9. Information about taxes and subsidies to electricity and other energy sources.
10. Current generation cost for electricity, i.e. average short term generation cost and long run cost. Future expansion in electricity generation, what technologies and fuels are envisaged at what cost.
11. Domestic fuel Subject, oil, coal and gas.
12. Information (historic, current, forecast) about exchange rates toward USD, electricity and fuel prices, interest, inflation, economic growth, taxation of domestic companies, tax credits for foreign companies, depreciation rules, import duties and possible exemptions for re technology.
13. Attitude to include renewable energy supply in the plans

B. Comments received

General info

Electrical power system in Oman, including capacity, type and location of power plants?

The following information and documentation were provided by Mr. Hilal:

- Report AER 2005 on CD
- Annual report 2006, Oman Power and Water Procurement Co.
- Annual report 2005, Rural Areas Electricity Co.
- Annual report 2005, Muscat Electricity Distribution Co.
- Annual report 2005, Mazoon Electricity Co.
- Annual report 2005, Majan Electricity Co.
- Annual report 2006, Oman Electricity Transmission Co.

The main interconnection system (MIS) included all areas of Oman except of Salalah region and RAECO areas.

Oman runs actually 7 gas fired power stations. Other power stations are in existence but basically used for industry or PDO. Surplus production is feed in the national grid depending on availability of grid.

Transmission is based on 50 Hz, 132 – 220 Volt

Some information about the AGCC grid was discussed. There are 3 phases of implementation of an AGCC grid interconnection. Discussions are going on for more than 10 years. Some connections between UAE and Oman are realised but the related contracts are still not finalised. The AGCC interconnection grid is managed by Saudi Arabia GCCIA (www.gccia.com.sa)

- 1. Phase: interconnection of Saudi / Qatar / Bahrain / Kuwait
- 2. Phase: interconnection of Oman / UAE (grid operates on 400 Volt basis)
- 3. Phase: integration of phase 1 + 2

Location of transmission lines and their voltage level

Mr. Hilal will try to provide a detailed map of the Omani national grid

Information on typical electrical distribution systems in main cities and in rural areas

- See annual report 2005, Rural Areas Electricity Co.
- Rural areas are shown in the annual report of AER. Musandam is also identified as rural area. These areas are supplied by diesel power generation.
- Oman counts approximately 250 such power stations with totally 415 MW installed capacity.
- Mr. Hilal provided a projection for electrification for rural areas. These projects are under planning. Renewable power could be added or substitute conventional solutions.

Maps of Oman (digital, hardcopy)

Digital maps could be collected from the Ministry of Tourism as well as the Ministry of Defense

Renewable energy resources

Solar energy

Copies of relevant studies of similar nature already prepared.

Studies for wind energy and solar energy have been handed over during the kick-off meeting on Sept. 5th.

Copies of relevant government strategies and plans, if any

There are no governmental strategies or plans to integrate renewable energy in Oman. This study will play an important roll for integration of RE in Oman.

Mr. Kevin Cleary will give an account of power generation strategy considered in the Omani government.

Relevant norms, standards, quality assurance systems.

The electricity norms are based on British standard. Recently they have been homologised in GCC and are reflecting basically European standards.

Availability of test station for solar systems, PV and thermal and solar thermal. Details on them.

Mr. Hilal provided a summary of reference projects of OMAN SOLAR SYSTEMS Co. (www.omansolar.com). This summary can be downloaded.

Energy sector, policy, legislation, prices and demand

Energy related legislation and regulations, i.e. energy law, electricity law, renewable energy law, energy efficiency law and similar.

- Mr. Hilal provided "The Law for Regulation and Privatisation of the Electricity and Related Water Sector".
- All power stations need environmental approval (EIA)
- There is no renewable energy law
- Important for the final report of RE in Oman is to advise about the establishment of a Renewable Energy Sources Act. That act makes it compulsory for operators of power grids to give priority to feeding electricity from renewable energies into the grid and to pay fixed prices for this.

Energy policy documents regarding electricity sectors, oil and gas sectors, energy and environment, targets for renewable energy share and energy policy tools under consideration, status in relation to Kyoto and climate change (energy taxes, environmental taxation (CO2), subsidies to renewable energy etc).

- Oman signed and ratified the Kyoto convention
- There is actually no DNA (designated national authority) in Oman to organise for example carbon credits for carbon trading certificates.
- AES (Barka I) proposed the implementation of carbon credits what couldn't be determined

because of missing DNA in Oman.

Energy sector structure and possible plans to privatise restructure and unbundled, especially electricity supply.

Oman plans to privatise the power market in the following phases:

- 1. phase: Power Stations
- 2. phase: Transmission Companies
- 3. phase: Distribution Companies

Information, i.e. annual reports, from energy/electricity suppliers. Historic data (technology, efficiency, fuel consumption and age), maps and production cost (split in fuel, fixed and variable cost) of generation, transmission and distribution facilities. Generation and transmission system expansion plans. Current and foreseen bottlenecks in the system. Load curves and factors.

See provided reports as mentioned above

Information about and annual report from Regulation Authority. Regulations regarding renewable energy production and licensing of electricity producers.

Report 2005 and 2006 have been provided digital

Information material and annual report from Ministry of Energy including annual energy statistics like Energy balance, Energy trade, Demand and Supply forecasts.

See provided reports as mentioned above

Information about taxes and subsidies to electricity and other energy sources.

The electricity market in Oman is officially subsidised only at the supply level.

- Generation
- Transmission
- Distribution
- Supply

(Probably there is an additional subsidy in the system which is not officially shown. It's masked in the prices of gas. Both the Omani gas production and purchased gas).

Current generation cost for electricity, i.e. average short term generation cost and long run cost. Future expansion in electricity generation, what technologies and fuels are envisaged at what cost.

- See provided reports as mentioned above
- Especially for this point the prior study of the provided reports is recommended.

C. Documents received

- Report AER 2005 on CD
- Annual report 2006, Oman Power and Water Procurement Co.
- Annual report 2005, Rural Areas Electricity Co.
- Annual report 2005, Muscat Electricity Distribution Co.
- Annual report 2005, Mazoon Electricity Co.
- Annual report 2005, Majan Electricity Co.
- Annual report 2006, Oman Electricity Transmission Co.
- Project list of Oman Solar Systems LLC

Appendix 2 Site visits

Photos from site visits, November 2007

Photo 1.
Small diesel engine to supply power for a gasoline station

Photo 2.
3.6 MW diesel generator from 1984 at Hijj power station.

Photo 3.
Cooling of 3.6 MW diesel engine. The heat could be used for desalination of heat driven cooling.

Photo 4.
Diesel meter at power station. On the visited plants only the total diesel consumption for all engines together is recorded. This does not allow for optimum operation of individual engines on basis of fuel consumption.

Photo 5.
View towards Masirah island approaching from west.

Photo 6.
10 m wind monitoring mast at Quiroon Hariti

Photo 7.
Potential area near Quiroon Hariti for installation of wind farm

Photo 8.
Representative landscape in the mountains north of Salalah

Appendix 3 Analysis of wind data

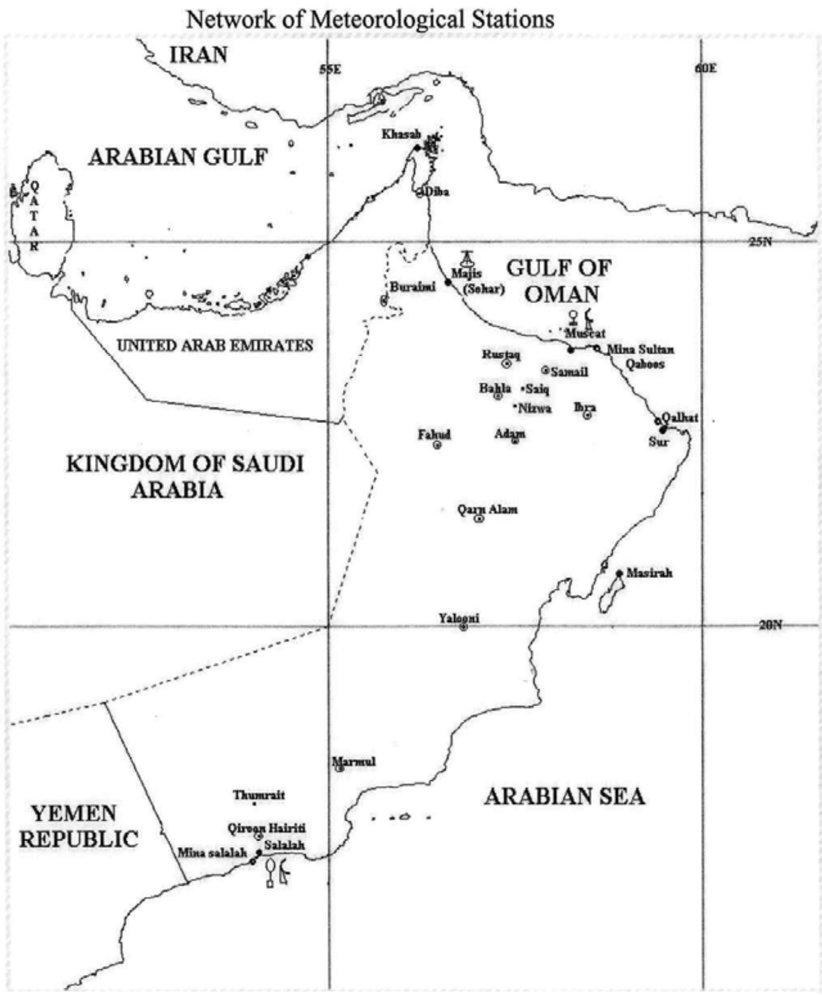


Table. 1

Geographic Location Details of Stations

STATION		W.M.O Index No.	Latitude "N" Deg.	Min.	Sec.	Longitude "E" Deg.	Min.	Sec.	Elevation (M) above M.S.L
Khasab Airport		41241	20	10		54	14	.0	30.36
Diba	*	41242	25	37		56	15		19.81
Buraimi	*	41244	24	14	29.10	55	47	13.80	298.89
Majis [Sohar]	*	41246	24	28	1.0	56	38	27.10	3.63
Saiq New	*	41251	23	04	26.30	57	36	59.50	2001.00
Ibri	*	41252	23	25	.0	56	03	.0	243.80
Rustaq	*	41253	23	24	33.37	57	25	43.10	322.00
Saiq	#	41254	23	04	29.0	57	38	33.50	1754.86
Nizwa	*	41255	22	51	31.38	57	32	37.10	459.53
Seeb	*	41256	23	35		58	17		8.40
Samail	*	41257	23	18	32.46	57	56	52.90	414.00
Mina Sultan Qaboos	*	41258	23	37	38.0	58	34	10.0	4.08
Jabal Shams	*	41259	23	07	48.0	57	09	36.0	3008.98
Fahud	*	41262	22	20	53.0	56	29	14.0	170.00
Bahla	*	41263	22	59	35.60	57	18	57.32	589.24
Adam	*	41264	22	23	40.15	57	31	16.40	285.09
Ibra	*	41265	22	44	25.53	58	30	18.59	469.20
Qalhat	*	41267	22	39		59	24		12.00
Sur		41268	22	32	15.60	59	28	31.0	13.77
Ras Al Haad	*	41270	22	18		59	48		10.00
Qarn Alam	*	41275	21	22		57	03		139.00
Joba	*	41287	20	50	88.0	58	15	49.0	46.00
Masirah		41288	20	40		58	54		18.80
Duqum		41290	19	37		57	38		4.00
Yalooni	*		19	57		57	07		153.60
Marmul	*	41304	18	08	23.0	55	10	39.0	269.00
Mina Salalah		41312	16	54		53	55		3.00
Thumrait		41314	17	40	22.80	54	01	35.70	466.90
Qairoon Hairiti	# *		17	15	17.60	54	05	6.70	878.30
Salalah	*	41316	17	02		54	05		20.00

* *Automatic Weather Station* # *Hill Station*

5

Table: 2

Details of Instrumentation

Meteorological Variable	Sensor	Height of Measurement (m)	Remarks
Air temperature	Ordinary thermometer Max-Min thermometers Thermister	1.25	Housed in a Stevenson screen
Ground & Soil temperature	Ordinary thermometer Platinum resistance thermometer	0.0, 0.05, 0.10, 0.2, 0.3, 0.6 & 1.20	Measured at various depths
Sea surface temperature	Thermistor	..	Attached to Waverider
Humidity	Wet & dry bulb thermometers Hygrometer (*Humicap*)	1.25	Housed in a Stevenson screen
Atmospheric Pressure	Precision aneroid barometer Barocap	1.0	
Surface Wind Speed Direction	Cup anemometer Wind vane	10.0	
Solar Radiation	Pyranometer (Kipp & Zonen)	1.25	
Sunshine duration	Sunshine recorder (Campbell-Stokes) Sun detector (bimetallic)	1.25	
Visibility	Visual & Transmissometer	2.0	
Evaporation	Atmometer (Piche's)		Housed in a Stevenson screen
Precipitation	Ordinary rain gauge Float-type rain gauge Tipping-bucket raingauge	0.40 - 1.0	
Upper air	Radiosonde	..	
Ocean waves	Heave sensor (buoy)	..	Housed in the hull of Waverider
Sea level / Tide	Tide gauge Float / stilling well type	..	

6

WindPRO 2 version 2.5.6.78 Jan 2007

Project:
Oman Sur

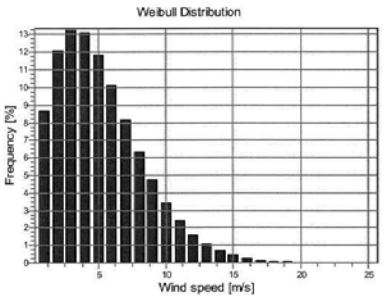
Printed/Page
19-12-2007 10:10 / 1
Licensed user:
COWI A/S
Parallelvej 2
DK-2800 Kgs. Lyngby
45 97 22 11
Calculated:
30-11-2007 10:24/2.5.6.78

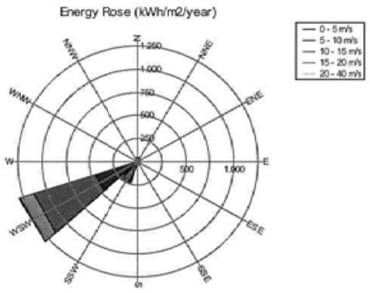
METEO - Wind Data Analysis

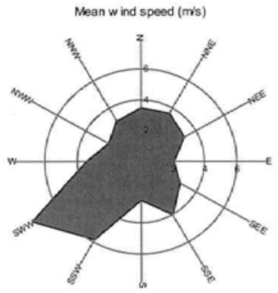
Calculation: Sur, V90 2MW 80m **Wind data:** A - Met station; Hub height: 10,0

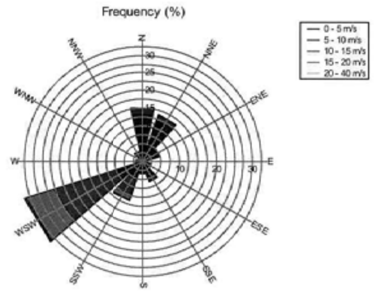
Weibull Data

Sector	A-parameter	Wind speed	k- parameter	Frequency	Wind gradient exponent
	[m/s]	[m/s]		[%]	
0 N	3,87	3,46	2,925	15,5	0,150
1 NNE	4,01	3,62	3,650	13,8	0,150
2 ENE	3,54	3,14	2,523	5,0	0,150
3 E	2,33	2,08	1,730	1,6	0,150
4 ESE	3,22	2,85	2,222	2,5	0,150
5 SSE	4,49	3,99	2,569	6,1	0,150
6 S	2,86	2,53	1,938	3,6	0,150
7 SSW	6,57	5,84	1,832	11,7	0,150
8 WSW	8,78	7,79	2,557	33,9	0,150
9 W	3,80	3,39	1,693	1,8	0,150
10 WNW	2,58	2,31	1,653	1,4	0,150
11 NNW	3,40	3,03	1,700	3,1	0,150
All	5,76	5,15	1,650	100,0	









WindPRO is developed by EMD International A/S, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk

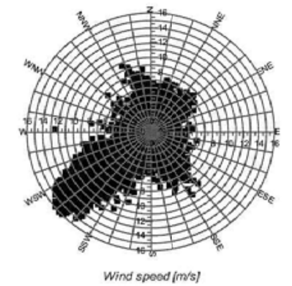
WindPRO 2 version 2.5.6.78 Jan 2007

Project:
Oman Sur

Printed/Page
21-11-2007 18:08 / 1
Licensed user:
COWI A/S
Parallelvej 2
DK-2800 Kgs. Lyngby
45972211
Calculated:
21-11-2007 18:08/

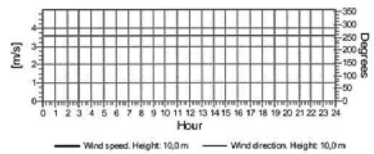
Meteo data report, height: 10,0 m

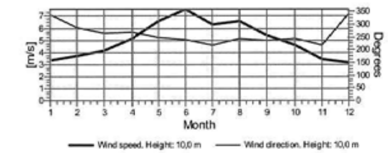
Name of meteo object: Met station

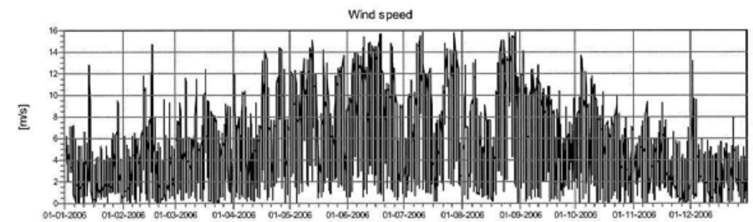


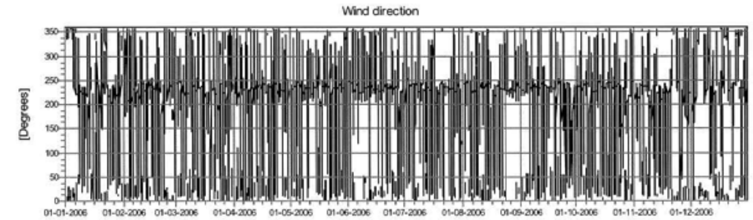
Monthly mean values of wind speed in m/s

Month	2006	mean	mean of months
Jan	3,3	3,3	3,3
Feb	3,7	3,7	3,7
Mar	4,2	4,2	4,2
Apr	5,2	5,2	5,2
May	6,5	6,5	6,5
Jun	7,6	7,6	7,6
Jul	6,3	6,3	6,3
Aug	6,6	6,6	6,6
Sep	5,4	5,4	5,4
Oct	4,6	4,6	4,6
Nov	3,4	3,4	3,4
Dec	3,2	3,2	3,2
mean, all data	5,0	5,0	
mean of months	5,0		5,0









WindPRO is developed by EMD International A/S, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk

WindPRO 2 version 2.5.6.78 Jan 2007

Project:
Oman Joba

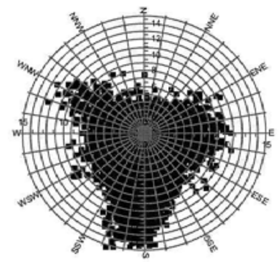
Printed/Page
21-11-2007 17:59 / 1

Licensed user:
COWI A/S
Parallelvej 2
DK-2800 Kgs. Lyngby
45972211

Calculated:
21-11-2007 17:59/

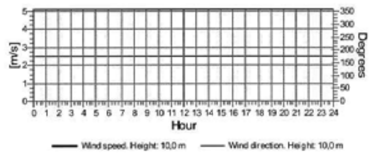
Meteo data report, height: 10,0 m

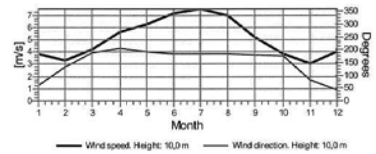
Name of meteo object: Met station

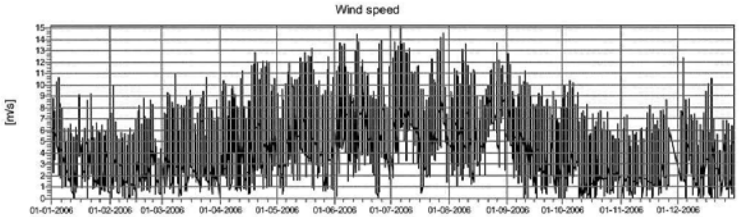


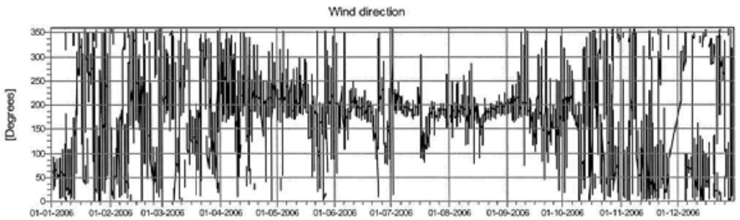
Monthly mean values of wind speed in m/s

Month	2006	mean	mean of months
Jan	3,8	3,8	3,8
Feb	3,3	3,3	3,3
Mar	4,2	4,2	4,2
Apr	5,6	5,6	5,6
May	6,3	6,3	6,3
Jun	7,1	7,1	7,1
Jul	7,5	7,5	7,5
Aug	7,0	7,0	7,0
Sep	5,2	5,2	5,2
Oct	3,8	3,8	3,8
Nov	3,0	3,0	3,0
Dec	4,0	4,0	4,0
mean, all data	5,1	5,1	
mean of months	5,1		5,1









WindPRO is developed by EMD International A/S, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk

WindPRO 2 version 2.5.6.78 Jan 2007

Project:
Oman Masirah

Printed/Page
19-12-2007 10:07 / 1

Licensed user:
COWI A/S
Parallelvej 2
DK-2800 Kgs. Lyngby
45 97 22 11

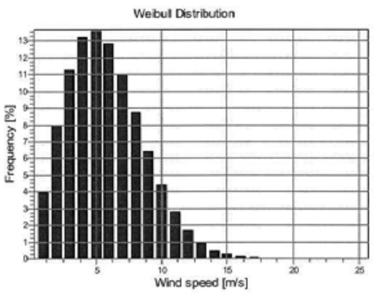
Calculated:
30-11-2007 10:18/2.5.6.78

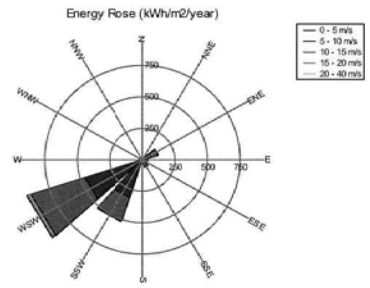
METEO - Wind Data Analysis

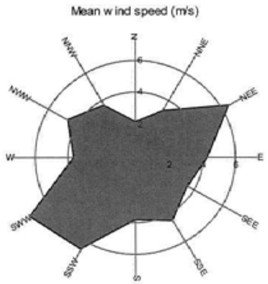
Calculation: Masirah, V90 2MW 80 **Wind data:** A - Met station airfield; Hub height: 10,0

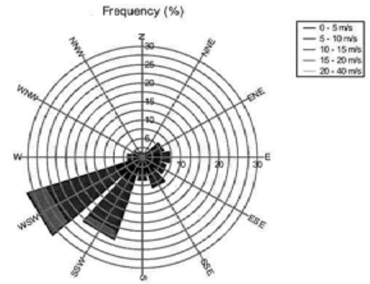
Weibull Data

Sector	A- parameter	Wind speed	k- parameter	Frequency	Wind gradient exponent
	[m/s]	[m/s]		[%]	
0 N	2,54	2,25	2,030	1,0	0,150
1 NNE	3,73	3,31	1,901	1,3	0,150
2 ENE	7,23	6,41	2,423	5,7	0,150
3 E	4,81	4,27	2,440	7,2	0,150
4 ESE	3,99	3,57	3,248	6,6	0,150
5 SSE	5,04	4,49	2,819	8,7	0,150
6 S	4,36	3,86	1,956	6,3	0,150
7 SSW	7,36	6,54	2,612	23,4	0,150
8 WSW	8,15	7,26	2,751	31,7	0,150
9 W	4,17	3,70	2,219	3,8	0,150
10 WNW	5,24	4,65	1,928	2,8	0,150
11 NNW	4,19	3,72	1,874	1,4	0,150
All	6,51	5,77	2,119	100,0	









WindPRO is developed by EMD International A/S, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk

WindPRO 2 version 2.5.6.78 Jan 2007

Project:
Oman Joba

Printed/Page
19-12-2007 10:09 / 1

Licensed user:
COWI A/S
Parallelvej 2
DK-2800 Kgs. Lyngby
45 97 22 11

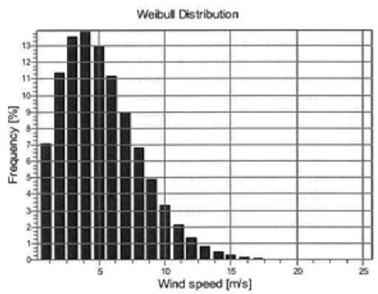
Calculated:
30-11-2007 10:21/2.5.6.78

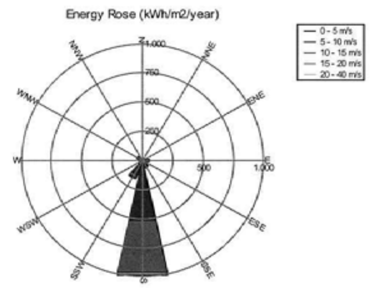
METEO - Wind Data Analysis

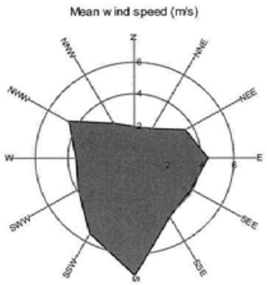
Calculation: Joba, V90 2MW 80m **Wind data:** A - Met station; Hub height: 10,0

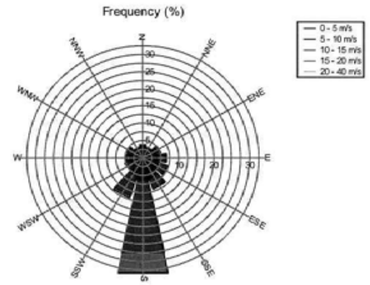
Weibull Data

Sector	A- parameter	Wind speed	k- parameter	Frequency	Wind gradient exponent
	[m/s]	[m/s]		[%]	
0 N	2,25	1,99	2,054	3,9	0,150
1 NNE	2,42	2,14	2,098	3,4	0,150
2 ENE	3,98	3,53	1,931	5,2	0,150
3 E	4,99	4,42	1,997	6,7	0,150
4 ESE	4,43	3,92	2,222	7,2	0,150
5 SSE	4,80	4,25	2,171	9,5	0,150
6 S	8,26	7,37	2,951	34,1	0,150
7 SSW	6,12	5,42	2,291	12,1	0,150
8 WSW	4,47	3,96	2,040	5,2	0,150
9 W	3,98	3,52	2,102	4,8	0,150
10 WNW	5,15	4,58	1,754	4,7	0,150
11 NNW	2,73	2,50	1,371	3,2	0,150
All	5,80	5,15	1,825	100,0	









WindPRO is developed by EMD International A/S, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk

WindPRO 2 version 2.5.6.78 Jan 2007

Project: **Oman Qairoon Hairiti**

Description: Met station

Printed/Page: 21-11-2007 17:17 / 1

Licensed user: **COWI A/S**
Parallelvej 2
DK-2800 Kgs. Lyngby
45972211

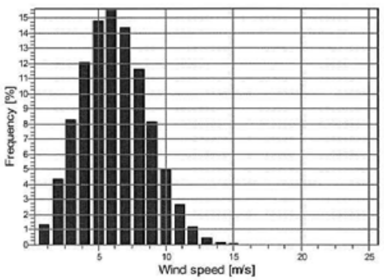
Calculated: 20-11-2007 22:05/2.5.6.78

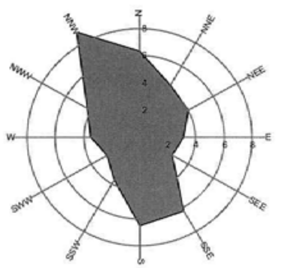
METEO - Wind Data Analysis

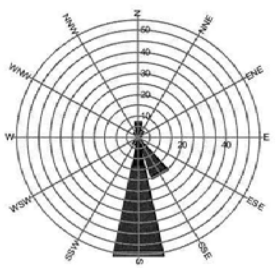
Wind data: A - met station; Hub height: 10,0

Weibull Data

Sector	A-parameter	Wind speed	k- parameter	Frequency	Wind gradient exponent
	[m/s]	[m/s]		[%]	
0 N	7,13	6,31	2,178	7,3	0,150
1 NNE	4,98	4,41	2,335	3,6	0,150
2 ENE	4,49	4,00	2,836	1,8	0,150
3 E	3,55	3,17	2,944	1,1	0,150
4 ESE	3,00	2,69	3,181	1,0	0,150
5 SSE	7,06	6,30	2,991	20,2	0,150
6 S	7,28	6,55	3,510	56,5	0,150
7 SSW	3,99	3,63	4,321	4,1	0,150
8 WSW	2,96	2,62	2,324	0,7	0,150
9 W	3,86	3,42	2,373	0,2	0,150
10 WNW	4,82	4,31	3,151	0,4	0,150
11 NNW	10,03	8,91	2,555	3,1	0,150
All	6,96	6,19	2,736	100,0	







WindPRO is developed by EMD International A/S, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk

WindPRO 2 version 2.5.6.78 Jan 2007

Project: **Oman Masirah**

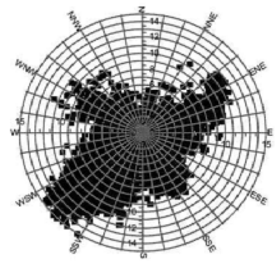
Printed/Page: 21-11-2007 17:46 / 1

Licensed user: **COWI A/S**
Parallelvej 2
DK-2800 Kgs. Lyngby
45972211

Calculated: 21-11-2007 17:46/

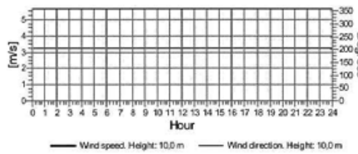
Meteo data report, height: 10,0 m

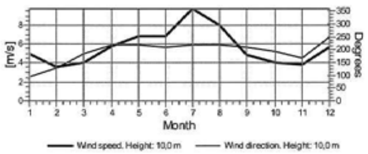
Name of meteo object: Met station airfield

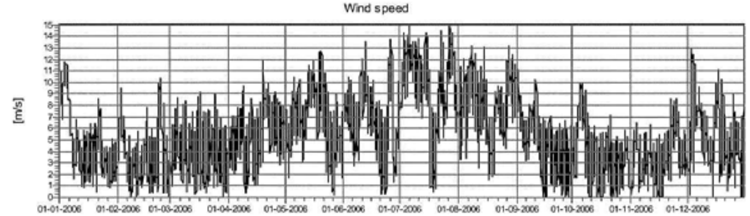


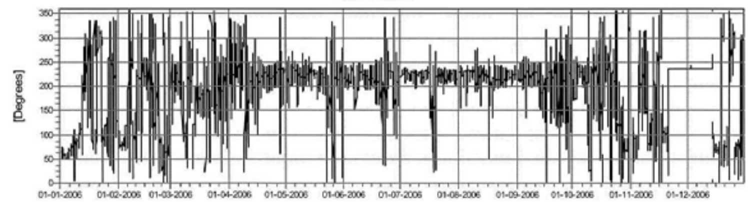
Monthly mean values of wind speed in m/s

Month	2006	mean	mean of months
Jan	4,9	4,9	4,9
Feb	3,6	3,6	3,6
Mar	4,1	4,1	4,1
Apr	5,7	5,7	5,7
May	6,8	6,8	6,8
Jun	6,8	6,8	6,8
Jul	9,7	9,7	9,7
Aug	8,0	8,0	8,0
Sep	4,9	4,9	4,9
Oct	4,0	4,0	4,0
Nov	3,8	3,8	3,8
Dec	5,6	5,6	5,6
mean, all data	5,7	5,7	
mean of months	5,7		5,7









WindPRO is developed by EMD International A/S, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk

WindPRO 2 version 2.5.6.78 Jan 2007

Project: **Oman Thumrait**

Printed/Page: 19-12-2007 10:04 / 1

Licensed user: **COWI A/S**
Parallelvej 2
DK-2800 Kgs. Lyngby
45 97 22 11

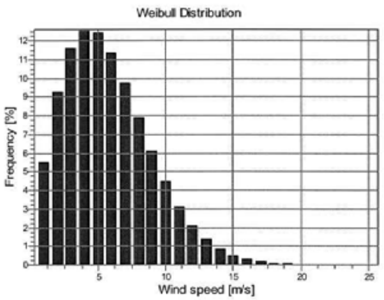
Calculated: 30-11-2007 10:13/2.5.6.78

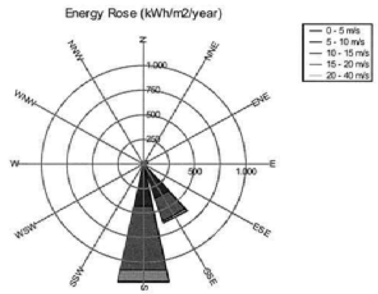
METEO - Wind Data Analysis

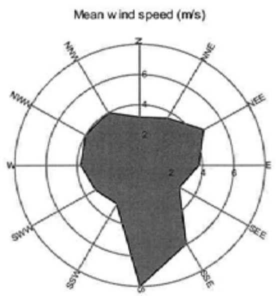
Calculation: Thumrait **Wind data:** A - Met station airfield; Hub height: 10,0

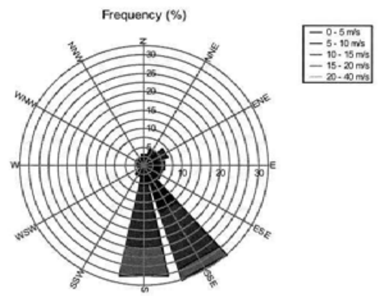
Weibull Data

Sector	A-parameter [m/s]	Wind speed [m/s]	k-parameter	Frequency [%]	Wind gradient exponent
0 N	3,63	3,21	2,102	3,1	0,150
1 NNE	4,05	3,59	2,413	4,6	0,150
2 ENE	5,28	4,70	2,794	6,6	0,150
3 E	4,25	3,77	2,009	5,5	0,150
4 ESE	3,31	2,93	2,210	5,2	0,150
5 SSE	6,73	5,96	2,174	32,9	0,150
6 S	9,01	8,01	2,733	30,9	0,150
7 SSW	3,29	2,92	1,856	3,3	0,150
8 WSW	3,60	3,21	1,672	1,6	0,150
9 W	4,24	3,76	2,447	1,9	0,150
10 WNW	4,52	4,01	1,912	2,0	0,150
11 NNW	4,59	4,07	2,162	2,4	0,150
All	6,50	5,77	1,871	100,0	









WindPRO is developed by EMD International A/S, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk

WindPRO 2 version 2.5.6.78 Jan 2007

Project: **Oman Qairoon Hairiti** Description: Met station

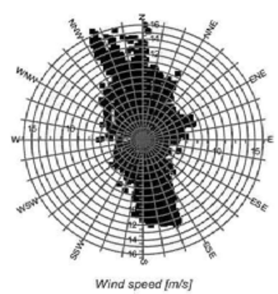
Printed/Page: 21-11-2007 18:10 / 1

Licensed user: **COWI A/S**
Parallelvej 2
DK-2800 Kgs. Lyngby
45972211

Calculated: 21-11-2007 18:10/

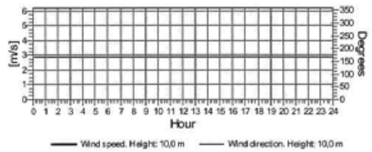
Meteo data report, height: 10,0 m

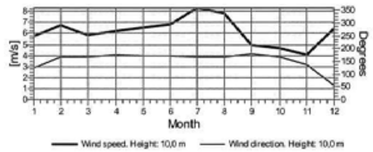
Name of meteo object: met station

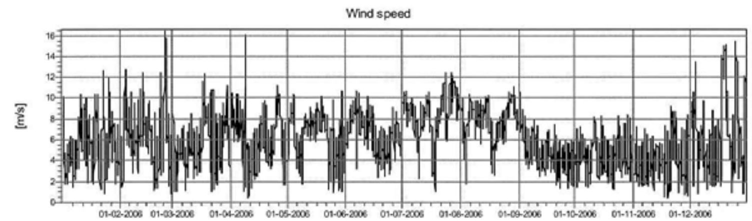


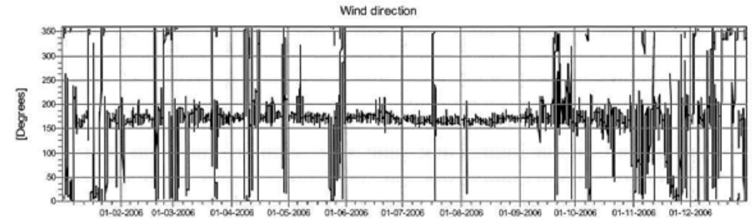
Monthly mean values of wind speed in m/s

Month	2006	mean	mean of months
Jan	5,8	5,8	5,8
Feb	6,8	6,8	6,8
Mar	5,9	5,9	5,9
Apr	6,3	6,3	6,3
May	6,5	6,5	6,5
Jun	6,8	6,8	6,8
Jul	8,3	8,3	8,3
Aug	7,8	7,8	7,8
Sep	5,0	5,0	5,0
Oct	4,6	4,6	4,6
Nov	4,1	4,1	4,1
Dec	6,4	6,4	6,4
mean, all data	6,2	6,2	
mean of months	6,2		6,2

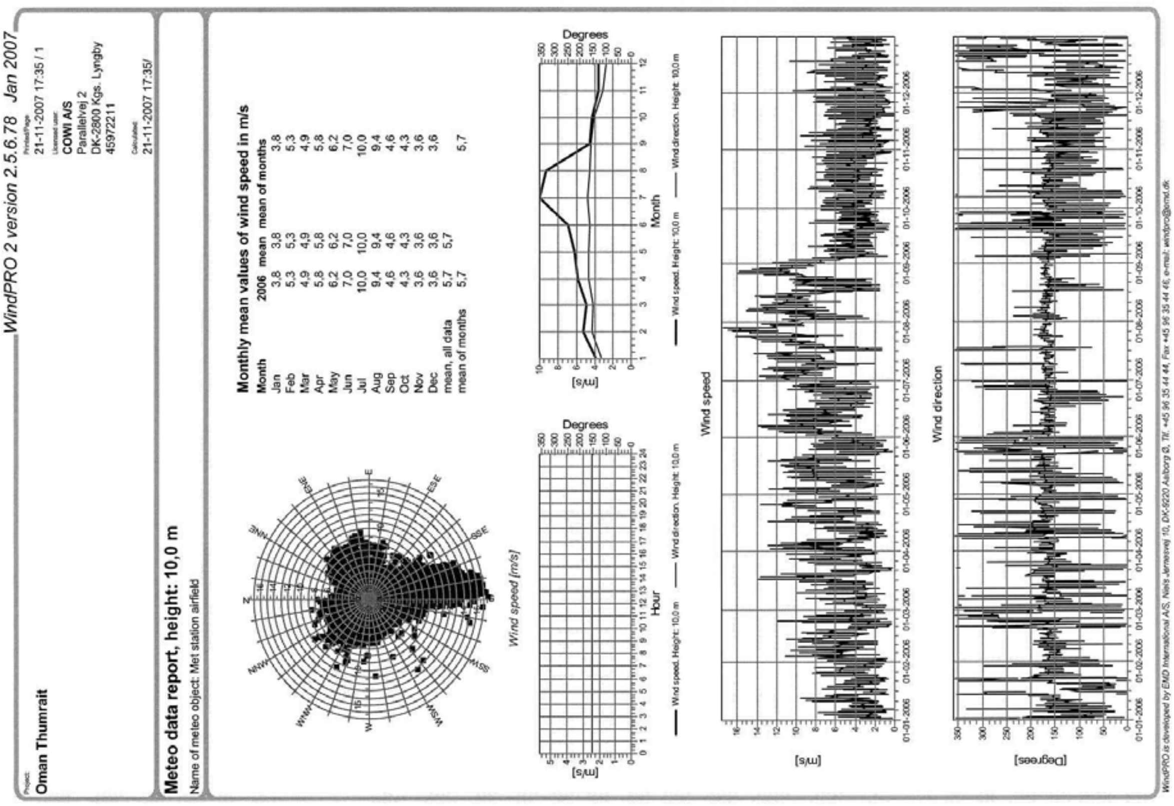








WindPRO is developed by EMD International A/S, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk



WindPRO 2 version 2.5.6.78 Jan 2007

Project:
Oman Thumrait

Printed/Page
21-11-2007 17:35 / 1

Licensed user:
COWI A/S
Parallelvej 2
DK-2800 Kgs. Lyngby
45972211

Calculated:
21-11-2007 17:35/

Meteo data report, height: 10,0 m

Name of meteo object: Met station airfield

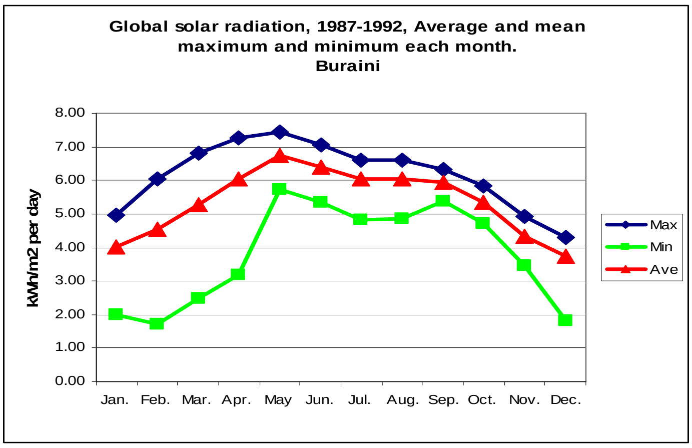
Monthly mean values of wind speed in m/s

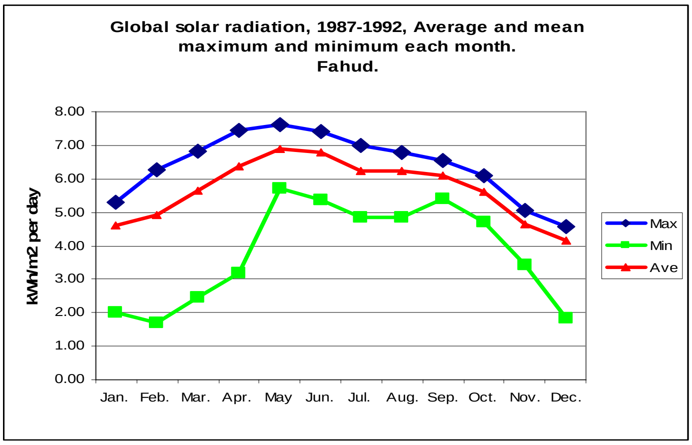
Month	2006	mean	mean of months
Jan	3,8	3,8	3,8
Feb	5,3	5,3	5,3
Mar	4,9	4,9	4,9
Apr	5,8	5,8	5,8
May	6,2	6,2	6,2
Jun	7,0	7,0	7,0
Jul	10,0	10,0	10,0
Aug	9,4	9,4	9,4
Sep	4,6	4,6	4,6
Oct	4,3	4,3	4,3
Nov	3,6	3,6	3,6
Dec	3,6	3,6	3,6
mean, all data	5,7	5,7	
mean of months	5,7		5,7

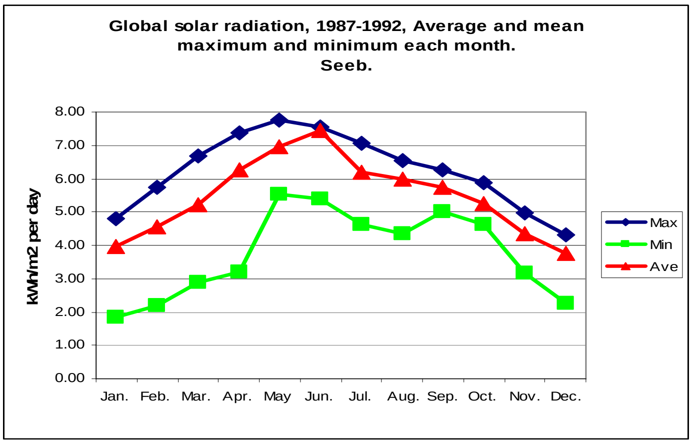
WindPRO is developed by EMD International A/S, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk

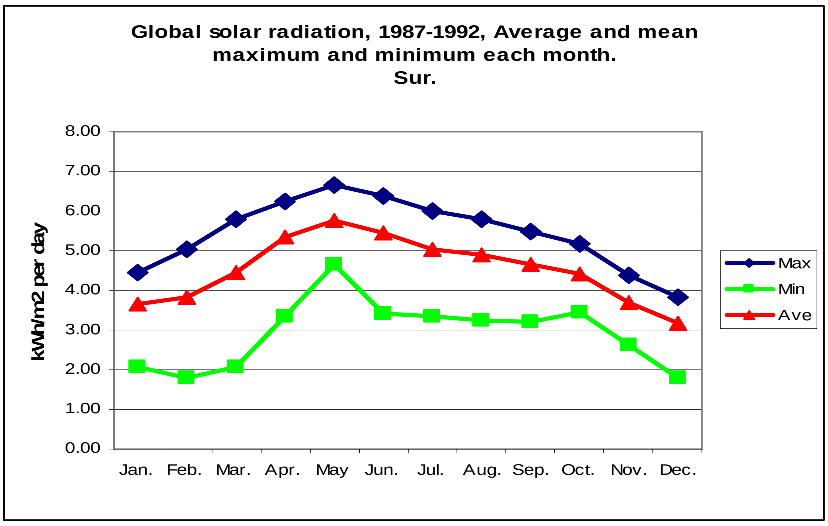
Appendix 4 Analysis of solar data

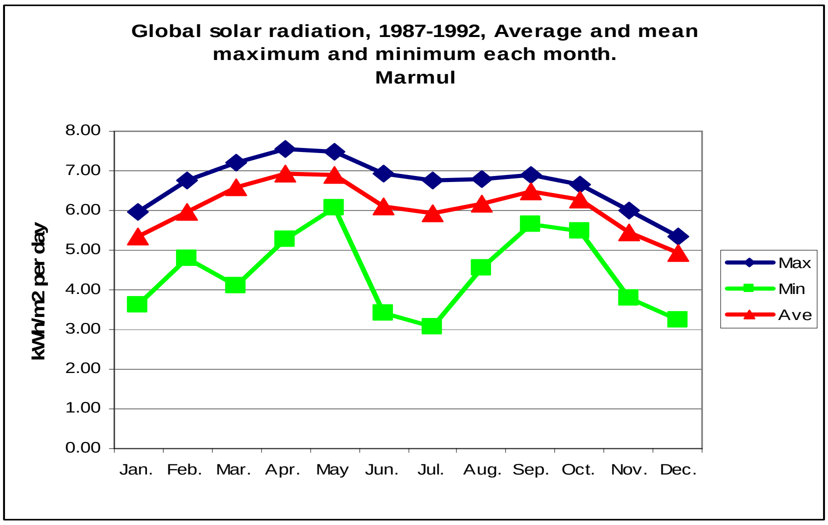
4.1 The mean, the minimum and the maximum values of the daily global insolation for each month for the period 1987-1992.

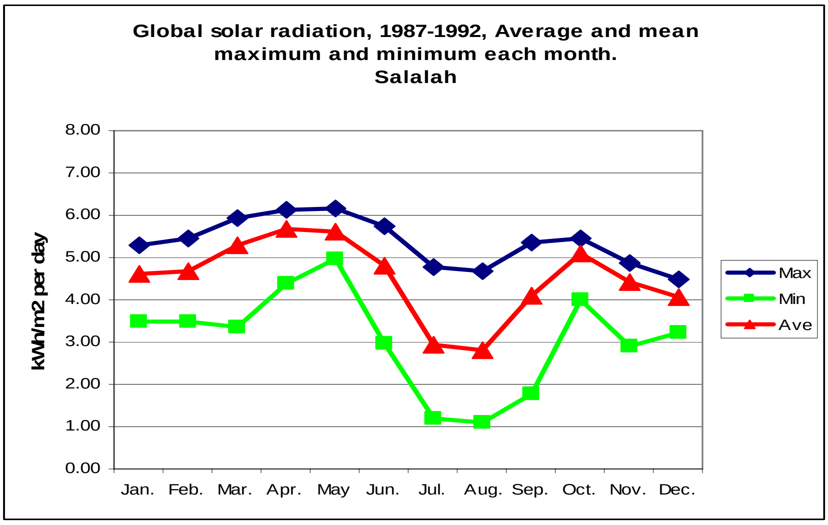







Global solar radiation, 1987-1992, Average and mean maximum and minimum each month.
Sur.
kWh/m2 per day
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Max
Min
Ave


Global solar radiation, 1987-1992, Average and mean maximum and minimum each month.
Marmul
kWh/m2 per day
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Max
Min
Ave


Global solar radiation, 1987-1992, Average and mean maximum and minimum each month.
Salalah
kWh/m2 per day
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Max
Min
Ave

Appendix 5 Geothermal data

PDO Block 6 corrected borehole temperatures

Well_Name	Abbr_Name	Easting	Northing	Corrected Temp	Depth_MSS
ABU THAYLAH-2H1	ABT-2H1	523333.630000	2393671.310000	102.70	2947.80
AL BASHAIR-2H1	ABH-2H1	407623.590000	2435407.710000	157.00	4884.70
AL FASIL-1H1	AFL-1H1	413911.950000	2269357.850000	116.61	4255.50
AL NOOR-1H1	ALNR-1	354872.660000	2034499.450000	101.40	4809.29
AMBRAH-1H2	AMB-1H2	237444.140000	1987405.680000	100.92	4830.77
ASEEL WSW-1	ASH-4H1	332422.420000	2064500.930000	100.48	4463.22
ASFOOR-2H2	ASF-2H2	368471.970000	2248788.090000	117.74	4135.90
BARIK-25H1	BK-25H1	448890.000000	2317740.050000	124.38	4282.19
DAFIQ-1H1	DAF-1H1	234323.060000	1989074.990000	103.00	4952.26
FAAL-1H2	FAL-1H2	320948.610000	2518523.540000	123.74	3152.54
FAHUD SOUTH EAST-1H1	FSE-1H1	455669.920000	2456949.810000	163.00	4553.60
FAHUD SOUTH-9H1	FS-9H1	450672.000000	2462622.330000	105.60	2164.99
FAYROUZ-1H1	FAY-1H1	244046.090000	1995673.040000	101.63	4336.20
INAAM-1H2	INAA-1H2	230179.160000	1985465.490000	153.84	2727.13
KHAZZAN-1H5	KZN-1H5	460712.430000	2387085.300000	157.65	5111.87
KHAZZAN-3H1	KZN-3H1	439811.390000	2403348.820000	145.74	4803.22
LAHAN-1H1	LHN-1H1	212048.510000	1998200.140000	129.64	5670.61
MABROUK-1H1	MBR-1H1	425681.450000	2349516.690000	121.10	3577.13
MABROUK-2H1	MBR-2H1	427005.890000	2347894.840000	114.40	3669.87
MAKAREM-3H1	MKM-3H1	452818.190000	2402455.000000	173.68	5258.75
MAKAREM-4H1	MKM-4H2	459490.110000	2435639.990000	170.00	5148.70
MAMOUR-1H1	MAM-1H1	233673.620000	1988770.870000	103.54	4735.88
MUSALLIM DEEP-1H2	MLMD-1H2	455512.550000	2396844.010000	147.54	4338.67
NIBRAS-1H1	NBR-1H2	560710.220000	2419533.100000	142.84	4761.49
QARN NIHAYDA-1H4	QN-1H4	488730.740000	2350088.990000	110.00	3768.48
QASHOOB-1H1	QASH-1H1	218036.740000	1976928.140000	115.40	5250.11
RABAB-1H1	RBB-1H1	251148.040000	2002750.090000	117.00	4342.10
SABEEL-1H1	SEL-1H1	477624.030000	2376869.560000	114.00	3087.28
SAKHIYA-2H1	SAK-2H1	243525.340000	1997890.050000	107.33	4519.02
SUWAIHAT-5H1	SHT-5H1	410141.480000	2212691.570000	106.40	4492.50
TIBR-2H1	TIB-2H1	461964.770000	2396963.060000	140.13	3636.60
YIBAL-192H1	Y-192H1	393932.180000	2449997.150000	137.20	4199.52
YIBAL-212H1	Y-212H1	392317.580000	2447988.720000	123.00	3499.68
YIBAL-214H1	Y-214H1	396130.490000	2444829.140000	111.00	2972.19
YIBAL-85H1	Y-85H1	398710.020000	2448005.690000	131.10	3995.93
ZALZALA-1H3	ZAZ-1H3	235343.580000	1993110.440000	107.10	5317.35

PDO Block 6 corrected borehole temperatures

Well_Name	Abbr_Name	Easting	Northing	Temp	Depth_MSS
AL HUSAIN-1H1	AHN-1H1	428148.081645	2425146.941580	125.00	3780.43
AL HUWAISAH-27H2	AH-27H2	410426.623117	2427655.769970	124.40	3862.74
AL HUWAISAH-46H1	AH-46H1	411027.547367	2427273.894430	110.00	3555.72
AL HUWAISAH-48H1	AH-48H1	410675.650000	2429439.110000	114.00	3290.24
AL HUWAISAH-56H1	AH-56H1	400903.611319	2428576.585610	124.00	3958.13
DHULAIMA-3H1	DM-3H1	342361.970000	2512031.290000	104.00	2392.57
DHULAIMA-7H1	DM-7H1	352676.810189	2510643.520570	157.80	4735.35
FAHUD-1H1	F-1H1	449714.760000	2464790.870000	130.00	3427.78
FUSHAIGAH-1H1	FG-1H1	521928.720000	2436094.720000	110.00	2682.63
HASIRAH-1H1	HSR-1H1	361113.192999	2257482.617400	103.30	3220.61
HASIRAH-2H1	HSR-2H1	353519.268250	2250847.433750	103.00	2920.65
LEKHWAIR-6H1	L-6H1	333087.450010	2528083.569970	101.70	2196.22
LEKHWAIR-70H1	L-70H1	331565.070000	2527149.590000	160.00	5078.94
LEKHWAIR-85H1	L-85H1	323676.350000	2533335.300000	147.00	4087.03
SAIH NIHAYDA-15H1	SN-15H1	497475.413167	2368687.715070	111.00	2922.91
SAIH RAWL-10H1	SR-10H1	468275.470000	2359207.910000	100.60	2911.83
SAIH RAWL-87H1	SR-87H1	469685.172322	2361201.580910	133.00	4597.58
SHUWAIQI-1H1	SQ-1H1	456875.120000	2410163.730000	118.90	3413.65
TAWF DAHM-1H1	TD-1H1	400701.391667	2365655.802500	121.10	3460.02

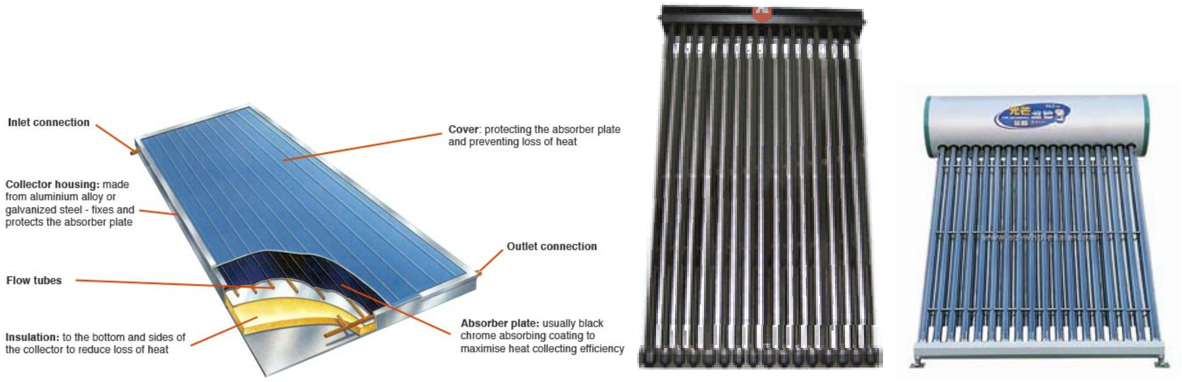
Appendix 6

Appendix 6 Solar technology, applications and efficiency

6.1 Solar thermal systems

For production of solar thermal energy at temperatures below 100 C there are two types of technology typically applied. One is a flat plate collector with an absorber covered by a special selective surface and a low iron glass cover, sometimes additional cover as well. The other is evacuated tubular collects in which the absorber is integrated into a glass tube with vacuum. The latter is more efficient for temperatures close to 100 C, but the flat plate is best for lower temperatures. These collectors convert up to 80 percent of the solar insolation to heat with a yearly average of up to 50% of the solar insolation. A popular system for a family consist of about 2 m2 of collector with an integrated storage tank located on top of the collectors so that a pump is not necessary to circulate the fluid in the collectors. Larger systems are made with collectors on the roof and a piping system for transfer of the heat to a storage tank in the building.

Fig. A 6.1 Flat plate collector, evacuated tubular collector and the same with integrated storage tank for hot tap water.



Another important application of solar thermal energy is for cooling. As cooling is most often provided with conventional electric compressors solar energy will also in this case replace electricity. The most typical system here is to use a higher temperature collector (often evacuated tubular collector, up to about 100 C) to produce heat for an absorption chiller. An important aspect here is that the system still uses electricity for pumping and other things which is sometimes significant.

6.2 Examples of applications at various types of areas.

The following table and the text below, show possible or recommended applications of solar technologies for city, rural locations and desert environment.

Application	Solar PV	Solar thermal power	Solar thermal
City (larger cities connected to national grid)	Grid connected PV owned by utility.	Not applicable	For production of hot tap water to replace electricity.
	Grid connected PV, private.		For thermal driven cooling processes (e.g. a**b**sorption and a**d**sorption cooling cycles), to replace electricity.
	Street light with battery.		To produce low to medium temperatures for industrial purposes.
	Not grid connected solar PV cooling.		
	Solar PV desalination (reverse osmosis) with storage of water.	Thermal driven desalination.	
Rural off grid city (larger city with a number of diesel units for production of electricity).	Grid connected PV owned by utility.		For production of hot tap water to replace electricity.
	Grid connected PV, private.		For thermal driven cooling processes (e.g. a**b**sorption and a**d**sorption cooling cycles), to replace electricity.
	Street light with battery.		To produce low to medium temperatures for industrial purposes.
	Not grid connected solar PV cooling.		
	Solar PV desalination (reverse osmosis) with storage of water.	Thermal driven desalination.	
Rural, small village	Solar home systems for single consumers.	Not applicable.	For production of hot tap water to replace electricity.
	Central solar PV plant with mini grid and back up, typical diesel. (hybrid system). Can include wind energy.		For thermal driven cooling processes (e.g. a**b**sorption and a**d**sorption cooling cycles), to replace electricity.
	Pumping and irrigation.		To produce low to medium temperatures for industrial purposes.
Desert	Large PV power plant without storage. Supply to national grid.	Large scale solar thermal power plant with backup (gas) and possibly short term storage of heat. Supply to national grid.	
	Large PV power plant with large scale storage (battery or other). Supply to national grid.		
	Mobile power supply with or without battery.		
	Solar PV desalination (reverse osmosis) with storage of water.	Thermal driven desalination.	
	Water pumping and irrigation.		

Application 1. City

A major application here is grid connected solar PV. This will feed into the grid in the same way as wind energy does. The PV can be located anywhere and be privately owned is the legal set up making this possible. The PV is connected to the grid via a converter and the surplus of electricity can be transferred to the grid. For this a tariff for selling and for buying is needed. In some countries the tariffs are the same for selling and buying in order to promote PV.

As long as the peak power demand coincides with the solar insulation (mid day) the solar PV can represent a real capacity on the grid. One MW solar PV will replace one MW conventional power plant. An important aspect here is that the time for realising solar PV capacity is much shorter than for conventional power (perhaps 1 year instead of 10 years). In Oman there seems to be two peaks in the use of electricity, midnight and midday. If the midnight peak is the biggest the PV will not represent a capacity. A way to deal with this could be to do other things to reduce the midnight peak through other measures.
PV street light with battery can be an option in parts of a city and will reduce the midnight peak.

Solar PV desalination can operate when the sun is shining and the water stored.
Solar thermal power is not applicable as an integrated part of the city.

The solar thermal applications which include solar thermal energy for heating of water and for cooling are essential for the city. These are demand side applications where it is the consumers who do the investment. The advantage with these technologies is that they reduce the consumption of electricity and also the demand for capacity of power plants. Possible approaches to promote these technologies are regulations and encouragements. For example it could be made forbidden to use electricity for heating of water and a grant could be provided for solar cooling.

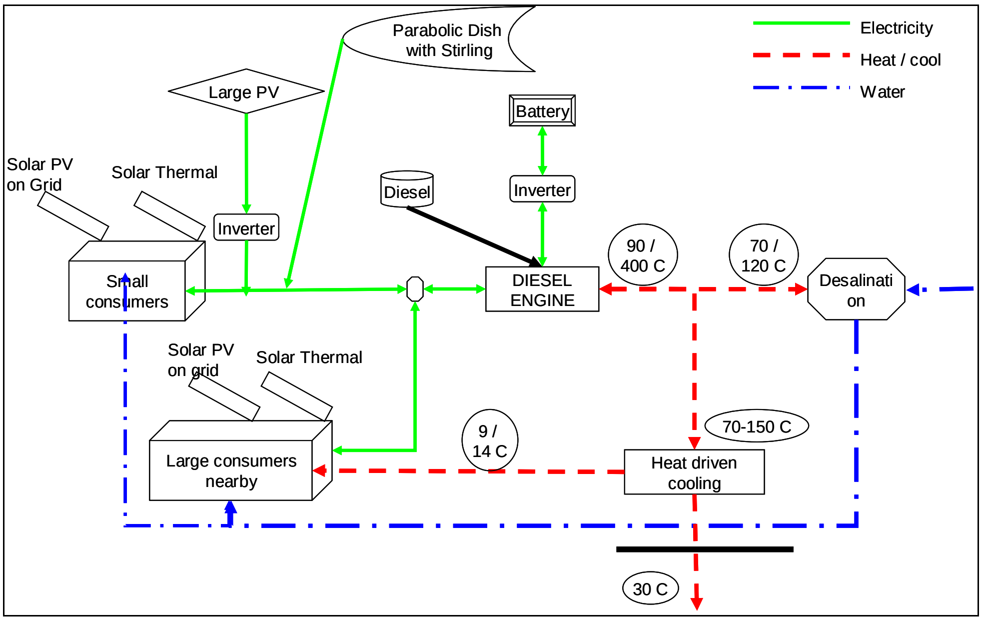
Application 2. Rural off grid city

It is here considered that there is a supply based on a number of smaller units (e.g. diesel) to supply the city but that it is not connected to the national grid.
For this purpose the applications mentioned under "city" are all relevant. As the cost of electricity is higher the demand side applications will be more favourable and a higher percentage of solar will be feasible.

Diesel engine can be made of more than one unit and a smaller battery bank can be included for improved fuel efficiency.

Heat from diesel engines (cooling and exhaust gas) can be used for operation of heat driven cooling (adsorption or absorption machine). The cooling from this could be supplied to larger consumers (office, shops etc.) via district cooling.

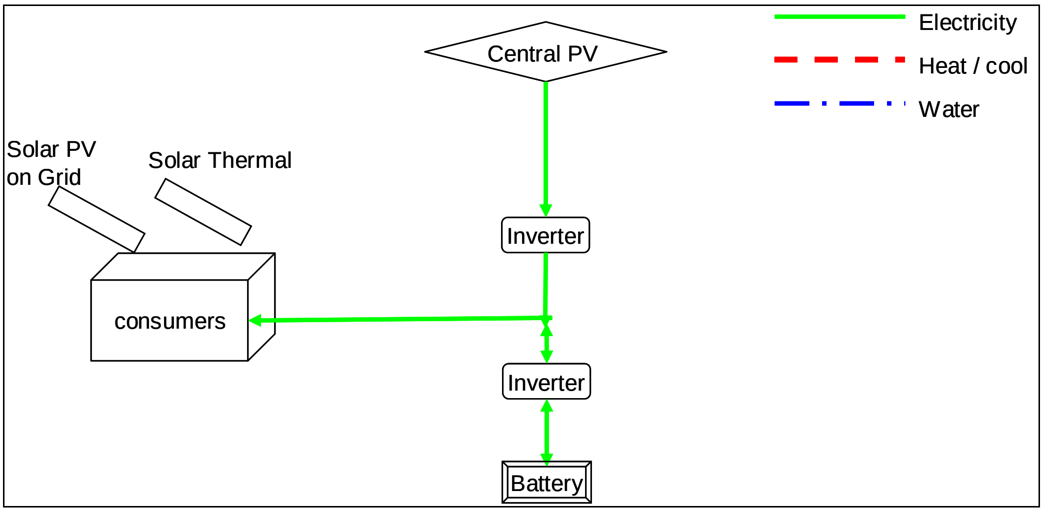
Fig. A 6.2   Example of rural system for power supply of few houses



Application 3. Rural, small village

Electricity supply to single users in off grid locations (so-called stand alone systems) with small demand can be supplied with the so-called solar home systems. These systems typically include a battery bank and a converter to convert DC to AC. There is no back up. Small systems supply only DC electricity for lighting and small appliances, for example a radio or television.

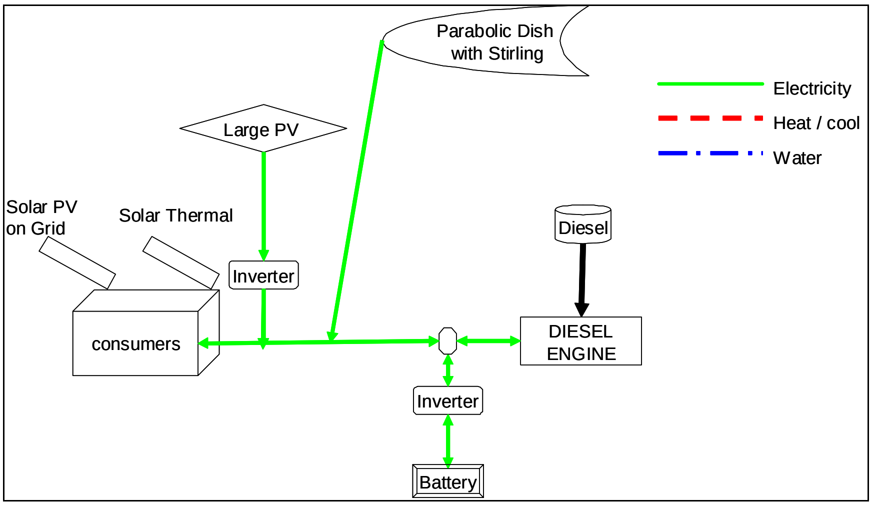
Fig. A 6.3   Example of single solar home system



Renewable electricity supply to off grid locations with higher demand (small villages) are often referred to as a hybrid system. There will be a mini grid, solar PV panels, diesel engine a central battery bank, a bi-directional DC-AC converter and sophisticated control. In Oman, the system could not be made without diesel backup due to the large difference between summer and winter consumption.

As indicated below the system could include parabolic dish with Stirling engine. The heat from the diesel engine could be used for desalination or cooling.

Fig. A 6.4 Example of system for rural village



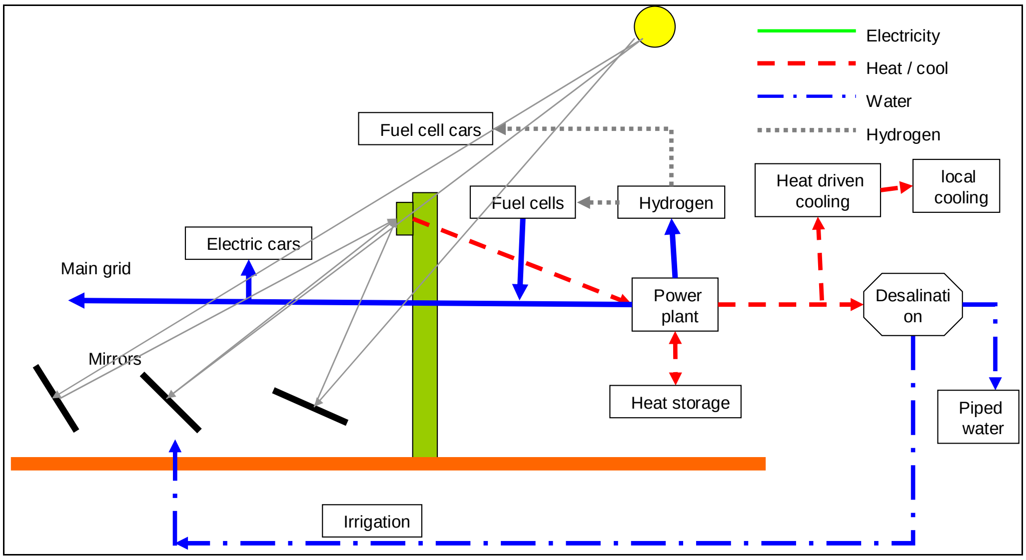
Application 4. The desert

The desert with its favourable solar conditions has a potential of developing into the major source of energy supply for a country like Oman. The resources available are enormous and might be a major export to Europe sometimes in the future, export of clean energy following depletion of the oil resources. With a high percentage of solar electricity (and wind electricity) there will be a surplus in the winter which could be exported to Europe where the consumption is highest in the winter.

The technologies to apply are large scale solar PV and in the future the large scale solar thermal power. The advantage with the latter is that power can be supplied all the time, not only when the sun is shining. In order to do this either the supplementary fuel should be renewable (e.g. biomass) or the technology for storage of high temperature heat should be applied. Geothermal energy may be an option at places. Alternatively solar desalination plants would allow for production of biomass to supplement the solar thermal power plant at night.
Calculations show that using only 1 % of the desert and semi desert areas of the world for such technologies could provide the present electricity consumption for the entire world.

The future perspective in the diagram below, shows the power plant running on solar or on the heat storage (molten salt). Surplus electricity can be used for production of hydrogen for transport or directly used for charging batteries in electric cars during off peak periods. The heat is used for heat driven cooling in local area and for desalination to produce piped water.

Fig. A 6.5 Example of large scale solar based energy supply system



6.3 Environmental impact on PV cell efficiency

The efficiency of solar PV modules are measured under standard conditions that are supplied by the manufacturers. These conditions are:

- A solar insolation of 1000 W/m2 on the module.
- A surrounding air temperature of 25 C.
- No dust on the module.

Under operation these conditions are not met, the insulation is on average smaller and the temperature higher and there will be some amount of dust on the module.

Calculation programmes for calculation of output from PV system always take into account the variation in insolation and the angle of radiation. The influence of the temperature and the dust is in most programmes counted for as a derating factor. In the programme HOMER, used in this analysis, a derating factor of 90% (10 % losses) has been used. This includes reduction for higher temperature and for dust and other minor losses.

For Oman the influence of the temperature is of particular interest as the temperature is very high. Therefore this has been analysed further.

On the basis of laboratory tests and mathematical analysis it has been established that the drop in efficiency for solar modules amount to about 0.4 percent per increase in module temperature.

The module temperature depends on the surrounding temperature, the insulation as well as on the way the module is mounted. A module mounted freely will be cooled by the air and the efficiency higher.

The analysis has been made with a linear temperature model. This model determines module temperature through linear dependence, from solar irradiation (G) as follows:

$T_{Module} = Ta + k * (G / GSTC).$

The value of the constant “k” is dependent on the type of module installation and a measurement for the maximum possible temperature at maximum insolation (GSTC = 1000 W/m2) compared with the external temperature “Ta”:

- Free-standing: k = 20°C.
- Roof-mounted, with ventilation space: k = 30°C.
- Roof or façade-integrated, without ventilation space: k = 45°C.

With this model and on the basis of hourly values for insolation and external temperature from SEEB in Oman the following table has been prepared.

Table A 6.1 Influence on the efficiency of solar PV modules by the cell temperature for different types of mounting

	Average outside air temperature during PV operational hours Degree C	Average Module temperature during operation Degree C	Average drop in efficiency, Percentage 1)
Free-standing	31	44	7.9
Roof-mounted, with ventilation space	31	51	10.6
Roof or facade-integrated, without ventilation space	31	60	14.5

1) Compared to standard test conditions for PV modules. Insolation of 1000 W/m2 a and surrounding air temperature of 25 C.

Table A 6.1 shows that the reduction in efficiency and output is about 8, 11 and 15 percent for the three different mounting. The corresponding maximum temperature (on the hottest day) is about 70 C, 80 C and 100 C for the three different mounting systems.

The influence of dust depends naturally on the environmental conditions as well as on the cleaning frequency. In climates with frequent rain there will after some time be a steady state where dust and dirt is removed by the rain in the same speed as it is coming. The percentage reduction will then depend on the slope and is believed to be about 10% for a slope of 15 degree and smallest with a slope of 45 degree, where the rain is still effective.

In Oman the slope should not be higher than 15 degree (for freely mounted modules) as this will reduce the output considerably. With the low and unpredictable rainfall it will be necessary to clean the PV panels from time to time in order not to reduce the output too much. For larger systems the efficiency will be continuously monitored and will indicate when a cleaning is necessary. Methods with use of water as well as without water exist. Also new materials and coatings for the glass have been developed that should reduce the problem.

For the purpose of the analysis in this report the reduction as a result of temperature has been set to 8 percent and the reduction caused by dust to 2 percent.

Appendix 7

Appendix 7 Calculation of wind farm output

WindPRO 2 version 2.5.6.78 Jan 2007

Project:
Oman Sur

Printed/Page
19-12-2007 10:10 / 1

Licensed user:
COWI A/S
Parallelvej 2
DK-2800 Kgs. Lyngby
45 97 22 11

Calculated:
30-11-2007 10:24/2.5.6.78

METEO - Main Result

Calculation: Sur, V90 2MW 80m

Name Met station
Site Coordinates
Geo East: 59°28'31,00" North: 22°32'15,60"

Air density calculation mode	Individual per WTG
Result for WTG at hub altitude	1,180 kg/m3
Hub altitude above sea level (asl)	93,7 m
Annual mean temperature at hub alt.	22,8 °C
Pressure at WTGs	1.002,4 hPa

Calculation is based on "Met station", giving the Weibull distribution for the wind speed on the site.
Using the selected power curve, the expected annual energy production is calculated.

A

Scale 1:25.000

Meteorological Data

Weibull data 10 m above ground level

Sector	A- parameter [m/s]	Wind speed [m/s]	k- parameter	Frequency [%]	Wind gradient exponent
0 N	3,87	3,46	2,925	15,5	0,150
1 NNE	4,01	3,62	3,650	13,8	0,150
2 ENE	3,54	3,14	2,523	5,0	0,150
3 E	2,33	2,08	1,730	1,6	0,150
4 ESE	3,22	2,85	2,222	2,5	0,150
5 SSE	4,49	3,99	2,569	6,1	0,150
6 S	2,86	2,53	1,938	3,6	0,150
7 SSW	6,57	5,84	1,832	11,7	0,150
8 WSW	8,78	7,79	2,557	33,9	0,150
9 W	3,80	3,39	1,693	1,8	0,150
10 WNW	2,58	2,31	1,653	1,4	0,150
11 NNW	3,40	3,03	1,700	3,1	0,150
All	5,76	5,15	1,650	100,0	

Calculation Results

Key results for height 50,0 m above ground level
Wind energy: 3.263 kWh/m2; Mean wind speed: 6,6 m/s;
Key results for height 80,0 m above ground level
Wind energy: 3.859 kWh/m2; Mean wind speed: 7,1 m/s;

Calculated Annual Energy

WTG type						Power curve		Annual Energy			
Valid	Manufact.	Type	Power [kW]	Diam. [m]	Height [m]	Creator	Name	Result [MWh]	Result-10,0% [MWh]	Mean wind speed [m/s]	Capacity Factor [%]
Yes	VESTAS	V90	2.000	90,0	80,0	EMD	Level 0 - 80m hub - Mode 0 - 06-2005	6.201,3	5.581	7,1	35,4

Project:
Oman Joba

Printed/Page
19-12-2007 10:08 / 1

Licensed user:
COWI A/S
Parallelvej 2
DK-2800 Kgs. Lyngby
45 97 22 11

Calculated:
30-11-2007 10:21/2.5.6.78

METEO - Main Result

Calculation: Joba, V90 2MW 80m

Name Met station
Site Coordinates
Geo East: 58°15'49,00" North: 20°50'58,00"

Air density calculation mode	Individual per WTG
Result for WTG at hub altitude	1,179 kg/m3
Hub altitude above sea level (asl)	80,0 m
Annual mean temperature at hub alt.	23,4 °C
Pressure at WTGs	1.004,0 hPa

Calculation is based on "Met station", giving the Weibull distribution for the wind speed on the site.
Using the selected power curve, the expected annual energy production is calculated.

A

Meteorological Data

Scale 1:25.000

Weibull data 10 m above ground level

Sector	A- parameter [m/s]	Wind speed [m/s]	k- parameter	Frequency [%]	Wind gradient exponent
0 N	2,25	1,99	2,054	3,9	0,150
1 NNE	2,42	2,14	2,098	3,4	0,150
2 ENE	3,98	3,53	1,931	5,2	0,150
3 E	4,99	4,42	1,997	6,7	0,150
4 ESE	4,43	3,92	2,222	7,2	0,150
5 SSE	4,80	4,25	2,171	9,5	0,150
6 S	8,26	7,37	2,951	34,1	0,150
7 SSW	6,12	5,42	2,291	12,1	0,150
8 WSW	4,47	3,96	2,040	5,2	0,150
9 W	3,98	3,52	2,102	4,8	0,150
10 WNW	5,15	4,58	1,754	4,7	0,150
11 NNW	2,73	2,50	1,371	3,2	0,150
All	5,80	5,15	1,825	100,0	

Calculation Results

Key results for height 50,0 m above ground level
Wind energy: 2.849 kWh/m2; Mean wind speed: 6,6 m/s;
Key results for height 80,0 m above ground level
Wind energy: 3.395 kWh/m2; Mean wind speed: 7,1 m/s;

Calculated Annual Energy

WTG type						Power curve		Annual Energy			
Valid	Manufact.	Type	Power [kW]	Diam. [m]	Height [m]	Creator	Name	Result [MWh]	Result-10,0% [MWh]	Mean wind speed [m/s]	Capacity Factor [%]
Yes	VESTAS	V90	2.000	90,0	80,0	EMD	Level 0 - 80m hub - Mode 0 - 06-2005	6.612,6	5.951	7,1	37,7

Project:
Oman Masirah

Printed/Page
19-12-2007 10:06 / 1

Licensed user:
COWI A/S
Parallelvej 2
DK-2800 Kgs. Lyngby
45 97 22 11

Calculated:
30-11-2007 10:18/2.5.6.78

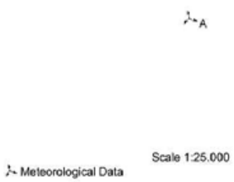
METEO - Main Result

Calculation: Masirah, V90 2MW 80

Name Met station airfield
Site Coordinates
Geo East: 58°54'00,00" North: 20°40'00,00"

Air density calculation mode	Individual per WTG
Result for WTG at hub altitude	1,177 kg/m3
Hub altitude above sea level (asl)	98,8 m
Annual mean temperature at hub alt.	23,3 °C
Pressure at WTGs	1.001,8 hPa

Calculation is based on "Met station airfield", giving the Weibull distribution for the wind speed on the site.
Using the selected power curve, the expected annual energy production is calculated.



Weibull data 10 m above ground level

Sector	A- parameter [m/s]	Wind speed [m/s]	k- parameter	Frequency [%]	Wind gradient exponent
0 N	2,54	2,25	2,030	1,0	0,150
1 NNE	3,73	3,31	1,901	1,3	0,150
2 ENE	7,23	6,41	2,423	5,7	0,150
3 E	4,81	4,27	2,440	7,2	0,150
4 ESE	3,99	3,57	3,248	6,6	0,150
5 SSE	5,04	4,49	2,819	8,7	0,150
6 S	4,36	3,86	1,956	6,3	0,150
7 SSW	7,36	6,54	2,612	23,4	0,150
8 WSW	8,15	7,26	2,751	31,7	0,150
9 W	4,17	3,70	2,219	3,8	0,150
10 WNW	5,24	4,65	1,928	2,8	0,150
11 NNW	4,19	3,72	1,874	1,4	0,150
All	6,51	5,77	2,119	100,0	

Calculation Results

Key results for height 50,0 m above ground level
Wind energy: 3.485 kWh/m2; Mean wind speed: 7,4 m/s;
Key results for height 80,0 m above ground level
Wind energy: 4.160 kWh/m2; Mean wind speed: 7,9 m/s;

Calculated Annual Energy

WTG type						Power curve		Annual Energy			
Valid	Manufact.	Type	Power [kW]	Diam. [m]	Height [m]	Creator	Name	Result [MWh]	Result-10,0% [MWh]	Mean wind speed [m/s]	Capacity Factor [%]
Yes	VESTAS	V90	2.000	90,0	80,0	EMD	Level 0 - 80m hub - Mode 0 - 06-2005	7.966,1	7.169	7,9	45,4

Project:
Oman Thumrait

Printed/Page
19-12-2007 10:02 / 1
Licensed user:
COWI A/S
Parallelvej 2
DK-2800 Kgs. Lyngby
45 97 22 11
Calculated:
30-11-2007 10:13/2.5.6.78

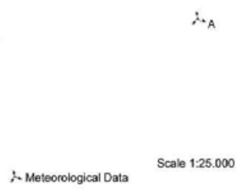
METEO - Main Result

Calculation: Thumrait

Name Met station airfield
Site Coordinates
Geo East: 54°01'35,70" North: 17°41'22,80"

Air density calculation mode Individual per WTG
Result for WTG at hub altitude 1,126 kg/m3
Hub altitude above sea level (asl) 546,0 m
Annual mean temperature at hub alt. 21,2 °C
Pressure at WTGs 951,4 hPa

Calculation is based on "Met station airfield", giving the Weibull distribution for the wind speed on the site.
Using the selected power curve, the expected annual energy production is calculated.



Weibull data 10 m above ground level

Sector	A- parameter [m/s]	Wind speed [m/s]	k- parameter	Frequency [%]	Wind gradient exponent
0 N	3,63	3,21	2,102	3,1	0,150
1 NNE	4,05	3,59	2,413	4,6	0,150
2 ENE	5,28	4,70	2,794	6,6	0,150
3 E	4,25	3,77	2,009	5,5	0,150
4 ESE	3,31	2,93	2,210	5,2	0,150
5 SSE	6,73	5,96	2,174	32,9	0,150
6 S	9,01	8,01	2,733	30,9	0,150
7 SSW	3,29	2,92	1,856	3,3	0,150
8 WSW	3,60	3,21	1,672	1,6	0,150
9 W	4,24	3,76	2,447	1,9	0,150
10 WNW	4,52	4,01	1,912	2,0	0,150
11 NNW	4,59	4,07	2,162	2,4	0,150
All	6,50	5,77	1,871	100,0	

Calculation Results

Key results for height 50,0 m above ground level
Wind energy: 3.722 kWh/m2; Mean wind speed: 7,4 m/s;
Key results for height 80,0 m above ground level
Wind energy: 4.416 kWh/m2; Mean wind speed: 7,9 m/s;

Calculated Annual Energy

WTG type						Power curve		Annual Energy			
Valid	Manufact.	Type	Power [kW]	Diam. [m]	Height [m]	Creator	Name	Result [MWh]	Result-10,0% [MWh]	Mean wind speed [m/s]	Capacity Factor [%]
Yes	VESTAS	V90	2.000	90,0	80,0	EMD	Level 0 - 80m hub - Mode 0 - 06-2005	7.644,5	6.880	7,9	43,6

Project: **Oman Qairoon Hairiti**

Description: Met station

Printed/Page: 19-12-2007 09:54 / 1

Licensed user:
COWI A/S
Parallelvej 2
DK-2800 Kgs. Lyngby
45 97 22 11

Calculated: 30-11-2007 10:09/2.5.6.78

METEO - Main Result

Calculation: Qairon Hariti

Name met station
Site Coordinates
Geo East: 54°05'06,98" North: 17°15'19,54"

Air density calculation mode	Individual per WTG
Result for WTG at hub altitude	1,083 kg/m3
Hub altitude above sea level (asl)	958,3 m
Annual mean temperature at hub alt.	18,6 °C
Pressure at WTGs	906,7 hPa

Calculation is based on "met station", giving the Weibull distribution for the wind speed on the site.
Using the selected power curve, the expected annual energy production is calculated.

A

Scale 1:25.000

Meteorological Data

Weibull data 10 m above ground level

Sector	A- parameter [m/s]	Wind speed [m/s]	k- parameter	Frequency [%]	Wind gradient exponent
0 N	7,13	6,31	2,178	7,3	0,150
1 NNE	4,98	4,41	2,335	3,6	0,150
2 ENE	4,49	4,00	2,836	1,8	0,150
3 E	3,55	3,17	2,944	1,1	0,150
4 ESE	3,00	2,69	3,181	1,0	0,150
5 SSE	7,06	6,30	2,991	20,2	0,150
6 S	7,28	6,55	3,510	56,5	0,150
7 SSW	3,99	3,63	4,321	4,1	0,150
8 WSW	2,96	2,62	2,324	0,7	0,150
9 W	3,86	3,42	2,373	0,2	0,150
10 WNW	4,82	4,31	3,151	0,4	0,150
11 NNW	10,03	8,91	2,555	3,1	0,150
All	6,96	6,19	2,736	100,0	

Calculation Results

Key results for height 50,0 m above ground level
Wind energy: 3.346 kWh/m2; Mean wind speed: 7,9 m/s;
Key results for height 80,0 m above ground level
Wind energy: 4.041 kWh/m2; Mean wind speed: 8,5 m/s;

Calculated Annual Energy

WTG type						Power curve		Annual Energy			
Valid	Manufact.	Type	Power [kW]	Diam. [m]	Height [m]	Creator	Name	Result [MWh]	Result-10,0% [MWh]	Mean wind speed [m/s]	Capacity Factor [%]
Yes	VESTAS	V90	2.000	90,0	80,0	EMD	Level 0 - 80m hub - Mode 0 - 06-2005	8.845,5	7.961	8,5	50,5

Appendix 8 and 9

Appendix 8 Electricity cost calculations

8.1 Cost analysis 20 MW solar PV system

The size of 20 MW corresponds to the largest plants made in worldwide so far and represents of course a major investment, but very few risks as the technology is proven with a long record of results.

A plant of this size will not only provide a measureable input to the grid, but also stimulate the market and can be part of a strategy to introduce local production and build up an export capacity in the area, on hardware as well as on know how.

Further a plan of this size can play a major role as part of public awareness campaign as it will make renewable energy very visible.

Fig. 10.3 20 MW solar PV in Beneixama (Spain), Province Alicante

Outline design and technology
The 20 MW PV system consist in principle of the following components:

- 20 MWp solar PV panels (approximately 200,000 m2 conventional panels) mounted in rows in a environment in the dessert.

- A 20 MW power converter to convert the DC from the panels to AC voltage for the grid.

- A connection to the grid including a power meter.

With a panel of 200,000 m2 the land area will be more than 500,000 m2, corresponding to more than 700 x 700 m.

Budget

The following budget represents the market cost for the technology and does not include design, project management, monitoring, evaluation, reporting etc.

Component	**Initial Capital**
	USD
PV Array including mounting	80,000,000
Converter and connections	8,750,000
Totals	88,750,000

Action plan

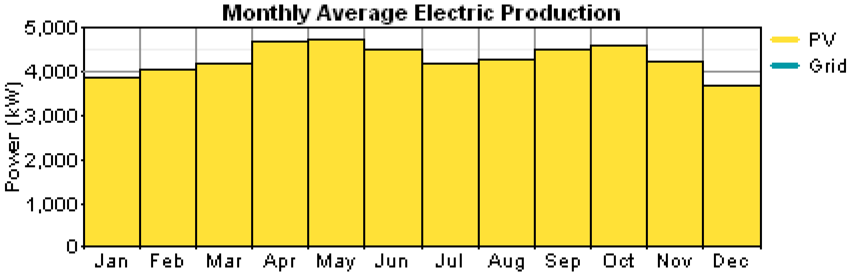
A small PV plant can be demonstrated in Oman on the basis of imported components. A major demonstration project like a 20 MW PV plant should incorporate development of local production and build up of local capacity on the various expertises involved in such plant in some kind of international business set up.

Oman has very many favourable locations for such PV plant which of course need to be located not too far from a sufficient grid connection.

Analysis

The analysis below has been made with the PC programme HOMER (Version 2.19, refer to https://analysis.nrel.gov/homer/) with the following assumptions.

- For the analysis of the performance the following has been used.
- Cost of PV, 4000 USD per kW
- Maintenance of PV, 0,5 % of investment per year.
- Lifetime of PV, 25 years
- Derating factor, 90% (10% losses due to high temperature, dust etc.)
- Cost of converter, 350 USD per kW
- Converter efficiency, 95 %
- Life time of converter, 15 years, replacement cost 200 USD per kW.
- Operation and maintenance cost of converter, 4 USD/year per kW
- Scaled annual global insolation, 5.44 kWh/m2
- Calculation interest rate, 8 %.
- Project life time, 25 years
- Slope of panels, 25 degree.
- Azimuth of PV, south facing.
- Ground reflection, 20%



The cost break down is shown in below table. The major cost is the annualised cost of PV.

Component	Initial Capital	Annualized Capital	Annualized Replacement	Annual O&M	Annual Fuel	Total Annualized
	($)	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)
PV Array	80,000,000	7,494,302	0	400,000	0	7,894,302
Converter	8,750,000	819,689	124,859	100,000	0	1,044,549
Totals	88,750,000	8,313,992	124,859	500,000	0	8,938,851

The annual production of electricity with this system is calculated to 35850 MWh, corresponding to 1792 kWh per installed kW peak power. The production corresponds to about 0.3 % of the consumption in Oman.

This lead to a unit cost of 8,938,851 / 35,850 = 250 USD per MWh.

Appendix 9 List of R&D references and activities on renewable energy

12. H. Bourdoucen, A. Gastli, "***Analytical Modelling and Simulation of PV Panel: and Arrays***", The Journal of Engineering Research (TJER), Vol. 4, No. 1, 2007 pp. 75-81.(Download)

13. A. Gastli and H. Bourdoucen, "***Study and Modeling of PV Arrays Built with Nor Equivalent Units***", Proceedings of the ICCCP'07, Muscat, February 19-21, 2007 pp. 187-191. (Download)

14.

Solar Systems (non-PV)

1. Al-Hinai H., Al-Nassri M.S., and Jubran B.A. (2002), ***"Parametric investigation of a double-effect solar still in comparison with a single-effect solar still,'*** Desalination J vol. 150, pp. 75-83.

2. Zurigat, Y.H., Al-Hinai, H., and Jubran, B.A. (2002), ***"Energy Efficient Building Strategies for School Buildings in Oman,"*** Int. J. of Energy Research, vol. 27, pp 241-253.

3. Abu-Arabi, M.K., Zurigat, Y.H., Al-Hinai, H. and Al-Hiddabi, S. (2003) ***"Modeling and performance analysis of a solar desalination unit with double-glass cover cooling,"*** Desalination J., vol. 143, pp.173-182.

4. Zurigat, Y.H., Al-Hinai, H. and Jubran, B.A. (2002), ***"Year round performance o; roofpond cooling technique under hot-arid climates,"*** (under review).

5. Abu-Arabi, M.K. and Zurigat, Y.H. (2003), ***"Comparison of year rounc performance of two types of double glass cover solar stills,"*** accepted fo presentation at the International Conference on RES for islands, tourism & wate desalination, 26-28 May 2003 in Crete, Greece.

6. Zurigat, Y.H. and Abu-Arabi, M.K. (2003), ***"Modeling and performance analysi: of a regenerative solar desalination unit,"*** Submitted to J. Of Applied Therma Engineering.

7. Al-Hinai, H.A. and Al-Alawi, S.M. (1995), ***"Typical Solar Radiation Data fo Oman", Applied Energy,"*** vol. 51, pp. 273-284, Elsevier Science, UK.

8. Childs, W.D. Dabiri, A.E., Al-Hinai, H. and Abdullah, H.A. (1999), ***"VARI-RC Solar-Powered Desalting Technology"***, Desalination, Elsevier, Vol. 125, pp. 155-166.

9. Al-Hinai, H. Al-Nassri, M. and Jubran, B. (2002), ***"Effect of climatic, design anc operational parameters on the yield of a simple solar still"***, Energy Conversior and Management, Elsevier Science, vol. 43, no. 13, pp. 1639-1650.

10. MM Sourour and Al-Hiddabi Saif, ***"Solar energy simulation studies; in the sultanate of Oman,"*** International-Journal-of-Power-and-Energy-Systems. Vol.15 no.1; 1995; p.22-8.

Wind Energy Systems:

1. A.S. Malik and A. Awsanjli, "***Energy Fuel Saving Benefit of a Wind Turbine***" 12th IEEE Mediterranean Electrotechnical Conference, MELECON 2004

7. A.S. Malik, A. Al-Khrousi, M. Al-Hindi and Y. Al-Mahrouqi, "***Demand-Side Management Energy Saving Potential in Commercial and Governmental/Institutional Sectors and its Impact on Power Planning – A Case Study of Central Grid of Oman***" 2nd International Green Energy Conference, Oshawa, June 25-29, 2006.

8. F.S. Al Mata'ni and A.S. Malik, "***Load Management in Industrial Sector and its Impact on Power Planning – A Case Study of Oman***" International Conference on Communication, Computer and Power, ICCCP'07, Muscat, 19-21 February 2007.

9. A.S. Malik, "***Impact on power planning due to DSM in commercial and government sectors with rebound effect – A case study of central grid of Oman***" Energy, Vol. 32, No. 11, November 2007, pp. 2157-2166.

Publications

The list of recent research works published by members of the RASERG is given below.

PV Systems:

1. H. Bourdoucen, J. Jervase, A. Al-Badi, A. Gastli, and A. Malik, "***Photovoltaic Cells and Systems-Current State and Future Trends-***", Journal of Science & Technology, Special Review, 2000, pp. 185-207. (Download)

2. J A. Jervase, H. Bourdoucen and A. Al-Lawati, "***Solar Cell Parameter Extraction Using Genetic Algorithms***", Measurement Science and Technology, Institute of Physics Publishing Ltd. (UK), Volume 12, Number 11, November 2001, pp. 1922-1925.(Download)

3. Al-Naamany, A. Gastli, H. Bourdoucen, "***Neuro-Fuzzy Maximum Power Point Tracker for PV Systems***", Accepted for presentation in The 6th IASTED International Conference on Artificial Intelligence & Soft Computing (ASC'2002) July 17-19, 2002, Banff, Alberta, Canada, pp. 281-286. (Download)

4. A. Gastli, H. Bourdoucen, S. Al-Alawi, "***ANN-Based Maximum Power Point Tracker for PV Systems***", International Solar Energy Society 2001 World Congress, Nov. 25-30, Adelaide Australia, 2001. (Download)

5. J. Jervase, H. Bourdoucen and A. Al-Lawati, "***A Genetic Algorithm Based Technique for Extracting Solar Cell Parameters,***" Proceedings of the Sharjah Solar Energy Conference, 19-22, February 2001, Sharjah, UAE.

6. A. Dorvlo, J. Jervase, and A. Al-Lawati, "***Solar Radiation Estimation Using Artificial Neural Networks***", Journal of Applied Energy, Vol. 71, 2002, pp. 307-319. (Download)

7. A. Al-Lawati, A. Dorvlo, and J. Jervase, "***Monthly Average Daily Solar Radiation Clearness Index Contour Maps Over Oman***", Journal of Energy Conversion and Management, Vol. 44, 2003, pp. 691-705. (Download)

8. J. Jervase, A. Al-Lawati, and A. Dorvlo, "***Contour Maps for Sunshine Ratio for Oman Using Radial Basis Function Generated Data***", Journal of Renewable Energy Vol. 28, 2003, pp. 487-497. (Download)

9. A.S. Malik and C.U. Sumaoy, "***Analytical hierarchy process approach in distribution utility local IRP,***" International Journal of Electrical Power and Energy Systems, Vol. 25, No. 8, October 2003, pp. 623-631.

10. Jubran, B.A., Al-Hinai, H., Zurigat, Y.H. and Al-Salti, S. (2003), "***Feasibility of using various photovoltaic systems for window-type air-conditioning units under hot-arid climates,***" Journal of Renewable Energy, vol. 28, no. 10.

11. H. Bourdoucen, A. Gastli, "***Analytical Modelling and Computer Simulation of Interconnected Panels and Arrays used in PV Applications***", Proceedings of the 8th Arab International Solar Energy Conference and The Regional World Renewable Energy Congress, Bahrain, 8-10 March, 2004.

- Analyze, design, implement and test high efficiency photovoltaic DC-AC power inverters using the aforementioned techniques.

- **Project 3: "*Solar Electric Vehicle*"**
Funded by: SQU started in Jan. 2000, for a duration of 36 months.
Project Number: IG/ENG/EEED/00/02
Investigators: A. Gastli, A. Al-Badi, A. Naamany, A. Malik, H. Bourdoucen, J. Jervase
Summary: The Solar Electric Vehicle at Sultan Qaboos University was planned to harness and develop technical know-how on solar energy. This research was intended to develop efficient production, storage, retrieval and use of the electrical energy produced from solar cells. This project concentrated on the electrical parts of the vehicle consisting of the solar panels, the battery charger and power optimizer, and the motor.
(Click here to download the report)

- **Project 4: "*Development of Eco-House for Hot and Humid Climates*"**
Funded by: SQU for a duration of 36 months.
Project Number: IG/ENG/MIED/02/01
Investigators: Y. Zurigat, Prof. B. Jubran, Dr. H. Al-Hinai, Dr. N. Sawaqed, Dr. M. Abu-Arabi, Dr. J. Ashour, Dr. A. Al-Jamrah, Dr. K. Al-Balushi, Dr. R. Siddiqui
Summary: The objective of this study is to develop a simulation tool that will be used for design assessments of the Eco-House. It will incorporate building cooling load model, greenhouse model, solar absorption refrigeration model, solar desiccant dehumidification model, and PV power generation model. Furthermore, models of several passive cooling techniques will be incorporated, i.e., roof pond, roof spray, evaporative cooling, and natural ventilation coupled with solar chimney. Also, a feasibility study will be carried out to investigate the biomass energy generation. Thus, the simulation tool to be developed in this study will serve as a computational laboratory where numerical/computational experiments can be conducted and different design alternatives be evaluated. Furthermore, small laboratory scale experiments will be conducted to evaluate different passive cooling techniques under local weather conditions and to aid in computer models validations. The method of approach adopted in this study consists of the following four tasks:

1. Development of computer models for different passive and hybrid cooling techniques. Passive cooling includes roofpond, roof spray, roof garden/pergula, evaporative cooling, natural ventilation coupled with solar chimney, and different shading scenarios. Hybrid cooling includes solar- and gas-fired absorption cooling coupled with desiccant dehumidification, evaporative cooling (direct and indirect), and desiccant cooling. The development of computer model of solar absorption refrigeration unit is essential for the Eco-House space air conditioning and for enhancing water harvesting in the green house dehumidification process.

2. Development of thermodynamic computer model of green house coupled with seawater desalination based on humidification and dehumidification processes. This will incorporate the modeling of several components such as evaporators, condensers, humidifiers, dehumidifiers, and solar collectors.

3. Design and execution of experiments using small laboratory scale models of the following components:

a. Evaporative cooling building jacket
b. Roof pond
c. Roof spray
d. Roof garden/pergola
e. Building shading
f. Biomass gas production unit

4. Applications of the computer simulations to Eco-House design and sizing of greenhouse and its components and the development of design recommendations.

A transient system simulation program TRNSYS available at MIE department will

Dubrovnik, 12-15 May 2004.

2. Al-Ismaily, H.A. and Probert, S.D. (1996), ***"Prospects for harnessing wind-power economically in the Sultanate of Oman, Applied Energy"***, vol. 55, no. 2, pp. 85-130.

3. A.S. Malik and A. Wahid, "***Wind energy potential in Maldives,***" Second ASEAN Renewable Energy Conference, Phuket, 6-9 Nov. 1997.

4. A. Gastli, M. Akherraz, A. Al-Badi, ***"Modeling and Simulation of a Variable Speed Self-Excited Induction Generator"***, International Journal of Renewable Energy Engineering Vol. 2, No. 3, December 2000, (ISSN 1442-133X), pp.221-227. (Download)

5. A. Sharaf, A. Gastli, ***"A Novel Compensation System for Standalone Wind Energy Induction Generator Scheme"***, Proceedings of the IEEE Canadian Conference on Electrical and Computer Engineering CCECE'2000, Halifax, NS Canada, May 7-10, 2000, CD ROM, TM4.2, pp. 527-530. (Download)

6. A. Gastli, M. Akherraz, M. Gammal, "***Matlab/Simulink/ANN Based Modeling and Simulation of A Stand-Alone Self-Excited Induction Generator***" Proceedings of the International Conference on Communication, Computer and Power, ICCCP'98, December 7-10 1998, Muscat, Oman, Sponsored by the IEEE and IEE, pp. 93-98. (Download)

7. A. Gastli, M. Akherraz, "***Matlab/Simulink Assisted Investigation of Variable-Speed Self-Excited Induction Generator***", Proceedings of the International Conference on Communication, Computer and Power, ICCCP'98, December 7-10 1998, Muscat, Sponsored by the IEEE and IEE, pp. 258-263. (Download)

Energy Planning and Management:

The following are research papers related to Energy conservation, Demand-side management/load management, and Integrated resource planning.

1. A.S. Malik and A. Badar, "***An assessment of reduced cycling cost of thermal units, due to DSM, in integrated resource planning,***" International Power Engineering Conference, IPEC '97, Singapore, 22-24 May 1997.

2. A.S. Malik and B.J. Cory, "***Impact of DSM on energy production cost and start-up and shut-down costs of thermal units,***" IEE International Conference on Advances in Power System Control, Operation and Management, APSCOM-97 Hong Kong, 11-14 Nov. 1997.

3. A.S. Malik, "***Dynamic generating costs in DSM planning,***" Energy, Vol. 24, No 1, January 1999, pp. 1-8.

4. A.S. Malik, "***Simulation of DSM resources as generating units in probabilistic production costing framework,***" IEEE Transactions on Power Systems, Vol. 13 No. 4, November 1998, pp. 1528-1533.

5. A.S. Malik, "***Modeling and economic analysis of DSM programs in generation planning,***" International Journal of Electrical Power and Energy Systems, Vol. 23, No. 5, May 2001, pp. 413-419.
6. A.S. Malik and C.U. Sumaoy, "***A case study of local integrated resource planning,***" Energy, Vol. 28, No. 7, July 2003, pp. 711-720.

Projects

Research projects:

- **Project 1: "*The role of renewable energy for decentralized Applications in the Sultanate of Oman*"**
  Funded by: SQU for a duration of 24 months, starting Jan.2000.
  Project Number: IG/ENG/EEED/
  Investigators: A. S. Malik, A. Al-Badi, A. Gastli, H. Bourdoucen, J. Jervase
  Summary: The objectives of the project were as follows:
  - Assess the solar and wind energy resource potential for decentralized applications in remote areas of selected sites of Sultanate of Oman;
  - Size stand-alone PV system, for a selected remote sites/villages in Sultanate for small power applications on the basis of estimated load for the villages;
  - Calculate the Long Run Marginal Cost for grid extension for supplying the required load power to the selected village;
  - Perform the economic analysis to calculate the Life-Cycle-Cost for PV & diesel generating systems for economic evaluation;
  - Size wind turbine, for at-least one selected remote site/village in Sultanate for small power applications on the basis of estimated load for the village;
  - Perform the economic analysis to calculate the Life-Cycle-Cost for wind & diesel generating system for economic evaluation;
  - Identify the most suitable and economic system for supplying electricity to the remote areas of Sultanate;
  - Carry out economic evaluation of PV irrigation system, wind pumps and diesel pumps for agricultural purposes;
  - Make energy policy analysis to promote these technologies.
- **Project 2: *Analysis, Modeling and Testing of Solar Cells, panels and Photovoltaic DC-AC power Inverters.***
  Funded by: UNESCO, Aug. 2001 for a duration of 12 months
  Project Number: IG/ENG/EEED/
  Investigators: H. Bourdoucen, A. Gastli, J. Jervase, A. Lawati, S. Al Alawi.
  Summary: The objectives of the project were as follows:
  - Perform experimental measurements on cells and panels under Oman's climatic and weather conditions.
  - Model and analyze cells and panels using search and optimization approaches based on GAs.
  - Use SPICE and MATLAB simulators to model and simulate different panel configurations and built Fuzzy Logic / ANN based power point trackers.

be used to carry out simulations using the computer models developed in thi: study. Also, a weather station (already ordered) will be used simultaneously witl the laboratory experiments to measure the weather conditions, i.e., dry-bulb relative humidity, solar intensity, and wind speed and direction.
(Click here to learn more about the project)

- **Project 5**: ***"Solar Water Desalination"***
Funded by: MEDRC with partners from Germany.
SQU Investigators: Hilal Al-Hinai and Ali Al-Alawi
Summary: This was a joint research project for investigations on an innovativ sea water desalination system using solar heat between the MEIE department anc the Bavarian Centre for applied Energy Research (ZAE Bayern) (Germany) anc two other German companies. The project was concluded successfully on Marcl 2001.

- **Project 6**: ***"Long-Term Testing of Japanese PV Solar Panels"***
Funded by: NEDO with partners from Japan).
SQU Investigators: Bassam Jubran, Hilal Al-Hinai, Saleh Al-Alawi, Ahmad Al Numanyan and Sami Al-Sulti.
Summary: This project is conducted in collaboration with the Japanese New Energy and Industrial Technology Development Organization (NEDO). Th project aims to test Japanese photovoltaic solar panels under the prevailing weathe conditions in Oman for a long period of time. Testing is in progress for module: from six Japanese companies since February 1999.

- **Project 7**: ***"Parabolic Solar Collector"***
Funded by: SQU Internal Funding.
SQU Investigators: Saif Al-Hadabi
Summary: The objective of this study is to design and fabricate a solar disl collector with a tracking control system. The fabricated system will be tested on th local environment to asses its performance.

- **Project 8**: ***"Convective cells in solar ponds"***
Funded by: SQU Internal Funding.
SQU Investigators: Saif Al-Hadabi, Bassam Jubran, Yousef Zuraigat, and Hila Al-Hinai
Summary: A numerical model of Salinity Gradient Solar Ponds has beer constructed and the behavior of the pond was studied. The effects of tilting angle o the wall, salt concentration and time of operation on the stability of the cells wer observed. (SQU Investigators: Hilal Al-Hinai and Ali Al-Alawi)

- **Project 9**: ***"The energy-efficient buildings in Oman"***
Funded by: PDO Funded
SQU Investigators: Bassam Jubran, Yousef Zuraigat, and Hilal Al-Hinai
Summary: The thermal performance aspects of building practice in hot climate: were investigated. The results obtained and the recommendations drawn serve a: guidance for building architects, designers, contractors, and builders as well as air conditioning equipment manufacturers.

- **Project 10**: "***Development of typical meteorological years for different location: in Oman"***
Founded by: PDO Funded
SQU Investigators: Yousef Zuraigat, Naseem Sawaqed, Hilal Al-Hinai, anc Bassam Jubran,
Summary: Typical meteorological year is an essential and indispensable tool ir simulations of thermal systems and comparison of their performance. TMY's have been developed for seven locations in Oman (Seeb, Masira, Salalah, Majis Marmul, Sur, and Fahud) A program has been developed based on Sandi: statistical method to generate the TMYs. Thus, a general tool has been developec which can be used to develop TMY's for other locations or to include more year: of data for the locations for which TMY's have already been developed.

- **Project 10**: "***Energy saving potential and its impact on power planning i. central grid of Oman using demand-side management"***

Founded by: SQU Funded (2005-2006)
Project Number: IG/ENG/ECED/05/02
SQU Investigators: ArifS. Malik and Ali Al-Maqrashi
Summary:

Undergraduate Student Projects

A number of student projects have been done on renewable energy system characterization, modeling and analyses during the previous few years. These projects were:

- The role of renewable energy for decentralized applications in Sultanate of Oman, June 2001 (Download Report Part I, Part II)
- Design of Solar Electric Vehicle Drive System, June 2001 (Download Report)
- Design of Solar Electric Vehicle PV System, June 2001 (Download Report)
- Solar Cells: Characterization, Data Acquisition and Modeling Under Oman's Climatic Conditions, June 2001
- Design and Simulation of a Maximum Power Point Tracker, 2002
- Design and Simulation of a DC Motor Controller, 2002
- Design and Simulation of a Battery Charger, 2002
- Design and Realization of Maximum Power Point Tracker for the solar Car Project, 2004
- Design and Implementation of a Solar Car Electric System, 2005
- Design and Implementation of a Solar Car Monitoring System, 2007.
- Design and Implementation of a Solar Water Pump for Irrigation, 2007.

Appendix 10, 11, 12 and 13

Appendix 10 Average production cost RAECO diesel generation stations

	2006 Jan - Jun		2006	
Al Wusta	RO /kWh	USD/kWh	RO/kWh	USD/kWh
Abu Mudabi	0,092	**0,238**	0,085	**0,222**
Al Kahal	0,081	**0,210**	0,077	**0,201**
Al khaluf				
Al Khuiaima	0,077	**0,200**	0,075	**0,195**
Al Lakbi	0,078	**0,203**	0,075	**0,195**
Alajaiz			0,338	**0,880**
Al Najdah				
Alnuhaidah				
Al Zhalah	0,153	**0,397**	0,128	**0,333**
Hij	0,058	**0,150**	0,053	**0,137**
Hitam				
Masirah	0,077	**0,200**		
Masrooq	0,484	**1,258**		
Ras Madraka	0,099	**0,258**	0,090	**0,234**
Sawgrah	0,104	**0,272**	0,092	**0,239**
Surab			1,435	**3,732**
Al Duqm	0,064	**0,168**	0,065	**0,170**
Total	**0,077**	**0,200**	0,069	**0,180**
Dhofar				
Al Halaniyat	0,146	**0,378**	0,153	**0,397**
Al-Mathfa	0,317	**0,824**	0,311	**0,808**
Ayboot-1	0,181	**0,470**	0,190	**0,494**
Ayboot-2			0,220	**0,572**
Ayun	0,154	**0,399**	0,155	**0,402**
Barbazum	0,100	**0,260**	0,098	**0,255**
Dalkut A	0,065	**0,168**	0,065	**0,169**
Dalkut B				
Dhahabun	0,077	**0,199**	0,079	**0,205**
Fakthat	0,299	**0,777**	0,315	**0,819**
Hasik	0,071	**0,184**	0,072	**0,187**
Hirweeb	0,094	**0,244**	0,090	**0,235**

Horaat	0,189	**0,490**	0,172	**0,447**
Mahwice	0,283	**0,736**	0,244	**0,635**
Maqshan	0,090	**0,233**	0,087	**0,226**
Mazyunah	0,065	**0,170**	0,057	**0,148**
Mitan	0,078	**0,202**	0,075	**0,196**
Mothorah				
Mudhai	0,065	**0,170**	0,072	**0,187**
Rakbut	0,139	**0,361**	0,149	**0,386**
Raysut A+B				
Saih Alkirat			0,049	**0,127**
Shahb Asayb	0,058	**0,151**	0,060	**0,155**
Sharbatat	0,084	**0,220**	0,083	**0,215**
Shasir	0,058	**0,151**	0,059	**0,153**
Tushnat	0,058	**0,150**	0,113	**0,294**
Total	0,072	**0,187**	**0,044**	**0,115**
Musandam				
Al Rawda	0,131	**0,340**	0,119	**0,310**
Dibba	0,053	**0,139**	0,051	**0,134**
HB Hameed	0,265	**0,690**	0,259	**0,674**
Khasab	0,051	**0,133**	0,048	**0,126**
Kumzar	0,200	**0,521**	0,215	**0,560**
Madha	0,055	**0,144**	0,055	**0,143**
Total	**0,053**	**0,137**	**0,050**	**0,130**
Total RAECO	0,061	**0,160**	**0,050**	**0,131**

Appendix 11 Examples of Tax Credit Schemes

Examples of national tax incentives for renewable energy

Austria
Private investors get tax credits for investments in using renewable energies (personal income tax). The amount is generally limited to about 3,000 € per year.

Belgium
13.5 – 14% of RES-investments deductible from company profits, regressive depreciation of investments. Reduced VAT on building refurbishing if energy efficiency is included (6% instead of 21%).

Denmark
The first 3,000 DKK of income from wind energy are tax free.

France
A deduction of 15% investment costs with a maximum of 3000 € per person and reduced VAT (5.5%) on renewable equipment (not applicable to installation costs) is available.

Germany
Losses of investments can be deducted from the taxable income. This fact increases return on investments into wind projects.

Greece
Up to 75% of RES-investments can be deducted.

Ireland
Corporate Tax Incentive: tax relief capped at 50% of all capital expenditure for certain RES-investments.

Portugal
Up to 30% of any type of investments on RES can be deducted with a maximum of 700 € per year. A reduction in VAT (12%) on renewable equipment.

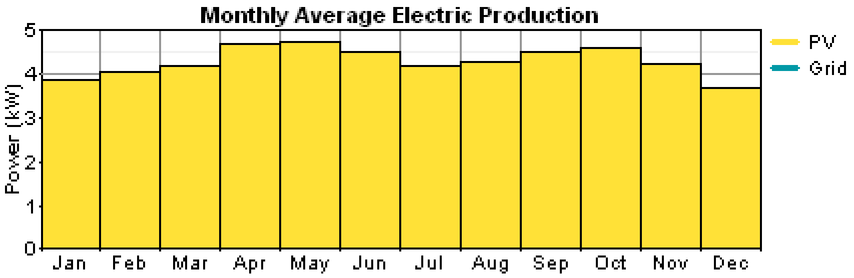
Spain
Corporation Tax: 10% (up to 20% in some autonomous regions) tax liability instead of 35% for investments in environment friendly fixed assets.

The Netherlands
EIA scheme: RES-investors (most renewable energy systems) are eligible to reduce their taxable profit with 55% of the invested sum. Lower interest rates from Green Funds: RES-investors (most renewable energy systems) can obtain lower interest rates (up to 1.5%) for their investments. Moreover, dividends gained are free of income tax for private investors.

Appendix 12 Details on 20 kW grid connected solar PV pilot project

Analysis
The analysis below has been made with the PC programme HOMER (Version 2.19, refer to https://analysis.nrel.gov/homer/) with the following assumptions.

- For the analysis of the performance the following has been used.
- Cost of PV, 6800 USD per kW
- Maintenance of PV, 0 %
- Lifetime of PV, 25 years
- Derating factor, 90 % (10% losses due to high temperature, dust etc.)
- Cost of converter, 700 USD per kW
- Converter efficiency, 90 %
- Life time of converter, 15 years, reinvestment cost 500 USD per kW
- Operation and maintenance cost of converter, 7 USD/year per kW
- Scaled annual global insolation, 5.44 kWh/m2
- Calculation interest rate, 8 %.
- Project life time, 25 years
- Slope of panels, 25 degree.
- Azimuth of PV, south facing.
- Ground reflection, 20%



The cost break down is shown in below table. The major cost is the annualised cost of PV.

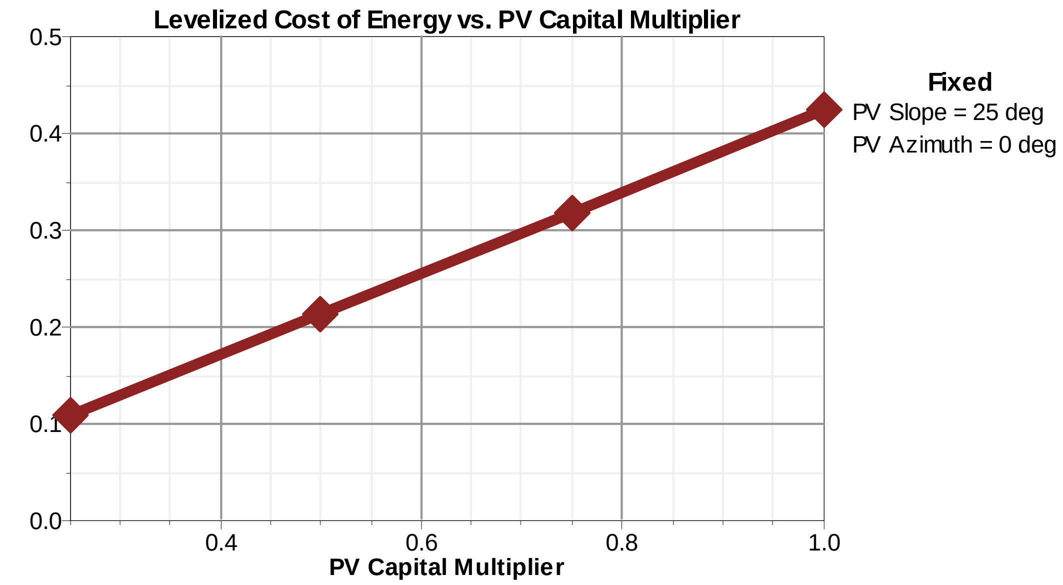
The annual production of electricity with this system is calculated to 33962 kWh, corresponding to 1698 kWh per installed kW peak power.

Component	Initial Capital	Annualized Capital	Annualized Replacement	Annual O&M	Annual Fuel	Total Annualized
	($)	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)
PV Array	136,000	12,740	0	0	0	12,740
Converter	14,000	1,312	250	140	0	1,701
Totals	150,000	14,052	250	140	0	14,442

This lead to a unit cost of 14442 / 33.962 = 425 USD per MWh.

The cost of PV is expected to drop significantly. The following graph show the influence of the cost on a reduction to 25 percent of today's cost.

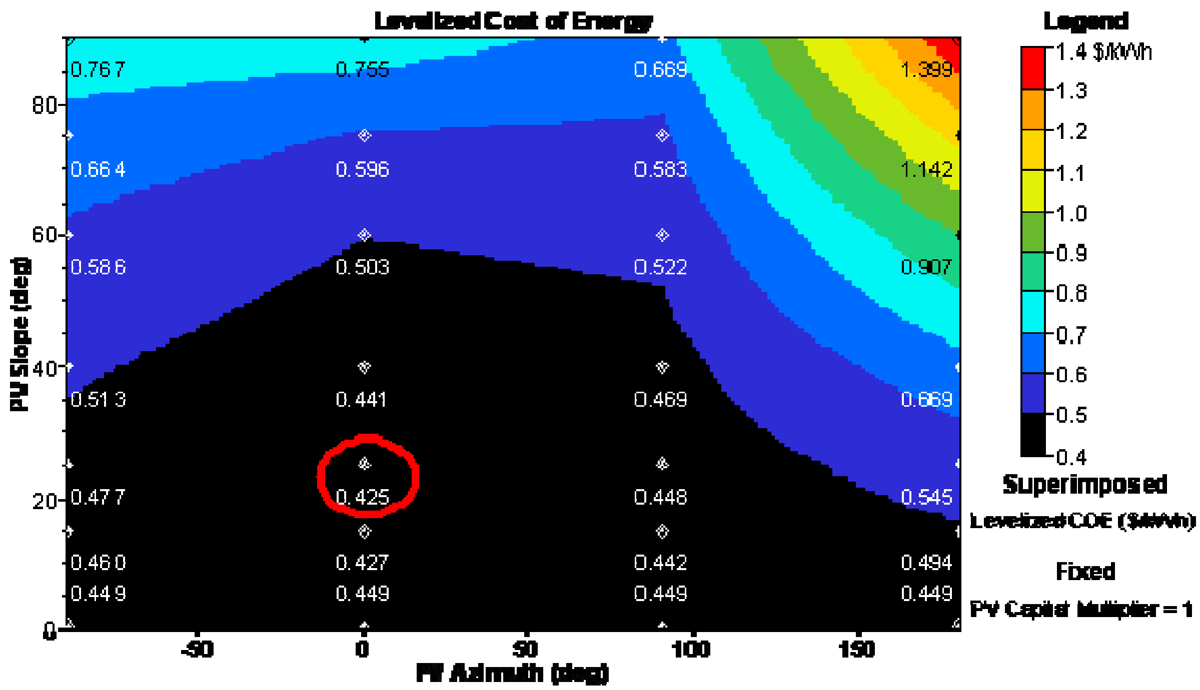
Fig. A 12.1 Cost of electricity from a 20 kW PV system as a function of a drop in cost of PV and components.



The production of electricity from PV panels depends of course of the orientation and slope of the panels. The following graph shows the influence of this on the levelised cost of electricity. The reference is the red circle. For Oman a slope from 0 to 30 degree is optimum. The slope should never be less than 15 so that water can drain off and clean the panels. For this small slope the production is rather independent on the azimuth meaning that the PV panels can be oriented freely. Only through north there is an increased cost. For vertical PV (on facades for example) it appears that the cost of production (the solar output) is increased considerably, in particular on north facades.

This calculation only consider the yearly production, the distribution over the year is also very dependent on the slope and orientation. Sloped PV panels tend to giver lower production in the summertime when demand is highest.

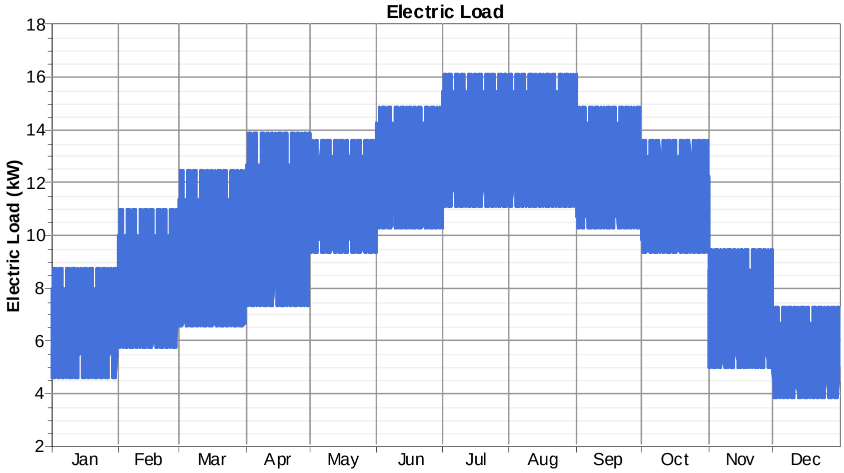
Fig. A 12.2 Levelized cost of electricity from a 20 kW grid connected PV system as a function of the slope (Y-axis, 0=horizontal, 90=vertical) and the azimuth (y-axis, 0=south, -90=Vest, 180= north).

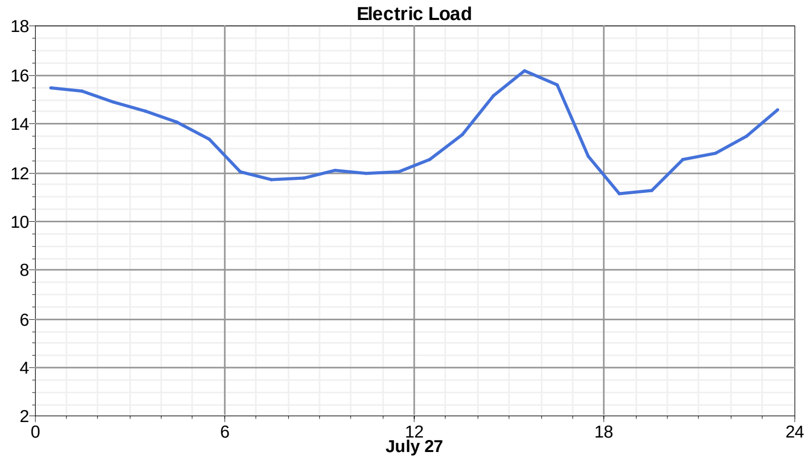


Appendix 13 Details on 10 kW PV/10 KW diesel hybrid pilot project

Outline design and technology

The demand is defined as an average of 10 kW over the year giving a total of 87600 kWh per year. The yearly load profile from Rural Area Electricity Company is used. There is no daily load profile available for rural areas and a load profile from the main grid on the 2nd of January and on the 25th of July has been used to represent the winter and the summer situation in rural areas. See below figure. In the summertime the peak is in night and late afternoon (air conditioning), in the "winter" time the much smaller peak is mid day and early evening (cooking).





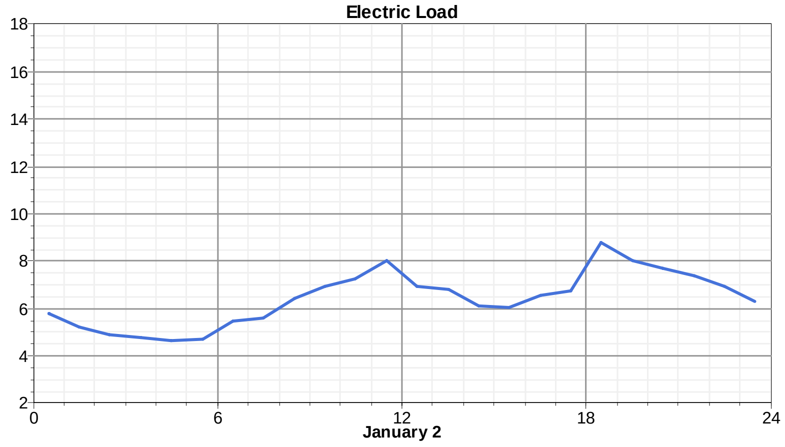


Fig. A 13.1 Load profile for analysis of 10 kW off grid system. The top graph show yearly distribution with monthly max and minimum value of demand. The middle graph the daily profile for July 27 and the bottom graph for January 2nd.

The analysis is made on a number of assumptions listed below.

PV

Capital cost	6800 USD per kW
Operation and maintenance	68 USD per year per kW
Lifetime:	25 yr
Derating factor:	90% (10% losses)
Slope:	25
Azimuth:	0 deg (south facing)
Ground reflectance:	20%

Generators

Capital cost	780 USD per kW
Replacement cost	500 USD per kW
Sizes to consider:	1) 0, 5, 10, 15, 20 kW, 2) 0, 7, 12
Lifetime:	25,000 hrs
Min. load ratio:	50%
Fuel used:	Diesel
Fuel curve intercept:	0.08 L/hr/kW
Fuel curve slope:	0.25 L/hr/kW

Diesel	
Price:	$ 0.38, 0.57, 0.76, 1.52/L
Lower heating value:	43.2 MJ/kg
Density:	820 kg/m3

Battery: Willard RT9d - 50% DOD	
Capital cost	200 USD per battery
Replacement cost	100 USD per battery
Quantities to consider:	0, 5, 10, 20, 50, 100
Voltage:	2 V
Nominal capacity:	254 Ah
Lifetime throughput:	490 kWh

Converter	
Capital cost	700 USD per kW
Replacement cost	500 USD per kW
Operation and maintenance	13 USD per year per kW
Sizes to consider:	0, 2, 5, 10, 20, 30, 50 kW
Lifetime:	15 yr
Inverter efficiency:	90%
Inverter can operate parallel with AC generator:	Yes
Rectifier relative capacity:	75%
Rectifier efficiency:	85%

Economics

Annual real interest rate:	8%
Project lifetime:	25 yr
Capacity shortage penalty:	$ 0/kWh
System fixed capital cost:	$ 0
System fixed O&M cost:	$ 0/yr

Generator control

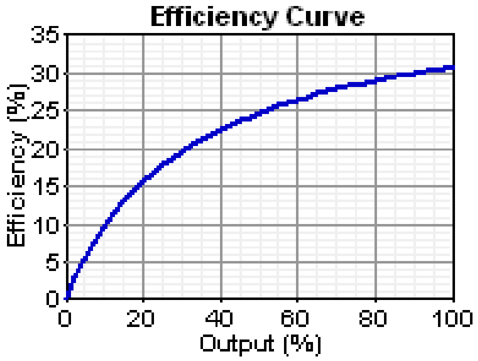
Check cycle charging:	Yes
Setpoint state of charge:	80%
Allow multiple generators to operate simultaneously:	Yes

Grid Extension

Capital cost:	$ 70,000/km
O&M cost:	$ 1,200/yr/km
Power price:	$ 0.04/kWh

For the operation of diesel systems it is important to consider that the fuel efficiency of the engine depends on the load. It is therefore important to run engines on full load and therefore often better to have two smaller engines or to include a battery storage wish will allow the engine to run on full load while charging the batteries. See Fig. A 13.2.

Fig. A 13.2 . Assumed fuel efficiency curve for diesel engines. It is further assumed that engines will not run on less than 50 % load.



The analysis made with HOMER identifies the combination of components (size and/or number) that will give the lowest levelized cost of energy. The optimum depends mainly on the specifications of the technologies involved, on the cost of these technologies, the cost of maintenance and replacements of equipment and on the fuel used. Not to mention the natural conditions and the demand that is typically kept constant for the analysis.

The cost of diesel in Oman is low and does not represent the cost of fuel for the 25 years of project lifetime which is considered here. Therefore a cost increase will be considered.

It is further expected that the cost of renewable energy will be reduced in the future. The analysis therefore includes cost reductions in order to be able to analyse the potential of these technologies sometimes in the future.

Optimal system type

With today's cost and with the assumptions used in this case the optimum system is a combination with two diesel engines (a 5 kW and a 12 kW engine, electric output) with 5 batteries and a 2 kW power converter. The levelized cost of energy is 236 USD/MWh. With 2 kW of PV providing 4 % of the power the levelized cost will increase to 242 USD/kWh and with 5 kW PV providing 10% of the power to about 260 USD per MWh.

With higher cost of diesel and with lower cost of PV solar PV will be part of the optimum solution. With for example a diesel cost of 1.5 USD per litre (as in Europe) PV will in the optimum system cover 12 percent of the demand even with today's cost of PV. With a reduction in cost of PV the percentage will increase to about 40% in the optimum system.

Cost break down

As an example Table A 13.1 shows the cost break down for the system with 2 diesel engines, 5 kW PV and 20 batteries with a storage capacity of few hours of consumption. The total initial investment is 54,760 USD while the yearly annualized cost is 22,768 USD. The annualized cost per MWh is 260 USD and the PV covers 11 percent of the electricity.

Table A 13.1 Cost break down and production for the system

Component	Initial Capital	Annualized Capital	Annualized Replacement	Annual O&M	Annual Fuel	Total Annualized
	($)	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)
PV Array	34,000	3,185	0	340	0	3,525
Generator 1	7,800	731	866	2,694	6,372	10,662
Generator 2	5,460	511	700	2,117	4,131	7,460
Battery	4,000	375	251	40	0	666
Converter	3,500	328	62	65	0	455
Totals	54,760	5,130	1,880	5,255	10,503	22,768

Optimum without diesel

If diesel is not included the installed PV capacity and battery capacity need to be very high in order to supply 100 % at any time. A shortage of more than 10 percent is probably not acceptable and the corresponding cost is about 1.0 USD/kWh of electricity. This is 4 times more expensive than the optimum system which include diesel. The reason for this is that the match between solar production and consumption is not optimal. Most important is that the consumption is much higher during the summer while the PV production is rather equal over the year. Therefore a large amount of PV produced in the winter time will not be utilized. For the system with 10 % shortage (cost 1.08 USD/kWh) the PV capacity is 75 kW, producing 141,000 kWh per year of which 28 percent is not used. A huge battery bank with 1500 batteries is included costing almost as much as the PV panels.

At an allowed capacity shortage of 70 %, meaning that 30% is supplied by solar the levelized cost is only half of the cost at 10% shortage allowed.

The conclusion is that such a system without diesel backup is not feasible technically as well as economically as the only system for supply of electricity with the demand defined. Only with a better match between production and consumption the system may be applicable.

Fig. A 13.5 Levelized cost of electricity supplied by a system with only solar PV and batteries as a function of the allowed capacity shortage.