University of Southern Queensland

Faculty of Engineering and Surveying

Economics of Photovoltaic Water Pumping System in Sultanate of Oman

A dissertation submitted by

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Abstract

The diesel driven water pumping systems have a great impact on irrigation in remote areas around the world. However the gradual increase of oil prices worldwide has a serious effect on the system that encourages the farmers to go for more reliable and cost effective alternative.

The aim of this project is to carry out an economic comparison between the diesel and photovoltaic (PV) pumping system. This will be of assistance to farmers especially in remote areas of Oman. Specifically, it aims to evaluate both systems over the life cycle period including the fuel cost, operation and maintenance cost and other recurrent costs.

Evaluating the solar radiation by the means of insolation data is an important issue, as it is considered to be the base of any solar system to perform the intended task satisfactorily.

Life cycle cost analysis for the both systems accounts for the higher initial cost of PV system compared with diesel, however the high recurrent costs for the diesel system could still encourage farmers to go for PV system considering its reliability, the longer life as well as the lower maintenance and operation costs.

The comparison between both systems was extended to cover the environmental impacts. Environmental impacts have been identified and discussed as nowadays there is a higher concern worldwide regarding environmental issues including greenhouses gases emissions.

There are some economical aspects have not been discussed in details in the project and that was due to shortage of data available as well as time. For example, the availability of a working PV system would have allowed more accurate economic assessment and therefore more reliable conclusions.

The solar power technology has not been used widely in Oman and unless the government supports and encourages people to go for it, it would be hard to convince people about its benefits economically as well as environmentally.

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Glossary of Terms

Array: Any number of photovoltaic modules connected together to provide a single electrical output. Arrays are often designed to produce significant amounts of electricity.

Cell: The basic unit of a photovoltaic panel or battery.

Current at maximum power: The current at which maximum power is available from a module.

Centrifugal Pump: A pumping mechanism that spines water by means of "impeller" water is pushed out by centrifugal force.

DC motor, Brush-type: The traditional DC motor, in which small carbon blocks, called "brushes" conduct current into the spinning portion of the motor. They are used in the DC surface pumps and also in some DC submersible pumps. Brushes naturally wear down after years of use, and may be easily replaced.

DC Motor, Brushless: High-technology motors used in centrifugal- type DC submersible. The motor is filled with oil, to keep water out. An electronic system is used to precisely alternate the current causing the motor to spin.

DC Motor, permanent magnate: All Dc solar pumps use this type of motor in some form.

Diaphragm Pump: A type of pump in witch water is drown in and forced out of on or more chambers, by flexible diagram.

Direct Insolation: Sunlight falling directly upon a collector.

Impeller: See Centrifugal pump.

Induction motor (AC): the type of electric motor used in conventional AC water pumps. It requires a high surge of current to start and a stable voltage supply, making it relatively expensive to run from by solar power. See inverter.

Inverters: devices that convert dc electricity into ac electricity (signal or multiphase), either for stand-alone systems or for utility-interactive systems.

Jet pump: A surface-mounted centrifugal pump that uses an "ejector' (venture) device to augment its suction capacity. In a 'deep well jet pump' the ejector is down in the well to assist the pump in overcoming the limitations of suction.

Kilowatt-hour (kWh): one thousand watts acting over a period of 1 hour. The kWh is a unit of energy. 1kWh=3600 kJ

Load: Anything in an electrical circuit that when the circuit is turned on, draws power from that circuit.

Module: A number of PV cells connected together, sealed with an encapsulant, and having a standard size and output power.

Ohm: the unit of resistance to the flow of a circuit.

Parallel connection: A way of joining two or more electricity –producing devices (i.e. PV cells or modules), by connecting positive loads together and negative loads together; such as a configuration increase e the current.

Photon: A partial of light that acts as an individual unit of energy.

Photovoltaic (PV): Pertaining to the direct conversion of light into electricity.

Photovoltaic (PV) system: A complete set of components fro converting sunlight into electricity by the photovoltaic process, including the arrays.

Power conditioning equipment: Electrical equipment, or power electronics, used to convert power from a photovoltaic array into a form suitable for subsequent use.

Positive displacement pump: Any mechanism that seals water in a chamber, and then force it out by reducing the volume of the chamber.

Pressure: the amount of force applied by water that is either forced by a pump, or by the gravity, in k-Pascal.

Priming: this process of hand-filling the suction pipe and intake of a surface pump. Priming is generally necessary when a pump must be located above the water source. A self priming-pump is able to draw some air suction in order to prime itself.

Pump Jack: A deep well piston pump. The piston and cylinder is submersed in the well water and actuated by a rod inside the drop pipe, powered by a motor at the surface.

Rectifier: A device that converts ac to dc, as in a battery charger or converter.

Semiconductor: Any material that has a limited capacity of conducting an electrical current. Generally falls between a metal and an insulator in conductivity.

Series connection: A way of joining photovoltaic cells or batteries by connecting positive leads to negative leads; such a configuration increases the voltage.

Solar energy: Energy from the sun. The heat that builds up in the car when it is parked in the sun is an example of solar energy.

Submersible pump: A motor/pump combination designed to be placed entirely below the water surface.

Surface Pump: A pump that is not submersible. It is placed above the surface of the water in the well.

Tracking array: The PV array that follows the path of the sun to maximize the solar radiation incident on the PV surface.

Chapter 1 Introduction

1.1 Photovoltaic (PV) System Background

Solar energy or photovoltaic (PV) energy is one of the most common forms of renewable energy. It is becoming increasingly appreciated because of its influence on living matters and the feasibility of its application for useful purposes. Solar energy is rapidly gaining the ground as a supplement to the non-renewable sources of energy.

Solar energy or photovoltaic (PV) energy could be used as a primary source with or without conventional power back-up. However, its use vary from low power applications such as supply for calculators or radios to higher power applications such as providing electricity in remote areas.

The main advantage of using photovoltaics as a renewable energy source is that it is clean and has minimal impact on the environment. The significant depletion of the stratospheric ozone layer, which shield the Earth from much of the biologically harm caused by solar ultraviolet radiation (UVR), also helped bring attention to solar radiation.

Solar radiation is unevenly distributed throughout the world because of such variables as solar altitude, which is associated with latitude and season, and atmospheric conditions that are determined by cloud coverage and degree of pollution.

Solar cells convert sunlight directly into electricity. Solar cells are often used to power calculators and watches. They are made of semi conducting materials similar to those used in computer chips. When these materials absorb sunlight, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. This process of converting light (photons) to electricity (voltage) is called the *photovoltaic (PV) effect.*

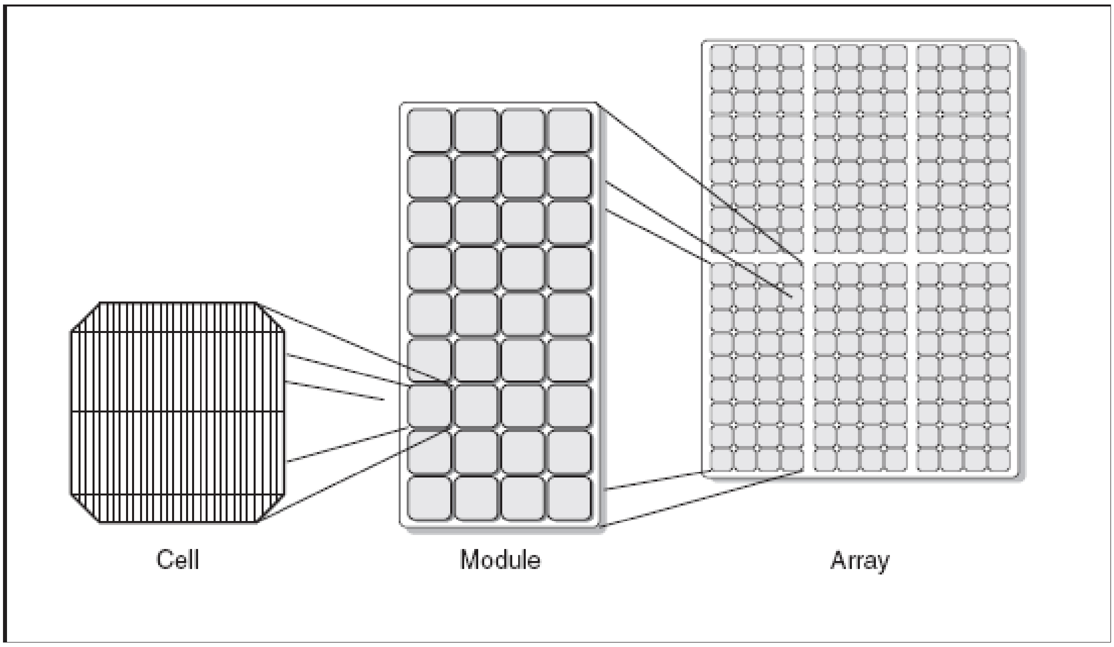

Figure 1.1: Photovoltaic cells, modules and Arrays (Introduction to PV system, 2005)

Solar cells are typically combined into modules that hold about 40 cells; about 10 of these modules are mounted in PV *arrays* that can measure up to several meters on each side. These *flat-plate* PV arrays can be mounted at a fixed angle facing the sun, or they can be mounted on a tracking device that follows the sun, allowing them to capture the most sunlight over the course of a day. About 10 to 20 PV arrays can provide enough power for a household; for large electric utility or industrial applications, hundreds of arrays can be interconnected to form a single, large PV system.

Some solar cells are designed to operate with concentrated sunlight. These cells are built into *concentrating collectors* that use a lens to focus the sunlight onto the cells. This approach has both advantages and disadvantages compared with flat-plate PV arrays. The main idea is to use very little of the expensive semiconducting PV material while collecting as much sunlight as possible. But because the lenses must be pointed at the sun, the use of concentrating collectors is limited to the sunniest parts of the country. Some concentrating collectors are designed to be mounted on simple tracking devices, but most require sophisticated tracking devices, which further limit their use to electric utilities, industries, and large buildings.

The performance of a solar cell is measured in terms of its efficiency at turning sunlight into electricity. Only sunlight of certain energies will work efficiently to create electricity, and much of it is reflected or absorbed by the material that makes up the cell. Because of this, a typical commercial solar cell has an efficiency of 15% - about one-sixth of the sunlight striking the cell generates electricity. Low efficiencies mean that larger arrays are needed, and that means higher cost. Improving solar cell efficiencies while holding down the cost per cell is an important goal of the PV industry, NREL researchers, and other U.S. Department of Energy (DOE) laboratories, and they have made significant progress. The first solar cells, built in the 1950s, had efficiencies of less than 4 %. (Go solar® company, 2005).

Photovoltaics, developed in its modern form in 1953-1954, has been used to power satellites in space since 1958; remote telecommunications, cathodic protection, and signaling systems since the mid-1960s; remote residential and commercial systems since the 1970s; and utility-intertied residential and commercial systems since the 1980s.

Today, with the price of the technology is coming down and the price (financial and environmental) of conventional fuels rising up; PV is entering a new area of international growth. (Sustainable power for the world, 2003)

1.2 How Photovoltaic System Works

PV cells convert sunlight directly into electricity without creating any air or water pollution. PV cells are made of at least two layers of semiconductor material. One layer has a positive charge, the other negative.

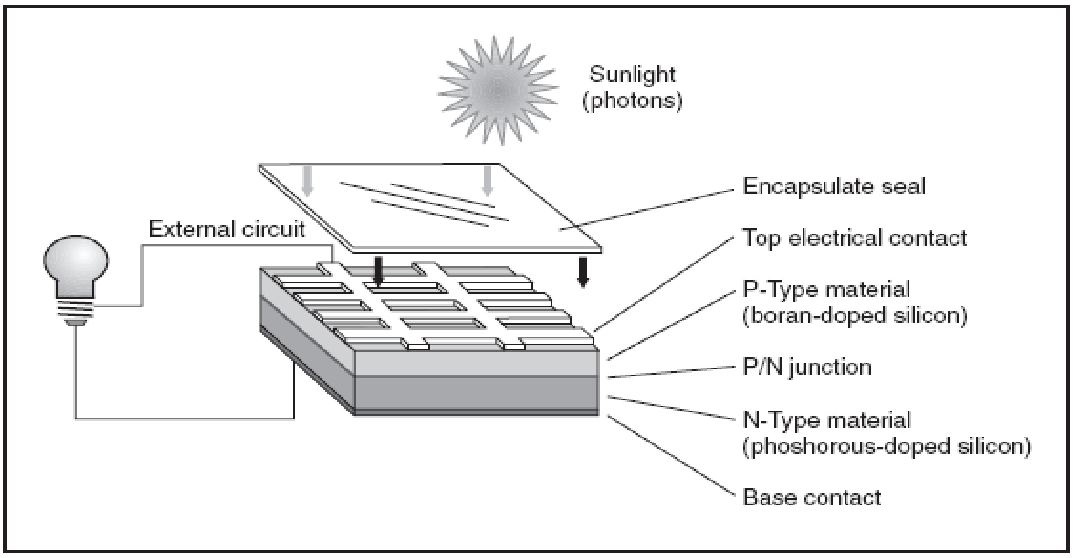

Figure 1.2: Basic operation of photovoltaic system. (Introduction to PV system, 2005)

When light enters the cell, some of the photons from the light are absorbed by the semiconductor atoms, freeing electrons from the cell's negative layer to flow through an external circuit and back into the positive layer. This flow of electrons produces electric current. To increase their utility, dozens of individual PV cells are interconnected together in a sealed, weatherproof package called a module. When two modules are wired together in series, their voltage is doubled while current stays constant.

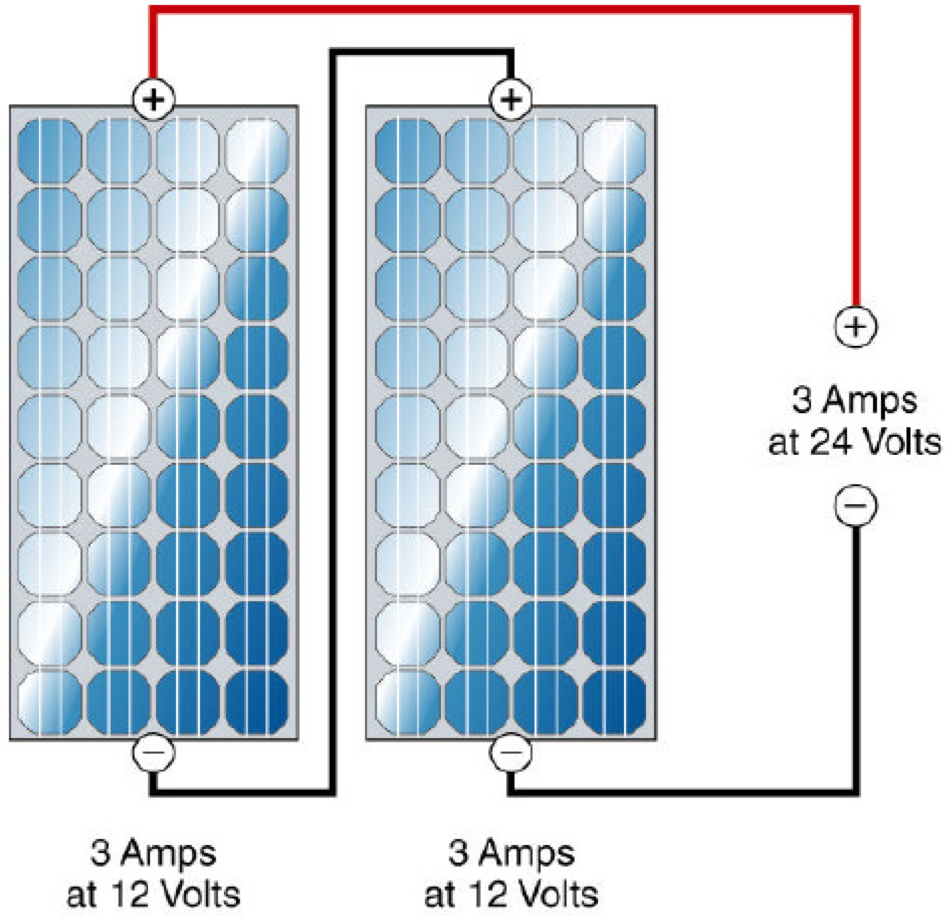

Figure 1.3: PV modules connected in series (photovoltaic modules, 2005)

To achieve the desired Voltage and current, modules are wired in series and parallel into what is called a PV array. The flexibility of the modular PV system allow designers to create solar power systems that can meet a wide variety of electrical needs, no matter how long or small.

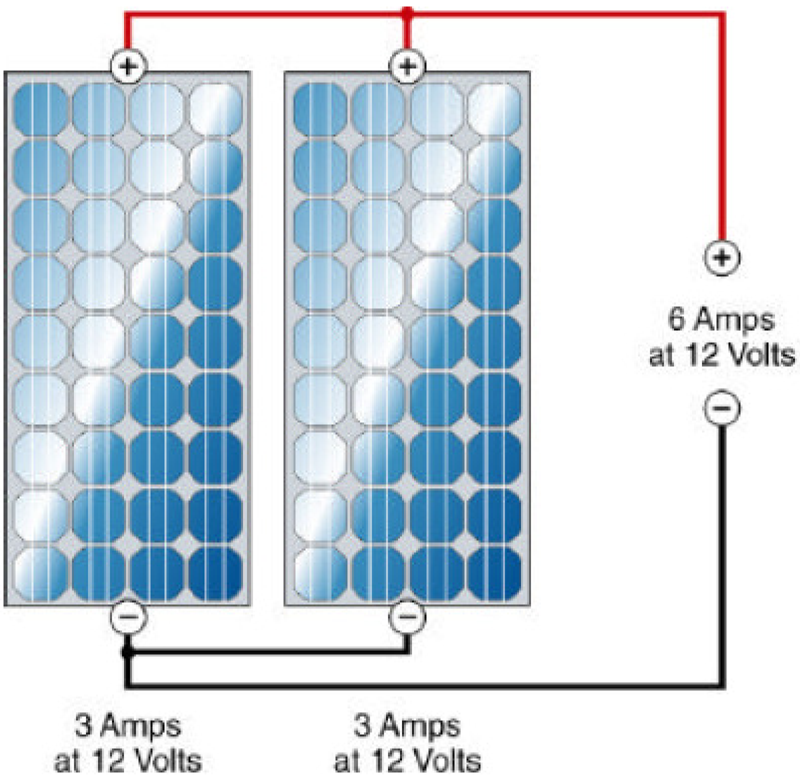

Figure 1.4: PV modules connected in parallel (Photovoltaic modules, 2005)

1.3 PV Pumping System

Water pumping has a long history; so many methods have been developed to pump water with a minimum of effort. These have utilized a variety of power source, namely human energy, animal power, hydro power, wind, solar and fossil fuels for small generators.

Photovoltaic water pumping systems currently comprise a significant proportion of PV sales, especially in the developing countries. For pumping applications the array must be sized to drive a pump that will deliver the required water volume each day, over the number of hours of operation.

The pump will operate during the daylight hours when there is an adequate light strike the system modules. Most pumping systems do not incorporate batteries. If water is needed at night time or in case of a cloudy day that there is no sufficient sunlight to drive the system, then a water storage tank would be used. It is easier and more efficient to store the pumped water then to store electricity technically as well as financially. The pump speed will therefore depend on the irradiance on the array.

Figure 1.5: Photovoltaic system. (PV pumping system, 2003)

The intensity of the light as we have said varies greatly throughout the day. Morning and afternoon sunlight is less intense because it is entering the Earth's atmosphere at a high angle and passing through a greater cross section of atmosphere, which reflects and absorbs a portion of the light. In such cases where the sunlight is varying during the day hours from morning to late in the afternoon, an important device called a maximum power point tracker is highly recommended to be used in the PV pumping system.

For a directly coupled system, where the pump motor is connected directly to the array, this requires careful matching of electrical characteristic between motor and array. This device enables the array to operate at its maximum power point at all times.

A typical PV system pumping installation (direct coupled) includes the following major components:

1. **Solar Array:** Is the full collection of all solar photovoltaic generators for a larger pumping system several dozens of PV modules are interconnected. They are mounted on ground installations using a simple frame that holds the modules at a fixed tilt angle towards the sun.
2. **Pump Controller:** Matching device used so systems will operate at optimum power, matching the electrical characteristics of the load and the array.
3. **Inverter:** Only required for AC pumps. Is the device that converts the direct current (DC) coming out of the battery into alternating current (AC). An inverter could be chosen to output in a variety of voltages, including 220 V and 110 V, single and/or 3 phase for very large loads.

4. **Pump Cable & Ground Wire:** It is used to connect the pump to the solar array. It must be sized properly to minimize line losses. Ground all equipment because water pumps attract lightning due to the excellent ground they provide. Avoid locating arrays on high spots. Consider erecting lightning rods on high ground around pump to attract lightning away from the pump.
5. **Storage tank:** Direct-coupled PV pumps deliver water only when the sun is shining. This may require some type of water storage in order to satisfy the need when the sun is not out.
6. **Pump:** DC motors are commonly used with PV for pumping to avoid the loss of efficiency and complexity when converting DC power to AC. DC motors work well at varying voltage and speed, which is ideal for operating from a constantly changing power source such as solar energy. PV pumps are only available for a set range of conditions of head and daily pumped volume. The upper limits for a PV pump are 200 meters of head and 400 m^3 of daily pumped volume.

1.4 Why Photovoltaic?

The concept of this project comes, as in Oman there is a huge quantity of solar energy available everyday. This is not really being discovered and does not get benefited from widely, as Oman is considered one of the petroleum countries. On the other hand, there are many farms that are located in remote areas and are still using the Diesel driven pumps in their water pumping system for all their water needs. For any system (product) to succeed, two issues must be present; in this case, in Oman we have both. First, we have the solar source which is there every day all year around, and second we have the demand as it can be used as power alternative to diesel.

There are many disadvantages including environmental as well as economical impacts with diesel, which causes concern about pollution. Furthermore, the cost of the diesel is high compared with other types of energy available.

As the main electricity services still have not reached those areas (as some farms are located far apart) it is not really worth to establish a new electricity transmission line for each farm, and hence photovoltaic water pumping system are the most attractive alternative to be used as the solar PV source presents several advantages that can qualify it to replace the present system and to solve the problem of energy supply in remote areas. Some of those advantages are the easy installation process, modularity and the maintenance needs. On the other hand, the PV system could be considered to have a large scale in the future specially in the remote areas because of the reasons that we have listed above. As an alternative, the PV system could replace the existing system that would be installed and would be ready for operation in a very short time.

Finally, the economy and reliability of solar power make it an excellent choice for remote water pumping.

1.5 Project Objectives

The aim of this project is to investigate the economics of using Photovoltaic water pumping in Oman. Specifically, the objectives are:

1. Economics comparison between photovoltaic system and the current diesel driven system.
2. Economic comparison between photovoltaic system and mains electricity sources that may become available in the future.
3. Investigate the adequacy of current water storage systems; and
4. Investigate the availability of local technical support.

1.6 Dissertation Outlines

This dissertation has six different chapters that explain the aspects that are related to the project aims. These aspects have all been researched and explained in this dissertation.

Chapter two titled "Sultanate of Oman Climatic Data" contains information on the climate and geographical data of Oman. The amount of solar radiation available at all six locations (being considered for this project) is detailed.

The economical analysis of the diesel driven water pump and the photovoltaic system is given in chapter 3, titled "Economical Analysis". A comparison of the two systems has also been completed in this chapter

Some technical information about the PV system configurations and the appropriate set of pumps and motors for different applications are discussed in chapter four, titled “System Sizing and Design”. In addition, system estimation and sizing process have been done upon the given data for the PV system that intended to replace the current diesel system.

Chapter five, titled “Environmental Impact Assessment” covers a discussion of the environmental impacts of the both systems, as well as a brief discussion about the environmental aspects in Oman, and how the government dealing with the environment.

Chapter six titled “Technical Considerations”; investigates the availability of technical support of PV system in Oman. This includes a comparison of the maintenance required to keep both systems operating.

The use of photovoltaic system in Oman and conclusions obtained from completing this project are presented in chapter seven, titled “Discussion and Conclusions”.

Chapter 2 Sultanate of Oman Climatic Data

2.1 Geography of Sultanate of Oman

Sultanate of Oman is a Middle Eastern country located on the south-eastern tip of the Arabian Peninsula.

Figure 2.1: Middle East map (yahoo education®, 2005)

The Sultanate of Oman's 1,700 km coastline extends from the Straits of Hormuz in the north and to the Arabian Sea in the south. To the west lies the United Arab Emirates, the kingdom of Saudi Arabia and the Republic of Yemen. The Sultanate encompasses an area of 300,000 square kilometres.

The country's climate is predominantly arid, however varies slightly from one region to another. In the coastal areas, the weather is hot and humid during the summer months, while it is dry further inland. Milder weather dominates the mountains and Dhofar region all year round. Winter temperatures can be as low as 15°C, while summer temperatures can be as high as 48°C in Muscat and 54°C in the desert. Table 2.1, shown below, indicates the average temperature in two main cities in Oman, Muscat and Dhofar, during the year. Dhofar, located in the southern region of the country, enjoys a regular monsoon between June and October, every year.

	Summer Temperatures		Winter Temperatures	
Cities in Oman	Day	Night	Day	Night
Muscat	43°C	32°C	25°C	17° C
Dhofar	30°C	28°C	28°C	20° C

Table 2.1: Average temperature in Oman (in degrees Celsius)

Oil, natural gas, agriculture, and fishing are the main industries. Although oil and natural gas are widely available in Oman, and they are considered relatively cheap for various applications, the future of oil as a form of energy is unsure, due to the limited supply that will undeniably be depleted one day.

2.2 Solar and Wind as Alternative Energy Sources in Oman

Solar and wind are both considered beneficial, renewable energies, with rapid development leading to widespread usage around the world. However, these two may not be considered viable in some places where they are not in excessive quantity.

In Oman, both solar and wind energy sources are available. However, in order to determine the most efficient of the two energy sources, there are four main aspects that have been considered in this research:

1. energy resources
2. climatic data
3. environmental considerations
4. economic considerations

In subsequent sections, these aspects will be considered for these two potential alternative energy sources.

2.3 Wind Energy

In evaluating the wind as a viable source of energy, factors such as wind velocity and predicted seasonal changes in the wind behaviour need to be analyzed. In the past, wind energy has been used for milling grain, pumping water and other mechanical power applications. Currently there are several hundred thousands windmills in operation around the world, many of which are used for water pumping. Wind energy is also one of the fastest growing renewable energy technologies worldwide. According to ***Boyle (2004)*** by the end of 2002 the worldwide wind generation capacity was estimated to be a total of 31000MW.

2.3.1 The source (wind)

The Earth's wind systems are due to the movement of atmospheric air masses as a result of variations in atmospheric pressure, which in turn, are the result of differences in the solar heating of different parts of the earth's surface.

2.3.2 Climatic data

In Oman the wind is always apparent, but wind speed varies from place to place. The lack of wind data available was the main reason that compelled me not to consider wind as a possible energy source. I essentially tried to search for wind data; however, unfortunately I could not acquire enough reliable information to prepare a well-informed researched project.

2.3.3 Environmental considerations

Because it has only minor impacts on the environment, wind energy is considered a green power technology. Wind energy produces no air pollutants or greenhouse gases; however, there are still some negative bearings which need to be considered, for example:

1. Noise: windmills produce two types of noise; noise produced by the gearbox and generator, which is well understood and easy to control. The more difficult problem is the noise that is caused by aerodynamic effects, mainly by fluctuating lift forces on the blade. The most serious effect is on downwind machines (where the rotor is leeward of the tower) and is caused by turbulence in the tower wake. The design of the tower itself has appeared to have minimal impact on the noise level.

2. Radio and TV Interference: metal rotors can reflect radio waves in a manner that interferes with radio and TV reception. Machines on the line of sight between transmitters and receivers cause amplitude modulations; machines outside the line of sight could cause periodic multi-path signals. All types of electromagnetic communication could be affected.

2.3.4 Economics considerations

Wind energy cost is decreasing over time. The U.S Department of Energy (2005), reported that the cost of the alternative energy source has dropped by 85% during the last 20 years. Wind energy is often attractive when life cycle costs are compared with other generation technologies.

2.4 Solar Energy (Photovoltaic)

Photovoltaic (PV) systems convert sunlight directly into electricity. A solar or PV cell consists of semiconducting material that absorbs the sunlight. The solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. PV cells are typically combined into modules that hold approximately 40 cells, about 10 of these modules are mounted in a PV arrays. PV is especially appealing in remote areas where extending utilities electricity grid is expensive or impossible. PV systems are easy to operate and rarely need maintenance.

2.4.1 The resource (sun)

Basically, the sun power is there every day, and it provides an energy that meets all our power needs. Solar resource information provides data on how much solar energy is available to a collector and how it might vary in respect to the time and locations.

2.4.2 Climatic data

There is a sufficient amount of sun radiation data that has been recorded regularly in Oman. The information required for this research project relating to solar radiation was obtained from the Directorate General of Civil Aviation and Meteorology.

2.4.3 Environmental considerations

During normal operation, PV power systems do not emit substances that may threaten human health or the environment. In fact, through the savings in conventional electricity production, they can lead to significant emission reductions.

2.4.4 Economics considerations

The best silicon PV modules, now available commercially, have an efficiency of over 17%, and it is expected that in about 10 years time module efficiencies will have risen to over 20 % (***Boyle, 2000***). Over the decade to 2002, the total installed capacity of PV system increased approximately tenfold, module costs dropped to below $4 per peak watt and overall system cost fell to around $7 per peak watt.

2.5 Evaluation

To conclude, from the simple discussion of both solar photovoltaic (PV) and wind that have been listed above, both alternatives investigated are useful because of the environmental and economical characteristics explained. However, in terms of source availability, solar energy is more likely to be used, as all the data shows, there is sufficient insolation available throughout the country, all year round.

According to the Directorate General of Civil Aviation and Meteorology (Oman), the wind data available is not supportive of the use of wind because of the lack of wind available throughout the year as well as its seasonal variation in various locations around the country. As a result this path of investigation had been discontinued during this research project.

2.6 Oman Climatic Solar Data

In this section, climatic solar data in Oman are presented and discussed, whilst highlighting the reasons for selecting solar PV as a potential alternative energy source.

The Omani climate varies significantly throughout the country. In the north of the country the coast is humid and hot in summer, while simultaneously, it is hot and dry in the interior. However at higher altitude locations, it can be temperate climatic conditions throughout the year.

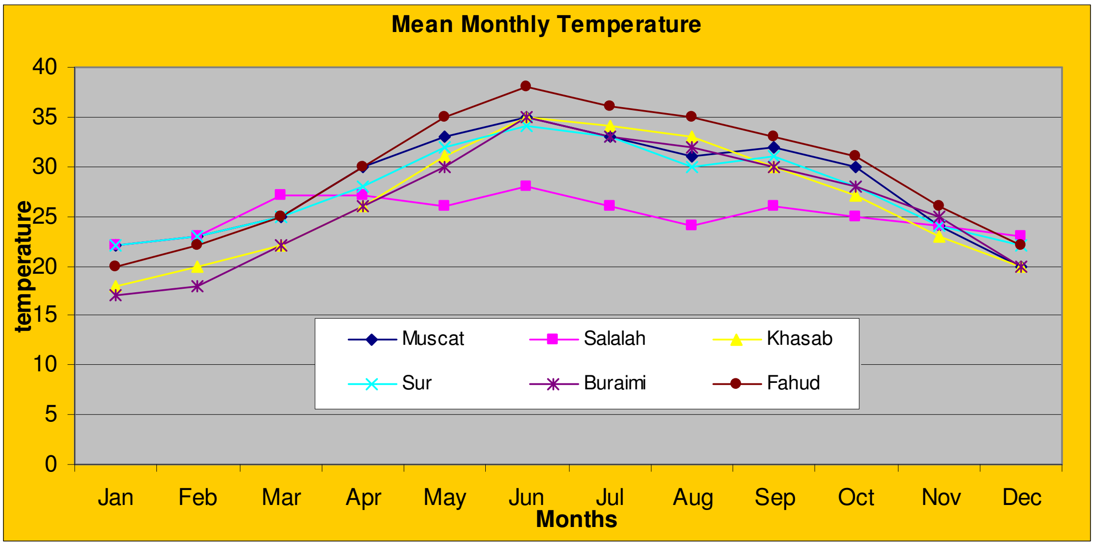

Figure 2.2: Mean monthly air-temperature observations exhibiting minima trends for the six locations in Oman. (Derived from information obtained from Directorate General of Civil Aviation and Meteorology, Oman)

The southwest monsoon, known locally as 'Al-Khareef' is a climatic feature of the Dhofar region. In August, some parts of the north experience inclement weather conditions, which cause dust hazes, and thereby reduce the transmitted direct radiation received at ground level. This condition also causes a minimum each year in the main monthly air temperature versus time plot (refer to Figure 2.2). However, the majority of northern regions do not exhibit this phenomenon.

Al-Khareef is the main reason for a significant drop in a temperature during the summer, and in particular in August, throughout the Dhofar region as shown, while dust-laden clouds lead to similar effects in the other regions. These phenomena affect the intensity of the transmitted insolation.

The minimum insolation intensities occur during July instead of August, as is the case for air temperature, for most locations except Shalala (capital of Dhofar region) and possibly the Dhofar region in parallel. The probable reason for this is that during July there are usually high winds (Sur, Masirah and Thumrait are among the areas most affected). The daily number of hours of bright sunshine is drastically reduced in Shalala, and the adjoining mountainous regions, in August. Other regions of the country are affected to the same extent.

2.7 Insolation Data

Insolation is the total amount of solar radiation that strikes a particular location over a given period of time, typically a single day. Insolation is incoming solar radiation. The amount of insolation received at the surface of the earth is always controlled by the sun's angle, state of the atmosphere, and altitude.

Figure 2.3: Oman Map, showing the six locations chosen (yahoo education®, 2005)

The monthly average daily global solar radiation is calculated using daily data of global solar radiation obtained by measurements at six different locations in Oman. The clearness index for typical data (at midday) of each month is then estimated for each location .The locations of the six cities are shown in Figure 2.3.

The solar radiation given is the global radiation received by a unit horizontal surface during a day, as recorded by the pyranograph. These data are outlined in the monthly climate summary reports issued by the Directorate General of Civil Aviation and Meteorology.

As discussed previously, the weather in Oman is generally hot all over the country in Summer, the maximum temperature goes to more than 40 degrees in the deserts. In Oman there are only two seasons, summer and winter. The summer season starts in April and ends in September, the winter lasts form September to March

Insolation data in MJ m^{-2} day^{1} for the six locations in Oman are presented in the tables shown in the following pages; each table contains the date for two different locations (cities).

Location	**a) Buraimi, Mean**			**b) Muscat, Mean**		
Months	Max	Min	Average	Max	Min	Average
Jan	17.8	7.2	14.5	17.3	6.6	14.3
Feb	21.7	6.1	16.4	20.7	7.9	16.4
Mar	24.5	8.9	19.0	24.1	10.4	18.8
Apr	26.1	11.5	21.8	26.6	11.5	22.6
May	26.8	20.6	24.3	27.9	19.9	25.1
Jun	25.4	19.3	23.0	27.2	19.4	26.8
Aug	23.8	17.4	21.7	25.4	16.6	22.6
Jul	23.8	17.5	21.8	23.5	15.7	21.6
Sep	22.8	19.4	21.4	22.6	18.0	20.7
Oct	21.0	17.0	19.3	21.1	16.0	18.9
Nov	17.7	12.4	15.6	17.9	11.4	15.6
Dec	15.5	6.6	13.4	15.5	8.2	13.5

Table 2.2: Buraimi and Muscat insolation data

Figure 2.4 the next page shows the Buraimi city isolation data. The maximum insolation received as shown in the period from March to almost October showing a maximum insolation of more then 20 MJ m^{-2} day^{1}.

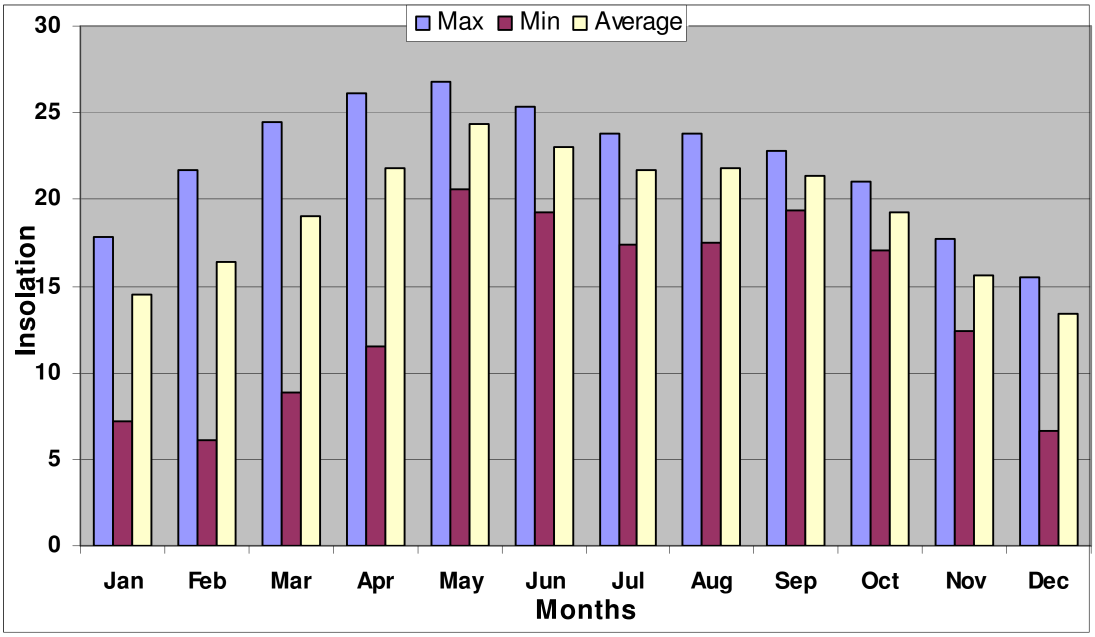

Figure 2.4: Buraimi insolation data

Muscat insolation data are also shown in Figure 2.5 below. Muscat is the capital of the country, which is a coastal city. Muscat is surrounded by mountains that really affect the weather in summer making the place extremely hot compared to other cities.

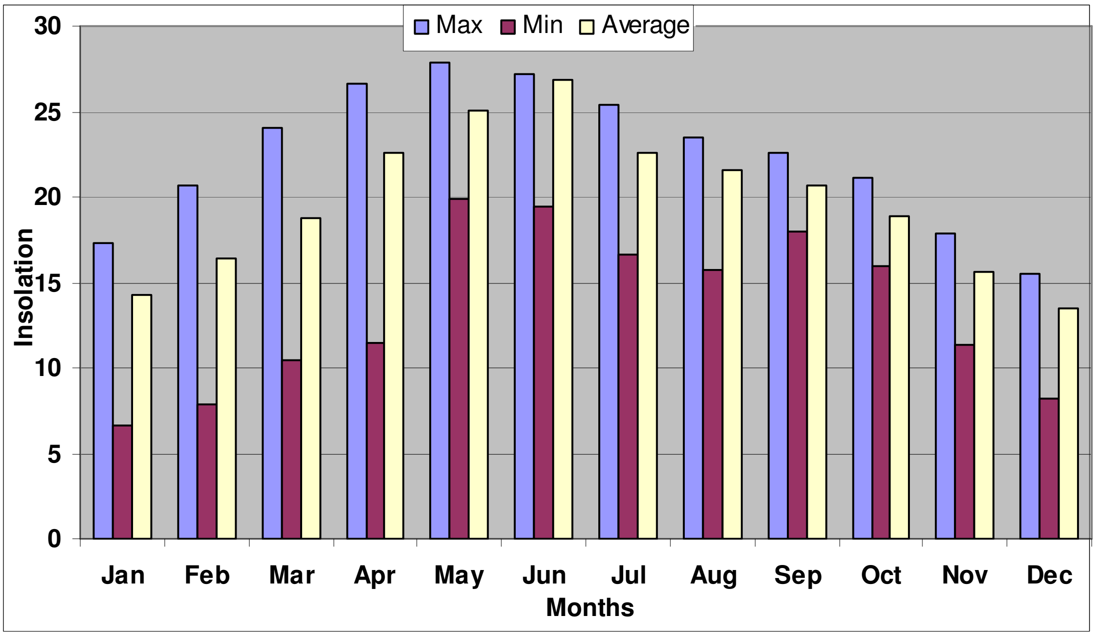

Figure 2.5: Muscat insolation data

The second table below, Table 2.3 shows the Insolation data for another two locations in Oman; Fahud and Sur. Fahud is located in the centre of Oman and it is a sandy desert area that contains most of the country's oil production fields.

Location	**c) Fahud, Mean**			**d) Sur, Mean**		
Months	Max	Min	Average	Max	Min	Average
Jan	19.1	7.2	16.6	16.0	7.5	13.1
Feb	22.6	6.1	17.7	18.1	6.4	13.8
Mar	24.6	8.9	20.3	20.9	7.5	16.0
Apr	26.8	11.5	23.0	22.5	12.1	19.3
May	27.4	20.6	24.8	24.0	16.8	20.7
Jun	267	19.3	24.4	23.0	12.3	19.6
Jul	25.2	17.4	22.5	21.6	12.1	18.1
Aug	24.4	17.5	22.5	20.8	11.7	17.6
Sep	23.6	19.4	22.0	19.8	11.5	16.7
Oct	21.9	17.0	20.2	18.6	12.4	15.9
Nov	18.2	12.4	16.7	15.8	9.4	13.3
Dec	16.5	6.6	15.0	13.8	6.4	11.4

Table 2.3: Fahud and Sur insolation data

Fahud insolation data shown in Figure 2.6 next page shows a gradual increase of insolation starting in December through to the insolation peak in May. It then experiences a gradual decrease from June through to its lowest in November.

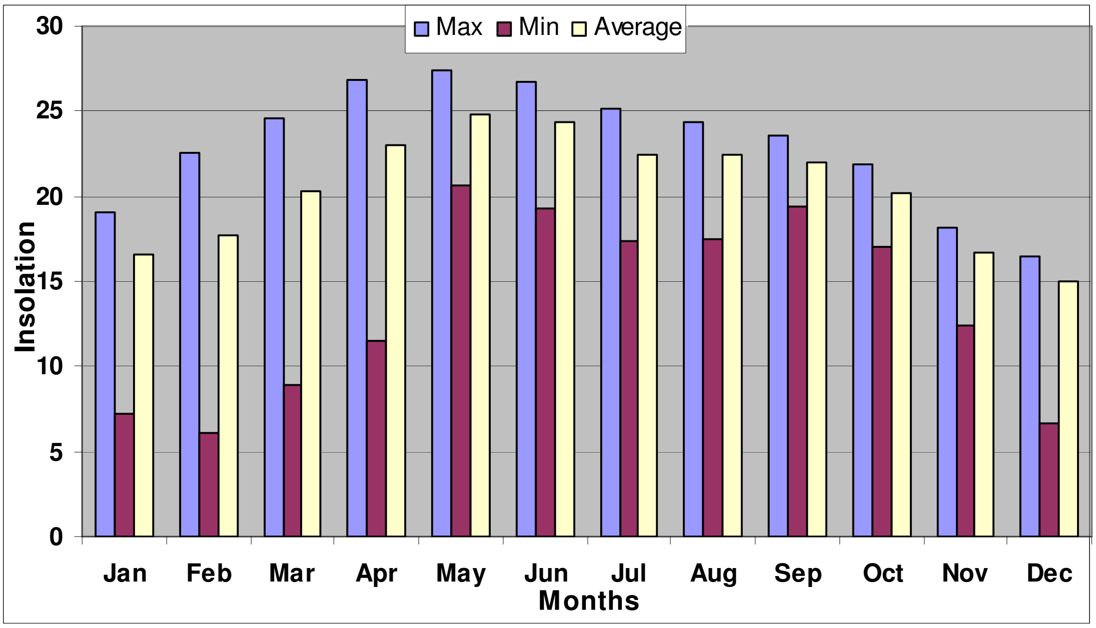

Figure2.6: Fahud insolation data

Sur is a coastal city, where the weather is hot and humid in summer. The insolation data in Figure 2.7 shows a good distribution throughout the year varying between around 12 MJ m^{-2} day^{1}.in December to 24 MJ m^{-2} day^{1} in April.

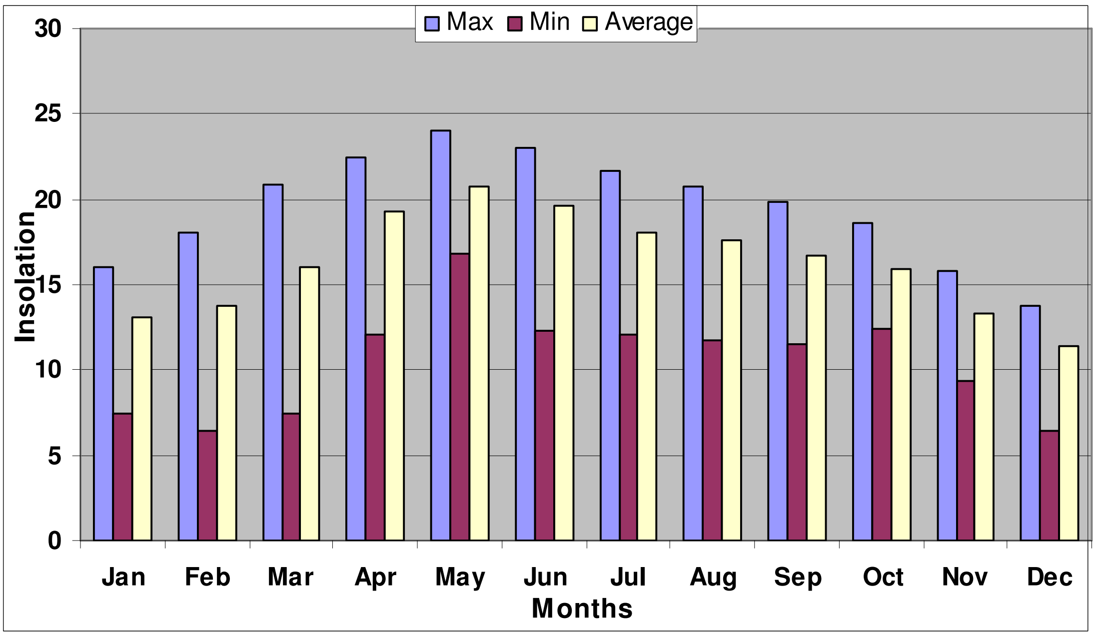

Figure 2.7: Sur city insolation data

The last two places chosen are Khasab in the top north and Salalah which is located in the south of Oman, Table 2.4 shows the insolation data for these two cities.

Location	e) Khasab, Mean			f) Salalah, Mean		
Months	Max	Min	Average	Max	Min	Average
Jan	21.5	13.0	19.3	19.0	12.6	16.6
Feb	24.3	17.2	21.5	19.6	12.5	16.8
Mar	26.0	14.8	23.7	21.4	12.1	19.1
Apr	27.2	19.0	24.9	22.1	15.8	20.4
May	27.0	21.8	24.8	22.2	17.9	20.2
Jun	25.0	12.3	22.0	20.7	10.7	17.3
Jul	24.3	11.0	21.3	17.2	4.3	10.6
Aug	24.4	16.4	22.2	16.8	3.9	10.1
Sep	24.8	19.3	23.4	19.3	6.4	14.8
Oct	23.9	19.8	22.6	19.6	14.9	18.3
Nov	21.6	13.7	19.6	17.5	10.4	15.9
Dec	19.2	11.7	17.7	16.2	11.6	14.6

Table 2.4: Khasab and Salalah insolation data

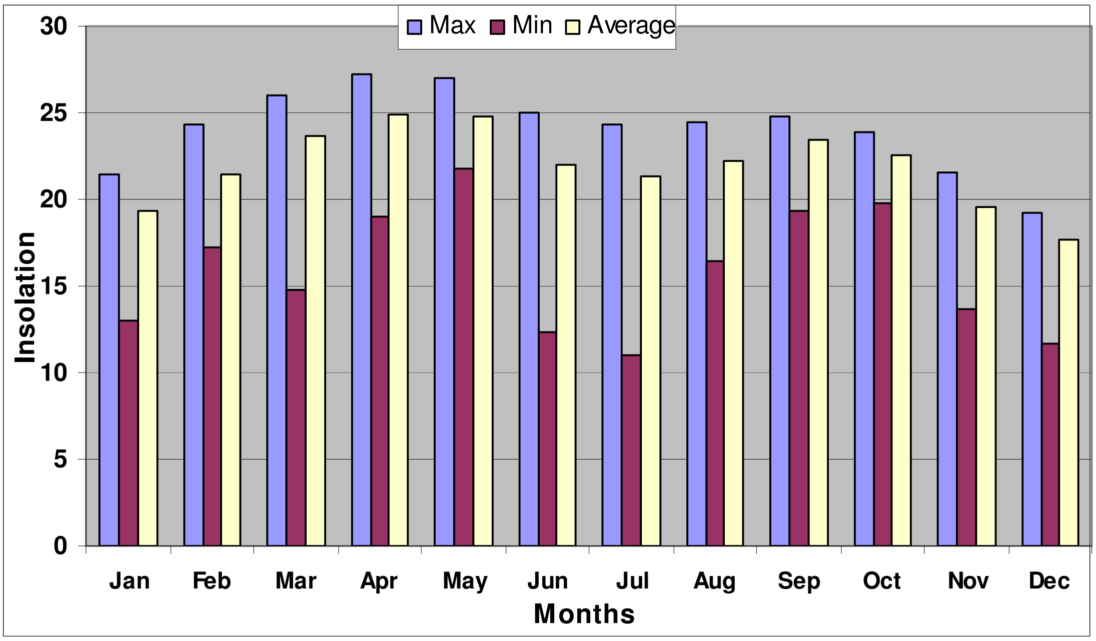

Figure 2.8: Khasab city insolation data

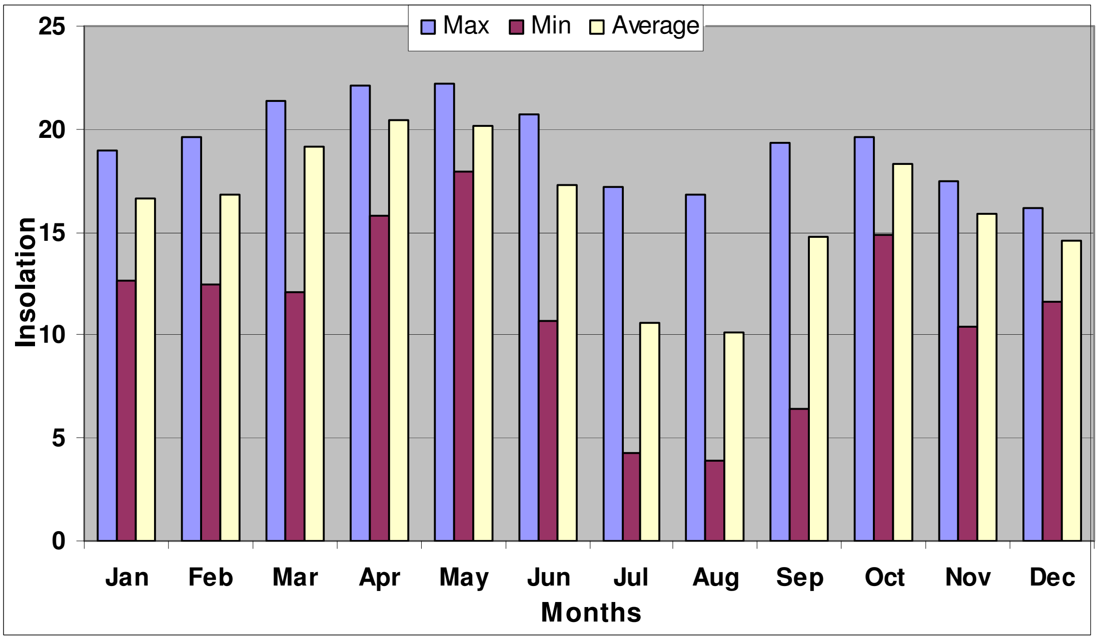

Figure 2.9: Salalah city insolation data

As shown in Figure 2.9 above, Salalah city received the lesser amount of insolation during the period from July to September compared with the other cities. This is due to the Al Khareef as previously mentioned in this chapter.

Chapter 3 Economical Analysis

3.1 Introduction

The goal of economic analysis is to compare whether the quantitative cost and benefit information will lead to efficient allocation of scarce funding resources. An economic analysis is one of several decision criteria; it is not the only factor used by the decision makers.

- An economic analysis prompts a clear understanding of the stated need, possible solutions and cost implications. It also allows the analyst to compare the options on an equal basis (in time).
- The economic analysis approach results in an objective assessment of all costs, benefits and the uncertain.

The steps of the economic analysis process could be explained as follows:

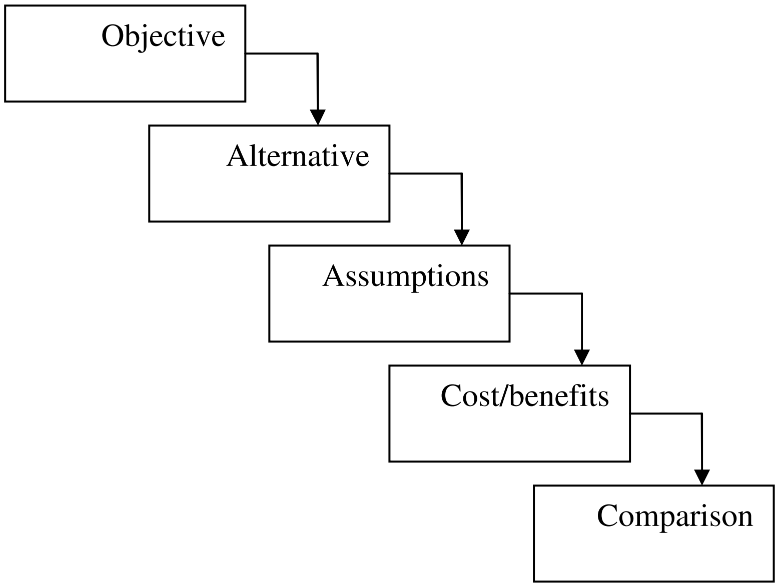

Figure 3.1: Economic analysis process

3.2 Economic Analysis Methods

There are many methods available to calculate specific economic performance measures. Used appropriately, these methods allow the planning and design team to analyze the economic consequences of particular design decisions and fairly evaluate alternative approaches. The main problem in doing the economic analysis is not the use of the techniques but the practical use of tools, the need to make assumptions, the availability of the correct data and the analysis. An economic evaluation is used to identify which alternative of pumping option achieves the maximum benefit for the least cost. Economic analysis of alternative systems is undertaken to find the most profitable alternative.

The various economic analysis methods that I have chosen (because of their relevance and understandability to readers) include:

- Life-Cycle Cost Analysis (LCCA)
- Net Benefits analysis (NBA)
- Payback period (PP)

Life-Cycle Cost Analysis (LCCA):

This is a method for assessing the total cost of facility ownership. It takes into account all costs of acquiring, owning, and disposing of a system. LCCA is designed to estimate the overall costs of project alternatives and to select the design that ensures the facility will provide the lowest overall cost of ownership consistent with its quality and function. LCCA is especially useful when project alternatives, that fulfill the same performance requirements, but differ with respect to initial costs and operating costs, have to be compared in order to select the one that maximizes net savings.

Net Present Value (NPV):

It is a traditional analytical method used to describe time-adjusted economic benefits or savings between competing alternatives. It is the difference between the sum of discounted cash flows, which are expected from the investment, and the amount that is initially invested. Where it could be calculated as follows:

1. calculate the expected free cash flows that result out of the investment.
2. subtract / discount for the cost of capital, this results in present value (PV).

3. subtract the initial investments, the end result called NPV.

Payback Period:

It is perhaps the simplest method of looking at one or more investment projects. It measures the time required to recover investment costs. If one ignores the time value of money (assume a zero discount rate), the method is called "simple payback" (SPB). If one takes into account the time value of money (assume a positive discount rate), the method is called "discounted payback" (DPB). DPB is a more accurate measure of payback than SPB.

However, there are two main problems with the Payback period method:

1. It ignores any benefits that occur after the payback period, which in this case, are highly recommended to be considered as the photovoltaic system could be still reliable in up to 30 years.
2. It ignores time value of money.

The main goal of this project is to minimize the total cost during the proposed life cycle of each alternative. From what we have discussed above, we could conclude that the LCCA is the most appropriate technique that matches what we are really trying to analyze.

3.2.1 Life Cycle Cost Analysis

In this research, implementing LCCA for the current system (diesel driven pump) and for the alternative that considered to replace it (PV pump system) gives the total cost of both - including all expenses incurred over the life period of the both systems.

There are two main reasons to implement Life Cycle Cost Analysis: 1) to compare different power options and 2) to determine the most cost-effective system designs.

The PV system produces power where there was no power before. For this type of application, the initial cost of the system is the main concern. However, even if PV power is the only option, the LCCA can be helpful for comparing costs of different designs and/or determining whether the Diesel powered pump system would be a cost-effective option.

An LCCA allows studying the effect of using different components with different reliabilities and lifetimes. For instance, a less expensive battery might be expected to last 4 years while a more expensive battery might last 7 years. Which battery is the best buy? This type of question can be answered with an LCCA.

For systems such as photovoltaic, fuelled generators, or extending utility power lines, the initial costs of these options will be different as will the costs of operation, maintenance, and repair or replacement. An LCCA can help compare the power supply options. The LCCA consists of finding the present worth of any expense expected to occur over the reasonable life of the system. To be included in the LCCA, any item must be assigned a cost, even though there are considerations to which a monetary value is not easily attached. For instance, the cost of a gallon of diesel fuel may be known; the cost of storing the fuel at the site may be estimated with reasonable confidence; but the cost of pollution caused by the generator may require an educated guess. Also, the competing power systems will differ in performance and reliability.

To obtain a good comparison, the reliability and performance must be the same. This can be done by upgrading the design of the least reliable system to match the power availability of the best.

In some cases, we may have to include the cost of redundant components to make the reliability of the two systems equal, but this issue was not considered relevant to this case. For instance, if it takes one month to completely rebuild a diesel generator, we should include the cost of a replacement unit in the LCC calculation. A meaningful LCC comparison can only be made if each system can perform the same work with the same reliability.

3.2.2 Life Cycle Cost calculation

The life-cycle cost of both alternatives listed in this project can be calculated using the formula:

LCC = CC + MC + EC+ RC - SC.

- **The capital cost (CC)** of a project includes the initial capital expense for equipment, the system design, engineering, and installation. This cost is always considered as a single payment occurring in the initial year of the project, regardless of how the project is financed.
- **Maintenance (MC)** is the sum of all yearly scheduled operation and maintenance (O&M) costs. Fuel or equipment replacement costs are not

included. O&M costs include such items as an operator's salary, inspections, insurance, property tax, and all scheduled maintenance.

- **The energy cost (EC)** of a system is the sum of the yearly fuel cost. Energy cost is calculated separately from operation and maintenance costs, so that differential fuel inflation rates may be used.
- **Replacement cost (RC)** is the sum of all repair and equipment replacement cost anticipated over the life of the system. If the system required a battery, the replacement of a battery is a good example of such a cost that may occur once or twice during the life of a PV system. Normally, these costs occur in specific years and the entire cost is included in those years.
- **The salvage value (SC)** of a system is its net worth in the final year of the life-cycle period. It is common practice to assign a salvage value of 20 percent of original cost for mechanical equipment that can be moved. This rate can be modified depending on other factors such as obsolescence and condition of equipment.

Future costs must be discounted because of the time value of money. One dollar received today is worth more than the promise of $1 next year, because the $1 today can be invested and earn interest. Future sums of money must also be discounted because of the inherent risk of future events not occurring as planned. Several factors should be considered when the period for an LCC analysis is chosen.

Firstly is the life span of the equipment. PV modules should operate for 20 years or more without failure. To analyze a PV system over a 5-year period would not give due credit to its durability and reliability, so twenty years is the normal period chosen to evaluate PV projects in regards to its modules operating life. However, most engine generators would not last 20 years so replacement costs for this option must be factored into the calculation if a comparison is to be made.

3.2.3 Discount rate discussion

For such a project, it is important to have a good discussion about the discount rate that is going to be used. Discount rate is one of the main aspects that need to be evaluated and to be used in the LCCA for calculating net present value. Bank practice is to use a rate of 10 or 12% to calculate the net present value of a project, to compare with the internal rate of return for economic analysis. However, economic rates of return differ considerably between sectors and countries.

The discount rate is meant to represent the cost of capital or the required rate of a return of a project. In the low inflation and the interest rate environment, both the cost of capital and the required rate of return on investment in the general economy have been falling.

Now, if the plane is to finance the project cost and we know what the interest rate on the loan would be, we can use the rate charged on the loan as the cost of borrowing for the project. Therefore, we would use the loan's rate as the "discount rate" in computing the Net Present Value for the project. (If the rate is variable, we may have to take a guess as to the average rate over the loan period, or do the computation under worst-case and best-case scenarios.) .

The discount rate selected for an LCCA has a large effect on the final results. It should reflect the potential earnings rate of the system owner. Whether the owner is a national government, small village, or an individual, money spent on a project could have been invested elsewhere and earned a certain rate of return. The nominal investment rate, however, is not an investor's real rate of return on money invested. Inflation, the tendency of prices to rise over time, will make future earnings worth less. Thus, inflation must be subtracted from an investor's nominal rate of return to get the net discount rate (or real opportunity cost of capital). For example, if the nominal investment rate was 7 percent, and general inflation was assumed to be 2 percent over the LCC period, the net discount rate that should be used would be 5 percent.

Different discount rates can be used for different commodities. For instance, fuel prices may be expected to rise faster than general inflation. In this case, a lower discount rate would be used when dealing with future fuel costs. In the example above the net discount rate was assumed to be 5 percent. If the cost of diesel fuel was expected to rise 1 percent faster than the general inflation rate, then a discount rate of 4 percent would be used for calculating the present worth of future fuel costs.

To conclude this discussion, if the farmers are planning to finance the new project by having loans, the discount rate obviously going to be calculated by the banks that they getting their loans from. In this project discount rate of 10% was estimated to be used (as it has been recommended by the major banks working in Oman) after we subtracted the inflation rate, which was 1 %. (Welcome to Oman, 2003).

3.3 Systems Overview

In next few sections, the diesel pumping system and the PV system are going to be explained, the systems components as well as their costs will also be analyzed.

3.3.1 Diesel water pumping system

The diesel pumping system is widely used in the remote areas in Oman. Because of the availability of the diesel and its price is considered relatively cheap compared to paying for a connection to the main electricity service line; farmers are still considering it as the best option for them to use.

Figure 3.1 below shows the diesel water pumping system using which as shown consists of the two main parts; the surface mounted pump type as well as the diesel engine to drive that pump.

Figure 3.2: The diesel pumping system widely used in Oman.

The conventional diesel pump system that is being using by farmers in Oman could be explained as follows:

- Diesel driven pump, (built-in fuel tank), it consist of the Pump and the diesel engine required driving that pump, as shown above in Figure 3.2.
- Pipe fittings from the well to the pump and from the pump to the water reservoir.
- Housing or shade covered the equipments; it could be constructed from wood or from cement some times.
- Water reservoir, normally it is made of cement.

The life cycle cost of diesel-powered engine consists of capital and recurrent cost. The capital costs comprise the diesel engine and pump set as well as other installation costs. The recurrent costs, on the other hand, include fuel and lubrication, spare parts, pump and engine replacements, labour costs for maintenance.

3.3.2 PV water pumping system

A typical PV system considered includes the following major components:

Solar Array: Is the full collection of all solar photovoltaic generators for a larger pumping system several dozens of PV modules are interconnected. They are mounted on ground installations using a simple frame that holds the modules at a fixed tilt angle towards the sun.

Inverter: It is the device that converts the direct current (DC) coming out of the battery into alternating current (AC). An inverter could be chosen to output in a variety of voltages, including 220 and 110, single and/or 3 phase for very large loads.

*Only required for AC pumps.

Pump Cable & Ground Wire: It used to connect the pump to the solar array. It must be sized properly to minimize line losses. Ground all equipment because water pumps attract lightning due to the excellent ground they provide. Avoid locating arrays on high spots. Consider erecting lightning rods on high ground around the pump to attract lightning away from the pump.

Storage tank: Direct-coupled PV pumps deliver water only when the sun is shining. This may require some type of water storage in order to satisfy the need when the sun is not out.

Pump-Motor set: DC motors are commonly used with PV for pumping to avoid the loss of efficiency and complexity when converting DC power to AC. DC motors work well at varying voltage and speed, which is ideal for operating from a constantly changing power source such as solar energy. PV pumps are only available for a set range of conditions of head and daily pumped volume. The upper limits for a PV pump are 200 meters of head and 400 m^3 of daily pumped volume.

Similarly**,** the life cycle cost of PV system consists of capital and recurrent costs. The capital costs comprise the solar panel and related hardware, submersible pump and installation costs. The recurrent costs, on the other hand include pump replacement, labour cost for maintenance.

3.4 Costs Distribution and System Analysis

To analyze the costs for the both systems, the following factors need to be considered for an optimum conclusion:

1. Term of analysis: considered to be 20 years; which is the useful life of the solar powered pump (***Sqrensen B, 2000***). The diesel powered pump is replaced periodically, subject to its useful life depending on the brand. The useful life of a diesel engine is 10 years; however, on the other hand, the pump has a useful life varied between 7 to 10 years.

System	Solar pump system	Diesel system
Economic life (years)	20-30	15
Term of analysis (years)	20	10

Table 3.1: life analysis for both systems

The age and economic life of the diesel engine, based on interviews with the farmers, is shown in the Table 3.1. The choice on the term analysis for diesel, however, is based on the result of the limited survey done.

2. Discount rate: the discount rate was decided to be 10 percent, (figure from the major banks working in Oman).

3. Costs and prices of equipment and all other related cost were evaluated on the interviews carried out with the farmers in July, 2005; and include all operation and maintenance costs for diesel system such as fuel and oil.
4. Daily operation period decided to be 6 hours, considering that is the maximum what we can get out of solar every day, taking into consideration also, non-cloudy day.
5. The replacement value is evaluated to be once during the life analysis for diesel that covers the diesel engine as well as the pump. For the PV system, the replacement cost covers the pump and the motor to be replaced once during same term of as analysis of 20 years.

Costs	**Diesel driven pumps system**	**PV system (for 6.54kWh system)**
Capital cost (Installation &equipment cost)	$8000	$32500
Operation and maintenance cost:	$300/year $300*20=$6000	$650
Fuel cost	$70*12=$840 $840*20=$16800	None
Replacement cost	$8000	None
Total cost	$38800	$33150

Table 3.2: Systems costs comparison

3.4.1 Costs estimation

The system costs have been estimated for the both systems as follows:

For the diesel system, the different costs have been estimated depends on the interviews that have been made with the farmers, and then by taking the average of different costs. The system initial cost was estimated to be $8000 for the both engine and the pump. The fuel cost including the transportation cost also as per the farmers was $70/month. Maintenance and operation cost was estimated to be $300/year.

For the PV system, the system costs were estimated by visiting some websites that illustrate costs for different PV systems; some of those costs have discussed chapter 4, System Design and Sizing.

Basically, Module costs represent 40-60% of total PV system costs. Some studies report that operation and maintenance costs are well correlated to the system size, so 2% of the total hardware costs operation and maintenance costs is expected. The most significant replacement cost will likely be the battery, if used. (Photovoltaic technologies and applications, 2004)

3.4.2 Comparison between the photovoltaic system and diesel system

A comparison of the two water-pumping system, diesel and PV system in terms of life cycle cost that shown in the Table 3.2

As shown in Figure 3.3 below, the PV pumping system has higher initial cost then the diesel-powered pump but its recurrent cost proved declining over the economic life; the opposite was noted for the diesel-powered pump, High recurrent costs were incurred. However, in remote areas aspects such as lower Operation & maintenance costs, the more reliability as well as the longer expected useful life of PV systems could economically justified the higher initial cost of PV systems.

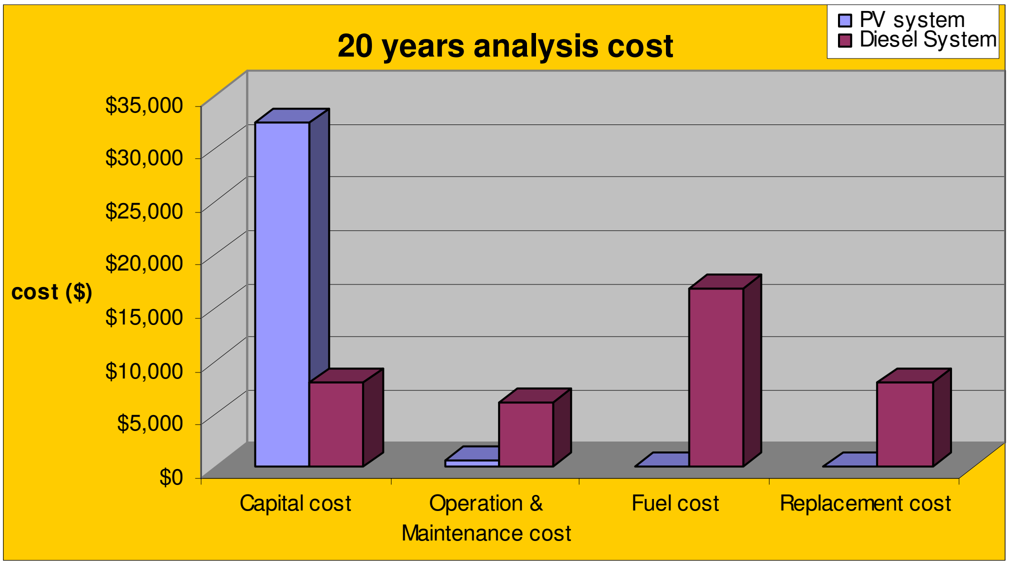

Figure 3.3: 20 years systems cost analysis

The comparison of the life cycle costs of the both systems also noted that the operation and maintenance cost and fuel cost are higher for the diesel system, and if we consider that fuel prices are increasing, these numbers could keep going up. The bar chart in Figure 3.3 above shows that the fuel cost of the diesel system is really high compared with other costs within the system such as operation & maintenance cost, replacement as well as the capital cost.

The total cost for the both system throughout the 20 years life cycle are shown in Figure 3.4 below.

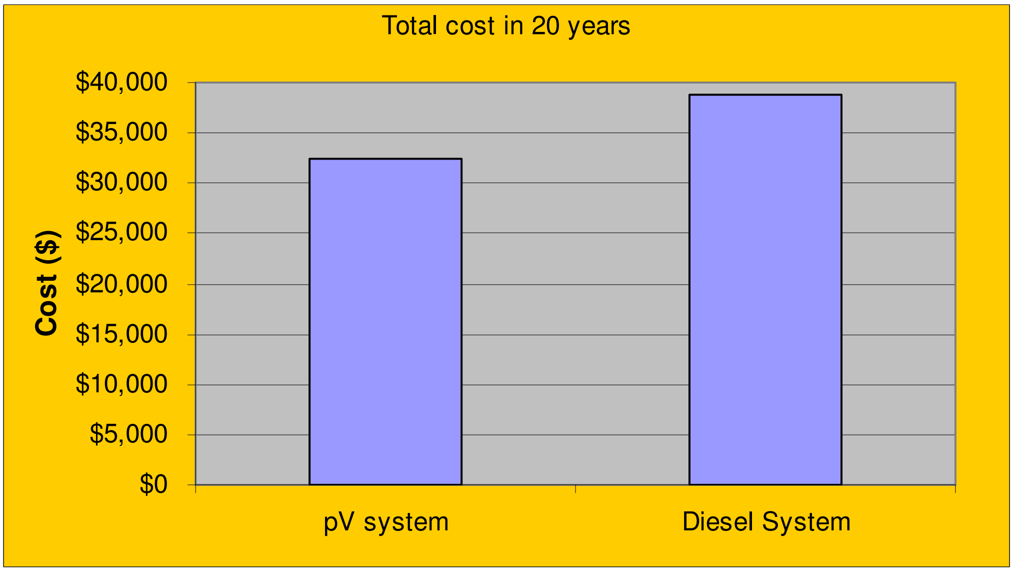

Figure 3.4: Total cost in 20 years

The significant number difference between the two systems could be increased if we consider oil prices are increasing every day.

3.4.3 Comparison between the photovoltaic system and main electricity line

As developmental growth continues in the country, the main electricity could be available soon which will cover different areas. In this issue, the government is subsidizing those people who are further from the main electricity line for different application by 25% of the total costs of the new line.

As some farmers who are using the main electricity line for the same applications in areas where the main line is provided, the monthly electricity bill varies from $20 to $25 per month. If this is the case, over 20 years the total bill cost would be around $6000 plus the motor-pump set maintenance. From the simple calculation done, the main line electricity would be the best option for the farmers even when compared with the PV system, as the farmer only need to press the on-switch to utilize the water without the need for other aspects such as maintenance and other related costs. Thus, the distance from the main electricity line to the farm, as well as the amount of government subsidization must be evaluated and discussed.

3.4.4 Discussion

The cost analysis used considered the distribution of the different costs throughout both systems' life-span. Actually it has been found that it is problematic to evaluate the benefit and cost analysis, because there is no present PV system that could be investigated and analyzed that would cover all the economical aspects.

On the other hand, there was a problem that we could really face doing this economical analysis, if we consider that the farmers do not really have enough money to install the PV system, as the initial cost of the PV system is considerably higher than the diesel system. However, the farmers currently install the diesel system and start to use it, utilizing the water to grow their crops to produce a profit at season's end. So if this is the case, the farmers are relying on their farms for their yearly income and would not be able to finance the PV system from banks, because of the interest rate and other banking factors.

An additional issue that needs to be considered is where the government stands on this issue, and whether the government really supports the farmers replacing the diesel system. Government support and educational programs would strongly encourage the farmers to adopt the PV system, by explaining to the farmers the benefits of the alternative system and all the economical issues related to both systems, where that the oil prices are actually increasing, thereby having a negative impact on the farmers in the future as well as the environmental impacts of the diesel system.

Finally, does the government have a policy to subsidize the farmers, and if so, by how much percentage? All the issues that have been discussed above would have a strong effect on the final decision made by the farmers.

Chapter 4 System Sizing and Design

4.1 Introduction

As we have discussed previously, the most common renewable energy sources for water pumping applications are wind and solar. However based on the evaluation that we have made earlier for both renewable resources, we have decided to under take this project using solar energy for pumping water as an alternative to the diesel powered pumps which are widely used in Oman.

Generally, the use of the PV pumping systems varies widely, depending on the requirements and the conditions under which water is pumped. The volume of water required also varies by season, time of day, and by the application that it's used for. The availability of water from a PV system over the year, as discussed previously, depends mainly on the availability of the solar radiation. This varies seasonally and of course by the time in the day. For all these reasons, a PV pumping system must be properly configured and well designed based on the need and the type of the application in which to perform well and to be economically viable.

The water pumping subsystem must be matched properly with the PV array for maximum use of the system; however, it is problematic with many PV systems. The main problems of the load matching with a PV array power source are related to the nonlinear solar irradiance and cell temperature-dependent voltage and current characteristics of the PV array generator.

In general, volumetric pumps are linear and can use the energy from the sun with the smart electronic controller. Centrifugal pumps are nonlinear; hence, water production drops when the pump operates away from the designed point. As we have mentioned before, the use of the solar generators (PV arrays) to run water pumps, especially in sunny and developing countries is very promising. The efficiency of the PV modules is about 15%, the motor-pump subsystem efficiency is 40%-60%, and inverters are about 95%. The overall efficiency of a PV system pump is 6.5%-9%.

Basically, the solar pump is powered by solar energy, either directly by converting the solar resource into electricity or indirectly by using solar-thermal heat collectors. However in this research, photovoltaic or PV technology that is directly converts solar energy into electricity are going to be used and discussed.
In this case, sunlight is the only source for electricity generation in such a system; the PV array output depends on the intensity of the solar radiation striking the array

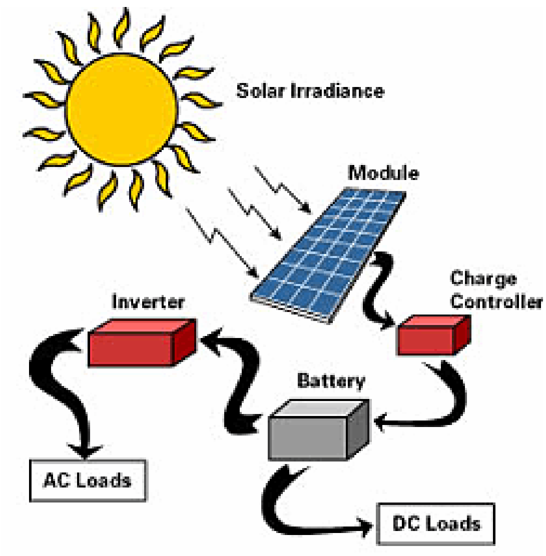

Figure 4.1: photovoltaic system arrangement

The amount of water delivered by the system depends mainly on the amount of solar radiation that is received by the system array, as previously stated, depends on the location, the size of the system array and the performance of the subsystems as well as power electronics component used.

The PV-powered pumping system is simple, consisting of a PV array, a motor and pump set and water storage. The PV array converts the received solar energy into DC electricity and the motor and pumps converts the electrical output into hydraulic power. Various types of pumps and motors are available for water pumping application depending on factors such as daily water demand, the pumping head, and the water source.

The most common commercially available configurations of motor-pump subsystems are listed below:

- **Submerged motor-pump system:** this is normally called a submersible centrifugal motor-pump. This type is considered as the most common and suitable type of solar pump of pumping system for village water supplies because of it its simplicity to install and safe. Either ac or dc motors can be incorporated into the pump set although an inverter would be needed for the ac systems.

Again if a brushed dc motor is used then the equipment will need to be pulled up from the well (approximately once every two years) to replace the brushes. If brushless dc motor is incorporated then electronic commutation would be required.

Figure 4.2: Submersible well pumps (Submersible well pumps, 2005)

- **Submersed centrifugal pump with a surface mounted motor:** this configuration is the widely installed and used in Oman with the diesel power. Although this type of a subsystem is advantageous for maintenance of the motor, the power losses in the shaft bearings and its high cost make it unattractive.

- **Floating motor-pump set:** this type of pumping unit is recommended for pumping surface water for irrigation from channels and open wells. It is portable and hence negligible chance of the pump running dry. Most of these types use a single stage submersed centrifugal pumps. The most common type utilizes a brushless (electronically commutated) dc motor.
- **Positive displacement pump (volumetric pump):** this type of pump is driven by a shaft from a surface-mounted motor, and is suitable for high head and low flow rate application.
- **Surface mounted motor-pump set:** this type of system has a self-priming mechanism and is recommended for low head duties. The section head should be as long as 6 meters. The pump may be centrifugal or positive displacement.

Practically, brushless dc motors are the most attractive for smaller pumping applications and ac motors (incorporated with inverters) are the most attractive for larger installations. Efficiencies of a motor-pump subsystem are 40%-60% depending on the motor, pump, and the power transmission. The optimum efficiency for motors is about 85%; for the pump about 70%; and for the suction and delivery pipe about 80%. Also the friction loss in pipes depends on the diameter and pressure in the pipe, as well as the amount and type of fittings used in the system.

4.2 Pumps

There are two basic types of pumps:

- **Volumetric (positive displacement).** These types of pumps are operating by mechanically advancing a sealed quantity of water by using several mechanisms such as pistons, cylinders, and elastic diaphragms. The flow rate or speed of a positive displacement pump is directly proportional to the motor speed and power output.
- **Centrifugal (rotodynamic) pumps**. These pumps are designed for a fixed head, meaning their efficiency decreases when the pumping head deviates from the design point. Unlike volumetric pumps, a significant decrease in a rotodynamic pump's power supply can cause it to fail at delivering water from a borehole because its vertical lifting capability is directly proportional to the power input.

The best type of equipment for a particular pumping application depends on the daily water requirement, pumping head, suction head (for surface mounted pump-sets), and for sure the water source. Generally, positive displacement pumps are best for low flows (less then 15 m^3/day) and high pumping heads (30-150 meters). Submersible centrifugal pumps are best for high flow rates (25-100m^3/day) and medium heads (10-30meters).

4.3 Motors

Generally motors are grouped into two types; ac motors and dc motors. Dc motors are divided into permanent magnet (brushed and brushless) and wound-field dc motors. In a permanent magnet motor, the permanent magnet is used to produce the magnetic field so no power is consumed in the field windings, which leads to higher efficiencies, making this type of motor more attractive for smaller PV applications.

The simplest and cheapest type of ac motor is the squirrel-cage induction motor. It is low cost and rugged construction makes it the most commonly used motor for wind/PV applications.

The main advantages of the permanent magnet dc motor are their simplicity and efficiency for smaller applications. Maintenance in brushless dc motors is minimal. However, brushed motor brushes need to be replaced periodically, and brushless motors have the extra expense of electronic commutation.

In contrast, ac motors are cheaper than dc motors and large ranges are available for different loads. However, ac motors are less efficient then dc motors and requires invertors for PV applications, which clearly add cost and increase breakdown risk.

4.4 Power Conditioning Devices

The main power conditioning devices used for the PV pumping systems are batteries, dc to ac converters, dc to ac invertors, and ac to dc rectifiers. The requirement of these listed devices depends on the system design and the application.

4.5 Photovoltaic Water Pumping System Sizing

Basically, daily water demand and the total pumping head are the two main factors that identify what size of PV system is capable for an application. These two factors are the main criteria for sizing any water pumping system. The daily water demand that is estimated for our project was around 60 m^3/day. The total pumping head is the total head that is required to pump water from the water source (in this case the water source generally is a well) to the reservoir; that is the sum of the pumping head, the friction and the discharge head. The discharge head is the height from the surface of the ground to the reservoir pipe outlet. The average pumping head is estimated to be 40 meters.

From the data given above, a PV water pumping system must be sized carefully and realistically. An undersized system will no doubt frustrate the user; an oversized system is a west of financial resources.

4.5.1 System sizing

Typically, commercial PV systems are installed at around $7-10 per watt.

The system hydraulic energy required, as we have discussed above, depends on the water volume required and the pumping head as well as the water density and gravity as follows:

Step 1:

The hydraulic energy required in (kWh/day)

= Volume required (m^3/day)* head (m)* water density* gravity/ (3.6*1000000);

where, gravity = 9.81, water density=1000 kg/m^3

$= 60 \times 40 \times 0.002725 = 6.54 kWh$

Step 2:

Now, the load required was estimated to be around 6.54kWh; as we have estimated, the system is going to be working for 6 hours daily. Also if we consider the efficiency of the whole system, which consists of:

1. Pump: efficiency of 0.8
2. Motor: efficiency of 0.7,
3. Power electronics: efficiency of 0.9;

So, the entire system has an efficiency (η) = 0.9*0.8*0.7=0.5, then 1/0.5=2;

$$6.54kWh \times 2 = 13.08kWh$$

Step 3:

Now to determine the array size needed; dividing the energy needed by the number of available sun hours per day:

$$13.08kWh / 6h = 2.18kW$$

Now, calculating the cost of the PV array system required is; multiply the size of the array by $10 per watt:

$$2.18kW \times \$10 = \$21800$$

Step 4 (optional):

If an AC system is used, an inverter is required, which will add a cost of multiplying $1 by rated watts:

$$2180W \times \$1 = \$2180$$

The other related cost includes wires, fuses etc;

$$2180W \times \$0.2 = \$436$$

Step 5:

The total estimated cost is:

$$\$21800 + \$2180 + \$436 = \$24416$$

(Estimating PV system sizing and cost, sheet No. 24)

4.5.2 Pump and Motor cost

A photovoltaic pumping system pumping 25 m^3/day through 20 m head requires a solar array of approximately 800Wp. Such a pump would cost approximately $6000. Other cost examples are shown in Table 4.1 below.

((The prices shown in the table below are not indicators of final prices, but rather average based figures; the prices are taken from the source identified below.)).

Motor/pump Configuration	Output (m^3/day)	Head (m)	Solar Array (Wp)	System Price US$
Submerged borehole motor pump	40 20	20 20	1200 800	7000-8000 6000-7000
Surface motor submerged pump	60	7	840	5000-6000
Reciprocating positive displacement pump	6	100	1200	7500-9000
Floating motor/pump set	100 10	3 3	530 85	4000 2000
Surface suction pump	40	4	350	3000

Table 4.1: PV system configuration and costs (Solar photovoltaic water pumping)

Permanent magnet DC motors are limited to ratings of a few horsepower and have a maximum speed limitation. DC systems also have high cable power losses as the distance from the power source increases. These limitations keep these types of motors applicable for small water pumping applications for limited cable distance from the power source to the motor.

To conclude, AC motors are the best used with our system design, as AC motors are generally used for medium to high power demand applications and it is available in either single phase or three phase.

4.6 Discussion

The best system performance, as always, can be achieved through a well-designed and proper system configuration. Choosing the system configuration depends on how far the technical services are from the farm that is using the PV system in case of system failure. Operation and maintenance should also be considered, and the degree of ease to reach the internal parts of motor as well as the pump in case of system failure. That is why some configurations are preferred in some places or for certain applications whereas the same configuration could not be the considered as convenient in other places.

Considering surface-mounted equipment, this type of equipment has several advantages with applications as deep as 8 meters making them easy to install and readily accessible for maintenance and repair. For such deeper wells, it is possible to submerge the pump and keep the motor on the surface. However, this configuration, also called the vertical turbine pump, is less attractive for deep wells because of bearing problems and installation difficulties. Submersible motor pumps (also called submersible centrifugal pumps) are highly reliable pumping options, especially for such wells with a depth of 60 meters which are ideal for the cases discussed in this project as the average depth considered was, in fact, 60 meters.

Some other configurations that are ideal and applicable for applications such as surface water pumping, (such as for lakes or rivers) are called floating pumps (Floating Motor Pumps).

Pumps must closely match the mechanical primary motor for better performance, most manufacturers sell pump-motor sets, especially in applications that require less then 10kW.

Finally, both AC and DC electric motors could be used for water pumping applications. Permanent-magnet DC motors are the commonly used in low-power applications (as high as 600W) while AC induction motors are highly considered for larger systems. Submersible equipment on the other hand requires the least minimum maintenance.

To conclude, for this reason and the discussion above, brushless DC and AC motors are often preferred even though there may be cost and efficiency penalties. Table 4.2 below explained different types of water pumps; listed by their type, advantages and disadvantages.

Pump	Use	Advantages	Disadvantages
Self-priming surface centrifugal.	Surface mounted motor and pump for high volume, low head applications. Commonly used for irrigation from lakes or rivers. Limited head: < 7m	Wide range capabilities, easy to install and serviced. Pumps using the water as a bearing lubricant.	Limited 5 meters suction head. Relatively inefficient compared to centrifugals that have flooded inlets.
Vertical Turbine	Medium volume,	Ease of	Shaft losses reduce efficiency

	medium head pump Head: < 24m.	maintenance with surface mounted pump. Wide range of capabilities.	compared to submersibles. Shaft and borehole alignment are critical to successful operation. Hard to install and maintain.
Submersible positive displacement (Diaphragm).	Medium head, low flow applications. Head: < 80m.	Few moving parts. High efficiency over range of heads. Low internal friction. Small size makes them easy to remove from wells. Can be used in portable applications.	Low capacity. Not appropriate for deep wells. Diaphragm must be replaced every 1-2 year. Limited to heads below 100 meters. Most designs use brushed DC motor requiring regular brush replacement.
Surface positive displacement-rotary or mono pumps (Helical Cavity).	Medium to high head, medium flow. Head: < 150m.	Efficient over wide range s of head except for under 20m. Simple construction. No back flow valve required.	Sand or very hard water can cause premature degradation of rubber stators. Requires gearing. Can overload motors if down stream valves are closed. Installation difficult. Requires batteries or power-

		Self-priming.	conditioning to supply high starting torque (current).
Submersible centrifugal.	Down-hole, medium-volume, high-head, integrated motor/pump unit Head: < 200m.	Motor is directly coupled to impellers. Easily cooled because it is submersed. Multistage impellers accommodate wide range of heads. No noise. Can pump from great depth. Use water as bearing lubricant.	Sand/grit causes impeller wear and decreasing efficiency. Saline conditions will corrode metal housing. High capital cost, highly expensive to repair, must remove pump from well. Can be damaged by running dry.

Table 4.2: water pumps specifications

Chapter 5 Environmental Impact Assessment

5.1 Introduction

No energy technology is free of environmental impacts. Most renewable energy technologies produce very little air and water pollution relative to fossil fuels. The areas of greatest environmental concern are the impacts caused by the construction and operation of renewable energy plants. The proper sitting, installation, and operation of renewable energy power facilities will help to control, reduce or even avoid any environmental impacts.

This section evaluates the environmental impacts that could occur during the construction or operation of the alternative technology. Environmental resources considered include land use, air quality, human health and other related impacts.

5.2 Development & the Environment in Oman

The sultanates of Oman's imaginative and futuristic environmental protection and conservation policies have won international recognition. The United Nation Environmental Program has cited Oman as a country with one of the best records in environmental conservation and pollution control measures.

The first environmental legislation was enacted in 1974 and in 1979, His Majesty the Sultan decided to chair the council for conservation of the environment and prevention of pollution. In May 1984, Oman becomes the first Arab country to set up a ministry exclusively concerned with the environment. The Sultanate celebrates the environment day on the 8th January each year.

The Sultan Qaboos prize for Nature Conservation was initiated by His Majesty in 1991, and was awarded for the first time to the Mexican Environmental Study Center. It is awarded every two years to a conservation body or individual chosen by UNESCO for environmental performance.

The Ministry stages regular oil pollution control exercises with Petroleum Development Oman (PDO), the royal Oman Police and the Ministry of Defense to test the National Oil Spill Contingency Plan (NOCP) in the event of major oil spill. Oman also cooperates with its neighbours on pollution control through participation in the Regional Organization for the Protection of the Marine Environment (ROPME). In 1995 a Royal Decree authorized the minister of Regional Municipalities & the Environment to sign the United Nation Agreement on prevention of desertification in countries facing severe arid conditions.

The Sultanate of Oman has always struck a judicious balance between the needs of development and the environment.

The Ministry stresses the role of the private sector in environmental protection and companies are urged to comply with ISO 14000 standards, which are globally accepted as a means of promoting sustainable development. Industrial constructions projects are required to have a certificate from the Ministry before they are allowed to go ahead. Before issuing a certificate, the Ministry examines the possibility of damage to the environment and ensures that all the measures have been taken to minimize pollution from waste products. (Ministry of Information, Oman)

5.3 Environmental Impacts of PV System

Health and environmental issues related to photovoltaic energy systems may arise at several stages in the energy cycle as follows:

1. Extraction, processing and refining of materials
2. Fabrication, installation, operation and maintenance of devices
3. Decommissioning of spent devices

Most attention has focused on the second stage because the activists are specific to photovoltaic system and they are the major ones involving potential chemical and physical hazards to environment, health as well as safety.

Some, such as the quantity of different pollutants, emitted during production of the material needed to make photovoltaic cells, are highly technologically dependent. Others, such as electric shock hazards to persons installing or maintaining photovoltaic devices are more generic. The type of environmental impacts associated with the production and use of several different photovoltaic cell types and applications are discussed below.

- **Air pollution:** the fabrication of thin-film photovoltaic cells will require large quantities of gases. Many of those gases are highly toxic, pyrophoric or flammable. Many gases likely to be used in thin-film cell production are already been used in industry, but the quantities and application modes will differ. The volumes of some gases, for example PH_3, used for large-scale photovoltaic cell fabrication will be larger then those used for all other purposes. Therefore the options of handling those gases and disposing of uncreated portions need careful considerations.

Accidental releases of hazardous air pollutants may result either from leaking from storage, distribution or processes systems or from the venting of processes and control equipment during abnormal conditions such as fire, power failure, etc. These could present substantial risks to populations living adjacent to those facilities because of the significant quantities of gases used.

- **Water pollution:** this type of pollution could be as a result of the solid waste that gets absorbed by the soil and in turn, affects the water resources.

- **Solid wastes:** Some of the solid waste such as cadmium and arsenic compounds may be hazardous and require careful handling and disposal in controlled conditions; recycling could be the best solution.

- **Occupational Health Risks:** In photovoltaic cell fabrication plants, the most important hazards to the workforce will probably arise from the large electrical equipment used in production; risks from mechanical or noise- related hazards appear to be small.

Electrical equipment could present spark generation, laser, electric shock, and radio-frequency (RF) hazards to workers if equipment is designed or used improperly. Heating elements and high voltage RF or DC power sources used in many thin-films deposition processes. Since flammable and explosive gases are also used in this process, the possibility of electric spark ignition may be present in occupational hazards.

The RF plasma systems present two potential hazards: electrical shocks from high intensity currents and biological effects from electromagnetic radiation. Non-solid state generators are high voltage equipment that can generate a fatal current if not properly grounded. RF radiation can damage human cells primarily by a thermal mechanism, but it also may present risks to exposed workers even at levels too low to heat the tissues.

Thermal hazards refer to risk of fire and of burns due to the contact with hot materials or surfaces. Most thin-film deposition methods considered require heating the substrate, and in some cases the feedstock, to temperature high enough for accidental contact to cause serious burns. In all cases, however, the hot surfaces must be well isolated within the reaction chamber, so the likelihood of occupational burns appears to be quite small.

- **Public Health Risks:** As for any type of electrical installation, homeowners or contractors installing, maintaining, or removing roof-top systems, unlike conventional alternatives, begin to generate electricity immediately upon exposure to the sunlight. Although grounding or contact with these circuits is unlikely, exposures to photovoltaic generated electricity could produce serious effects. It has been evaluated that, the voltage generated by six average size modules connected in series is sufficient to cause ventricular fibrillation and possible death under normal temperature conditions.

The users also could face hazards of fires that caused by short circuits and spontaneous combustion due to heat build up in dead-air space.

- **Land use impact:** land use impacts of installed photovoltaic systems will differ for decentralize and centralized applications. In such applications, photovoltaic systems may be mounted on existing roofs (roof-top) or on the ground (ground-mounted). No additional land is required for roof-top applications. Land area requirements for ground-mounted systems will depend on several factors including isolation and system efficiency. Land most suitable for large central-station applications lie in areas where annual isolation is high such as Oman, as was previously maintained. Other factors such as proximity to population centers however may influence the decision.

- **Visual and Noise Impacts:** As with land use impacts discussed above, visual impacts will vary with the type of the application.

  Finally, there are no noise problems associated with the fabrication or application of photovoltaic power systems as we have mentioned previously that the PV technology is silence technology.

5.4 Discussion

During normal operation, photovoltaic (PV) power systems emit no gaseous or liquid pollutions or substances that may threaten human health or the environment. However, there are several indirect environmental impacts related to PV power systems require further considerations. In the case of using CIS or CdTe modules, which include very small quantities of toxic substances, there is a slight risk that fire in an array might cause small amounts of these chemicals to be released into the environment. In fact, through the savings in conventional electricity production they for sure can lead to significant emission reduction.

The production of present generation PV power systems is relatively energy intensive, involves the use of large quantities of bulk materials and relatively smaller quantities of substances that are scarce or toxic. In addition, during operation, damaged modules, or as we have said, a fire, may lead to the release of hazardous substances. Finally, at the end of their useful life period PV systems have to be decommissioned, and obviously there would be a waste need to be managed.

So, for better understanding, evaluation and analysis of the environmental impact and safety of the PV power systems, we have to consider all the aspects that have direct relation to the PV systems as well as the non-direct.

As discussed earlier in this dissertation, a normal photovoltaic system consists of the following set of component:

- Photovoltaic modules and panels.

- Batteries, depends on the system requirement.
- Electrical and electronic equipment.
- Inverter, if required.

Now, let us consider one component at a time and analyze it.

5.4.1 Photovoltaic modules and panels

Photovoltaic modules have no moving parts, so they are safe in the mechanical sense, produce no pollution, emit no noise and have a long life span. However, as with other electrical equipment, there are some risks of electric shock, especially in larger systems operating at voltages substantially higher then the 12-48 Volts that employed in some small PV installations.

Photovoltaic arrays do, off course, have some visual impact, and may or may not be regarded as attractive. This issue is not really important if we consider the system going to be installed in the farms. However, it is considered as a concern if the system going to be installed in houses; as roof-top arrays are normally visible to neighbours.

Several companies nowadays have produced special PV modules in form of roof tiles that blond into roof structures in a more unobtrusively conventional module design which really solved this problem.

Figure 5.1 below shows the life cycle of the PV panels, if we consider analyzing their life, the first step is mining operation with associated hazards to the miners and inputs of diesel fuel and machinery.

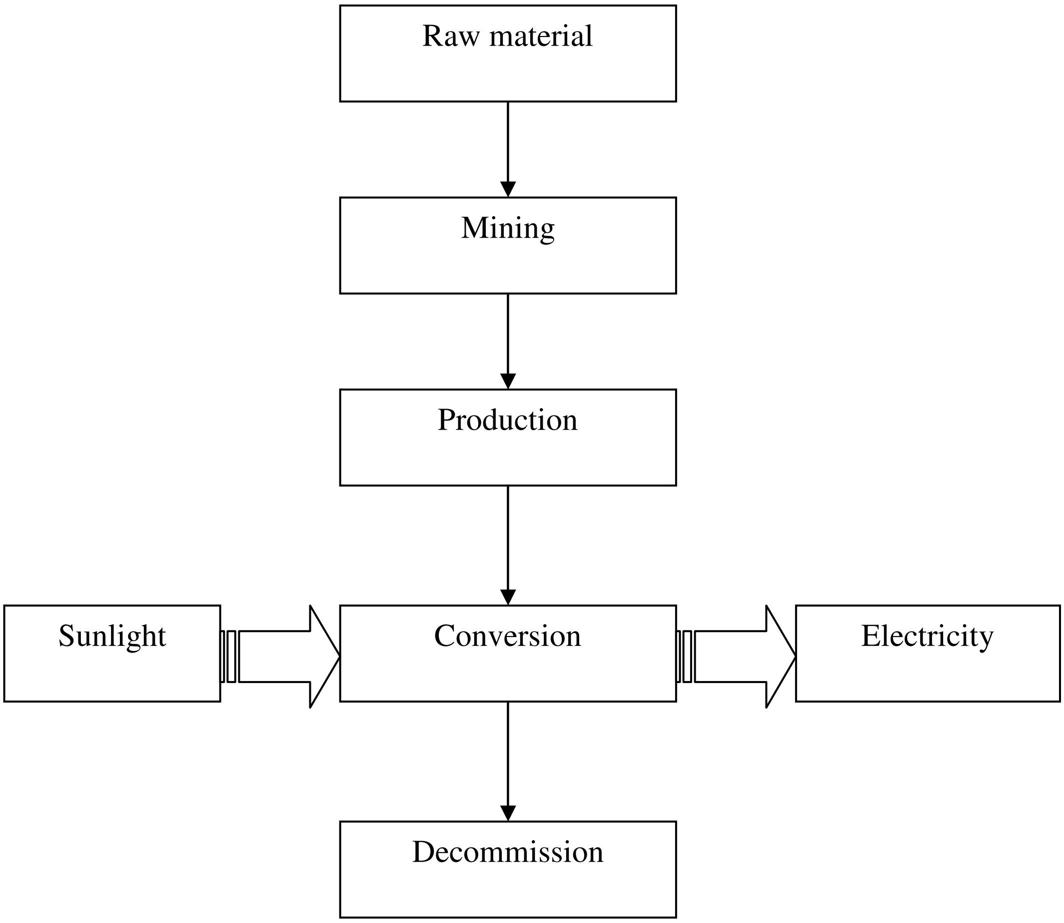

Figure 5.1: Life cycle of the PV panels

The environmental impact of manufacturing silicon PV cells is unlikely to be significant, except in the unlikely event of major accident at a manufacturing plant. The basic material, from which the vest majority of PV cells are made, silicon, is not intrinsically harmful. However, small amounts of toxic chemicals are used in the manufacturing of some PV modules. Cadmium is obviously used in the manufacture of cadmium telluride modules. Small amounts of cadmium are also currently used in manufacturing CIS and CIGS modules although new processes now available allow this to be eliminated.

In addition, Metallurgical grade silicon is made in large quantities for the steel industry, with a small fraction going as input to the semiconductor industry. It is major emission is silica dust which can cause lung disease, and there is a substantial energy input. The materials for construction of the structure of the PV system, other then the PV modules, are steel, aluminum, and concrete which are associated with the standard industrial hazards. Also, the energy used in manufacturing the PV modules and the other components of the PV system is derived from the fuel mix of energy system and is therefore associated with emissions of greenhouse gases and acidic gases.

On the other hand, the decommissioning of silicon photovoltaic modules does not cause any environmental problem. It can be considered as construction waste. This is not the case when other types of substances are used to manufacture the photovoltaic cells, such as in the case of the CulnSe2 and CdTe modules. The disposal of CdTe modules should be controlled more strictly then CIS modules and recycling the materials is more important both for environmental reasons and for the value of the Cd and Te.

Table 5.2 in the next page shows a summary of the main environmental impacts identified in the life of a silicon module. In this table the impacts have been quantified from high environmental impact to low environmental impact. Places where the impact has not been quantified means that no environmental impact has been detected.

	Mining	Production	Conversion	Decommissioning
Exhaustion of row material		Medium		
Energy needed	Medium	High		Low
Global warming	Medium	High		Low
Waste	Medium	Low		Medium
Land use	High	Low	Low	

Table 5.1: Environmental impacts of silicon PV modules

Even though PV arrays are considered as very long-lived devices, eventually they will come to the end of their useful life and off course will have to be disposed of or, preferably, recycled. Some manufacturers are already recycling PV modules, and draft EU regulations on module recycling are in preparation.

5.4.2 Batteries

PV systems may use batteries to store the electricity they produced. The evaluation of the environmental impacts of the production and decommissioning of the batteries depends on the type of the batteries used. The most common battery types in use are lead-acid and nickel-cadmium that are also widely used in developing countries, this type of battery are less expensive then PV batteries.

When the batteries are in use, there is a little danger of those elements being ingested or absorbed by human or animals.

	Mining	Technology production	Conversion	Decommissioning
Exhaustion of material		Medium		
Energy needed	Medium	Medium		Low
Global Warming	Low	Medium		Low
waste	Medium	High		High
Land use	Low	Low		Medium (if it is not recycled)

Table 5.2: Environmental impacts of batteries

Basically the manufacture of batteries involves heavy metals. PV batteries use cadmium, a very toxic chemical, and that should be recycled. The most appropriate use of the exhausted batteries is to reuse the load contained in or recycle them. There are alternative battery technologies available, such as nickel-iron, nickel-metal hydride, lithium-iron, and chloride, which pose fewer environmental hazards. Table 5.2 above shows the main environmental impacts detected during the life of the battery.

5.4.3 Electrical and electronic equipments

The materials for construction of electric and electronic equipments in a PV system are basically steel, aluminum, copper and regular electronic equipment, which are associated with the standard industrial hazards.

5.5 Environmental Comparison between Diesel System and PV System

We have evaluated and discussed the environmental impacts of photovoltaic power systems above and we have listed every aspect that could be considered as an impact. Now, we have to evaluate and discuss the other alternative or the diesel power system.

Generally, the mining, processing, transportation and conversion of fossil fuels to energy have many environmental impacts. Many scientists believe that the carbon dioxide ($CO2$) and other gases released by burning fossil fuels contribute to the "greenhouse" effect, which may cause global climate change. Burning fossil fuels also results in the emission or formation of carbon monoxide (CO), sulfur dioxide ($SO2$), nitrogen oxides (NOx), volatile organic Compounds (VOC), particular matter (PM), and heavy metals such as lead and mercury.

The above list all has negative impacts on the environment and human health. $SO2$ causes acid rain, and CO and NOx contribute to ground level ozone. PM results in hazy conditions in cites and scenic areas, and along with ozone, contributes to asthma, difficult or painful breathing, and chronic bronchitis, especially in children and the elderly. Thousands of barrels of oil spill or leak every year while being transported on ships, trains, and trucks and off course in pipelines.

Chapter 6 Technical Considerations

6.1 Introduction

For any system, the installation, operation and maintenance would vary depends on the application, the system configuration and the operating environment. Solar-powered water pumping systems are very easy to assemble and install, because of their simplicity they are very ideal to be used in remote areas. Good installation, operation and maintenance are the key factors for the system to achieve its reliability and safety; the best equipments however, could fail to perform satisfactory if the users do not follow the operation and maintenance manuals properly.

Generally, when a system purchased, the supplier should supply the total system information design, drawings as well as installation and set up instructions.

6.2 System Technical Support

In Oman, the solar power technology is still considered as a new technology. Although many organizations and ministries have started to use solar energy to power some different applications, diesel energy is still considered as the first option to be used in remote areas of the country.

Communications and weather stations in remote areas of Oman are constructed with photovoltaic systems instead of diesel powered generators to avoid the costs, and also because photovoltaic systems can perform unattended operations.

For the reasons listed above, there are less companies dealing with solar power devices and components. Oman solar Systems Company (LLC) is regarded as the leading company that deals extensively with solar applications. There are some stores that are located in big cities performing sub-dealer duty. Those sub-dealers could supply the devices and the components that are required for any solar system application, however the costumer needs to wait for some time for the equipments to be delivered.

Technical support is also provided by the supplier, but because the suppliers are located in the cities, it needs some time for the technical support teams to deal with system problems or system failures that could arise in surrounding areas.
Some companies dealing with solar systems in Oman are listed in appendix A, together with contact details.

6.3 Comparison of Both Systems Maintenance

The maintenance of the diesel pumping system and the solar-powered pumping system is not a complicated issue. The degree of difficulty varies between the two systems.

The diesel system consists of the diesel engine and the pump. From the interviews done with the farmers, they said that the diesel system needs regular maintenance that includes the oil change and cleaning. The system failure due to some mechanical problems also appears sometimes, however it is not a problem as issues are easily dealt with. The diesel system is not a complicated system, so the technicians around could easily deal with any problems that could arise, However, the replacement of parts more often makes the system relatively costly to run.

On the other hand, the solar-powered pumping system is very simple and provides a simple and low labor watering options for the farmers. The PV systems do not require regular maintenance.

Generally, the PV systems dealers offering a warranty that covers parts as well as labour. The warranty on the PV modules can now be as much as 25 years, depending on the type of the modules and manufacturers policies. The only maintenance required is the modules cleaning and wiring connections check up. One main problem that could occur is if the system failed to perform, regardless of the reason, the distance of the technical support from the farm, and the time taken to resolve the problem.

6.4 Electricity Storage Devices or Water Storage

The electricity storage devices (batteries) are not highly recommended to be used in solar pumping systems. Although it seems a good idea to have a battery in the system to dispose of the water storage, however, there are number of disadvantages involved that make the battery an unwanted device.

Batteries generally reduce the efficiency of the overall system. The system modules operating voltage is dictated by the battery bank and is reduced substantially from levels that are achieved by operating the pump directly.

In addition, batteries make the system more complicated, require additional maintenance and under over-charge protection circuitry which adds more cost and complicity to the system. For these reasons, it is better to have the water storage reservoir instead of batteries.

6.5 Water Storage System

Solar water pumps could provide simple and low labor watering options for farms that require water in remote areas. The system should meet the farmers' requirements in ways to success. Direct-coupled PV pumps deliver water only when the sun is shining. This may require some type of water storage in order to satisfy the need when the sun is not there.

The system should use some type of water storage, the idea currently circulating many farmers in Oman was to provide a water storage reservoir constructed mainly from concrete. The storage water reservoir normally located at the nearest point to the well just above the land surface (by one meter or so) and it has four outlet hand valves, one in each side.

Basically, these storage reservoirs have the capacity to save the water for two days in case of emergency. Normally this capacity of water storage is varying from farm to another depends on the type of plants they are growing and the size of the land.

With the new solar water pump system; the storage should be an issue as the system is going to rely on the sun to get their need from water.

The idea is to store water, rather than use batteries to store electricity, in ways to reduce the cost as well as the complexity. So the size of the tank or reservoir should be considered with the new technique and by resizing the current reservoir or by adding another storage tank; if not from concrete it could be made from metal or plastic in way to reduce the cost.

Chapter 7 Discussion and Conclusions

7.1 Discussion

The implementation of photovoltaic technology as a source of electricity around the world is increasing. Nowadays, PV products are used for a wide variety of applications where reliable electrical and environmentally friendly power is needed. It is uniquely well-suited to remote stand-alone applications where electricity is needed far from existing power lines or fuel supplies and it is increasingly popular in urban applications where clean, quiet, easily-sited electrical power is needed to supplement grid power. Both the worldwide and the European PV markets have grown at an average annual rate of approximately 35% over the past five years, and at the beginning of 2004, 562 MWp were installed in Europe. (A vision of PV Technology, 2004)

The main objective of this project was to go through an economical analysis of the current water pumping system (the diesel system) and the photovoltaic pumping system in Oman. Throughout the process of the project both systems have been discussed and analyzed. The analysis of the both systems covers the economical as well the environmental impacts, in way to have a clear picture of which system is the more economical to be used as well as the less harm to the environment through its life period.

To cover all aspects of both systems in way to have a proper conclusion that could be useful to consider and to evaluate the best alternative to be implemented, Table 7.1 below shows the advantages and the disadvantages associated with the both systems.

System type	Advantages	Disadvantages
Solar-powered system.	Low maintenance. Clean. No fuel needed. Easy to install. Reliable long life. Unattended operation. Low recurrent costs. System is modular and can be matched closely to need.	Relatively high initial cost. Lower output in cloudy weather.
Diesel-powered system.	Moderate capital cost. Can be portable. Extensive experience available. Easy to install.	Need maintenance and replacement. Maintenance often inadequate, reducing life. Fuel often expensive and supply intermittent. Noise, dirt and fume problem.

Table 7.1: Advantages and disadvantages of both systems

7.2 Conclusion

To conclude, both systems show some advantages over each other as well as some disadvantages. The initial cost of the PV system considered as the only disadvantage over the diesel system, however, particularly in remote areas the higher initial value of the PV system could be still justified by the savings in the lower operation and maintenance as well as the increased reliability throughout the useful longer life of the PV system.

The life cycle cost analysis done that covered both systems proves that the PV water pumping system is the more economical choice over the diesel water pumping system because of several reasons such as no fuel needed to run PV system, low maintenance and operation costs compared with diesel pumping system and the longer reliable life.

In addition, as the environment becomes one of the main considerations of the world nations; at the point of generation, photovoltaic energy generally produces no air pollution, hazardous wastes and no noise. Photovoltaic also produce significantly lower levels of environmental air pollutants compared with fossil energy. Although photovoltaic (PV) systems have minor effect during operation however, PV cells manufacture still needs to be carefully controlled due to the use of potentially toxic materials.

Unless there is significant subsidization and encouragement from the government, PV systems cost is still considered too high to be used widely especially in remote areas. Despite the cost limitation, the use of PV systems worldwide is increasing rapidly, costs are decreasing steadily to economical levels with new manufacturing developments.

According to ***SolarBuzz,*** sales of solar cells in 2004 were 927MW, up 62.4% over 2003, and the world largest manufacturer's sales should increase to about 1,600 MW by 2006.

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Appendix A PROJECT SPECIFICATION

University of Southern Queensland

Faculty of Engineering and Surveying

ENG 4111/4112, 2005 RESEARCH PROJECT PART 1/2

Student: Ibrahim A. Al-Busaidi

Title: The economics of photovoltaic water pumping n Oman

Supervisor: Dr. Tony Ahfock

Enrolment: Start February 2005 and finish November 2005

Aims: To investigate the possibility of using photovoltaic (PV) energy instead of diesel to drive the pumps.

Programme : ISSUE 1, MARCH 2005

1. Economics comparison between photovoltaic system and the current diesel driven system.
2. Economic comparison between photovoltaic system and main electricity that may become available in the future.
3. The adequacy of current water storage systems; and
4. Availability of local technical support.

Signed: ______________________ (Student)

Date: ______________________

Signed: ______________________ (Supervisor)

Date: ______________________

Appendix B List of Solar systems suppliers in Oman

This is a partial list of suppliers that dealing with solar systems equipments, attached with their contacts and addresses. The list of suppliers has prepared by the writer of this project. In addition, this list does not mean that all the suppliers are listed; it just to show the availability of the technical support needed of PV systems in Oman.

1. **Oman Solar Systems Company. L.L.C**

   P.O.Box 1922, Ruwi, Oman 112

   Tel: +968- 24595756/ 24592807

   Fax: +968-24591122

   E-mail: nrraooss@omantel.net.com

   [Design and installation of PV systems, small wind energy, small wind turbine]

2. **Mohamed & Ahmed Alkhanji L.L.C**

   P.O.Box 73 Muscat, Oman 113

   Tel: 795007

   Facsimile: 968-795958

   E-mail: khanji1@omantel.net.om

   Website: www.alkhonji.com