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DEPARTMENT OF ENERGY CENTER

Feasibility Study for Replacement of Diesel Water Pumping System with PV Water Pumping System
(A case of Borana Zone Water Supply, Ethiopia)

A thesis submitted to the School of Graduate Studies of Addis Ababa Institute of Technology in partial fulfillment of the Degree of Masters of Science in Energy Technology

By: **Muleta Bonsa**

Advisor: **Dr.-Ing. Abebayehu Assefa**

June, 2013

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Candidate

Muleta Bonsa

APPROVED BY BOARD OF EXAMINERS

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Declaration

I hereby declare that the work which is being presented in this thesis entitled "Feasibility Study for Replacement of Diesel Water Pumping System with PV Water Pumping System" is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for the thesis have been duly acknowledged.

By Muleta Bonsa Date
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This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

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(Advisor)

Acknowledgment

First I would like to thank God for giving me the health, the patience and the blessing that I have received from the beginning to the end of the Master’s study. Next, I would like to express my deepest gratitude to my advisors, Dr.-Ing. Abebayehu Assefa for his expert guidance, constructive comments, suggestions and encouragement without which this work could not have been completed. He has been a constant source of inspiration throughout my study period.

Abstract

This study assess the economic viability of solar PV systems for water pumping project in Borana zone, where groundwater is the main source of water for the population, and compare it with the conventional option of using decentralized Diesel-powered generators to supply electricity to pump water from bore hole.

Life cycle cost analysis for both systems have been done by accounting for the higher initial cost of PV system and compared it with Diesel system. However, the high running costs for the Diesel system could still encourage the selection of PV system considering its reliability, the longer life as well as the lower maintenance and operation costs.

AC submersible water pumps have been investigated to analyze the feasibility of the system because of the unavailability of DC submersible pumps that can operate at higher depth and discharge. There are 13 wells on this site and all of them are designed to operate with a diesel generator of 75 kW. The investigation is done on three wells with AC pumps of 22 kW, 25 kW, 30 kW, and discharge of 7.5 l/s, and total head of 165 m and 170 m to analyze the amount energy saved in each case and the total area required for PV installation. The rest of the wells have similar discharge, head and aquifer with the selected wells because the distance between each well is 500 m only.

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

The result obtained indicates that the project will start generating profit in the fourth year of operation, the unit water cost for all cases of PV system are less than that of unit cost of DG systems and important financial parameters such as IRR, equity pay-back and NPV show solar energy is the viable alternative source of energy for water pumping systems in the study area.

The economic analyses were done using RETScreen-4 software to investigate the financial feasibility and cash flows for water pumping system.

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Nomenclature

PV……………..Photovoltaic

DG…………….Diesel generator

CSP……………Concentrated solar power

GHG…………..Greenhouse gas

GW…………....Giga watt

kW…………….Kilo watt

W………………Watt

kWh…………...Kilo watt hour

NO_x…………….Nitrous oxide

NASA………….National Aeronautics and Space Administration

Si……………….Silicon

DC……………...Direct current

AC……………...Alternate current

V………………..Volt

a-Si……………...Amorphous silicon

MPPT……………Maximum power point tracker

P………………….Power

I…………………..Current

Temp……………..Temperature

T………………….Torque

Ea…………………Internal voltage generated

Ia………………….Armature current

Va…………………Load voltage

Ra…………………Winding resistance

jX_s…………………..…Synchronous reactance

DP…………………….Diesel powered pump

LCC………………….Life cycle cost

IRR………………….Internal rate of return

NPV………………….Net present Value

B-C………………….Benefit cost ratio

NB…………………..Net benefit

NC…………………..Net cost

ALCC……………….Annual life cycle cost

SPP………………….Simple payback period

USD………………….United states’ dollar

PW…………………….Present worth

A…………………….Equal annual cost

i……………………. Discount rate

n…………………….Economic life of project

F…………………….Future value

SV…………………….Salvage value

I_c…………………….Initial cost

AW…………………..Annual worth

$PW_{(DG)}$………………Present worth of Diesel system

$PW_{(PV)}$………………Present worth of PV system

$AW_{(DG)}$……………..Annual worth of Diesel system

$AW_{(PV)}$……………..Annual worth of PV system

UWC………………..Unit water cost

AWD………………Annual water delivery

AS………………….Annual saving

GRC………………..Greenhouse gas reduction cost

O&M……………….Operation and maintenance

PBP…………………Payback period

NMAE……………...National Metrological Agency of Ethiopia

Vmp………………...Voltage at maximum power

Imp………………….Current at maximum power

Voc………………….Open circuit voltage

Isc…………………...Short circuit current

kVA………………...Kilo volt ampere

Gen-set……………...Generator set

CSA…………………Central Statistical Agency

E……………………..Irradiance

CHAPTER ONE

1. General Background

1.1 Introduction

Water resources are essential for satisfying human needs, ensuring food production, and the restoration of ecosystems, as well as for social and economic development and for sustainable development.

However, according to UN (2003), World Water Development Report, it has been estimated that two billion people were affected by water shortages in over forty countries, and 1.1 billion did not have sufficient clean drinking water. There is a great and urgent need to supply environmentally sound technology for the provision of drinking water. Remote water pumping systems are a key component in meeting this need because most of the peoples in developing countries are living in off-grid area.

Water pumping has a long history and many methods have been developed to pump water with a minimum effort. These have utilized a variety of power sources, including human, animal, wind, solar, hydropower and fossil fuels. Utilization of these power sources has their own advantages and disadvantages.

Historically pumping from boreholes in Ethiopian off-grid areas has been predominantly achieved with Diesel generators. Diesel water pumping systems became more attractive during the second half of the twentieth century with the development of the fuel supply infrastructure and the technology to allow Diesel driven engines to pump water from boreholes. Diesel pumps have the advantage of pumping water on demand, also in varying daily discharge, depending on the operating times and over high heads. Diesel engines have a fairly low capital cost but higher operation costs because it relies on fossil fuel cost variations and exchange rate fluctuations. Furthermore, Diesel engines require regular maintenance which is linked to the hours of operation and have a fairly short life. Its life is highly depends on the level of maintenance, the operating conditions and the quality of the engine and the installation.

Hand pumps are used for pumping water from shallow wells particularly in the communal areas. These are rugged devices which are easy to maintain and have low capital cost. They are, however, limited in terms of the pumping volumes and depth of installation (hydraulic load limit of less than 250 m^4/ day).

Wind pumps have a long service life, are able to deliver water from depths of 300 to 400m, require basic skills but are work intensive to maintain. Wind pumping systems are, however, not simple to install and require larger water storage than for example a Diesel or solar pumps to provide for periods of low wind.

Solar pumping systems offer a clean and simple alternative to fuel-burning engines and generators for domestic water, livestock and irrigation. Solar pumps are most effective during dry and sunny seasons and require no fuel deliveries, minor maintenance, easy to install, naturally matched with solar radiation as usually water demand increases during summer when solar radiation is a maximum, and less expensive than other alternative sources of energy such as windmills.

1.2 PV System Background

Solar energy technologies have a long history. Between 1860 and the First World War, a range of technologies were developed to generate steam, by capturing the sun’s heat, to run engines and irrigation pumps (Smith, 1995). Solar PV cells were invented at Bell Labs in the United States in 1954, and they have been used in space satellites for electricity generation since the late 1950s (Hoogwijk, 2004). The years immediately following the oil-crisis in the seventies much interest has been seen in the development and commercialization of solar energy technologies. However, this development of solar energy industry of the 1970s and early 80s collapsed due to the sharp decline in oil prices and a lack of sustained policy support (Bradford, 2006). Solar energy markets have regained momentum since early 2000, showing a phenomenal growth recently. The total installed capacity of solar energy based electricity generation capacity has increased to more than 40 GW by the end of 2010 from almost negligible capacity in the early nineties (REN21, 2011).

Solar energy has experienced a remarkable technological shift. While early solar technologies consisted of small-scale photovoltaic cells, recent technologies are represented by concentrated solar power and also by large-scale PV systems that feed into electricity grids. The costs of solar energy technologies have dropped substantially over the last 30 years. For example, the cost of high power band solar modules has decreased from about $27,000/kW in 1982 to about $4,000/kW in 2006; the installed cost of a PV system decreased from $16,000/kW in 1992 to around $6,000/kW in 2008 (IEA-PVPS, 2007; Solar buzz, 2006, Lazard 2009). The rapid expansion of the solar energy market can be attributed to a number of supportive policy instruments, the increased volatility of fossil fuel prices and the environmental externalities of fossil fuels, particularly greenhouse gas (GHG) emissions.

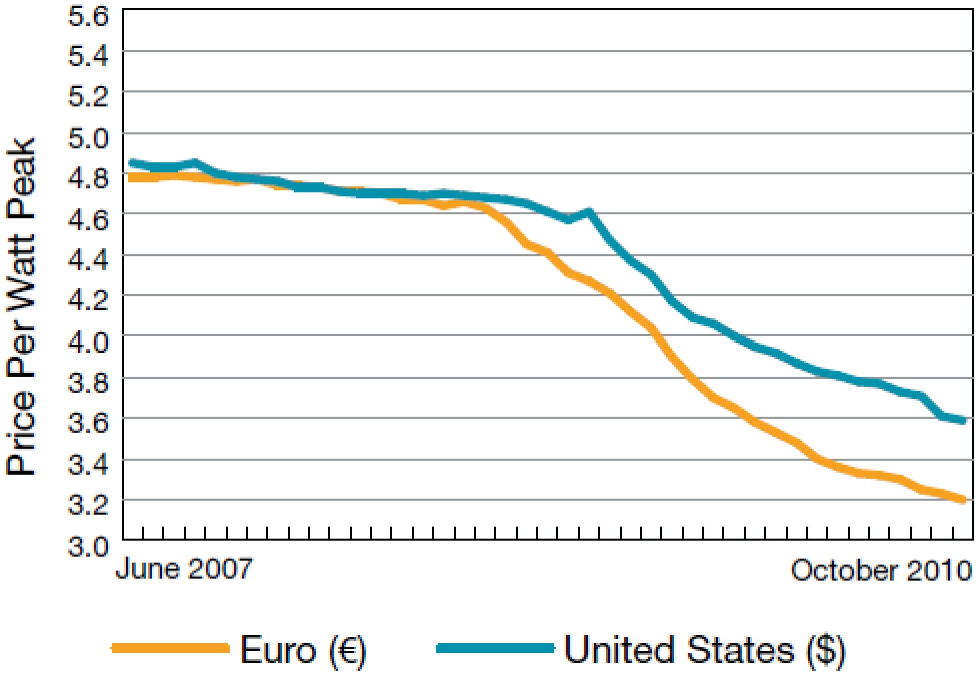
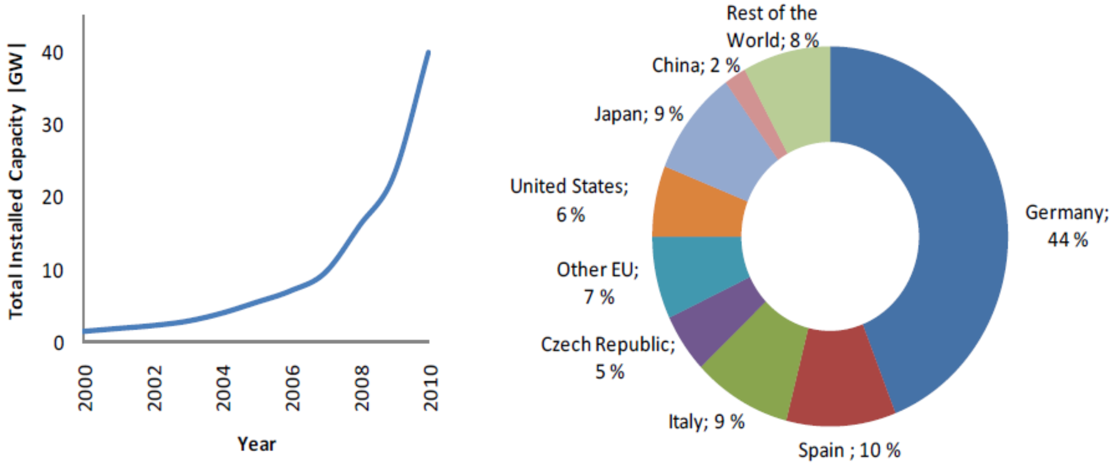


Figure 1.1 Declining costs of PV modules

Source: www.solarbuzz.com/Moduleprices.htm

By December 2010, global installed capacity for PV had reached around 40 GW of which 85% was grid connected and the remaining 15% off-grid (REN21, 2010). This market is currently dominated by crystalline silicon-based PV cells, which accounted for more than 80% of the market in 2010. The remainder of the market almost entirely consists of thin film technologies that use cells made by directly depositing a photovoltaic layer on a supporting substrate.



(a) **Trend of global installed capacity** **(b) Country share in the global installation in 2010**

Source: REN21, 2011

Figure 1.2 Total installed capacity of PV at the global level

Recent global developments appear to guarantee a market for green renewable energy. Among several sources of renewable energy currently explored, photovoltaic systems appear to be promising in view of their environmentally clean nature and the advantage of direct conversion to electrical energy. Of course, the sun is the original primary source of most of the other renewable energy resources: wind, wave, hydroelectric, biomass, etc. The sun provides almost all the energy needed that supports life. On average, the earth receives about $1.2x10^{17}$W of solar power. The challenge for a sustainable future is to tap a tiny fraction of this energy to supply the relative modest demands of human activities [32-35].

Isolated regions, where connection to the utility grid is highly expensive, if not technically affordable, have found in solar energy an excellent solution to their needs. In developed countries, it has become another alternative energy source and is seeing application in residential electrification, refrigeration and air conditioning solar electricity as well as small food industries, agriculture and health services [26-31]. In some cases, where the generated power exceeds the demand, electricity is sent into the grid.

1.3 Statement of the Problem

Energy demand in Ethiopia has grown very highly. However, the proportion of clean energy supply for water pumping in off-grid area has not grown at the same rate. Fossil fuels are the main sources of energy which are currently believed to be running out. Moreover, these sources of energy can cause significant damage to our environment. It is difficult to reverse such environmental consequences. Harmful gases created from the combustion of fossil fuels are CO_2, CO and NO_x. These gases are the main sources of greenhouse gases and also responsible for the global warming. This environmental challenge can be minimized by looking for alternative clean energy resources. One of these clean and renewable alternative resources is solar energy.

Nowadays, the use of solar radiation as alternative energy source is seriously constrained by low efficiency of solar cells. Additionally, the higher initial cost of solar cells limits the use of solar energy in developing countries. A number of research activities on alternative solar cell from cheap polymer materials are undertaking [40]. The findings are indicative of possible cheap solar cells production in the near future. Therefore, the use of solar energy for water pumping in remote area is an alternative future direction and a possibility. On the basis of these trends, there is a need to assess potential of PV generators to replace Diesel generators for water pumping in Yabelo area of Borena zone.

Research questions are**:**

- Can photovoltaic solar power sufficiently meet the power requirements currently placed on water pumping?
- What are the greatest benefits of the community from photovoltaic water pumping systems?
- What is the breakeven point between photovoltaic water pumping systems and Diesel water pumping systems?

1.4 Objectives

The general aim of this study is to analyze the recent trend in the uses and costs of PV pumping systems and to conduct a comparative cost benefit analysis between Diesel and PV pumps, based on the life cycle costing approach. This will be a great assistance to farmers especially in remote areas of the country. It aims at evaluating both systems over the life cycle period including the fuel cost, operation and maintenance cost and other recurrent costs.

The specific aim of this study is to design PV system and investigate the economic viability of replacing Diesel water pumping system with Photovoltaic water pumping system.

1.5 Significance of the Study

The importance of the present study is to provide comprehensive information on the potential of PV generators to replace Diesel generators for water pumping in Borana Zone. From this point of view, the study could be considered as a reference for solar energy utilization technology to pump water, which is now considered as a possible solution to the energy problems of the remote areas of the country.

In this study, the feasibility analysis of PV generators to replace Diesel generators in Borena zone will be made available. The result of the study can be used:

- For future solar energy plan for water pumping by government, entrepreneurs and NGO’s.
- To promote environmentally friendly water pumping systems.
- To know the payback period of PV pumping systems.
- To choose the most cost effective and reliable water pumping system over its life time.
- To use as a reference for further study.

1.6 Methodology

The overall research methodology is categorized into literature review, data collection, design of different scenarios, economical evaluation and output analysis.

A feasibility analysis of PV water pumping system is a task that involves gathering of relevant information from a variety of sources. The first step includes collecting data on existing wells in

Borana Zone Yabalo area, which are designed to operate by Diesel generator to pump water at average discharge of 7 l/s and heads of 65 m and 70 m. This information is gathered from the Oromia Water Works Design and Supervision Enterprise and Oromia Water Resource and Energy Bureau.

In addition, literature review was carried out in order to select the best configuration, and to understand the basis of the use of solar energy for water pumping. This included reviewing relevant literature in the field, searching the internet as well as by establishing contact with organizations which are conducting different research on solar energy utilization.

The second step includes design of different configurations and scenarios and data processing by using computer programs and also making economical evaluation.

A number of advanced specific computer programs exist today dealing with solar energy analysis, the design of a PV as well as calculations regarding the economic aspects of solar energy. RETScreen program has been used to analyze the general economic aspects, PV power production, GHG analysis as well as sensitivity and risk analyses of the solar energy.

The third step included discussion and output analyses, in addition to conclusions and recommendations. All general procedures done in RETScreen are listed in Appendix A.

1.7 Limitation of the Study

The project has a number of limitations; some of them are obvious from the beginning, while some have emerged at the beginning of data collection. Information from some sources was difficult to acquire. For example, exact price for PV modules and power conditioners from the producers are not available. There is no information on what services are included in the price. Prices available in ranges from different organizations are used in the economic analysis of this project. This is, however, never as exact as a final offer from a producer such as would have been optimal to receive.

Another imprecise figure is the annual fuel escalation rate, inflation and discount over the life of the PV module. Even these were approximated through other sources. Even though there are no alternatives than making assumptions about these rates, it is important to first investigate the past and the future trends of the country's economy. Using an incorrect assumption for long-term economic analysis can lead to erroneous results, which in turn can be misleading for the end users. For these reasons, actual cost information should be used as much as possible and realistic assumptions must be made to reduce the risks inherent in any economic analysis. The same is valid for many figures used in the project such as interest rates, various parts of the operational and maintenance costs, etc.

In developing countries like Ethiopia, there are very few meteorological stations that measure solar radiation. Under such conditions, interpolation technique is required to estimate the solar radiation for those stations which have homogeneous terrain with similar climatic properties. But the interpolation and extrapolation of point-specific measurement predictions of solar radiation to all areas is generally not appropriate because most of the locations are affected by strong local variations.

For this specific work, the solar data which are recorded by the satellite from NASA have been used, because there are no solar data collected or recorded by the National Metrological Agency in the Borana Zone, Yabelo area. These data are not as precise as data recorded on the ground at the project site.

CHAPTER TWO

2. Literature Review

2.1 PV Based Water Pumping System in Ethiopia

One of solar PV water pumping system which is installed in our country is found in a rural community of Asela area in the Rift Valley of Ethiopia. The location is 1669 m above sea level and its coordinates are latitude 7º 30' N and longitude 38º 30' E. The average annual insolation on a horizontal surface is 6.69kWh/m^2/day, and the average maximum and minimum annual temperatures are respectively 21ºC and 16ºC. The monthly average is 12 hours of daylight per day; however, irradiance is more than 400 W/m^2 for only 8 hours per day.

At the site, water is typically found around 15 m below the surface; thus, an effective height of 18 m is considered in the calculations. A water flow of 12.5 m^3 per day is considered to cover the needs of a small rural community of about 250 people.

The other project is located in the Chancho Kebena Kebele, Jeldu District, in the West Showa Zone of the Oromia Regional State, in the Federal Democratic Republic of Ethiopia [39].

In this project DC voltage is utilized for operating the pump. The water level is selected to be of shallow nature, i.e. not exceeding 100 m, in order to satisfy the specifications of the DC/AC submersible pump to function a DC only mode. In most similar projects, when the water head exceeds 100 m, an AC system needs to be used due to the lack on the market of DC submersible pumps able to operate at that depth.

Table 2.1 Summery of pumping system in Chancho

Water source	discharge	Head from the spring	Water reservoir	Population served	Solar panel	pump
Spring	1.2 l/s	65m	15m^3	1500	6BP3170	DC

2.2 Comparative Analysis of PV versus Diesel Water Pumping System

One of the most comprehensive recent studies comparing solar to Diesel powered pumps is the 2006 report "*Feasibility Assessment for the Replacement of Diesel Water Pumps with Solar Water Pumps",* issued by the Ministry of Mines and Energy of Namibia, prepared by EmCon Consulting Group. According to this study solar energy has been used for pumping in Namibia for over 25 years and from 2001 to 2006, 669 solar-powered wells were installed – creating a large field for study. This report furnishes overwhelming evidence that for small to medium sized wells, solar (photovoltaic pump) is much cheaper on a life cycle cost basis than Diesel-powered (DP) pumps. When looking beyond the original purchase price, PV pumping systems cost anywhere from 22-56% of what Diesel pumps cost and can achieve a payback over DPs in as little as 2 years.

This study shows a comparison for solar and Diesel water pumps that includes a range of pumping heads (10m to 200m) and a range of daily flow rates (3,000 – 50,000 liters). The life cycle costs were calculated over a 20 year period taking into account operating costs, maintenance costs, and replacement costs.

The following studies are older and therefore are based on fuel costs that are not realistic today. All of the studies cited below were favorable to solar at the time of writing and would be even more favorable if written today with current fuel prices.

A Sandia National Lab study of 3 different sized solar pumping systems (106 Wp, 848 Wp, 1530 Wp) in Mexico showed that all had lower life-cycle costs than Diesel-powered pumps. The PV systems vs. Diesel had paybacks of 2, 2.5 and 15 years respectively when replacing fueled pumps (gas or Diesel).
Note: At the time of this study, 1998, crude oil prices were $11/barrel vs. $100 today (Source: Energy Information Agency, U.S. Government)

In a comparison of fueled pumps vs. PV, a German study showed PV powered pumps to have the lowest life-cycle costs for PV array sizes of 1kWp and 2kWp and the same cost as fuel pumps for

power ratings of 4kWp. (The largest PV pump SELF has installed to date for village water supply is 1.9kWp).
Note: The date of this study is unknown, but it was before 2006, when the price per barrel of crude oil was $68 compared to the $100 price of today.

A study by GTZ (Posorski, Haars, 1995) in seven countries concluded that PV pumping systems for drinking water are economically competitive in the range of small Diesel pumps (1-4 kWp solar systems).
Note: At the time of this study, the price of crude oil was $17 per barrel, compared to $100 per barrel today**.**

2.3 Proposed System Overview

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 than to store electricity technically as well as financially.

The intensity of the irradiance 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.

2.4 PV Pumping System Elements

A solar water pumping system consists of four main parts: the pump set, pump controller, the solar electric panels and a storage unit.

A typical PV pumping system consists of a photovoltaic cell array, a power conditioner and the load, Figure 2.1. Other accessories that form the PV system are the energy storage, cabling and protection. The power conditioning stage consists of a power converter associated with a suitable control unit. The load, for a pumping system, consists of a motor and a pump.

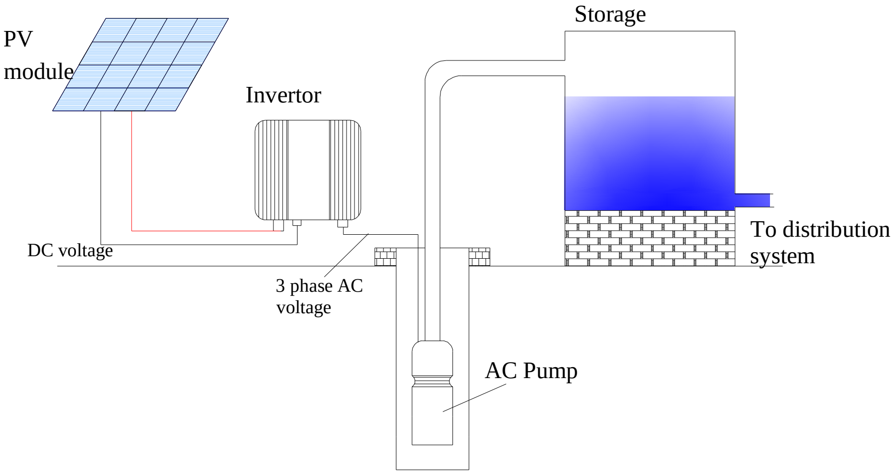


Figure 2.1 Block diagram of a stand-alone PV water pumping system.

2.4.1 PV Module

To make modules, PV manufacturers use crystalline silicon wafers or thin film technologies. In the former, single crystal silicon (single-Si), polycrystalline silicon (poly- Si) or ribbon silicon (ribbon-Si) wafers are made into solar cells. Solar cell manufacturers then assemble the cells into modules or sell them to module manufacturers for assembly. Because the first important applications of PV involved battery charging, most modules in the market are designed to deliver direct current (DC) at slightly over 12 Volts. A typical crystalline silicon module consists of a series circuit of 36 cells, encapsulated in a glass and plastic package for protection from the environment. This package is framed and provided with an electrical connection enclosure, or junction box. Typical conversion (solar energy to electrical energy) efficiencies for common crystalline silicon modules are in the 11 to 15% range [38].

There are four advanced thin film technologies. Their names are derived from the active cell materials: cadmium telluride (CdTe), copper indium diselenide (CIS), amorphous silicon (a-Si) and thin film silicon (thin film-Si). Amorphous silicon is in commercial production while the other three technologies are slowly reaching the market. Thin film modules are made directly on the substrate, without the need for the intermediate solar cell fabrication step.

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.

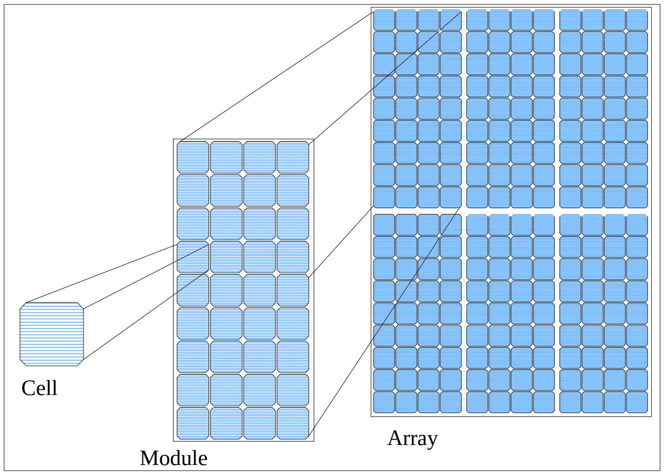


Figure 2.2 Photovoltaic cells, modules and Arrays.

The direct conversion of solar irradiance into electrical current is done by the solar generator. It consists of mounting units called panels which again consist of solar modules. Modules are made of solar cells in which the conversion is performed as shown in Figure 2.3.

When sunlight impinges on a solar cell, the positive charge carriers (the holes) and the negative charge carriers (electrons) appear in pairs. If those pairs are able to reach the electric field before they recombine (meaning to reunite and, hence, to neutralize themselves), they are ultimately separated, with the electrons moving toward the front wall (the n-type layer), where they collect on metallic contact fingers mounted above the surface and then return, by way of the external circuit, to the full-face, metal coated back wall of the cell, where they ultimately recombine with the holes.

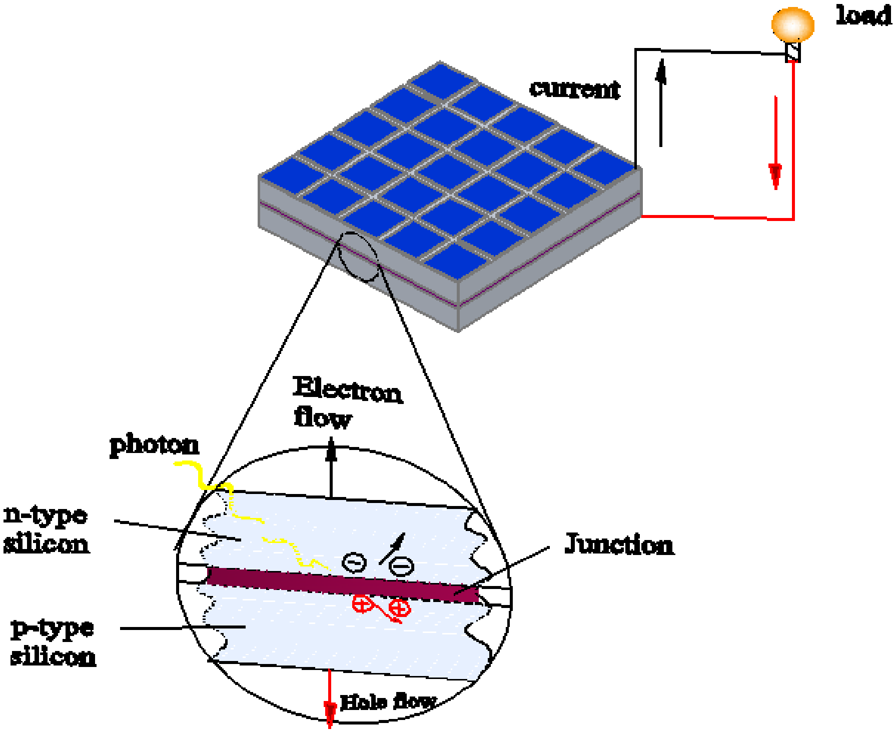


Figure 2.3 Basic operation of photovoltaic system.

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.

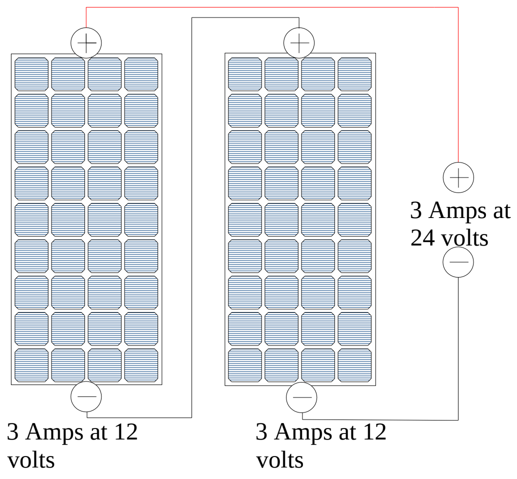


Figure 2.4 PV modules connected in series.

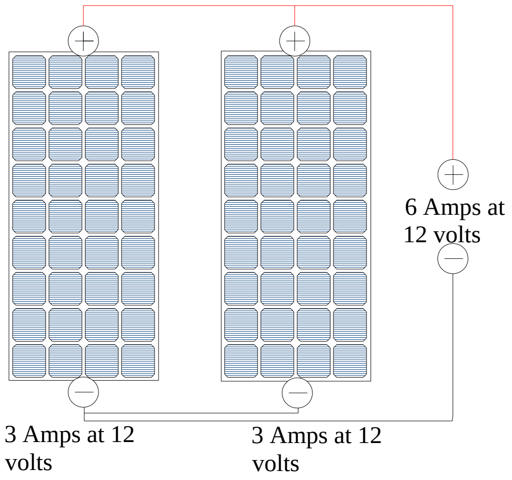


Figure 2.5 PV modules connected in parallel

2.4.2 Power Conditioner

Several electronic devices are used to control and modify the electrical power produced by the photovoltaic array. These include:

- Battery charge controllers - regulate the charge and discharge cycles of the battery;
- Pump Controller- Matching device used so systems will operate at optimum power, matching the electrical characteristics of the load and the array.

- Inverter- Is a device that converts the direct current coming out of the PV into alternating current (AC). An inverter could be chosen to output in a variety of voltages, including 220 V and 380V, single and/or 3 phase for very large loads.

Inverters for stand-alone systems

Because of the specific operating conditions of stand-alone inverters, different design aspects have to be considered.

The most important requirements on inverters for stand-alone photovoltaic systems are summarized in the following list.

- Large input voltage range (−10% to +30% of the rated voltage).
- Output voltage as close to sinusoidal as possible.
- Little fluctuation in the output voltage and frequency.
- ±8% voltage constancy, ±2% frequency constancy.
- High efficiency for partial loading; an efficiency value of at least 90% at 10% partial load.
- Lowest possible over voltages for inductive and capacitive loads.
- Able to withstand short circuits.

Maximum power point trackers (MPPT) - maintain the operating voltage of the array to a value that maximizes array output. In a real field configuration, both factors take effect simultaneously, Figure 2.6. There is a certain duty point at which the achievable power output reaches its maximum. It varies as a function of irradiance and temperature.

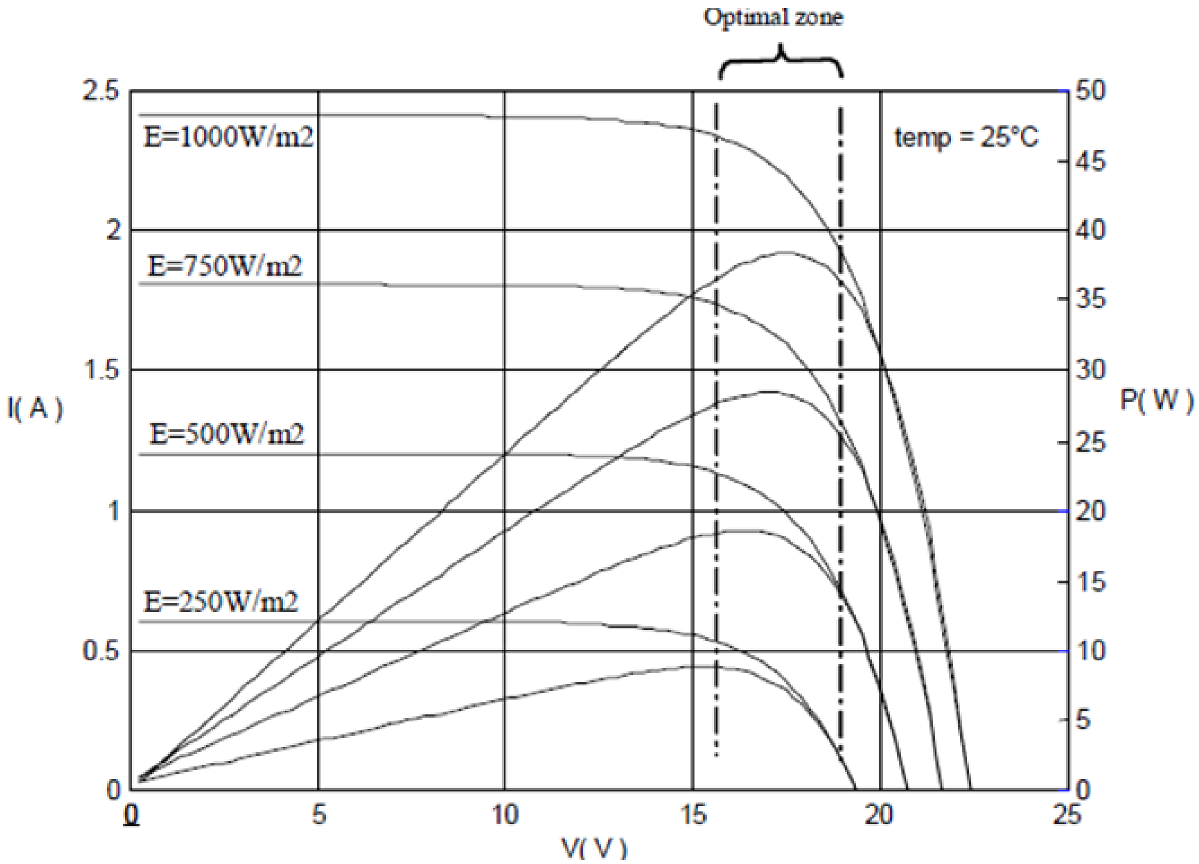


Figure 2.6 PV module characteristics [41]

2.4.3 Pumps

For water pumping applications, several types of pumps may be used. They can be categorized according to their design type (rotating or positive displacement pumps), to their location (surface or submersible), or to the type of motor they use (AC or DC). Rotating pumps (e.g. centrifugal pumps) are usually preferred for deep wells or boreholes and large water requirements. The use of displacement pumps is usually limited to low volumes. Positive displacement pumps (e.g. diaphragm pumps, piston pumps and progressive cavity pumps) usually have good lift capabilities but are less accessible than surface pumps and are more sensitive to dirt in the water. Figure 1.9, which is adapted from Barlow et. al. (1993), suggests possible pump choices as a function of the head (total height the water has to be lifted) and the daily water requirement.

Finally, the choice between a DC and an AC motor to drive the pump will depend on many factors, including price, reliability and technical support available. DC motors are usually very efficient and are easier to match with the photovoltaic array. AC motors, on the other hand, are cheaper and more readily available, but they require an inverter to be connected to the array.

The selection of AC pumps comparing to the selection of DC pump:

1. AC pump is a general model standard product. It is easy to choose type and find compatible system combination; DC pump is a special pump which works only with fixed type of controllers, thus generated standardization problems.
2. AC motor pump has higher overdrive capacity and long life span. DC motor pump can't overdrive for too long, otherwise the demagnetization might damage the motor and it needs more replacement.
3. AC solar pump uses no storage battery, the structure is simple, cost is low, and reliability is high. Storage battery in a solar pumping system has short life span, needs regular service and replacement, and higher cost. Lead-acid battery is not environment friendly and difficult to dispose after scrapped. The charge and discharge of battery also requires additional controller, and the conversion efficiency is low. This also reduced the system reliability.

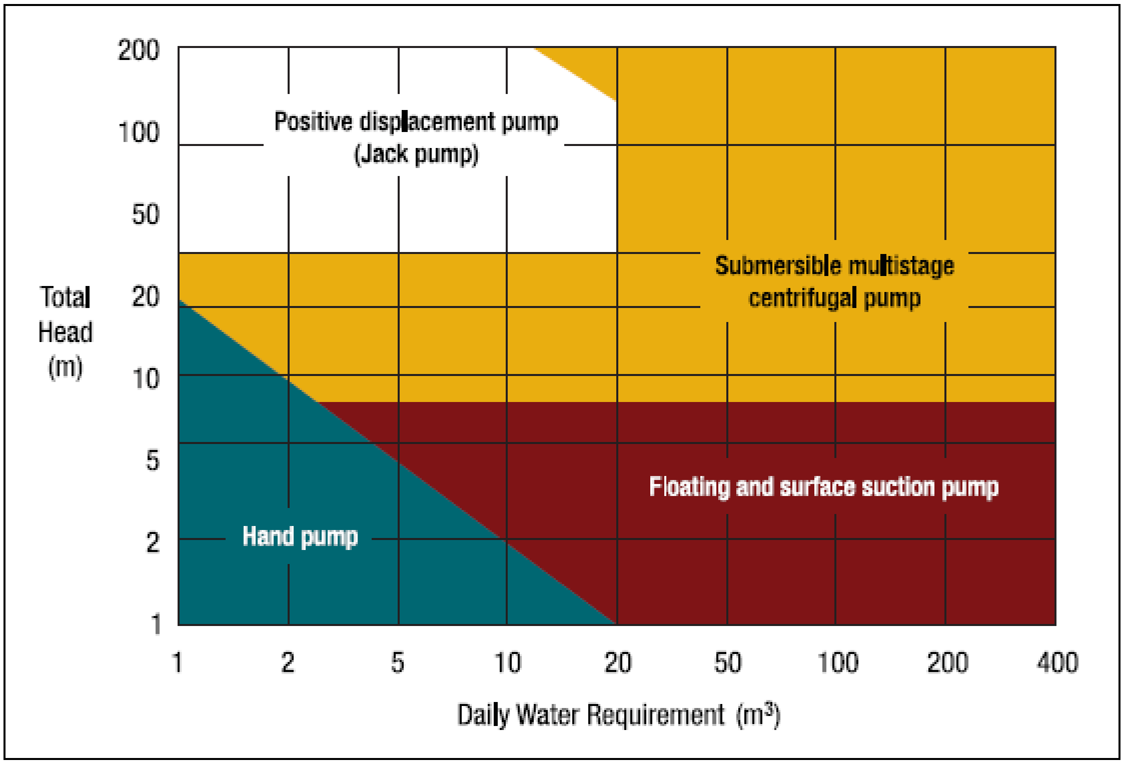


Figure 2.7 Pump type selection [adapted from Barlow et al., 1993]

2.4.4 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.

2.4.5 Water Storage

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.

Advantages of PV system are:

- Low running costs that helps to offset the high initial costs
- Less environmental impact or pollution than other forms of energy-driven pumps (Diesel, petrol, etc.)

- Less human contact with water supply equipment so less deterioration.
- Utilize a free and abundant source of energy
- Extended operational life of water supply systems as long as the pump is well cared for and maintained.

Disadvantages of PV system are

- Excessively high initial cost
- Requires elevated storage tanks to store pumped water
- Pump powered by solar energy usually has an operation life less than that of the solar panel and also requires more aggressive maintenance and repair
- Lower energy output thus less water observed during extended cloudy periods, which are likely to occur during the main rainy season

2.4.6 Diesel Generator

A Diesel generator is simply a normal electric generator driven by a Diesel engine (prime mover). An electric generator is an electromechanical system that converts mechanical energy into electrical energy through the interaction of electromagnetic and electrostatic fields within the system.

Figure 1.10 shows the per-phase equivalent circuit of a synchronous generator driven by a prime mover, which in this case is the Diesel engine. T is the mechanical torque of the prime mover, Ea is the internal voltage generated, Ia is the armature current, $Ra + jXs$ is the synchronous impedance, and Va is the load voltage.

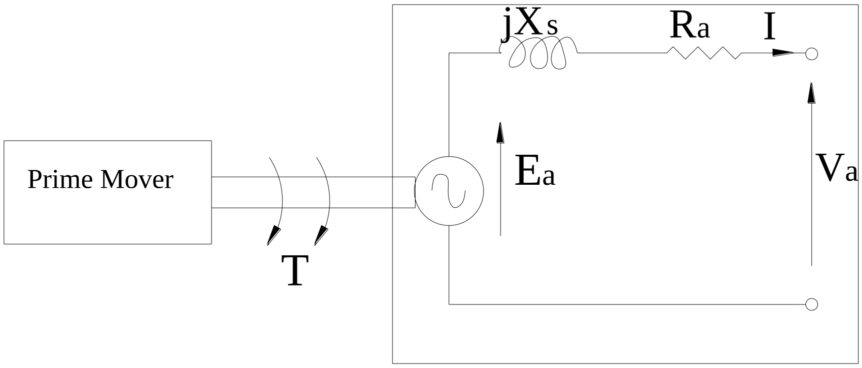


Figure 2.8 Equivalent circuit of a synchronous generator driven by a Diesel engine

The maintenance requirements of the Diesel engines are standard which means a minor service every 250 hours and a major service every 500 to 1,000 hours. The life expectancy of the engines differs, based on the quality of the unit and whether the maintenance has been conducted as per requirements. The life expectancy is in the range of 8,000 to 35,000 hours.

Advantage of Diesel system

- Quick and easy to install
- Low capital costs
- Widely used
- Can be portable

Disadvantage of Diesel system

- Fuel supplies erratic and expensive
- High maintenance costs
- Short life expectancy
- Noise and fume pollution

2.5 Literature Review Summary

Nowadays, the prime installation price of solar cells is still high (with the absence of governmental support in most countries), therefore, one has to properly size and optimize the system operation. Much research work concentrates on the optimal use of photovoltaic generator units which constitute 60-80% of the system price depending on whether storage means are used or not. The PV systems can be operated as a stand-alone, hybrid or grid connected systems. Stand-alone schemes have found wide application in remote regions to meet small, but essential electric power requirement such as water pumping systems. Research work has also emphasized this aspect [5-8].

Early studies focused on ways of sizing, matching and adapting PV pumping systems since a proper match between the installed capacities with the isolated load is essential in optimizing such installations [36-38]. Various works were done on the choice of the drive system to interface to the PV source, type of pumps to use and ways to control and optimize the whole system.

The literature review showed that most of the previous works focused on small head and discharge. Few of the literature I found are older and the price of crude oil at the time of the study was very cheap as compared to current price of crude oil.

CHAPTER THREE

3. Borana Zone Climatic Condition

3.1 Introduction

This study was undertaken in the Borana administrative zones of Ethiopia, where pastoralism is the predominant livelihood activity.

The Borana administrative zone is situated in Ethiopia's Oromia regional state. This zone is divided into 10 woredas (districts) and its capital is Yabello which lies 570 km south of Addis Ababa. It is bordered on the south by Kenya, on the west by the Southern Nations Nationalities and Peoples Regional State (SNNPRS), on the north by the Bale zone and on the east by the Somali region. The Borana zone covers a total area of 48,743 km^2 (CSA, 2008). It lies at an altitude of less than 1500 m above sea level. It is an arid and semi arid area, with pockets of sub-humid zones. The rangelands are dominated by tropical savannah vegetation with varying proportions of open grasslands and perennial woody vegetation (Pratt and Gwynne, 1977: in Homann*et al.*, 2007). Perennial rivers in the area include the Dawa and Segen rivers.

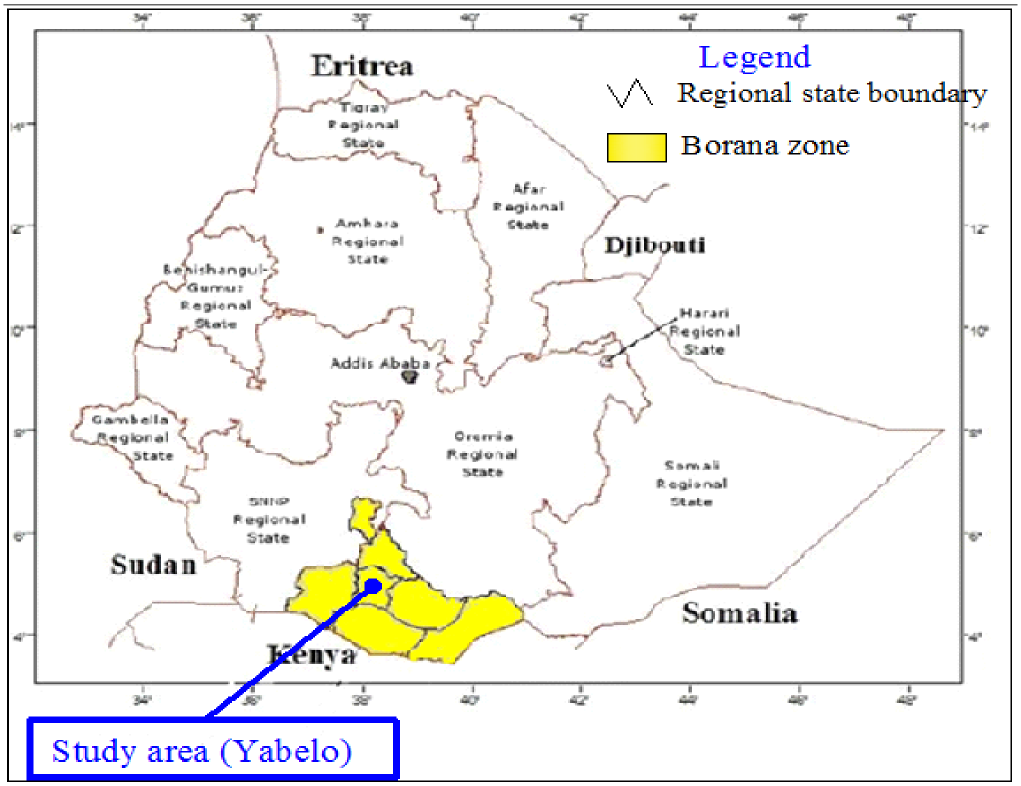


Figure 3.1 Location of the study area

3.2 General Climate Information

In Borana, the average annual rainfall ranges between 350 and 900 mm, with considerable spatial and temporal variability in quantities and distribution. Rainfall in the area is bimodal, with 60% occurring in the long rainy season (Gana), which occurs from March to May, and the short rainy season (Hagaya) from September to November (Coppock, 1994: in Homann*et al.*, 2007). The long dry season (Bonahagaya) occurs from December to February, and the short dry season (Adolessa) occurs from June to August. The average annual temperature ranges between 19 and 26°C (CORDAID and FSS, 2009). Variable rainfall results in great variability in forage and range production. To cope with variable range production, communities in Borana area often combine mobility and sedentary livestock management.

Table 3.1 Seasons in Borana Zone

Months	J	F	M	A	M	J	J	A	S	O	N	D
Seasons	Bona Hagaya (long dry season)		Ganna (long rainy season)			Adolessa (short dry season)			Hagaya (short rainy season)			

3.3 Climatic Data

The climatic data are taken from NASA because there is no solar data collected or recorded by National Metrological Agency Ethiopia from this site. The climatic data location is Yabelo which is the specific site of my study.

Table 3.2 Daily solar radiations on horizontal and tilted surface

Months	Daily solar radiation horizontal [kWh/m^2/d]	Daily solar radiation tilted [kWh/m^2/d]
January	6.36	6.60
February	6.73	6.89
March	6.41	6.45
April	5.69	5.63
May	5.46	5.34
Jun	5.13	4.99
July	5.03	4.91
August	5.43	5.35
September	5.9	5.89
October	5.36	5.44
November	5.49	5.65
December	5.98	6.22
Annual	5.74	5.77

CHAPTER FOUR

4. PV System Design

There are 13 wells on this site and all of them are designed to operate with a diesel generator of 75 kW. The investigation is done on three wells with AC pumps of 22 kW, 25 kW, 30 kW, and discharge of 7.5 l/s, and total head of 165 m and 170 m to analyze the economic viability of Photovoltaic water pumping system and the total area required for PV installation.

4.1 PV Module Selection

PV module selection is based on the performance characteristics given by the manufacturers. The selection is actually based on the efficiency and maximum power of the module. Top five world's most efficient currently commercially available mono-crystalline silicon PV module producers are given below.

Manufacturer	**Module efficiency** [%]
Sunpower	20.4
AUO	19.5
Sanyo Electric	19
Jiawei	18.3
Crown Renewable Energy	18.3

Source : http://www.solarplaza.com/top10-crystalline-module-efficiency/

For this study PV module produced by Sun Power with model mono-Si-SPR-320E-WHT is selected because universities and independent research laboratories around the world compared the performance of solar panels from SunPower against other technologies and in each case SunPower solar panels were the clear leader [38]. The selection is based on technical performance of the module because the exact prices of PV modules from the producers are not available. The specification of the selected PV module is given in table 4.1 and Appendix D.

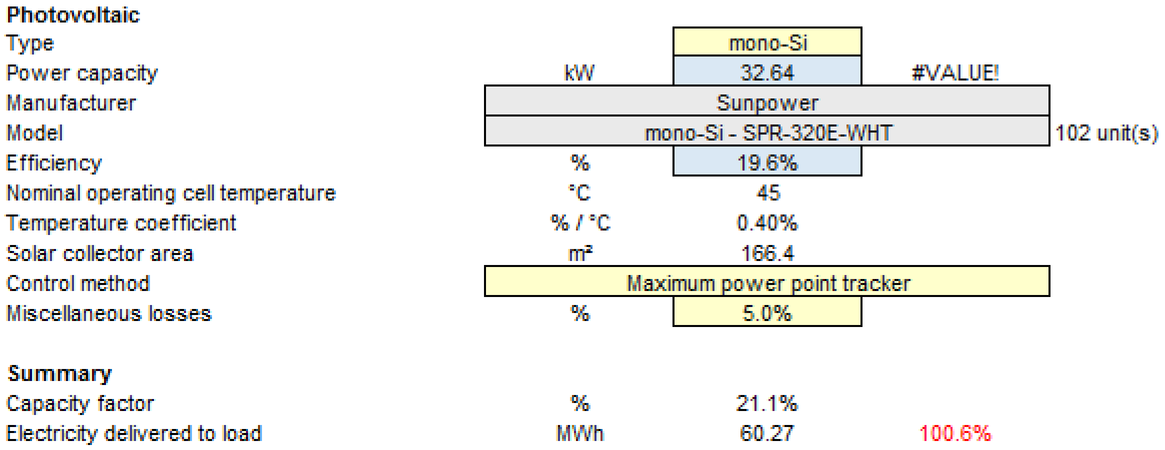
Table 4.1 Specification of mono-Si-SPR-320E-WHT module at standard conditions (E=1000W/m^2, Air mass=1.5, Cell tempreture=25°c)

Maximum power	320 W
Maximum power voltage	54.7 V
Maximum power current	5.86 A
Open circuit voltage	64.8 V
Short circuit current	6.24 A
Area	1.62 m^2

The number of PV module required for each well is obtained from RETScreen software. The software determines the number of modules based on the amount of electricity delivered to the load.

For well P1-PW08

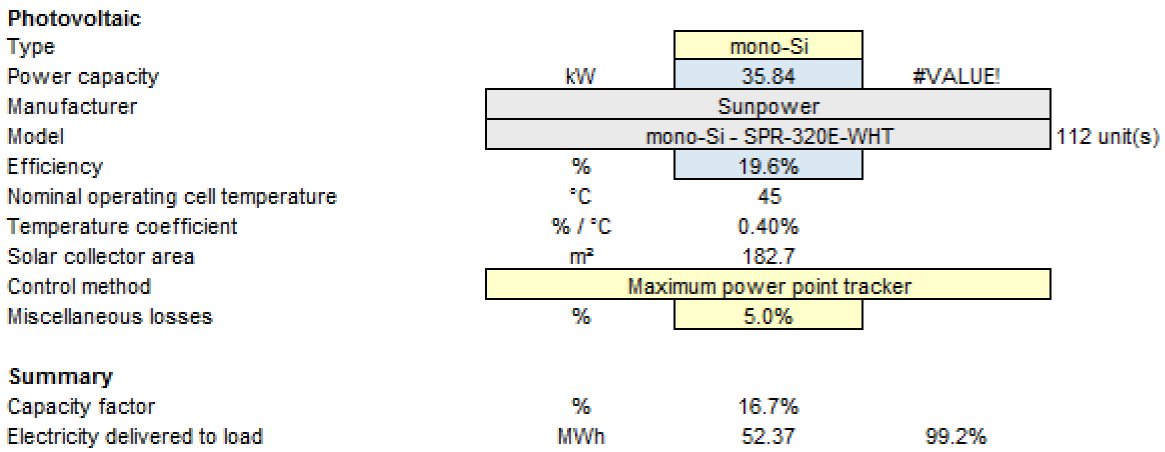
Total number of PV module = 102



Photovoltaic			
Type		mono-Si	
Power capacity	kW	32.64	#VALUE!
Manufacturer		Sunpower	
Model		mono-Si - SPR-320E-WHT	102 unit(s)
Efficiency	%	19.6%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	166.4	
Control method		Maximum power point tracker	
Miscellaneous losses	%	5.0%	
Summary			
Capacity factor	%	21.1%	
Electricity delivered to load	MWh	60.27	100.6%

For well P1-PW09

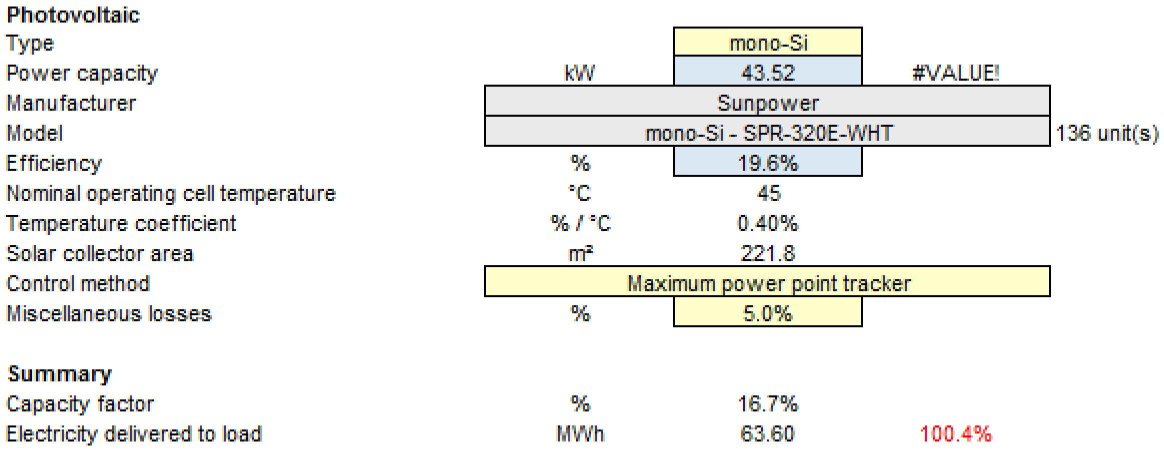
Total number of PV module = 112



Photovoltaic			
Type		mono-Si	
Power capacity	kW	35.84	#VALUE!
Manufacturer		Sunpower	
Model		mono-Si - SPR-320E-WHT	112 unit(s)
Efficiency	%	19.6%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	182.7	
Control method		Maximum power point tracker	
Miscellaneous losses	%	5.0%	
Summary			
Capacity factor	%	16.7%	
Electricity delivered to load	MWh	52.37	99.2%

For well P1-BTW07

Total number of PV module = 136



Photovoltaic			
Type		mono-Si	
Power capacity	kW	43.52	#VALUE!
Manufacturer		Sunpower	
Model		mono-Si - SPR-320E-WHT	136 unit(s)
Efficiency	%	19.6%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	221.8	
Control method		Maximum power point tracker	
Miscellaneous losses	%	5.0%	
Summary			
Capacity factor	%	16.7%	
Electricity delivered to load	MWh	63.60	100.4%

4.2 DC to AC Inverter Selection

The inverter is used if the system power load is AC; it converts the low-voltage DC electricity into standard AC voltage output. The power of the selected inverter should be equal to the peak load of the system which is equal to the power of AC pump.

The specification of selected inverter is given in table 4.2 .The input of inverter have to be matched with the inverter input voltage specification while its output should fulfill the specifications of the maximum power of the pump. As shown below in the table 3.2 the inverter input voltage should be in the range of 310 to 450 DC volts whereas the output voltage is 380 AC volts.

Table 4.2 Type of inverter selected

Inverter type: MNE-SP11KV3…MNE-SP30KV3	
Input	Output
(310 -450) DC volt	380 AC volt, 3 phase, 50 HZ
Rated power: 22, 25 and 30 KW	

To determine the number of module connected in series in order to get the voltage in the range of inverter input (i.e. 310 -450 V) divides input voltage by module's maximum voltage.

For well P1-PW08

According to the output from the software the total number of modules is 102 and total collector area is 163.1 m^2. The selected input voltage is 328.2 V which is in the range of the above input voltage. Then the number of module connected in series is given by equation 3.1.

$$Npvm = \frac{Selected\ DC\ input\ voltage}{Vmp} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..3.1$$

where, Npvm = number of module in series

V_{mp}= maximum power voltage

$$Npvm = \frac{328.2\ V}{54.7\ V} = 6$$

Therefore the block diagram of PV module arrangement in the array is shown in figure 3.1

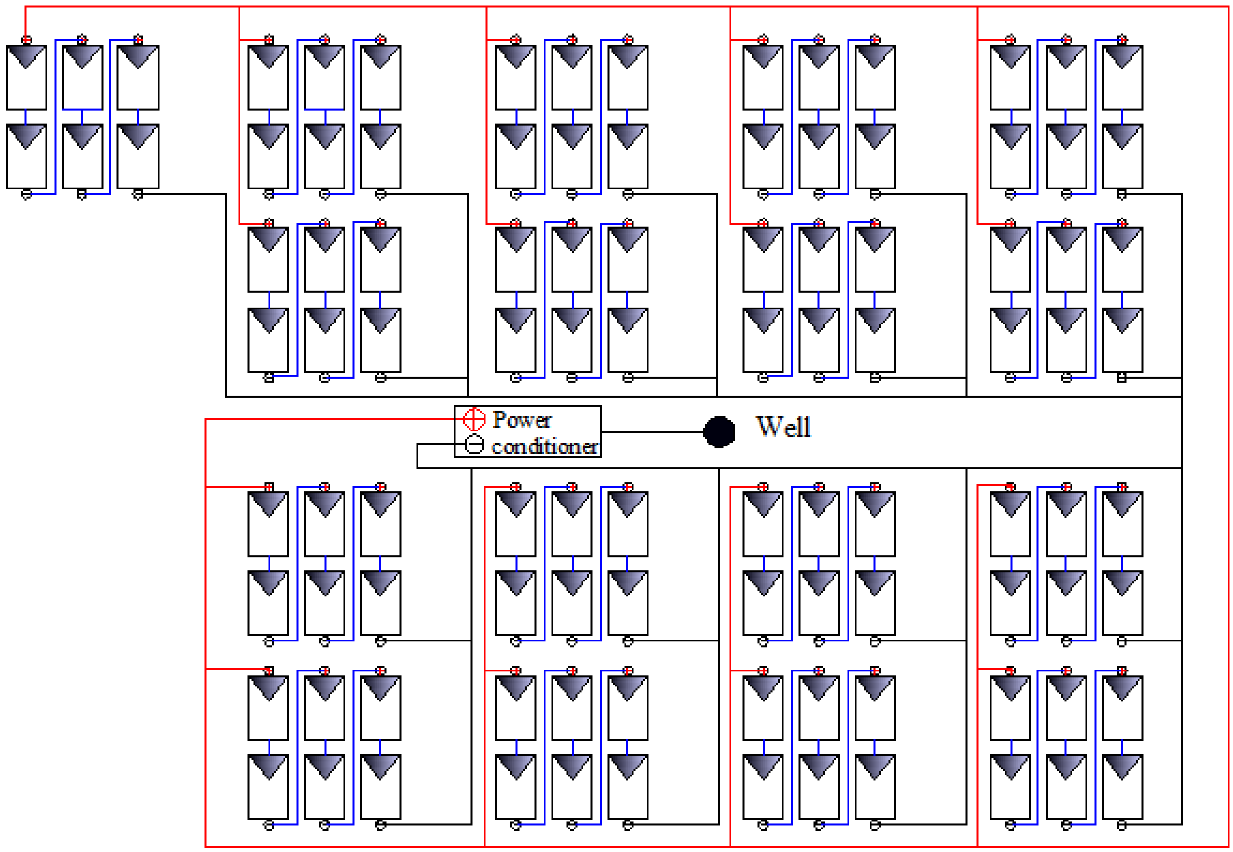


Figure 4.1 Block diagram for the arrangement of module in the array for well P1-PW08

For well P1-PW09

According to the output from the software the total number of modules is 112 and total collector area is 184.3 m^2. The selected input voltage is 438 V which is in the range of the above input voltage. Then the number of module connected in series is given by equation 3.1.

$$Npvm = \frac{438\,V}{54.7\,V} = 8$$

Therefore the block diagram of PV module arrangement in the array is shown in figure 3.2

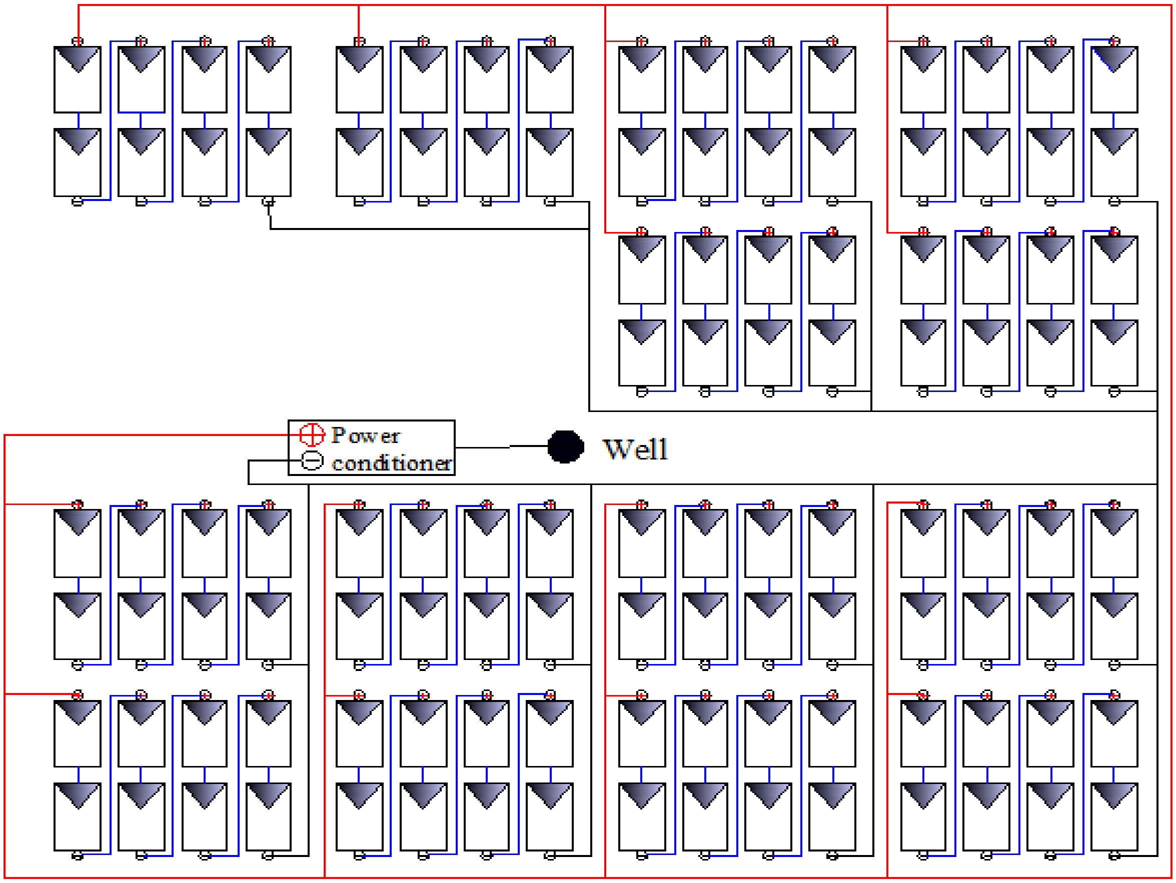


Figure 4.2 Block diagram for the arrangement of module in the array for well P1-PW09

For well P1-BTW07

According to the output from the software the total number of modules is 136 and total collector area is 221.8m^2. The selected input voltage is 438 V which is in the range of the above input voltage. Then the number of module connected in series is given by equation 3.1.

$$Npvm = \frac{438\ V}{54.7\ V} = 8$$

Therefore the block diagram of PV module arrangement in the array is shown in figure 3.3

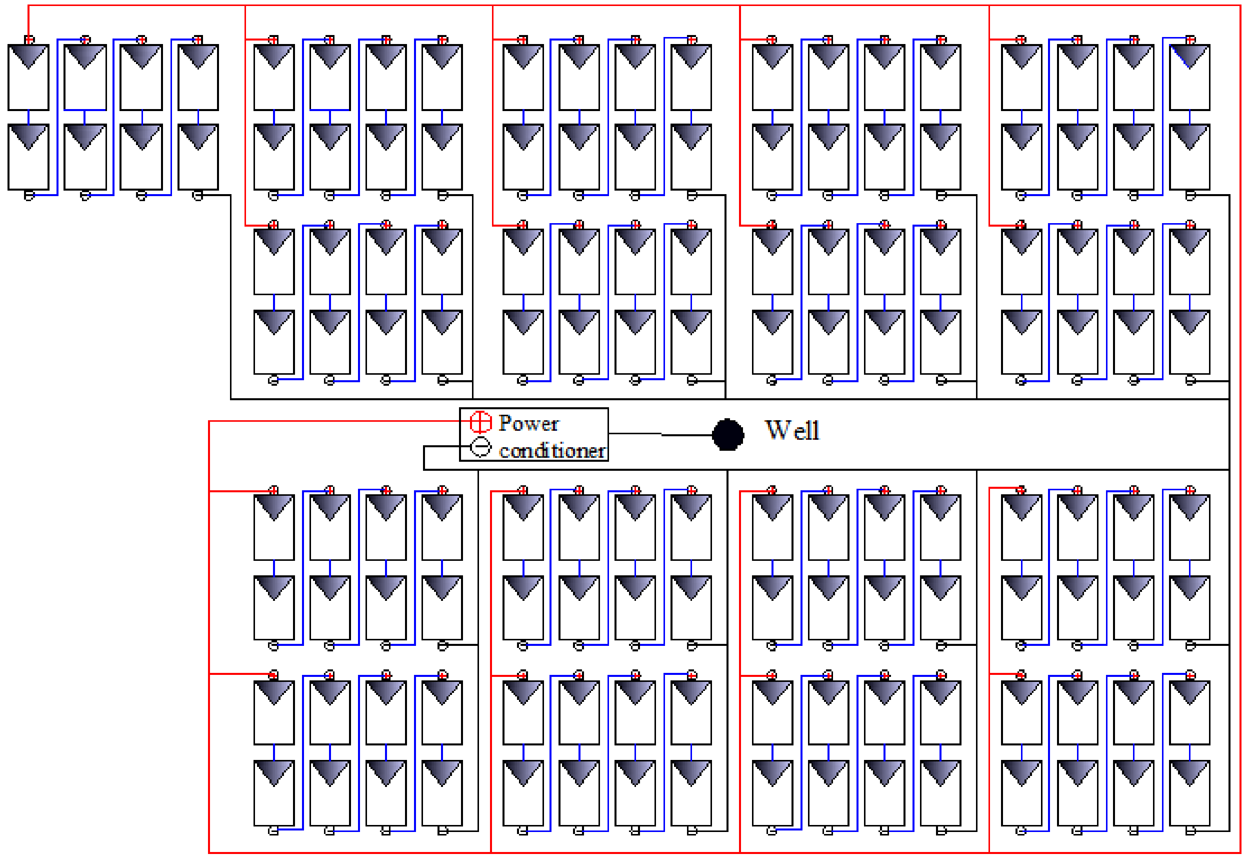
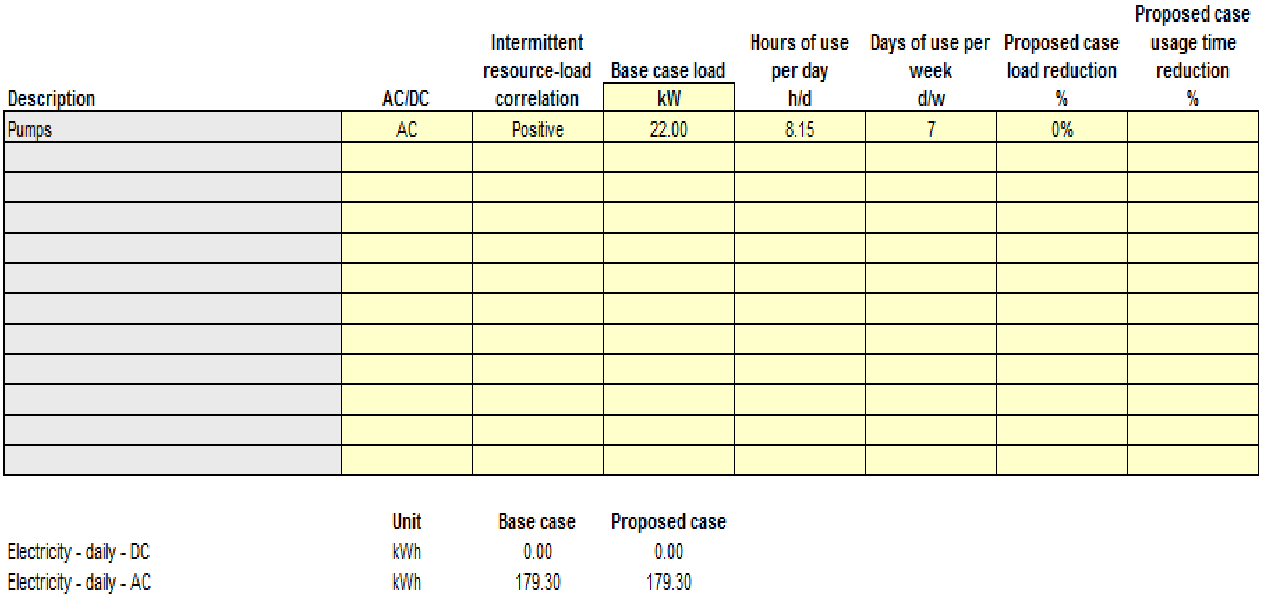


Figure 4.3 Block diagram for the arrangement of module in the array for well P1-BTW7

4.3 Pump Selection

Pump selection depends on the daily water pumping rate and the hydraulic head. The AC submersible pumps that have been used in this study are designed and selected by Oromia Water Works Design and Supervision Enterprise. RETScreen software needs base-case AC load to determine daily electricity required for the proposed system (PV system). I have taken the AC load from the electrical motor of the water pump which is used in the software to design a PV system. The specification of each electrical motor of the pump is given in appendix F.

It is shown here that the input parameters required for RETScreen software to determine daily electricity required for the proposed system (PV system).



Description	AC/DC	Intermittent resource-load correlation	Base case load kW	Hours of use per day h/d	Days of use per week d/w	Proposed case load reduction %	Proposed case usage time reduction %
Pumps	AC	Positive	22.00	8.15	7	0%	

	Unit	Base case	Proposed case
Electricity - daily - DC	kWh	0.00	0.00
Electricity - daily - AC	kWh	179.30	179.30

CHAPTER FIVE

5. Economic Analysis

5.1 Introduction

Once the technical requirements of a PV application have been stated and a PV system design completed, the economic analysis can be carried out. The economic assessment includes both costs and benefits of the system.

The purchase of a PV system represents an expenditure of capital resources at a given time with the expectation of benefits in the form of electric energy delivered over some future period, which is generally the life of the PV system. Other benefits, such as reductions in greenhouse gases, might be quantified. For large systems, the construction expenditures may occur over more than one year. The future benefits, primarily the value of the electricity generated, may be realized over a 10- to 20-year period. Thus, the basic issue is how to measure the value of future benefits from a present expenditure. Further, the issue is how to compare that value for a PV system with a consistently defined value for an alternative system such as a Diesel-electric system. Salvage value at the end of the system life is also a future benefit. In many cases, there will not only be future benefits but future costs as well. The cost of maintenance and the replacement of failed modules are primary examples. In addition, qualitative benefits, such as energy independence or reduction in the risk of future escalation of energy costs, may enter the decision process, although they are not dealt with here.

We generally recognize intuitively that the value of a cost or benefit in the future is not equal to the same cost or benefit today. This is to say that there is a “time value of money,” and defining that time value pervades the whole process of economic analysis for PV systems. These expenditures and benefits, as measured in monetary terms, are usually called cash flows.

5.2 Economic Analysis Method

Some traditional methods for analyzing investment costs are life cycle cost (LCC); net present cost (NPC); internal rate of return (IRR); benefit-to-cost ratio (BCR) or savings-to-investment ratio (SIR); net benefits or savings (NB or NS); annuity and cost annuity comparison method;

and payback period. From the three most common techniques in economic analysis the LCC, the IRR, and the payback period, the LCC method is the most complete approach and is widely used.

5.2.1 Life Cycle Cost Analysis

LCC is the sum of the capital cost and the present worth of the recurrent and replacement costs.
In order to compare different systems offering the same service or output the life cycle costing approach is used. This approach allows systems to be compared on an equal basis by reducing all future costs, which occur at different intervals of the systems life, to one value, referred to as the LCC of a system or project. Future costs include operating costs (Diesel consumption, transport), maintenance costs (engine oil, filters, brushes, valves, rotor, impellers, labor, transport etc) and replacements (Diesel engine, pump, motor, inverter, labor and transport).

When the pumping system is to supply drinking water, the comparative LCC of renewable energy source solar pumping systems must be established with that of conventional systems. This is necessary because the economic benefits of supplying water are difficult to quantify. For example, if both a PV pump and a Diesel pump can reliably furnish the same quantity of water, it is safe to assume that they provide equal benefits. In this case, the lower cost option is preferred. In LCC analysis, the net present value (NPV) of all the capital and recurrent costs of a pump is compared to the NPV of all the costs of other pumping options. For example, if the NPV costs of a PV pumping system are less than the costs of other alternatives, PV should be the first choice for the power source. However, in most cases alternative pumping systems cannot provide as much water as conventional systems. For this reason, it is convenient to make comparisons in terms of unit water cost rather than the lowest cost pumping option.

5.2.2 Net Present Value

The net present value method calculates the present value of all the yearly cash flows (i.e. capital costs and net savings) incurred or accrued throughout the life of a project, and summates them. Costs are represented as a negative value and savings as a positive value. The sum of all the present values is known as the net present value (NPV). The higher the net present value, the more attractive the proposed project.

If the resulting NPV is greater than zero, then a project is determined to be economically viable.

5.2.3 Internal Rate of Return

Identifies the discount rate at which the present value of the net benefit stream is equal to the present value of the net cost stream. If the resulting IRR is greater than the chosen discount rate, the project is deemed to be economically viable.

5.2.4 Benefit-Cost Ratio

Compares the total discounted benefits with total discounted costs, as a ratio, and provides an indication of the scale of return on the investment. This is done by examining the ratio of the present value of benefits to the present value of costs. If the ratio of benefits to costs is greater than one, the project can be viewed as desirable from an economic point of view.

5.2.5 Payback Period

This is the simplest technique that can be used to appraise a project. The simple payback period can be defined as the length of time required for the running total of net savings before depreciation to equal the capital cost of the project. In theory, once the payback period has ended, all the project capital costs will have been recouped and any additional cost savings achieved can be seen as clear profit. Obviously, the shorter the payback period, the more attractive the project becomes. The length of the maximum permissible payback period generally varies with the business culture concerned.

5.2.6 Sensitivity Analysis

In the economic (financial) analysis, a sensitivity analysis can be used to evaluate the effects of uncertainty when input parameters, such as interest rate, discount rate, inflation rate, energy escalation rate, service life, investment and operation costs, and income are varied by a certain amount (percentage) from the expected value. Sensitivity analysis is used to quantify the economic consequences of a potential but unpredictable development in important parameters.

Sensitivity analysis covers a range of possible application loads. It is used to determine how the NPV, LCC varies from the base case as the key parameters such as equipment capital cost, conventional fuel cost (Diesel) discount and interest rates, expected lifetime for conventional equipment (engine) and renewable energy sources (solar radiation) change.

5.2.7 Financial Risk Analysis

The value of the solar energy is only estimation and not a fact and therefore the risk remains that this value will be overestimated. It is not only the price that is estimated, all the costs related to balance of systems as well as running and maintaining PV systems are estimated figures and this must be borne in mind throughout the project planning. A thorough high quality planning is vital in order to diminish the risk of overestimation of the possible profitability.

5.2.8 Financial Parameters

Table 5.1 Financial parameter for LCC analysis

Parameters	Unit	Value
Project life	Years	21
Inflation rate	%	8
Discount rate	%	10.5
Fuel escalation rate	%	5
Loan rate	%	8.5

5.3 Cost Estimation and Distribution

5.3.1 Cost Estimation

Table 5.2 Cost estimation of PV system

Component description	Cost [USD]
PV module	3500 \$/kW
Inverter	800 \$/kW
Storage	130 \$/m^3
Operation & Maintenance	349 \$ /year

5.3.2 Capital Investment Cost

The capital costs occur once at the beginning of the project. It comprises the cost of the equipment and accessories. The capital costs used in the calculations are listed in the table 5.3.

Table 5.3 Capital cost of PV and DG

Well description	Capital investment cost [$]	
	PV system	DG system
P1-PW08	212,000.00	10,795.00
P1-PW09	226,560.00	10,795.00
P1-BTW07	256,320.00	10,795.00

*For PV system Initial cost = (module + inverter + reservoir) cost

5.3.3 Operating Cost

The operating costs are only applicable to the Diesel pumping system. The operator costs (person starting the Diesel engine, person looking after the PVP system) are ignored for both the Diesel as well as the PVP installation.

The liters of Diesel consumed per annum are calculated from the running time of the Diesel pump. A fuel cost escalation of 5% has been assumed but the fact remains that this is an indeterminable parameter as it depends on oil reserves, conflict in oil producing countries and exchange rate.

5.3.4 Maintenance and Replacement Cost

The maintenance and replacement of the pumping systems is applicable to both the PVP and Diesel pumps. The maintenance schedule and details are dependent on the technology employed. The replacement schedule is dependent on the ruggedness of the system, the operating environment (water quality, Diesel quality, direct exposure to sunlight, excessive temperature etc) as well as the level of maintenance performed.

The replacement costs for the motor, pump and controller are equivalent to the initial purchase cost.

5.3.4.1 PV System

The service interval depends on the pump systems used. In most cases the service interval is 5 years. Service intervals are also highly dependent on water quality and depth of installation. It is assumed that all main components in a PVP excluding the solar modules will have to be replaced within certain intervals.

5.3.4.2 Diesel Generator System

Diesel generator requires minor service, major service and overhauls in regular intervals. A minor service includes oil change and air, fuel and oil filters replacement. A major service includes adjustments of engine valve, fan and alternator belt, change or test of fuel injector requires skilled personnel which are assumed to be in the region or at a Private system. An overhaul includes the tasks of a minor and major service, replacements of parts (e.g. crankshaft, piston rings) and drilling of cylinders and requires skilled personnel.

The following schedule has been selected for the service and replacement intervals of high quality and low quality Diesel engines.

Table 5.4 Maintenance and replacement interval for Diesel engines

Maintenance and replacement	Good quality engine [hours]	Low quality engine [hours]
Minor service	250	250
Major service	1000	1000
Overhaul	10,000	5,000
Replacement	35,000	10,000

Table 5.5 Maintenance cost of Diesel engines under the study

Maintenance	Cost [USD]
Engine service	2351/year
Overhaul	60% of new=6477

The minor service is done locally and no transport costs have been added. The major service is done by professional services on site. The overhaul of a Diesel engine is done in the workshop and thus requires professional services as well as services trips. The replacement of an engine is determined by its condition (either overhaul or replace) and this is usually assessed in the workshop.

CHAPTER SIX

6. Environmental Impact Assessment

6.1 Introduction

Energy systems are known as a major source of environmental pollution. Therefore, the selection of a particular energy system can influence the extent of pollutant emissions dispersed into the environment. Criteria developed to choose from various energy technologies need to take into consideration not only technical but also socio-political aspects to ensure that the social and environmental costs and benefits of a chosen energy technology have been taken into account.

Emissions generated during the life-cycle of a given energy system are dispersed into the environment and impose a burden on living systems. These burdens have an impact on the physical and biological environment as well as on human health, and thus these impacts impose significant costs on society. Costs imposed by pollution have in the past been treated as external to the energy economy and have not been incorporated into the total costs of energy production and distribution.

6.2 Environmental Impact of PV System

Hazardous emissions connected to PV technology are primarily related to energy consumption in the manufacturing process, as direct process emissions are almost zero. Therefore cadmium emissions from CdTe technology can be lower than those of most other energy options. Risks from the use of cadmium telluride in modules appear to be quite low, provided that the material is kept well-encapsulated (double-glass encapsulation) and that it can be recovered from waste modules.

PV pumping systems do not use battery to sore energy hence there is no risk of disposing chemicals used in battery.

6.3 Environmental Impact of Diesel System

Hazardous emissions connected to Diesel generator include exhausting air quality, noise and climate.

Air quality is defined by ambient air concentrations of specific pollutants of concern with respect to the health and welfare of the general public. Air quality can be affected by air pollutants produced by Diesel generator.

Noise is unwanted or annoying sound that is generated by both natural and manmade sources. Noise can have negative effects on physical and psychological health, affect workplace productivity, and degrade quality of life. Loudness is the relative measure of the magnitude of a sound and is typically measured in decibels (dB). Decibels are the ratio of the intensity of the sound to a reference intensity based on atmospheric pressure.

Climate includes the meteorological conditions, including temperature, precipitation, and wind, that characteristically prevail in a particular region. Engine exhaust gases are the major source of GHG which significantly affect the climate.

6.4 Environmental Impact Comparison

The environmental benefits associated with the substitution of the Diesel powered system with the solar powered system can easily be estimated by determining the reduction in the production of air pollutants associated with this substitution.

CHAPTER SEVEN

7. Results and Discussion

The results are presented in this subsection and include the life cycle cost breakdown for a water pumping installation, the life cycle cost for a range of delivery heads, the breakeven between the two options, the unit water cost and the sensitivity and risk analysis.

The recommended methodology has been applied to analyze a stand-alone PV water pumping system, which is designed to supply water for drinking in Borena zone Yabelo area, Ethiopia (4.9^0N, 38.1^0E, and 1483m). The load profile is assumed to be constant with a total daily requirement of 220 m^3 of water and a reservoir of 600 m^3 has been considered for three days of water supply when the weather condition is cloudy.

Each well is designed to provide 220m^3/day out of which 50% of the daily water requirement is for livestock because the people in this zone are pastoralist. During the rainy season the load could be lower by 50% because the water required for livestock in rainy season is available from the rain.

According to Oromia Water Works Design and Supervision Enterprise boreholes will be protected at least through a protection zone of 20 m diameter surrounding each borehole which could be appropriate area for PV array installation. This zone should be fenced by protection walls/wires to prevent entrance by animals and to prohibit the entrance of non-officials. The spacing between each well is around 500 m.

The technical characteristics of three wells, Diesel generator, PV module and motor pump under the study is given in table 7.1.

Table 7.1 Technical characteristics of three wells Diesel generator and PV module

Well description	Total head [m]	Load [kW]	Electricity daily required [kWh]	Diesel generator [kW]	Proposed PV generator [kW]
P1-PW08	165	22	180	75	32.6
P1-PW09	165	25	204	75	35.8
P1-BTW07	170	30	245	75	43.5

All comparisons are based on the assumption that the pumping systems are fully utilized, i.e. the solar pump is used every day of the year and the Diesel pumps are used every day for 8.15 hours to meet the average daily total water requirement.

Assumptions

The assumptions for the costing calculations are as follows:

- The boreholes have a sufficiently strong yield to allow for the generally higher flow rates of the Diesel pump in comparison to the PVP.
- The water in the borehole is of reasonable quality.
- The cost of the reservoir for additional water storage in the case of PV system is included for the calculation.
- Costs for the local operator are not included.
- The economic growth of our country will keep the same rate for the coming 21 years.
- Fuel transportation cost is not included.

7.1 Cash Flow Diagram and Cost Breakdown

Under normal operating conditions the life of the Diesel generator is assumed to be 20,000 hours and to satisfy the daily water requirement it has to operate for 8.15 hours every day. Based on this the generator must be replaced after 7 years of operation.

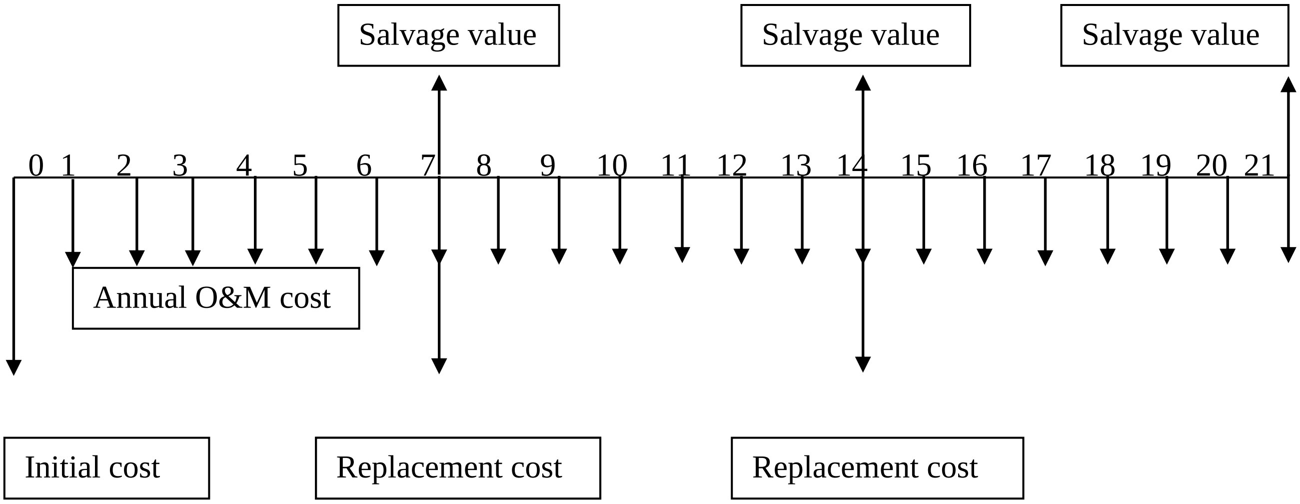


Figure 7.1 Cash flow diagrams for Diesel generator

For well P1-PW08

Table 7.2 Diesel generator cost breakdown for well P1-PW08

S/n	Cost description	Cost [$]
1	Initial cost	10,795.00
2	Annual O&M	40,629.00
3	Replacement cost	10,795.00
4	Salvage value	1,619.00

*salvage value is 15% of initial cost

For well P1-PW09

Table 7.3 Diesel generator cost distribution for well P1-PW09

s/n	Cost description	Cost [$]
1	Initial cost	10,795.00
2	Annual O&M	49,830.00
3	Replacement cost	10,795.00
4	Salvage value	1,619.00

For well P1-BTW07

Table 7.4 Diesel generator cost distribution for well P1-BTW07

s/n	Cost description	Cost [$]
1	Initial cost	10,795.00
2	Annual O&M	58,135.00
3	Replacement cost	10,795.00
4	Salvage value	1,619.00

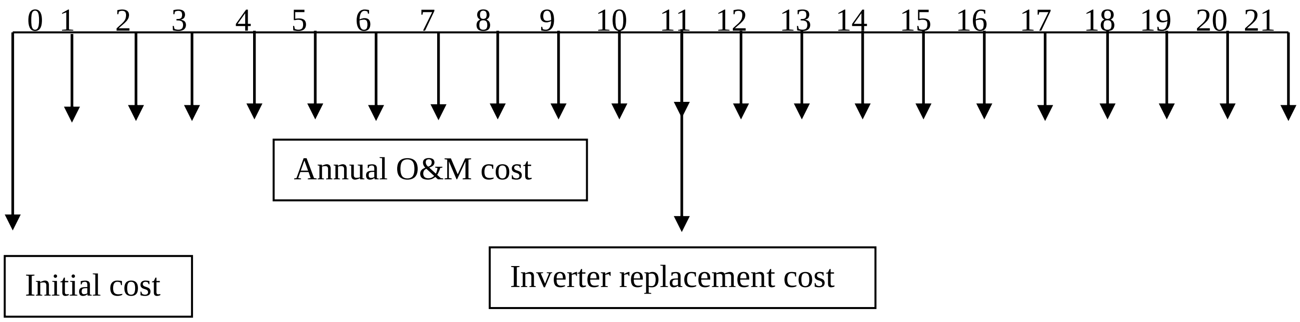


Figure 7.2 Cash flow diagrame for PV generator

For well P1-PW08

Table 7.5 PV cost distribution over its life for well P1-PW08

s/n	Cost description	Cost [$]
1	Initial cost	212,000.00
2	Annual O&M	349.00
3	Inverter replacement cost	20,000.00

*Initial cost = (module + inverter + reservoir) cost

For well P1-PW09

Table 7.6 PV generator cost breakdown for well P1-PW09

s/n	Cost description	Cost [$]
1	Initial cost	226,560.00
2	Annual O&M	371.00
3	Inverter replacement cost	20,000.00

For well P1-BTW07

Table 7.7 PV generator cost breakdown for well P1-BTW07

s/n	Cost description	Cost [$]
1	Initial cost	256,320.00
2	Annual O&M	416.00
3	Inverter replacement cost	20,000.00

7.2 LCC Analysis Present Worth Approach

Present value is the value on a given date of a future cost (or series of cost), given an interest or a discount rate to reflect the changing value of money over time. A cost to be paid with annual amortizations can be considered as a sum of costs, one for each year where the present value of the cost equals the sum of the present values of all cost payments as shown in Equation 7.1 below.

To Find *Present (P)* given annual cost (*A)*

The term (P / A i, n) represent the uniform-series present worth factor which begins at the end of year 1 and extends for n years at an interest rate i.

$$PW = \frac{A}{1+i} + \frac{A}{(1+i)^2} + \cdots + \frac{A}{(1+i)^n} = A\sum_{j=1}^{n}\frac{1}{(1+i)^j} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7.1$$

This can also be shown with a geometric series shown in Equation 7.2.

$$PW = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \quad , i\neq 0\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7.2$$

where, PW - Present Value (worth)
A - Equal Annual cost
i -Discount Rate
n- Economic Life of Project (years)

To find *Present (P)* given *future value (F)* (*P/F, i, n*)

$$P = F[1+i]^{-n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7.3$$

The term (P / F, i, n) represent the factor that can determines the present worth P of a given future amount F after n years at interest rate i.

According to figure 7.1(i. e cash flow diagram of DG) the present worth is given by equation 7.4.

$$PW(DG) = Ic + A(P/A\,,i,n) + Rc(P/F\,,i,7) - SV(P/F\,,i,7) + Rc(P/F\,,i,14) - SV(P/F\,,i,14) - SV(P/F\,,i,n) \ldots\ldots\ldots 7.4$$

where, PW $_{(DG)}$ - Present worth of DG

Ic - Initial cost

A - Annual M&O cost

SV - Salvage value

n - Economic Life of Project (years)

i - Discount rate

Rc- Replacement cost

The factors:

- (P/A , i, n) is $\left[\frac{(1+i)^n-1}{i(1+i)^n}\right]$, n is economic life of the project
- (P/F, i, n) is $[(1+i)^n]$, n is the year at which the future value is considered

For Well P1-PW08

PW $_{(DG)}$ = Ic+ A(P/A, 10.5, 21) + Rc(P/F, 10.5, 7) - SV(P/F, 10.5, 7) + Rc(P/F, 10.5, 14) -SV(P/F, 10.5, 14) - SV(P/F, 10.5, 21)

= 10795+ 40629(8.3537) + 10795(2.011) - 1619(2.011) + 10795(4.046) - 1619(4.046) – 1619(8.139)

= 10795 + 339,402.47 + 21,708.75 – 3,255.81 +43,676.57 – 6,550.47 - 13,177.04

= **$392,599.47**

According to figure 7.2 (i. e cash flow diagram of PV system) the present worth is given by equation 7.5.

$$PW(PV) = Ic + A(P/A\,,i,n) + Rci(P/F\,,i,11) \ldots\ldots\ldots 7.5$$

where, PW $_{(PV)}$- Present worth of PV system

Ic- Initial cost

A- Annual O&M cost

i- Discount rate

n- Economic Life of Project (years)

Rci- Inverter replacement cost

PW $_{(PV)}$ = Ic + Rci(P/F 10.5, 11) + A(P/A10.5, 21)

= 212,000.00 + 20,000(2.99) + 349(8.3537)

= **$274,715.44**

Then the equivalent annual worth is given by equation 7.6.

AW = PW (A / P i, n)

$$AW = PW\left[\frac{i(1+i)^n}{(1+i)^n-1}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7.6$$

where, n = 21

Therefore, the annual worth of DG and PV systems are calculated as shown below.

AW $_{(DG)}$ =PW$_{(DG)}$* $\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$

=392,599.47*(0.119)

=**46,719.33**

AW $_{(PV)}$ =PW$_{(PV)}$* $\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$

=274,715.44*(0.119)

=**32,691.14**

For Well P1-PW09

The present worth for a Diesel system is computed according to equation 7.4.

PW $_{(DG)}$ = Ic+ A(P/A, 10.5, 21) + Rc(P/F, 10.5, 7) - SV(P/F, 10.5, 7) + Rc(P/F, 10.5, 14) – SV(P/F, 10.5, 14) - SV(P/F, 10.5, 21)

=10795+49830(8.3537) + 10795(2.011) - 1619(2.011) + 10795(4.046) - 1619(4.046) - 1619(8.139)

= 10795 + 416,264.87 + 21,708.75 – 3,255.81 + 43,676.57 – 6,550.47 - 13,177.04

= **$469,461.87**

The present worth for a PV system is computed according to equation 7.5.

PW $_{(PV)}$ = Ic + Rci(P/F 10.5, 11) + 371(P/A10.5, 21)

= $226,560.00 + 20,000(2.99) + $371(8.3537)

= **$289,459.22**

Equivalent annual worth for both systems is calculated below as shown in equation 7.6.

AW $_{(DG)}$ = PW $_{(DG)}$* $\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$

= 469,461.87*(0.119)

= **55,865.96**

AW $_{(PV)}$ = PW $_{(PV)}$ * $\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$

= 289,459.22*(0.119)

= **34445.65**

For Well P1-BTW07

The present worth for a Diesel system is computed according to equation 7.4.

PW $_{(DG)}$ = Ic+ A(P/A, 10.5, 21) + Rc(P/F, 10.5, 7) - SV(P/F, 10.5, 7) + Rc(P/F, 10.5, 14) – SV(P/F, 10.5, 14) - SV(P/F, 10.5, 21)

=10795+58135(8.3537) + 10795(2.011) - 1619(2.011) + 10795(4.046) – 1619 (4.046) – 1619(8.139)

= 10,795.00 + 485,642.35 + 21,708.75 – 3,255.81 + 43,676.57 – 6550.47 - 13,177.04

= **$538,839.35**

The present worth for a PV system is computed according to equation 7.5.

$PW_{(PV)} = Ic + Rci(P/F\ 10.5, 11) + A(P/A10.5, 21)$

$= 256{,}320.00 + 24000(2.99) + 416(8.3537)$

= **$331,555.14**

Equivalent annual worth for both systems is calculated below as shown in equation 7.6.

$AW_{(DG)} = PW_{(DG)} * \left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$

$= 538{,}839.35*(0.119)$

= $**64,121.88**

$AW_{(PV)} = PW_{(PV)} * \left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$

$= 331{,}555.14*(0.119)$

= $**39,455.06**

The decision rule for LCC analysis is to choose the alternative with the lowest LCC. Since PV has the lowest LCC it should be chosen.

7.3 Unit Water Cost

The unit water cost (UWC) reflects the cost of water and therefore provides a measure for the cost at which water at a particular installation needs to be sold at in order to recover the all-inclusive costs for providing the water supply service.

To determine the unit water cost, the LCC should be converted into the annual equivalent life cycle cost. In other words, the LCC will be distributed equally over the system's economic life. Then the ALCC (AW) is divided by the annual water production (requirement) to determine the unit water cost as shown in equation 7.7.

$$UWC = \frac{AW}{AWP} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 7.7$$

where, AWP-annual water production [m^3]

For Well P1-PW08

$$\text{UWC}_{\,(DG)} = \frac{46{,}719.33}{80{,}300}$$

$$= \mathbf{0.58\ \$/m^3}$$

$$\text{UWC}_{\,(PV)} = \frac{32{,}691.1}{80{,}300}$$

$$= \mathbf{0.41\ \$/m^3}$$

For Well P1-PW09

Unit water cost for both systems is calculated below as shown in equation 7.7.

$$\text{UWC}_{\,(DG)} = \frac{55{,}865.96}{80{,}300}$$

$$= \mathbf{0.69\ \$/m^3}$$

$$\text{UWC}_{\,(PVG)} = \frac{34{,}445.6}{80{,}300}$$

$$= \mathbf{0.43\ \$/m^3}$$

For Well P1-BTW07

Unit water cost for both systems is calculated below as shown in equation 7.7.

$$\text{UWC}_{\,(DG)} = \frac{64{,}121.88}{80{,}300}$$

$$= \mathbf{0.79\ \$/m^3}$$

$$\text{UWC}_{\,(PV)} = \frac{39{,}455.06}{80{,}300}$$

$$= \mathbf{0.49\ \$/m^3}$$

7.4 Financial Viability Analysis

The results produced in the economic analysis show that the PV system in all three cases is highly economically feasible and these are:

7.4.1 Payback Period

The simple payback is the number of years it takes for the cash flow (excluding debt payments) to equal the total investment (which is equal to the sum of the debt and equity). The year-to-positive cash flow *(*Equity pay-back*)* is the first year that the cumulative cash flows for the project are positive.

For Well P1-PW08

The project's initial investment will be fully recovered within 6.3 years.

Equity pay-back period is 4 years.

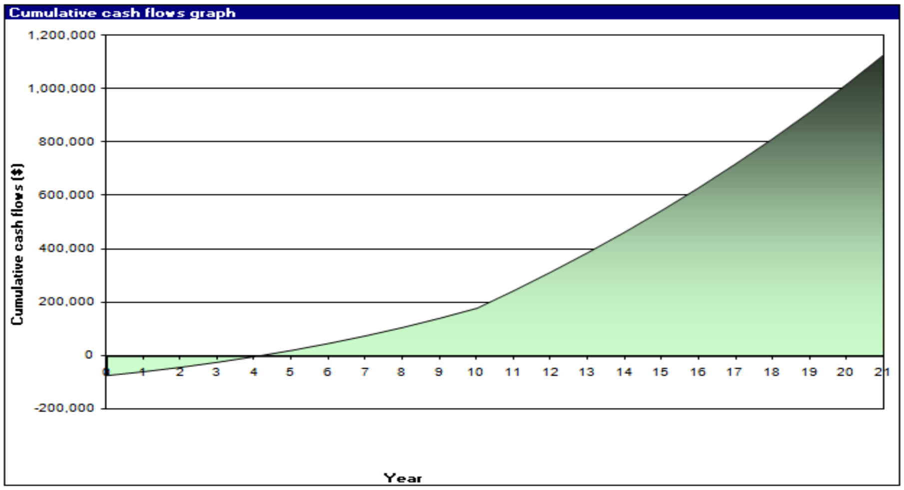


Figure 7.3 Cumulative Cash Flow diagram for well P1-PW08

For well P1-PW09

The project's initial investment will be fully recovered within 5.4 years.

Equity pay-back period is 3 years.

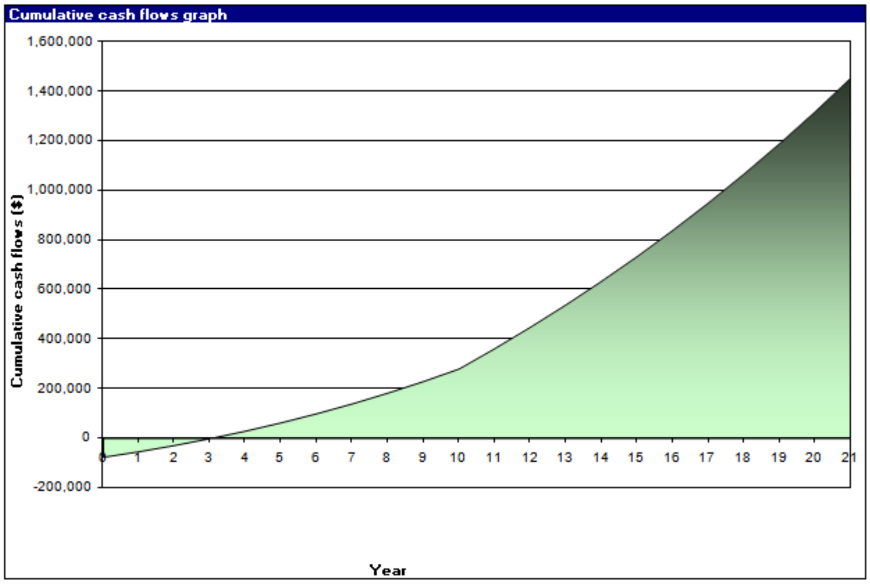


Figure 7.4 Cumulative cash flows graph for well P1-PW09

For Well P1-BTW07

The project's initial investment will be fully recovered within 5.1 years.

Equity pay-back period is 2.8 years.

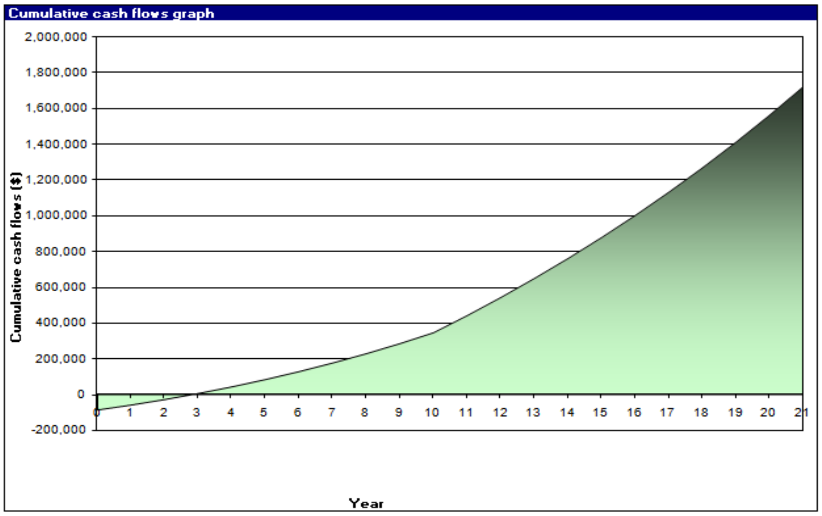


Figure 7.5 Cumulative cash flows graph for well P1-BTW07

7.4.2 Internal Rate of Return

The model calculates the pre-tax internal rate of return on equity and asset, which represents the true interest yield provided by the project equity and assets over its life before income tax. It is calculated using the pre-tax yearly cash flows and the project life. It is calculated by finding the discount rate that causes the net present value of the equity and assets to be equal to zero.

For Well P1-PW08

The calculated IRR on equity of the project is 32.6 % and IRR on asset is 14%.

For Well P1-PW09

The calculated IRR on equity of the project is 40.2 % and IRR on asset is 16.7%.

For Well P1-BTW07

The calculated IRR on equity of the project is 42.6 % and IRR on asset is 17.5%.

7.4.3 Net Present Value

The net present value of a project is the value of all future cash flows, discounted at the discount rate, in today's currency. Under the NPV method, the present value of all cash inflows is compared against the present value of all cash outflows associated with an investment project. The difference between the present values of these cash flows, called the NPV, determines whether or not the project is generally a financially acceptable investment. Positive NPV values are an indicator of a potentially feasible project.

For Well P1-PW08

The net present value at 10.5% discount rate is Birr 260420 $.

For Well P1-PW09

The net present value at 10.5% discount rate is Birr 361103 $.

For Well P1-BTW07

The net present value at 10.5% discount rate is Birr 435,022 $.

7.4.4 Annual Life Cycle Saving

The model calculates the annual life cycle savings which is the nominal yearly savings having exactly the same life and net present value as the project. The annual life cycle savings are calculated using the net present value, the discount rate and the project life.

For Well P1-PW08

Based on the cash flow statement, ALCS is 31174 $/year.

For Well P1-PW09

Based on the cash flow statement, ALCS is 43226 $/year.

For Well P1-BTW07

Based on the cash flow statement, ALCS is 52,075 $/year.

7.4.5 Benefit Cost Ratio

The benefit-cost ratio is an expression of the relative profitability of the project. The model calculates the net Benefit-Cost ratio, which is the ratio of the net benefits to costs of the project. Ratios greater than 1 are indicative of profitable projects.

For well P1-PW08

The benefit cost ratio is 4.65.

For well P1-PW09

The benefit cost ratio is 5.75.

For Well P1-BTW07

The benefit cost ratio is 6.07.

7.4.6 Total Annual Saving and Income

The total annual savings and income represents the annual savings and/or income realized due to the implementation of the proposed case system.

For well P1-PW08

Based on the cash flow statement, AS is 36119 $.

For well P1-PW09

Based on the cash flow statement, AS is 45320 $.

For Well P1-BTW07

Based on the cash flow statement, AS is 53,625 $.

7.4.7 GHG Reduction Cost

The GHG Emission reduction cost (GRC) represents the nominal cost to be incurred for each tone of GHG avoided.

For Well P1-PW08

Based on the cash flow statement, the GHG reduction cost is 362 $/$tco_2$.

For Well P1-PW09

Based on the cash flow statement, the GHG reduction cost is 425 \$/tco$_2$.

For Well P1-BTW07

Based on the cash flow statement, the GHG reduction cost is 426 \$/tco$_2$.

7.4.8 Breakeven Between PV and Diesel Generator

The choice between PV generators and Diesel generators technology should be made based on comparative life cycle costing where the solution with a lower cost over the project life is selected. An indicator of attractiveness is the year to breakeven which is when the cumulative LCC of PV becomes lower than the cumulative LCC of DG. The shorter the years to breakeven, the more attractive the renewable energy solution becomes and the higher the cost savings over the project life.

Figure 7.6 shows a typical graph presenting the years to breakeven. In this case a PV generator is compared with a Diesel engine, pumping for eight hours every day (assuming that the necessary reservoirs are in place).

For well P1-PW08

The breakeven occurs after five years.

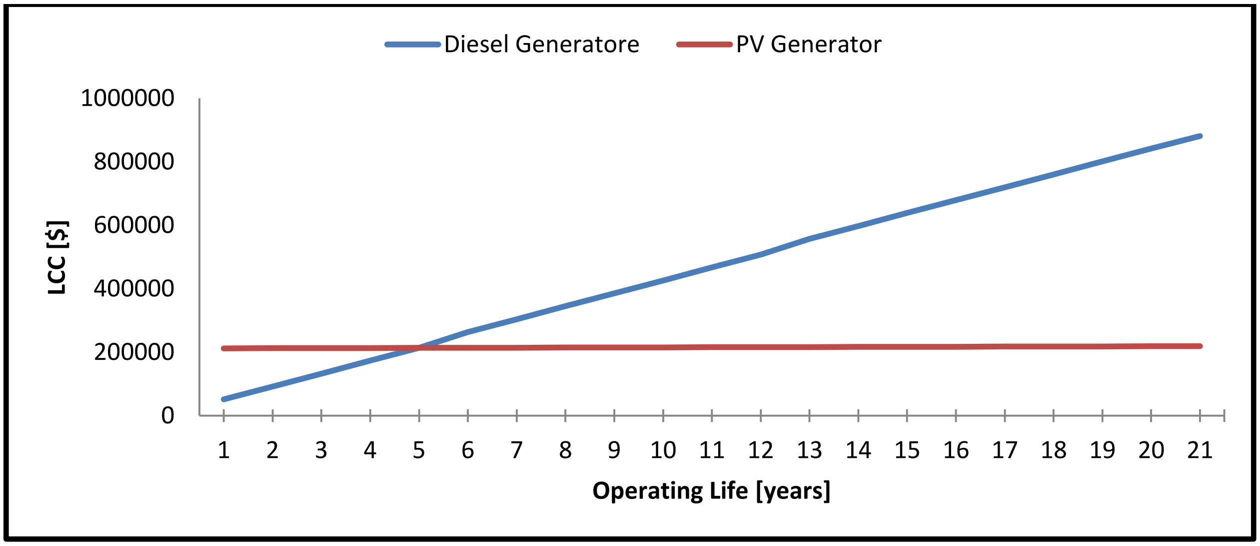


Figure 7.6 Break-even between PV and DG for well P1-PW08

For well P1-PW09

The break even occurs after four and half years.

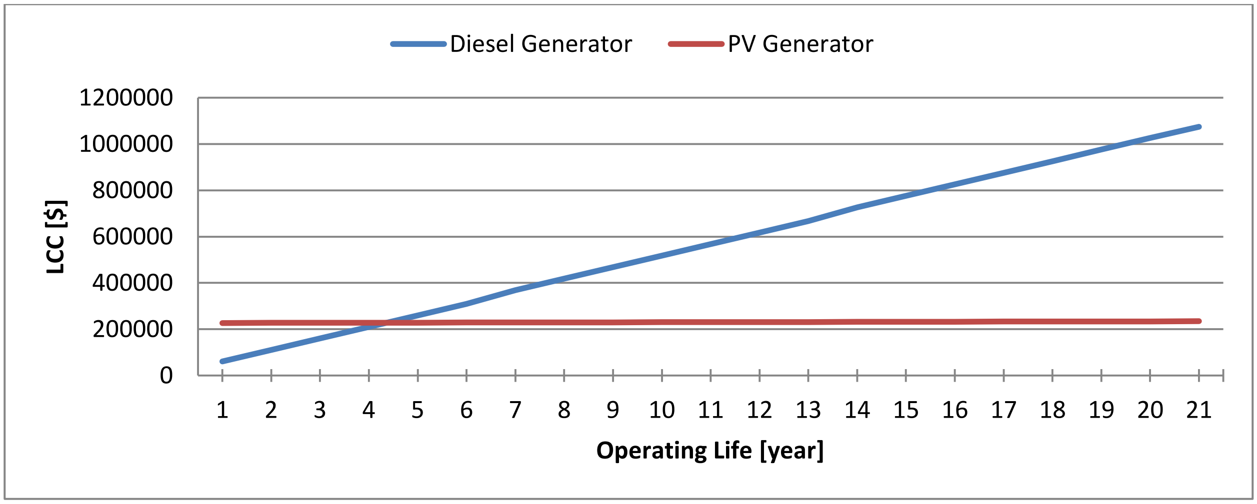


Figure 7.7 Break-even between PV and DG for well P1-PW09

For Well P1-BTW07

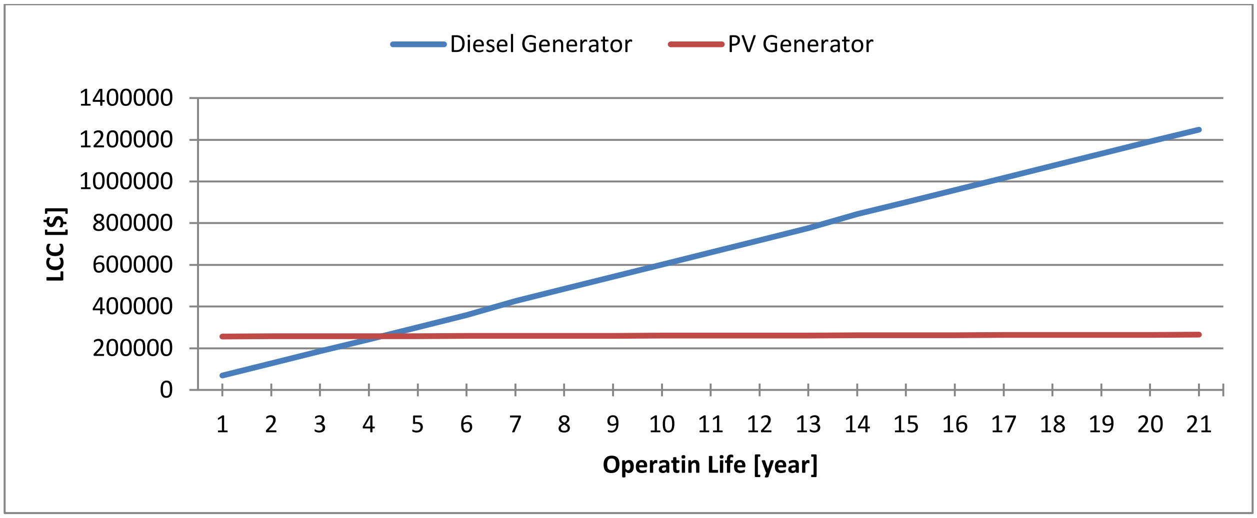


Figure 7.8 Break-even between PV and DG for well P1-BTW07

7.5 Financial Risk Analysis

The risk analysis is performed using a Monte Carlo simulation by RETScreen software that includes 500 possible combinations of input variables resulting in 500 values of after-tax IRR - equity, after-tax IRR - assets, equity payback or Net Present Value. The risk analysis allows to assess if the variability of the financial indicator is acceptable, or not, by looking at the distribution of the possible outcomes. An unacceptable variability will be an indication of a need to put more effort into reducing the uncertainty associated with the input parameters that were identified as having the greatest impact on the financial indicator.

The simulation consists of two steps:

1. For each input parameters, 500 random values are generated using a normal (Gaussian) distribution with a mean of 0 and a standard deviation of 0.33 using the random number generation function in Microsoft Excel's Data Analysis Tool Pack. Once generated, these random numbers are fixed.
2. Each random values is then multiplied by the related percentage of variability (range) specified in the Risk analysis worksheet. The result is 500 x 9 matrix containing percentage of variation that will be applied to input parameters' initial value in order to obtain 500 results for the output financial indicators.

Table 7.8 Input Parameters and Output Indicators associated with the Monte Carlo simulation performed in the RETScreen Risk Analysis Model.

Technical and Financial Parameters (Input parameters)	Financial Indicators (Output indicators)
Initial cost	after-tax IRR-equity
O&M	after-tax IRR – assets
Fuel cost- base case	equity payback (year to positive cash flow)
Debt ratio	Net Present Value
Debt interest rate	
Debt term	

7.5.1 Impact Graph

The impact graph shows the relative contribution of the uncertainty in each key parameter to the variability of the financial indicator. The X axis at the bottom of the graph does not have any units, but rather presents a relative indication of the strength of the contribution of each parameter.

The longer the horizontal bar, for a given input parameter, the greater is the impact of the input parameter on the variability of the financial indicator.

The input parameters are automatically sorted by their impact on the financial indicator. The input parameter at the top (Y axis) contributes the most to the variability of the financial indicator while the input parameter at the bottom contributes the least. This "tornado graph" will help us to determine which input parameters should be considered for a more detailed analysis, if that is required.

The direction of the horizontal bar (positive or negative) provides an indication of the relationship between the input parameter and the financial indicator. There is a positive relationship between an input parameter and the financial indicator when an increase in the value of that parameter results in an increase in the value of the financial indicator. For example, there is usually a negative relationship between initial costs and the Net Present Value, since decreasing the initial costs will increase the NPV.

7.5.1.1 Impact of Input Parameters on After-tax IRR-equity

For well P1-PW08

Impact of input parameters on IRR-equity is shown in figures 7.9, 7.10 and 7.11 for each well. The figures shows that the input parameters like initial cost, debt interest rate and O&M lay on the negative side of the horizontal bar but the parameters like base-case fuel cost and debt ratio lay on the positive side. This implies increasing in initial cost strongly reduces IRR on equity whereas increasing base-case fuel cost and debt ratio will improve it.

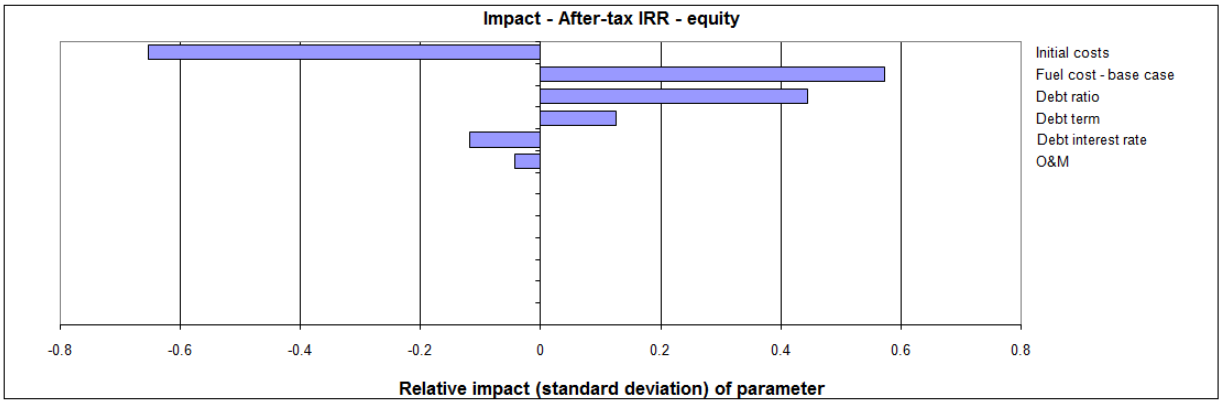


Figure 7.9 Impact on After-tax IRR-equity for well P1-PW08

For well P1-PW09

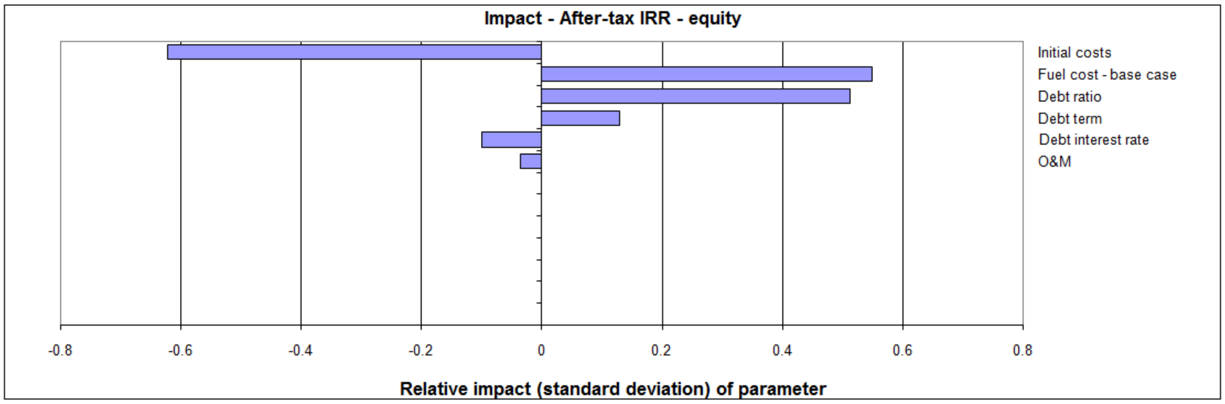


Figure 7.10 Impact on After-tax IRR-equity for well P1-PW09

For well P1-BTW07

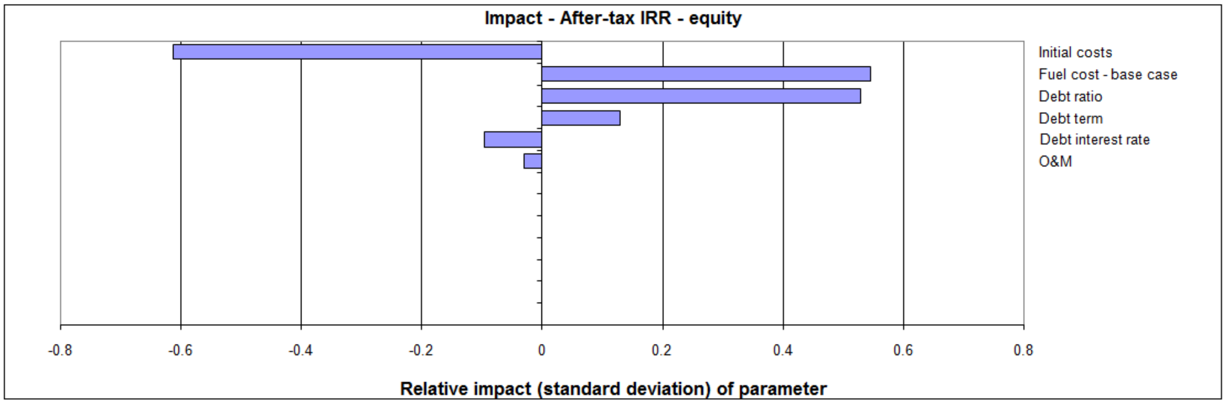


Figure 7.11 Impact on After-tax IRR-equity for well P1-BTW07

7.5.1.2 Impact of Input Parameters on After-tax IRR-asset

For well P1-PW08

The impact of the input parameters on IRR-asset is shown in figures 7.12, 7.13 and 7.14 for each well. Figure 7.12 clearly shows all the input parameters fall on the negative side of the horizontal bar except base-case fuel cost. This implies that increasing the value of input parameters on the negative side of the horizontal bar will reduce IRR on asset whereas increasing the base-case fuel cost which lay on positive side of the horizontal will bar improve IRR on asset.

In figure 7.13 and 7.14 the debt term lay on positive side of the horizontal bar but the rest parameters are similar with figure 7.12.

The impact of initial cost and base-case fuel cost is higher than the rest of the input parameters.

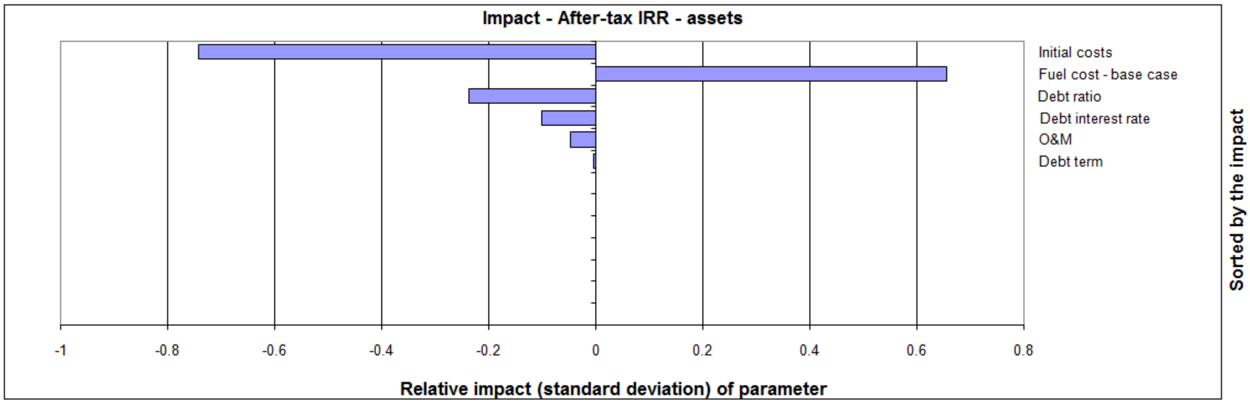


Figure 7.12 Impact on After-tax IRR-asset for well P1-PW08

For well P1-PW09

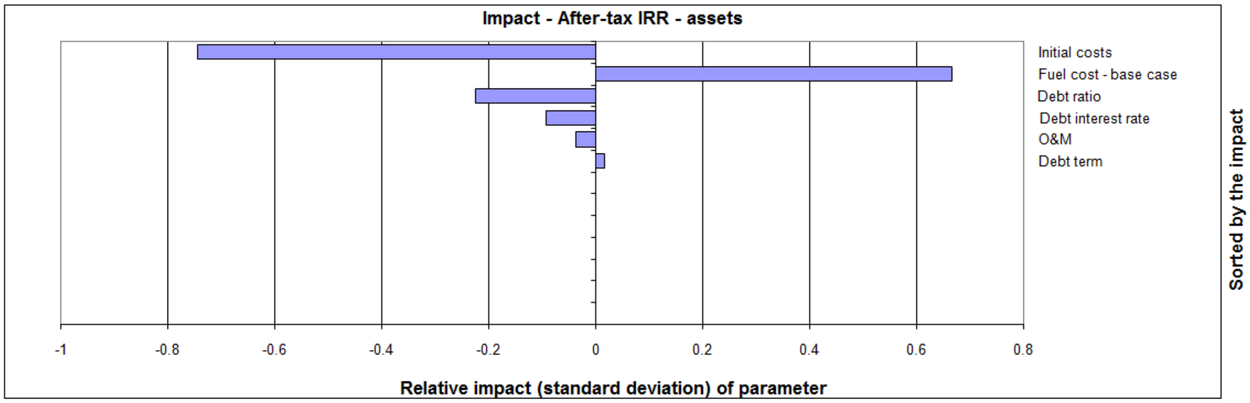


Figure 7.13 Impact on After-tax IRR-asset for well P1-PW09

For well P1-BTW07

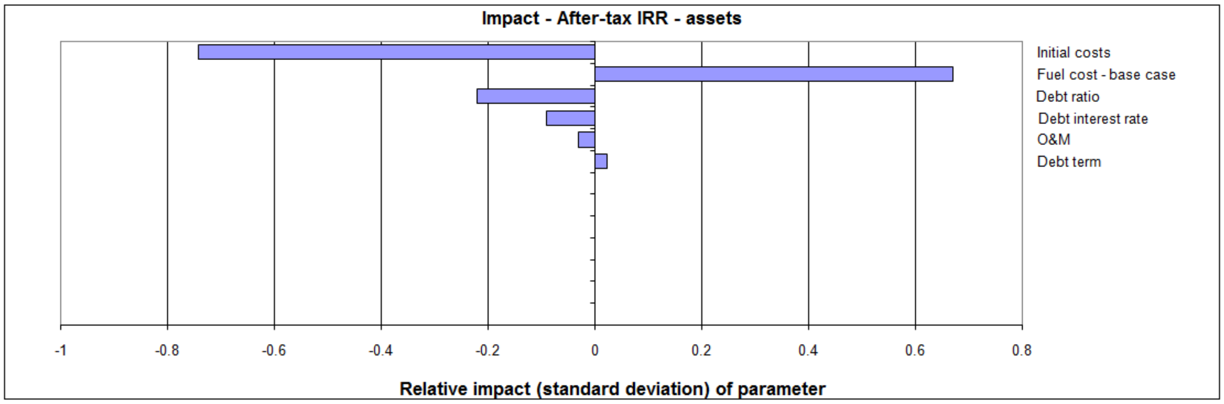


Figure 7.14 Impact on After-tax IRR-asset for well P1-BTW07

7.5.1.3 Impact of Input Parameters on Equity Payback

The impact of input parameters on equity payback is given in figures 7.15, 7.16 and 7.17 for each well.

The figures shows the impact of initial cost and base-case fuel cost are higher than the rest input parameters. Since base-case fuel cost lay on the negative side of the horizontal bar an increasing of this value will reduce the number of years to equity pay back and vise versa for initial cost. This implies big attention has to be given to these parameters in order to minimize over estimation of the project payback period.

For well P1-PW08

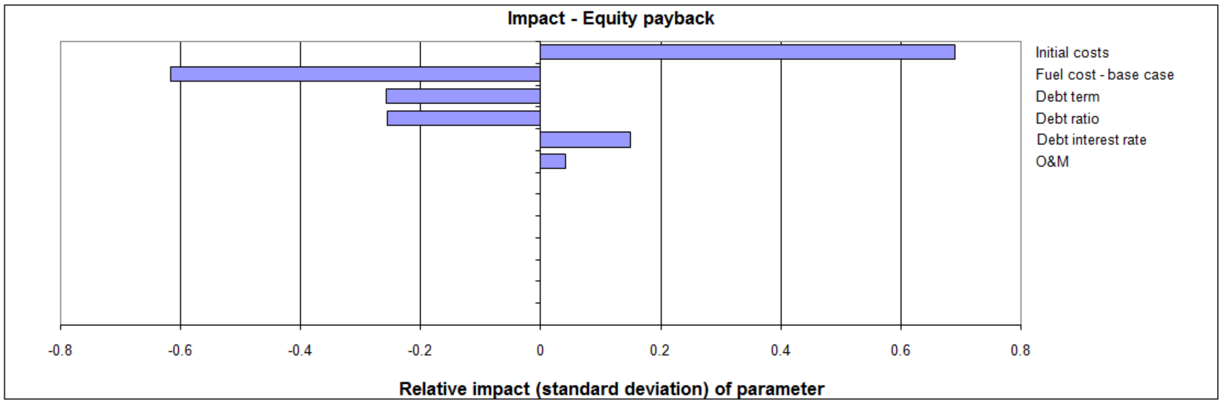


Figure 7.15 Impact on Equity payback for well P1-PW08

For well P1-PW09

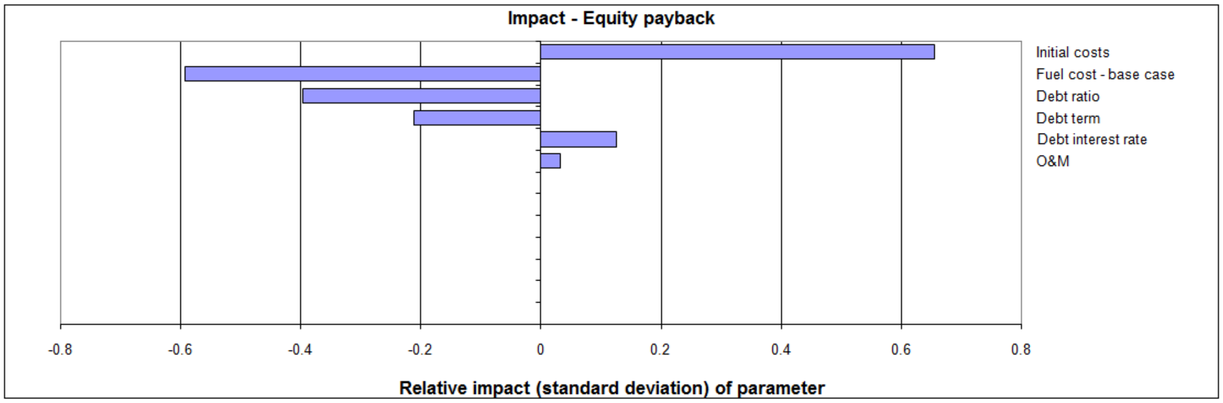


Figure 7.16 Impact on Equity payback for well P1-PW09

For well P1-BTW07

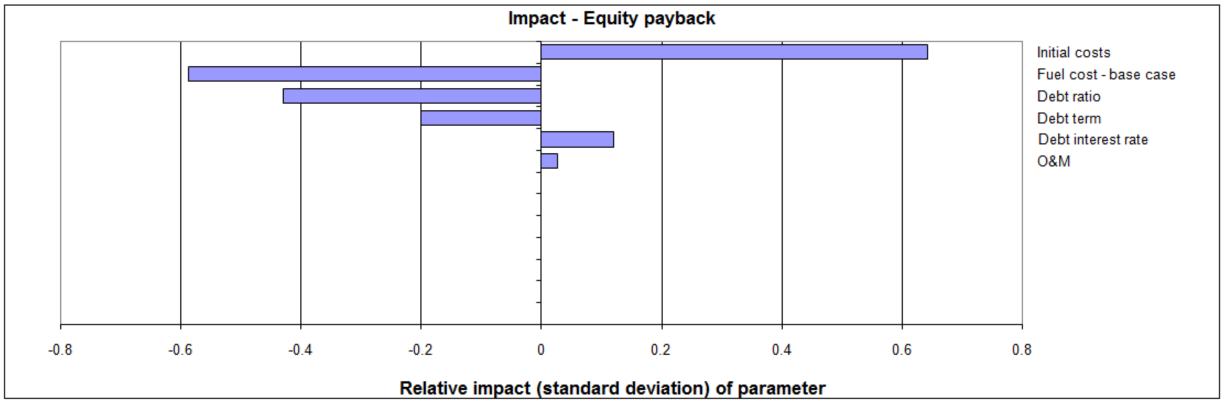


Figure 7.17 Impact on Equity payback for well P1-BTW07

7.5.1.4 Impact of Input Parameters on NPV

The impact of input parameters on NPV is given in figures 7.18, 7.19 and 7.20 for each well. As can be seen from the figures the impact of base-case fuel cost is more significant than the other parameters. If the base-case fuel cost is increased then the NPV will be improved whereas increasing of initial cost will reduce it.

For well P1-PW08

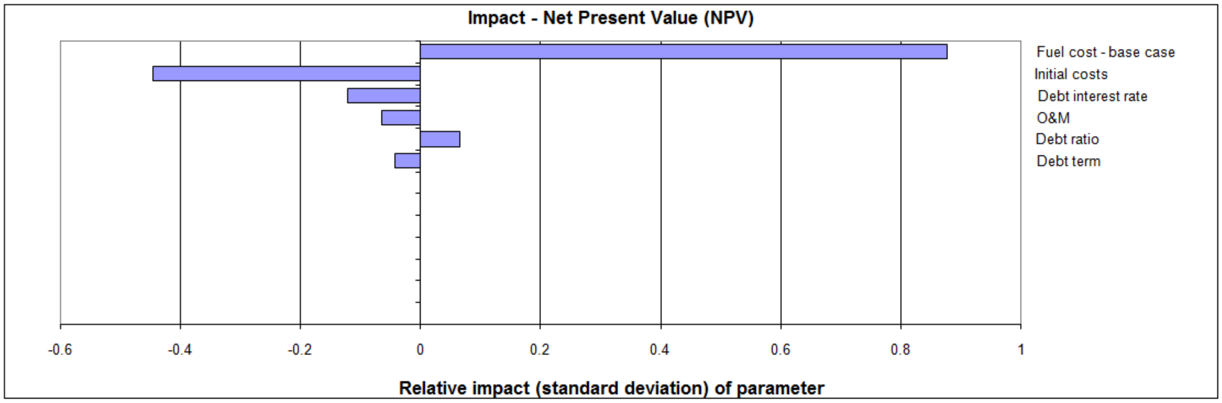


Figure 7.18 Impact on NPV for well P1-PW08

For well P1-PW09

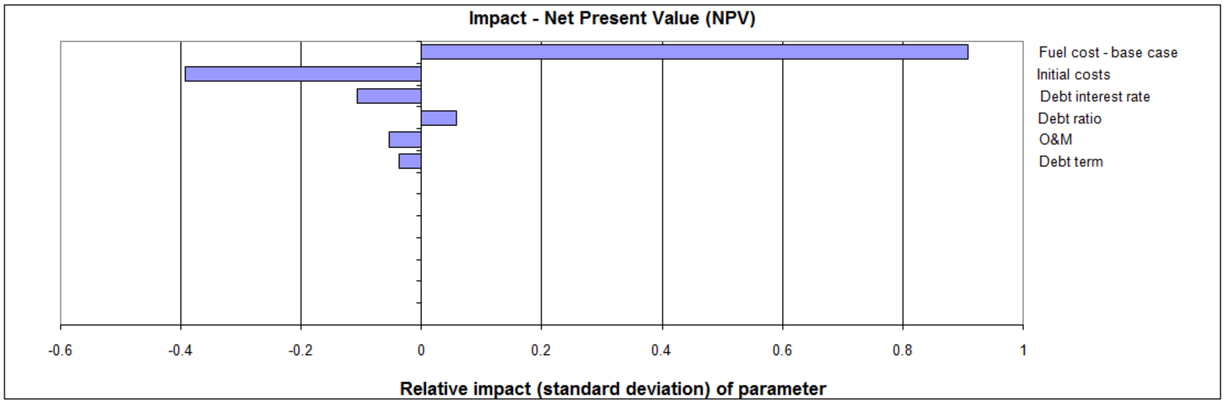


Figure 7.19 Impact on NPV for well P1-PW09

For well P1-BTW07

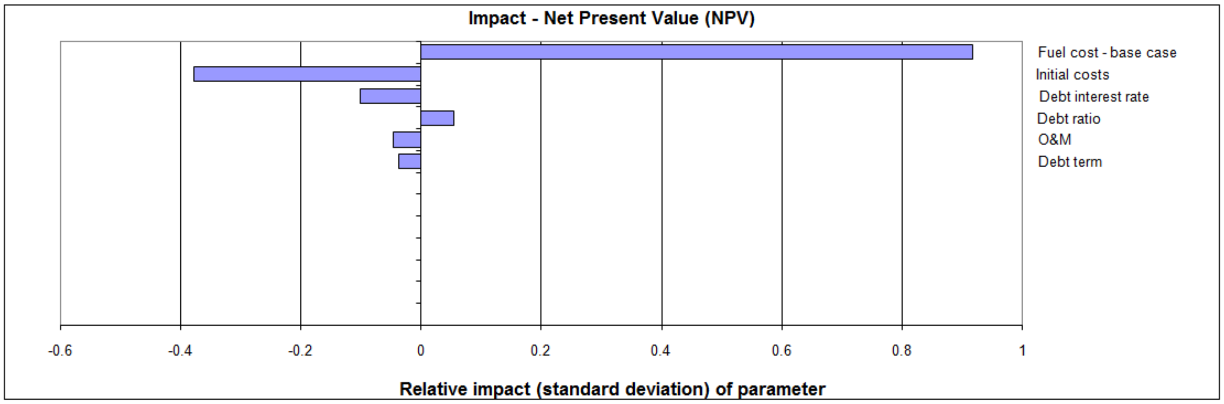


Figure 7.20 Impact on NPV for well P1-BTW07

7.5.2 Distribution Graph

This histogram provides a distribution of the possible values for the financial indicator resulting from the Monte Carlo simulation. The height of each bar represents the frequency (%) of values that fall in the range defined by the width of each bar. The value corresponding to the middle of each range is plotted on the X axis.

Looking at the distribution of financial indicator, we are able to rapidly assess its' variability.

For well P1-PW08

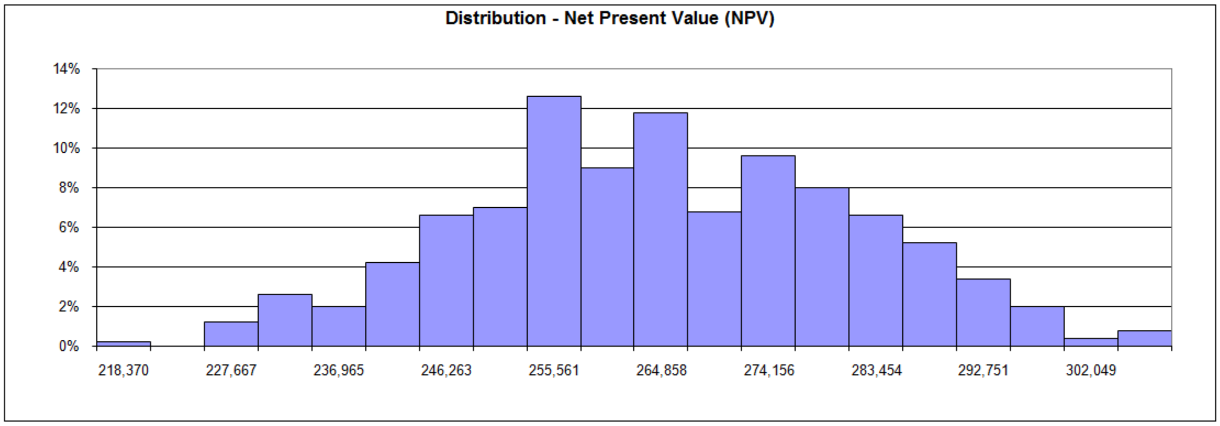


Figure 7.21 Distribution graph of NPV for well P1-PW08

For well P1-PW09

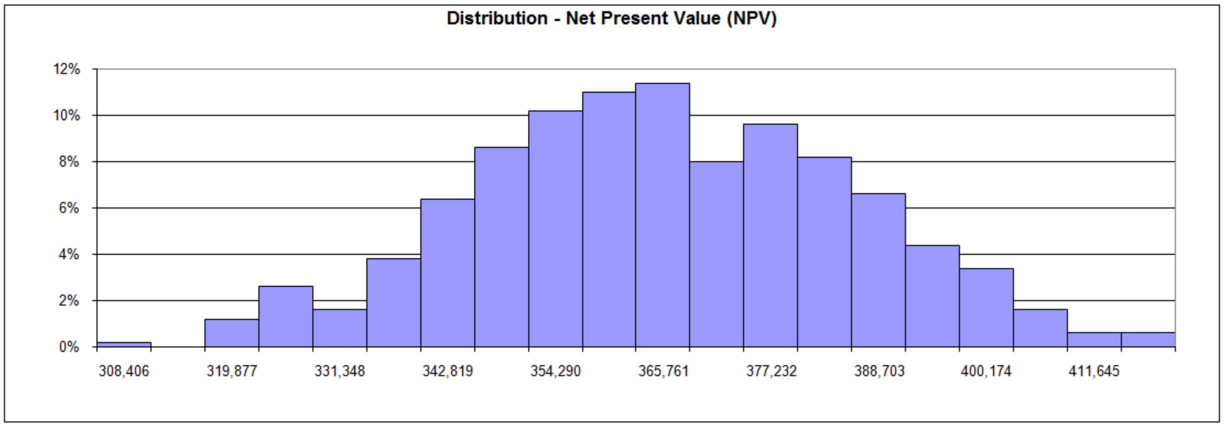


Figure 7.22 Distribution graph of NPV for well P1-PW09

For well P1-BTW07

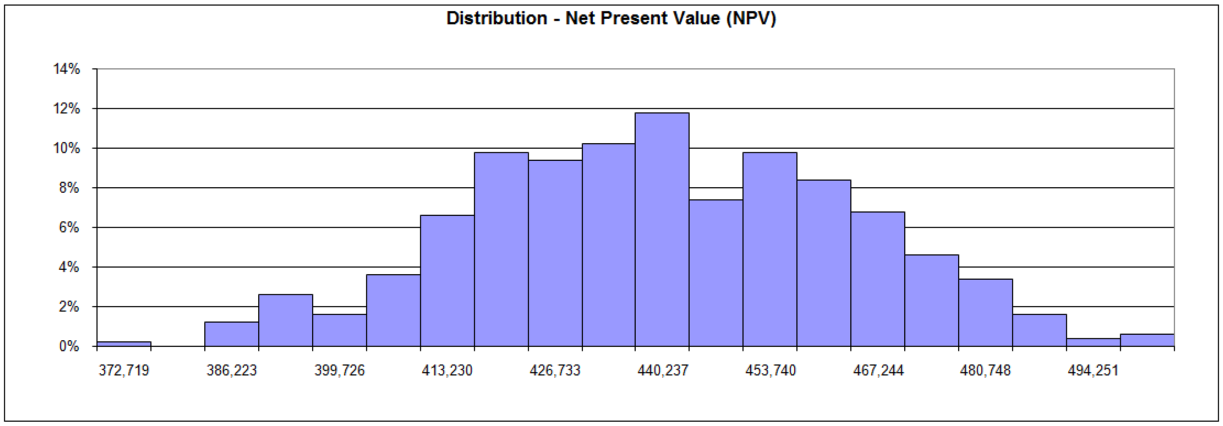


Figure 7.23 Distribution graph of NPV for well P1-BTW07

For well P1-PW08

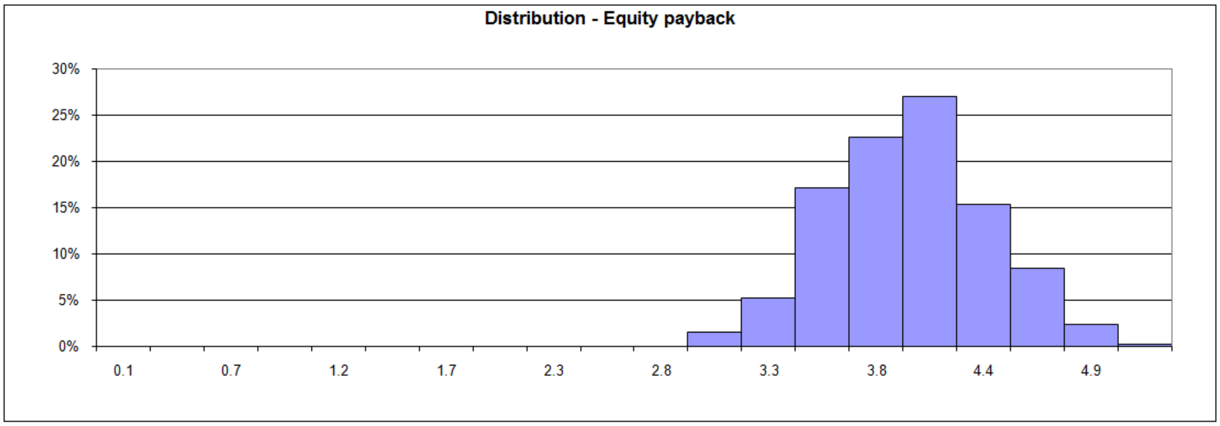


Figure 7.24 Distribution graph of Equity payback for well P1-PW08

For well P1-PW09

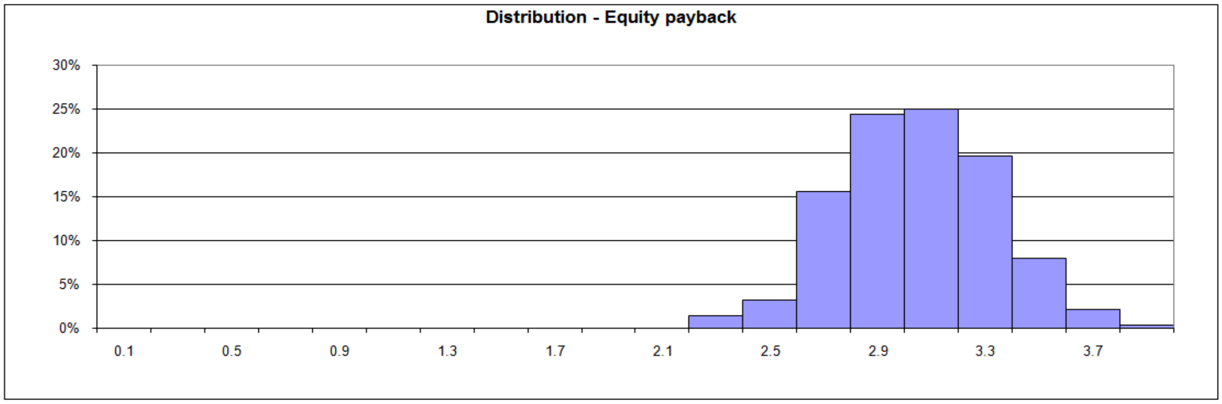


Figure 7.25 Distribution graph of Equity payback for well P1-PW09

For well P1-BTW07

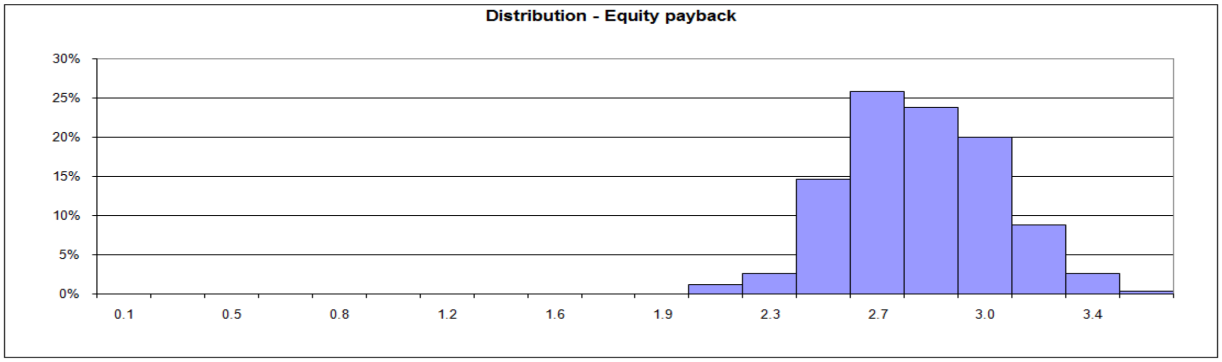


Figure 7.26 Distribution graph of Equity payback for well P1-BTW07

For well P1-PW08

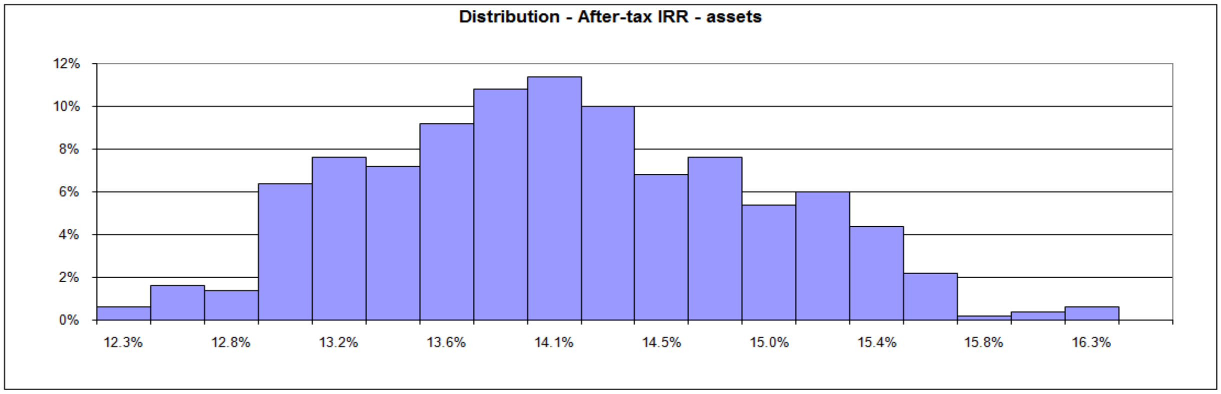


Figure 7.27 Distribution graph of After-tax IRR-asset for well P1-PW08

For well P1-PW09

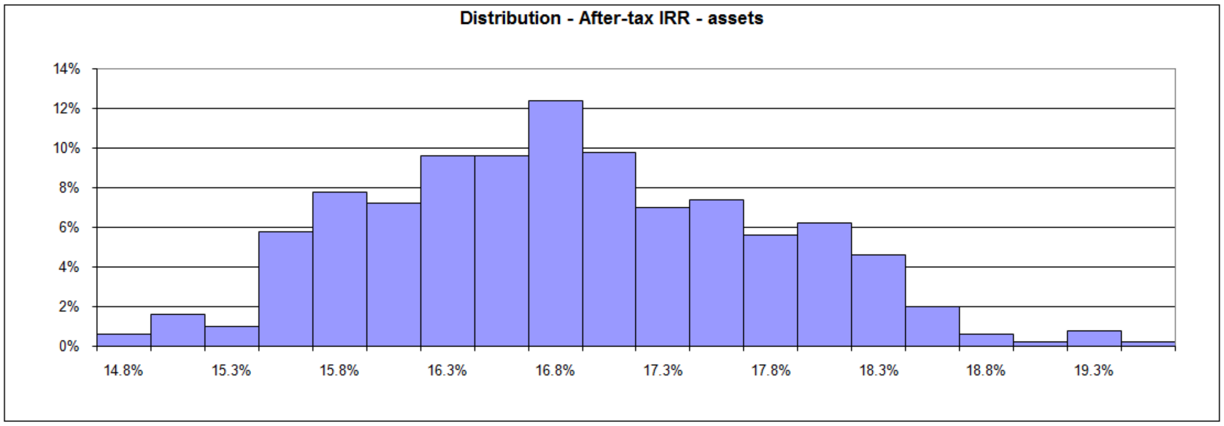


Figure 7.28 Distribution graph of After-tax IRR-asset for well P1-PW09

For well P1-BTW07

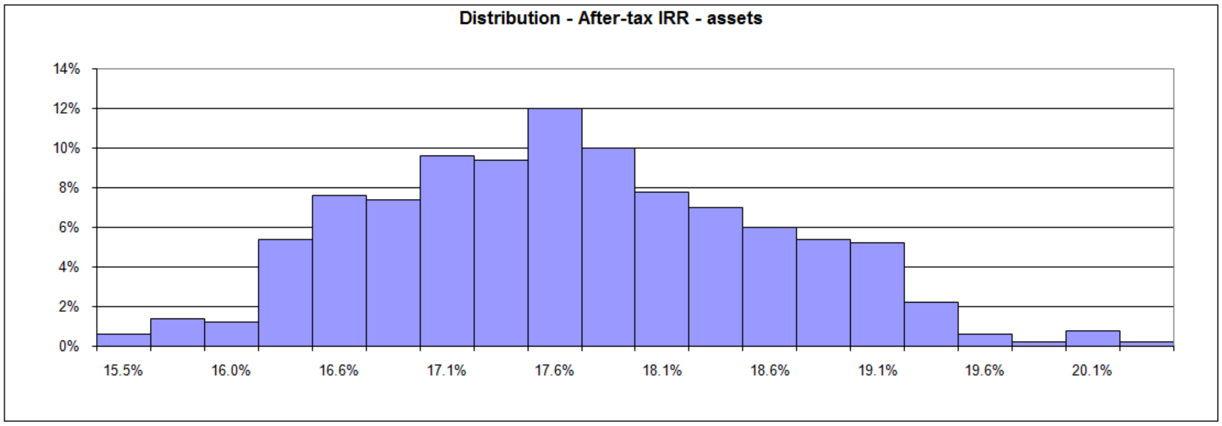


Figure 7.29 Distribution graph of After-tax IRR-asset for well P1-BTW07

For well P1-PW08

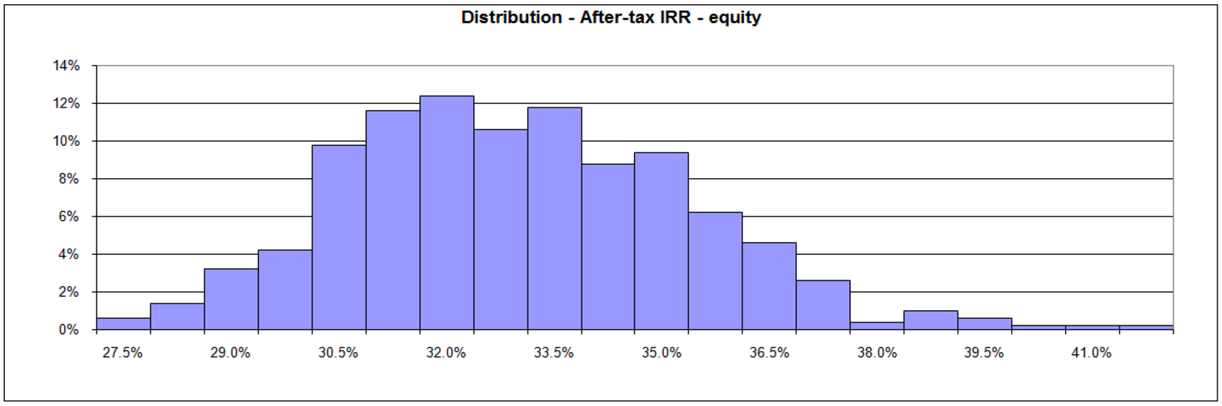


Figure 7.30 Distribution graph of After-tax IRR-equity for well P1-PW08

For well P1-PW09

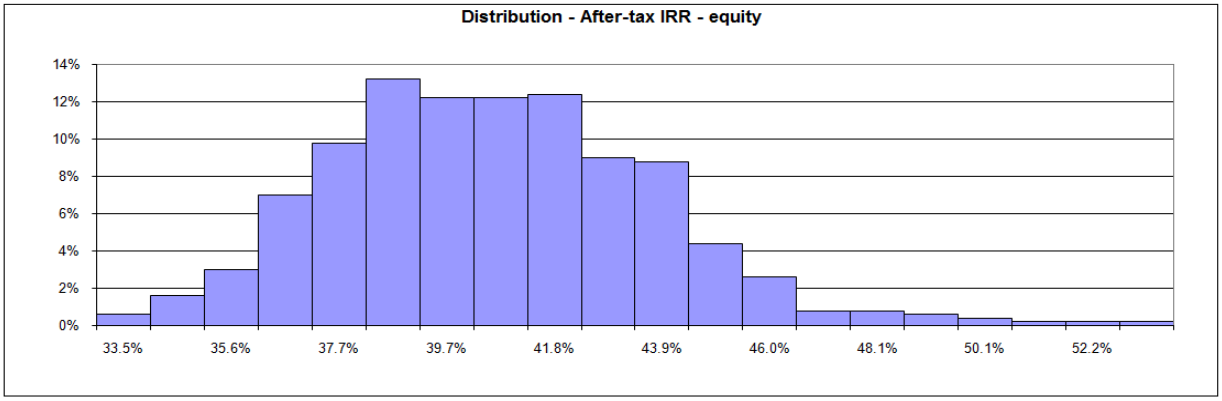


Figure 7.31 Distribution graph of After-tax IRR-equity for well P1-PW09

For well P1-BTW07

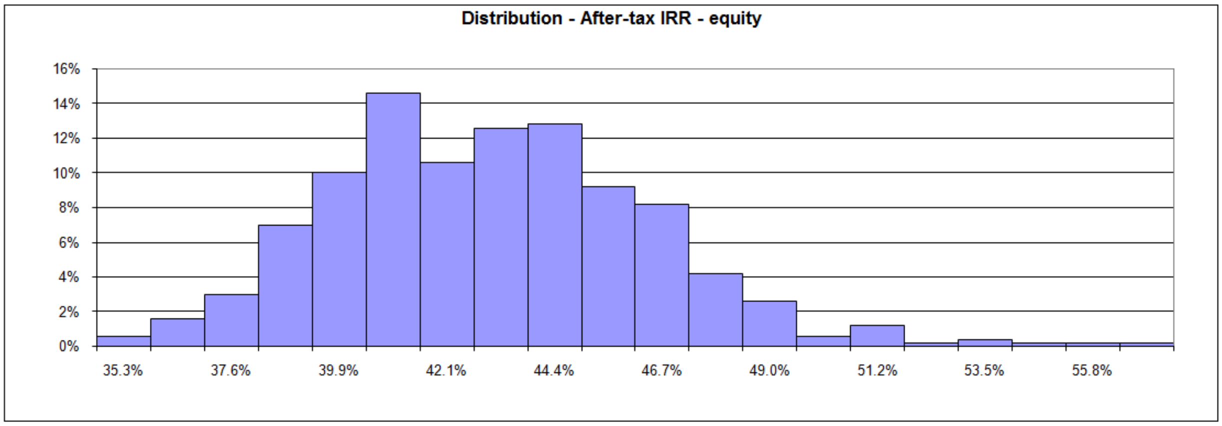


Figure 7.32 Distribution graph of After-tax IRR-equity for well P1-BTW07

7.5.3 Sensitivity Analysis

This section presents the results of the sensitivity analysis. Each table shows what happens to the selected financial indicator (e.g. After-tax IRR - equity) when two key parameters (e.g. Initial costs and O&M) are varied by the indicated percentages.

In the sensitivity analysis the projects economical calculations are presented in tables where different components of the calculations are highlighted and their effect on the final outcome is discussed.

The threshold is the value under which (for the "After-tax IRR - equity," "After-tax IRR - assets" and "Net Present Value (NPV)") or over which (for "Equity payback") the project designer considers that the proposed project is not financially viable. Results which indicate an unviable project, as defined by the threshold, will appear as orange cells in the sensitivity analysis results tables.

Table 7.9, 7.10 and 7.11 show what happens to After-tax IRR -asset when Initial costs and fuel cost-base case are varied by the indicated percentages.

- **Case I Sensetivity range = 10% and Threshold = 11%**

Sensitivity of After-tax IRR-asset when Initial costs and fuel cost-base case are varied

Table 7.9 Sensitivity of After-tax IRR-asset when Initial costs and fuel cost-base case are varied for well P1-PW08

			Initial costs			$
Fuel cost - base case		214,034	225,925	237,815	249,706	261,597
$		-10%	-5%	0%	5%	10%
32,507	-10%	14.1%	13.2%	12.3%	11.5%	10.8%
34,313	-5%	15.0%	14.0%	13.1%	12.3%	11.6%
36,119	0%	15.9%	14.9%	**14.0%**	13.1%	12.4%
37,925	5%	16.7%	15.7%	14.8%	13.9%	13.1%
39,731	10%	17.6%	16.5%	15.6%	14.7%	13.9%

Table 7.10 Sensitivity of After-tax IRR-asset when Initial costs and fuel cost-base case are varied for well P1-PW09

			Initial costs			$
Fuel cost - base case		228,228	240,907	253,587	266,266	278,945
$		-10%	-5%	0%	5%	10%
40,788	-10%	16.8%	15.8%	14.8%	14.0%	13.2%
43,054	-5%	17.8%	16.8%	15.8%	14.9%	14.1%
45,320	0%	18.8%	17.7%	**16.7%**	15.8%	14.9%
47,586	5%	19.8%	18.7%	17.6%	16.7%	15.8%
49,852	10%	20.8%	19.6%	18.5%	17.5%	16.6%

Table 7.11 Sensitivity of After-tax IRR-asset when Initial costs and fuel cost-base case are varied for well P1-BTW07

			Initial costs			$
Fuel cost - base case		257,243	271,534	285,825	300,117	314,408
$		-10%	-5%	0%	5%	10%
48,262	-10%	17.6%	16.5%	15.6%	14.7%	13.9%
50,944	-5%	18.7%	17.6%	16.5%	15.6%	14.8%
53,625	0%	19.7%	18.6%	**17.5%**	16.6%	15.7%
56,306	5%	20.8%	19.6%	18.5%	17.5%	16.6%
58,987	10%	21.8%	20.6%	19.4%	18.4%	17.4%

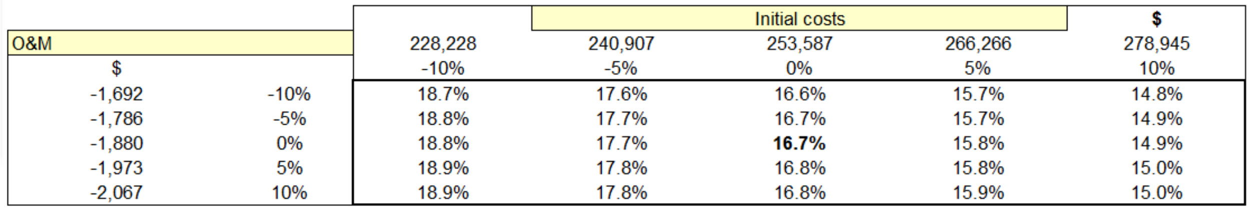
7.5.3.1 Sensitivity of After-tax IRR-asset when Initial costs and O&M costs are varied

Table 7.12, 7.13 and 7.14 show what happens to After-tax IRR-asset when Initial costs and O&M are varied by the indicated percentages.

Table 7.12 Sensitivity of After-tax IRR-asset when Initial costs and O&M costs are varied for well P1-PW08

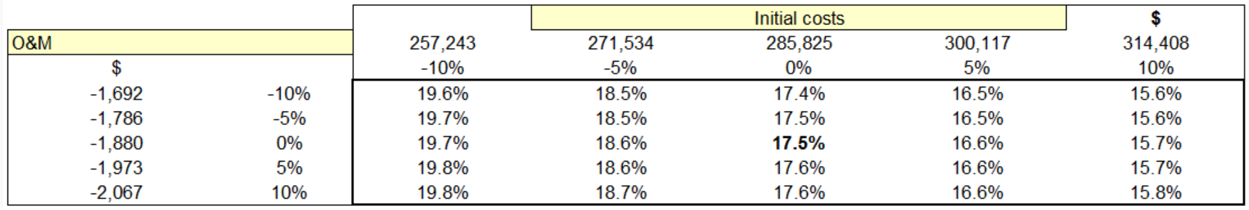
			Initial costs			$
O&M		214,034	225,925	237,815	249,706	261,597
$		-10%	-5%	0%	5%	10%
-1,692	-10%	15.7%	14.8%	13.9%	13.0%	12.3%
-1,786	-5%	15.8%	14.8%	13.9%	13.1%	12.3%
-1,880	0%	15.9%	14.9%	**14.0%**	13.1%	12.4%
-1,973	5%	15.9%	14.9%	14.0%	13.2%	12.4%
-2,067	10%	16.0%	15.0%	14.1%	13.2%	12.5%

Table 7.13 Sensitivity of After-tax IRR-asset when Initial costs and O&M costs are varied for well P1-PW09



			Initial costs			$
O&M		228,228	240,907	253,587	266,266	278,945
$		-10%	-5%	0%	5%	10%
-1,692	-10%	18.7%	17.6%	16.6%	15.7%	14.8%
-1,786	-5%	18.8%	17.7%	16.7%	15.7%	14.9%
-1,880	0%	18.8%	17.7%	**16.7%**	15.8%	14.9%
-1,973	5%	18.9%	17.8%	16.8%	15.8%	15.0%
-2,067	10%	18.9%	17.8%	16.8%	15.9%	15.0%

Table 7.14 Sensitivity of After-tax IRR-asset when Initial costs and O&M costs are varied for well P1-BTW07

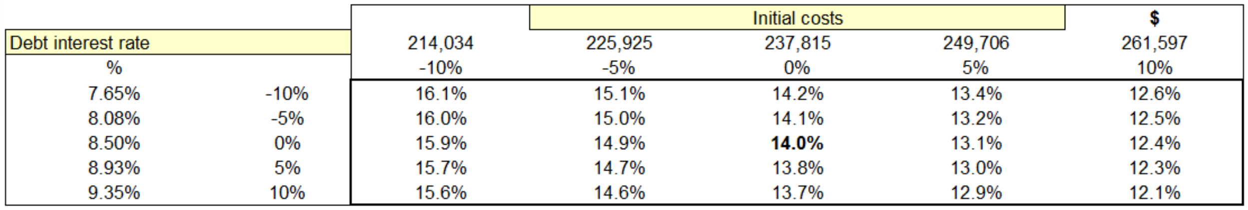


			Initial costs			$
O&M		257,243	271,534	285,825	300,117	314,408
$		-10%	-5%	0%	5%	10%
-1,692	-10%	19.6%	18.5%	17.4%	16.5%	15.6%
-1,786	-5%	19.7%	18.5%	17.5%	16.5%	15.6%
-1,880	0%	19.7%	18.6%	**17.5%**	16.6%	15.7%
-1,973	5%	19.8%	18.6%	17.6%	16.6%	15.7%
-2,067	10%	19.8%	18.7%	17.6%	16.6%	15.8%

7.5.3.2 Sensitivity of After-tax IRR-asset when Initial costs and Debt interest rate are varied

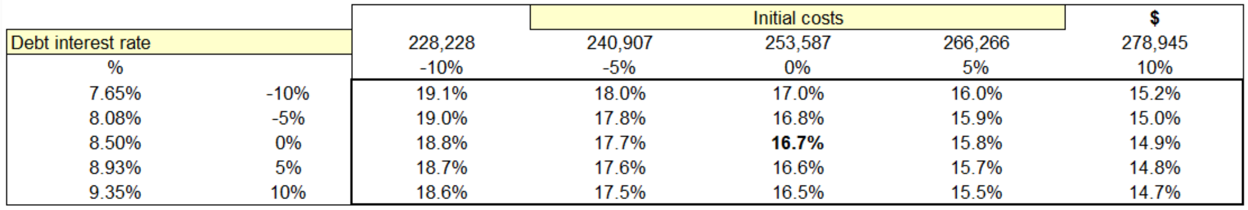
Table 7.15, 7.16 and 7.17 show what happens to After-tax IRR asset when Initial costs and debt interest rate are varied by the indicated percentages.

Table 7.15 Sensitivity of After-tax IRR-asset when Initial costs and debt interest rate are varied for well P1-PW08



			Initial costs			$
Debt interest rate		214,034	225,925	237,815	249,706	261,597
%		-10%	-5%	0%	5%	10%
7.65%	-10%	16.1%	15.1%	14.2%	13.4%	12.6%
8.08%	-5%	16.0%	15.0%	14.1%	13.2%	12.5%
8.50%	0%	15.9%	14.9%	**14.0%**	13.1%	12.4%
8.93%	5%	15.7%	14.7%	13.8%	13.0%	12.3%
9.35%	10%	15.6%	14.6%	13.7%	12.9%	12.1%

Table 7.16 Sensitivity of After-tax IRR-asset when Initial costs and debt interest rate are varied for well P1-PW09



			Initial costs			$
Debt interest rate		228,228	240,907	253,587	266,266	278,945
%		-10%	-5%	0%	5%	10%
7.65%	-10%	19.1%	18.0%	17.0%	16.0%	15.2%
8.08%	-5%	19.0%	17.8%	16.8%	15.9%	15.0%
8.50%	0%	18.8%	17.7%	**16.7%**	15.8%	14.9%
8.93%	5%	18.7%	17.6%	16.6%	15.7%	14.8%
9.35%	10%	18.6%	17.5%	16.5%	15.5%	14.7%

Table 6.17 Sensitivity of After-tax IRR-asset when Initial costs and debt interest rate are varied for well P1-BTW07

				Initial costs		$
Debt interest rate		257,243	271,534	285,825	300,117	314,408
%		-10%	-5%	0%	5%	10%
7.65%	-10%	20.0%	18.8%	17.8%	16.8%	15.9%
8.08%	-5%	19.9%	18.7%	17.6%	16.7%	15.8%
8.50%	0%	19.7%	18.6%	**17.5%**	16.6%	15.7%
8.93%	5%	19.6%	18.4%	17.4%	16.4%	15.6%
9.35%	10%	19.5%	18.3%	17.3%	16.3%	15.4%

7.5.3.3 Sensitivity of Equity Payback when Initial costs and Fuel cost-base case are varied

Table 7.18, 7.19 and 7.20 show what happens to equity pay back when Initial costs and fuel cost-base case are varied by the indicated percentages.

Table 7.18 Sensitivity of equity payback when Initial costs and fuel cost-base case are varied for well P1-PW08

Perform analysis on	Equity payback	
Sensitivity range	10%	
Threshold	5	yr

				Initial costs		$
Fuel cost - base case		214,034	225,925	237,815	249,706	261,597
$		-10%	-5%	0%	5%	10%
32,507	-10%	4.0	4.4	4.9	5.4	5.9
34,313	-5%	3.6	4.0	4.4	4.9	5.3
36,119	0%	3.3	3.6	**4.0**	4.4	4.8
37,925	5%	3.0	3.3	3.7	4.0	4.4
39,731	10%	2.8	3.1	3.4	3.7	4.0

Table 7.19 Sensitivity of equity payback when Initial costs and fuel cost-base case are varied for well P1-PW09

				Initial costs		$
Fuel cost - base case		228,228	240,907	253,587	266,266	278,945
$		-10%	-5%	0%	5%	10%
40,788	-10%	3.0	3.3	3.6	4.0	4.4
43,054	-5%	2.7	3.0	3.3	3.6	3.9
45,320	0%	2.5	2.8	**3.0**	3.3	3.6
47,586	5%	2.3	2.5	2.8	3.0	3.3
49,852	10%	2.2	2.4	2.6	2.8	3.0

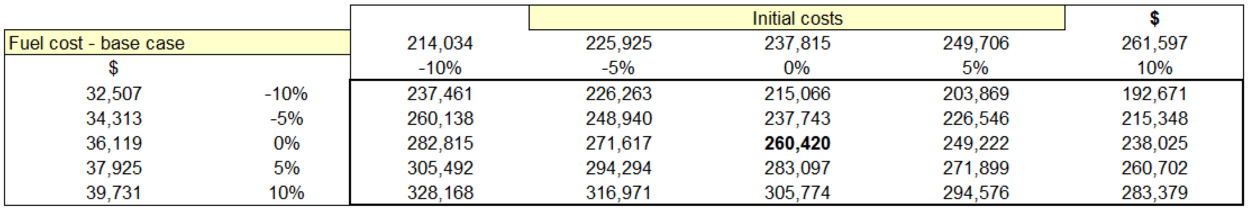
Table 7.20 Sensitivity of equity payback when Initial costs and fuel cost-base case are varied for well P1-BTW07

				Initial costs		$
Fuel cost - base case		257,243	271,534	285,825	300,117	314,408
$		-10%	-5%	0%	5%	10%
48,262	-10%	2.8	3.1	3.4	3.7	4.0
50,944	-5%	2.5	2.8	3.1	3.3	3.6
53,625	0%	2.3	2.6	**2.8**	3.1	3.3
56,306	5%	2.2	2.4	2.6	2.8	3.1
58,987	10%	2.0	2.2	2.4	2.6	2.8

7.5.3.4 Sensitivity of NPV when Initial costs and Fuel cost-base case are varied

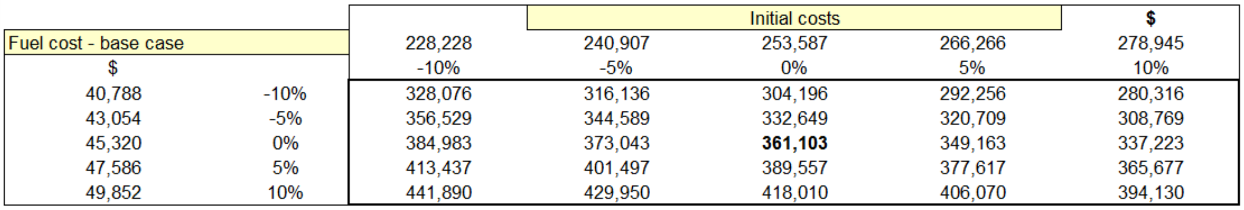
Table 7.21, 7.22 and 7.23 show what happens to NPV when Initial costs and fuel cost-base case are varied by the indicated percentages.

Table 7.21 Sensitivity of NPV when Initial costs and fuel cost-base case are varied for well P1-PW08



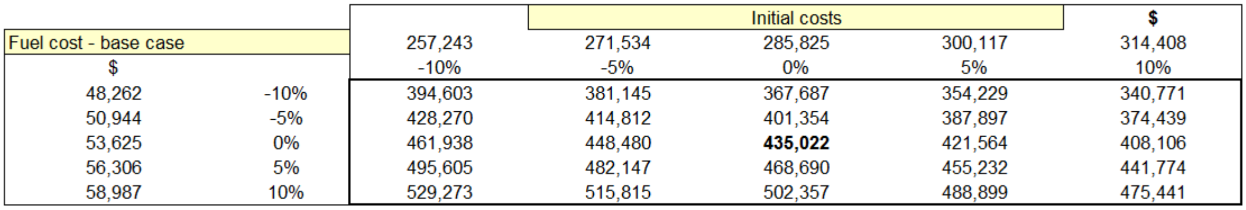
				Initial costs		$
Fuel cost - base case		214,034	225,925	237,815	249,706	261,597
$		-10%	-5%	0%	5%	10%
32,507	-10%	237,461	226,263	215,066	203,869	192,671
34,313	-5%	260,138	248,940	237,743	226,546	215,348
36,119	0%	282,815	271,617	**260,420**	249,222	238,025
37,925	5%	305,492	294,294	283,097	271,899	260,702
39,731	10%	328,168	316,971	305,774	294,576	283,379

Table 7.22 Sensitivity of NPV when Initial costs and fuel cost-base case are varied for well P1-PW08



				Initial costs		$
Fuel cost - base case		228,228	240,907	253,587	266,266	278,945
$		-10%	-5%	0%	5%	10%
40,788	-10%	328,076	316,136	304,196	292,256	280,316
43,054	-5%	356,529	344,589	332,649	320,709	308,769
45,320	0%	384,983	373,043	**361,103**	349,163	337,223
47,586	5%	413,437	401,497	389,557	377,617	365,677
49,852	10%	441,890	429,950	418,010	406,070	394,130

Table 7.23 Sensitivity of NPV when Initial costs and fuel cost-base case are varied for well P1-BTW07

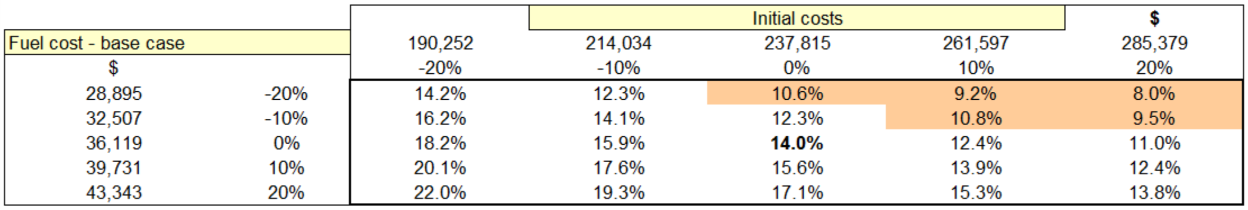


				Initial costs		$
Fuel cost - base case		257,243	271,534	285,825	300,117	314,408
$		-10%	-5%	0%	5%	10%
48,262	-10%	394,603	381,145	367,687	354,229	340,771
50,944	-5%	428,270	414,812	401,354	387,897	374,439
53,625	0%	461,938	448,480	**435,022**	421,564	408,106
56,306	5%	495,605	482,147	468,690	455,232	441,774
58,987	10%	529,273	515,815	502,357	488,899	475,441

- **Case II Sensetivity range = 20% and Threshold = 11%**

7.5.3.5 Sensitivity of After-tax IRR-asset when Sensitivity range is 20%

Table 7.24 Sensitivity of After-tax IRR-asset when Initial costs and fuel cost-base case are varied for well P1-PW08



				Initial costs		$
Fuel cost - base case		190,252	214,034	237,815	261,597	285,379
$		-20%	-10%	0%	10%	20%
28,895	-20%	14.2%	12.3%	10.6%	9.2%	8.0%
32,507	-10%	16.2%	14.1%	12.3%	10.8%	9.5%
36,119	0%	18.2%	15.9%	**14.0%**	12.4%	11.0%
39,731	10%	20.1%	17.6%	15.6%	13.9%	12.4%
43,343	20%	22.0%	19.3%	17.1%	15.3%	13.8%

Table 7.25 Sensitivity of After-tax IRR-asset when Initial costs and fuel cost-base case are varied for well P1-PW09

				Initial costs		$
Fuel cost - base case		202,869	228,228	253,587	278,945	304,304
$		-20%	-10%	0%	10%	20%
36,256	-20%	16.9%	14.7%	12.9%	11.4%	10.1%
40,788	-10%	19.2%	16.8%	14.8%	13.2%	11.8%
45,320	0%	21.5%	18.8%	**16.7%**	14.9%	13.4%
49,852	10%	23.7%	20.8%	18.5%	16.6%	15.0%
54,384	20%	25.9%	22.8%	20.3%	18.3%	16.5%

Table 7.26 Sensitivity of After-tax IRR-asset when Initial costs and fuel cost-base case are varied for well P1-BTW07

				Initial costs		$
Fuel cost - base case		228,660	257,243	285,825	314,408	342,991
$		-20%	-10%	0%	10%	20%
42,900	-20%	17.7%	15.5%	13.6%	12.0%	10.7%
48,262	-10%	20.1%	17.6%	15.6%	13.9%	12.4%
53,625	0%	22.4%	19.7%	**17.5%**	15.7%	14.1%
58,987	10%	24.8%	21.8%	19.4%	17.4%	15.8%
64,350	20%	27.1%	23.9%	21.3%	19.2%	17.4%

Table 7.27 Sensitivity of After-tax IRR-asset when Initial costs and O&M costs are varied for well P1-PW08

				Initial costs		$
O&M		190,252	214,034	237,815	261,597	285,379
$		-20%	-10%	0%	10%	20%
-1,504	-20%	17.9%	15.6%	13.7%	12.2%	10.8%
-1,692	-10%	18.0%	15.7%	13.9%	12.3%	10.9%
-1,880	0%	18.2%	15.9%	**14.0%**	12.4%	11.0%
-2,067	10%	18.3%	16.0%	14.1%	12.5%	11.1%
-2,255	20%	18.4%	16.1%	14.2%	12.6%	11.2%

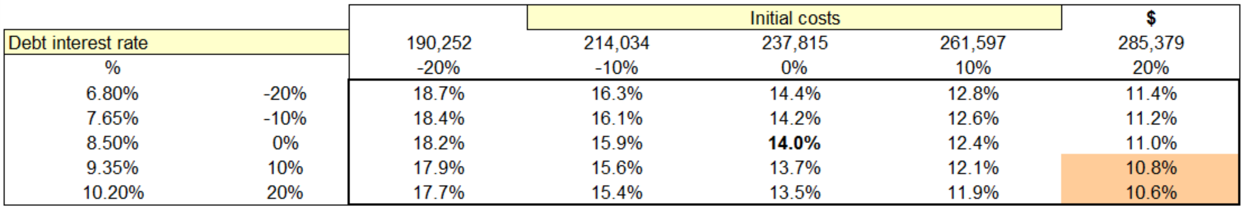
Table 7.28 Sensitivity of After-tax IRR-asset when Initial costs and O&M costs are varied for well P1-PW09

				Initial costs		$
O&M		202,869	228,228	253,587	278,945	304,304
$		-20%	-10%	0%	10%	20%
-1,504	-20%	21.2%	18.6%	16.5%	14.7%	13.2%
-1,692	-10%	21.3%	18.7%	16.6%	14.8%	13.3%
-1,880	0%	21.5%	18.8%	**16.7%**	14.9%	13.4%
-2,067	10%	21.6%	18.9%	16.8%	15.0%	13.5%
-2,255	20%	21.7%	19.0%	16.9%	15.1%	13.6%

Table 7.29 Sensitivity of After-tax IRR-asset when Initial costs and O&M costs are varied for well P1-BTW07

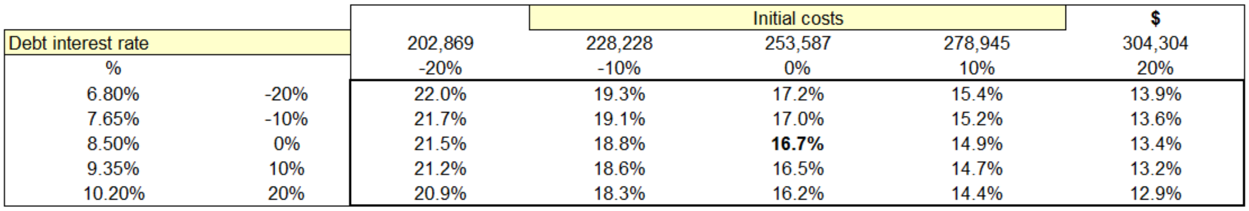
				Initial costs		$
O&M		228,660	257,243	285,825	314,408	342,991
$		-20%	-10%	0%	10%	20%
-1,504	-20%	22.2%	19.5%	17.3%	15.5%	14.0%
-1,692	-10%	22.3%	19.6%	17.4%	15.6%	14.0%
-1,880	0%	22.4%	19.7%	**17.5%**	15.7%	14.1%
-2,067	10%	22.5%	19.8%	17.6%	15.8%	14.2%
-2,255	20%	22.6%	19.9%	17.7%	15.8%	14.3%

Table 7.30 Sensitivity of After-tax IRR-asset when Initial costs and debt interest rate are varied for well P1-PW08



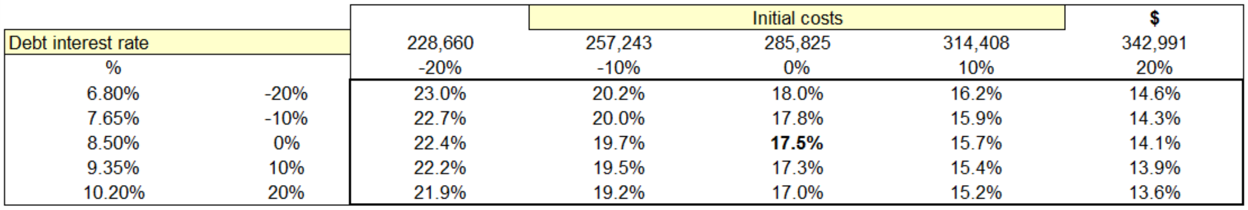
				Initial costs		$
Debt interest rate		190,252	214,034	237,815	261,597	285,379
%		-20%	-10%	0%	10%	20%
6.80%	-20%	18.7%	16.3%	14.4%	12.8%	11.4%
7.65%	-10%	18.4%	16.1%	14.2%	12.6%	11.2%
8.50%	0%	18.2%	15.9%	**14.0%**	12.4%	11.0%
9.35%	10%	17.9%	15.6%	13.7%	12.1%	10.8%
10.20%	20%	17.7%	15.4%	13.5%	11.9%	10.6%

Table 7.31 Sensitivity of After-tax IRR-asset when Initial costs and debt interest rate are varied for well P1-PW09



				Initial costs		$
Debt interest rate		202,869	228,228	253,587	278,945	304,304
%		-20%	-10%	0%	10%	20%
6.80%	-20%	22.0%	19.3%	17.2%	15.4%	13.9%
7.65%	-10%	21.7%	19.1%	17.0%	15.2%	13.6%
8.50%	0%	21.5%	18.8%	**16.7%**	14.9%	13.4%
9.35%	10%	21.2%	18.6%	16.5%	14.7%	13.2%
10.20%	20%	20.9%	18.3%	16.2%	14.4%	12.9%

Table 7.32 Sensitivity of After-tax IRR-asset when Initial costs and debt interest rate are varied for well P1-BTW07



				Initial costs		$
Debt interest rate		228,660	257,243	285,825	314,408	342,991
%		-20%	-10%	0%	10%	20%
6.80%	-20%	23.0%	20.2%	18.0%	16.2%	14.6%
7.65%	-10%	22.7%	20.0%	17.8%	15.9%	14.3%
8.50%	0%	22.4%	19.7%	**17.5%**	15.7%	14.1%
9.35%	10%	22.2%	19.5%	17.3%	15.4%	13.9%
10.20%	20%	21.9%	19.2%	17.0%	15.2%	13.6%

7.6 Summary of Financial Analysis

Table 7.33 Summary of financial analysis

S/n	Well description	PW_{DG} [$]	PW_{PV} [$]	NPV [$]	B-C	ALCS [$/year]	GRC [$/$tco_2$]	PBP [year]		IRR [%]		UWC [$/$m^3$]	
								Simple	Equity	Asset	Equity	DG	PV
1	P1-PW8	392599	274715	260420	4.6	31174	362	6.3	4	14	32.6	0.58	0.41
2	P1-PW9	469461	289459	361103	5.7	43226	425	5.4	3	16.7	40.2	0.69	0.43
3	P1-BTW7	538839	331555	435022	6.1	52075	426	5.1	2.8	17.5	42.6	0.79	0.49

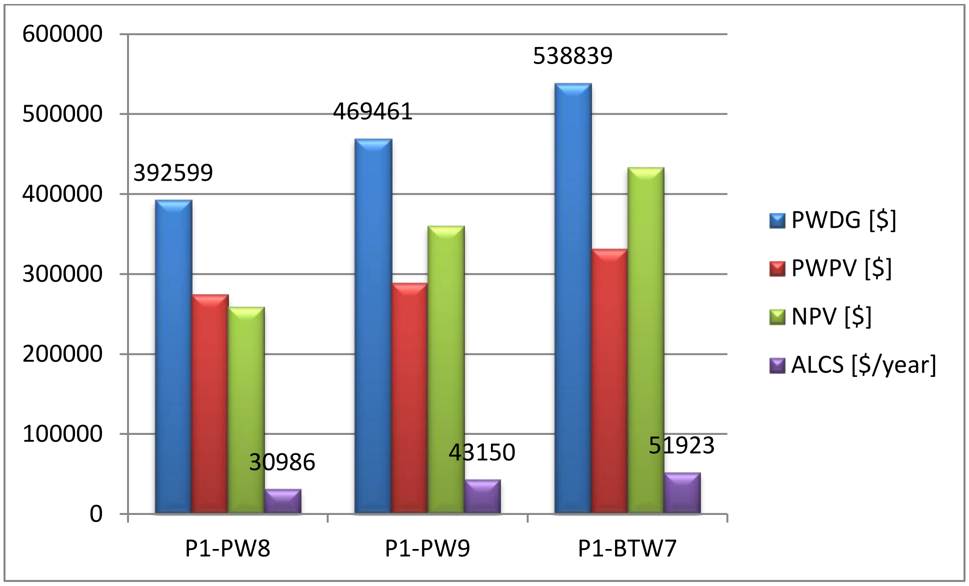


Figure 7.33 Comparison of PW, NPV and ALCS for three wells

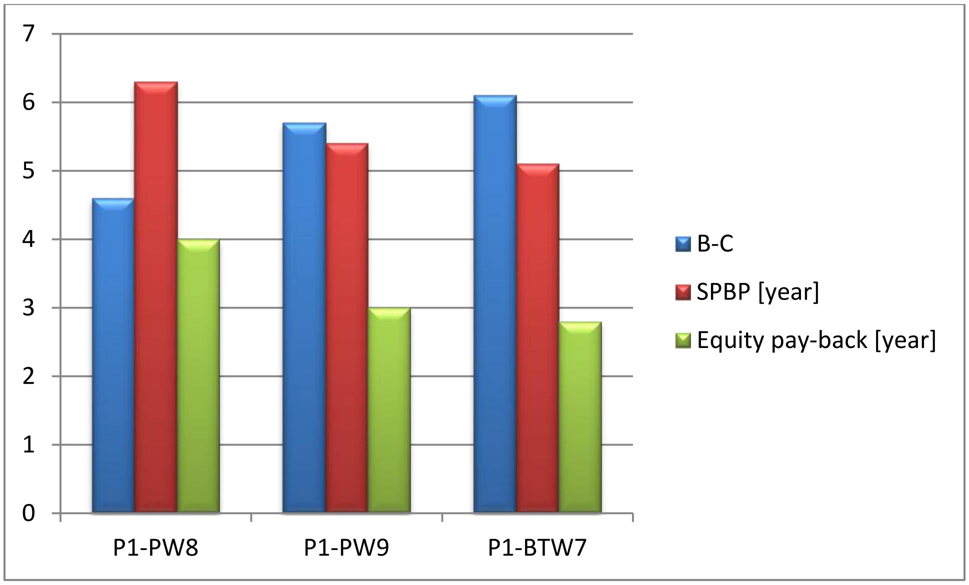


Figure 7.34 Comparison of B-C, SPBP and equity pay-back for all wells

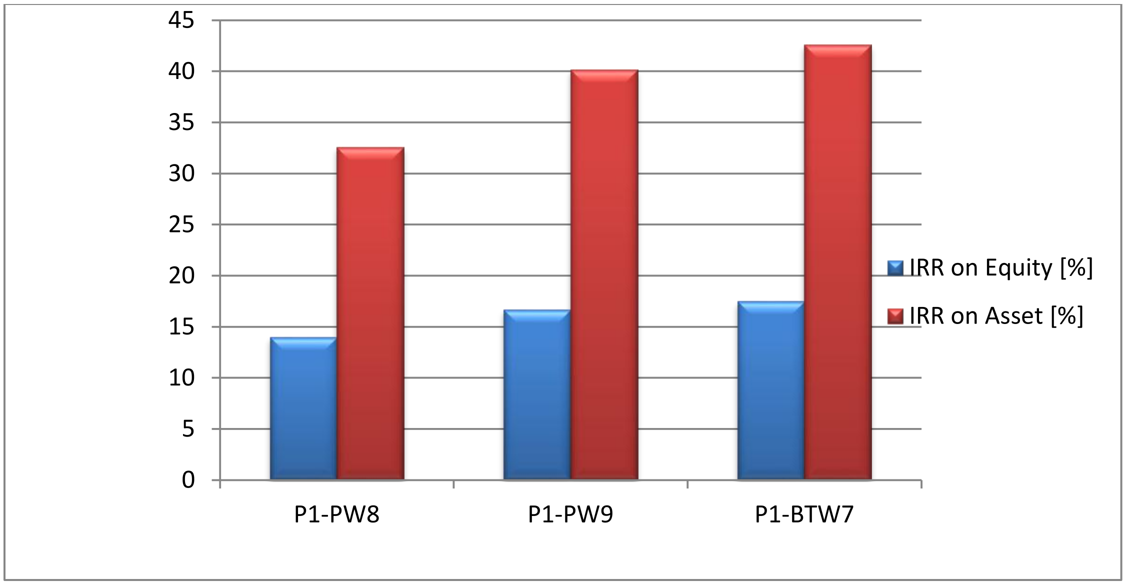


Figure 7.35 IRR on equity and IRR on asset comparison for all wells

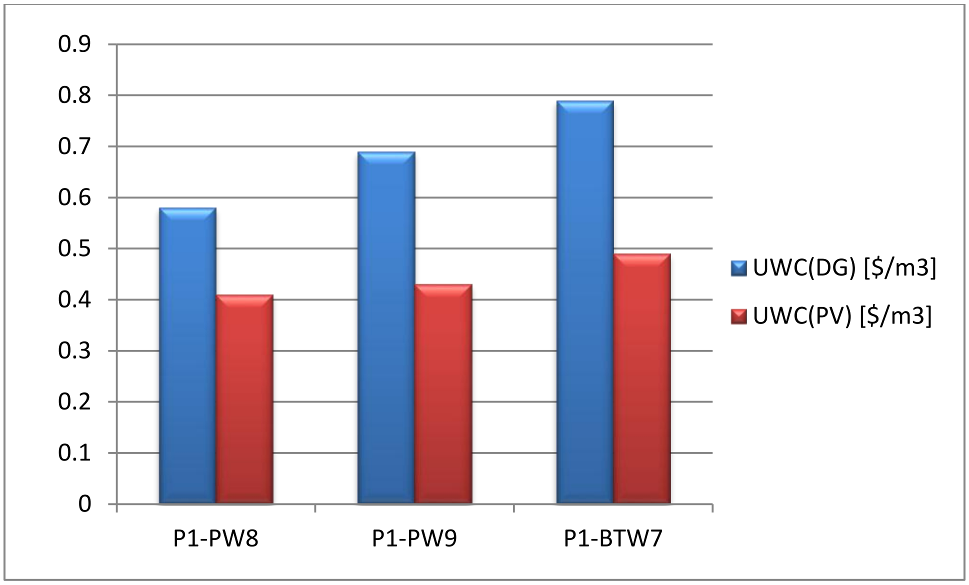


Figure 7.36 UWC comparison of Diesel and PV system for all wells

Figure 7.36 shows that the cost of a cubic meter of water produced by PV system is around 70 % of a cubic meter of water produced by DG for all wells under the study.

CHAPTER EIGHT

8. Conclusion & Recommendations

8.1 Conclusion

Based on the results obtained from this study, the following conclusions are drawn:

The major disadvantage of the DG over the PV system is the higher O&M cost and environmental impact. The initial cost of the PV system considered as the only disadvantage over the Diesel system, however, particularly in remote areas the higher initial cost of the PV system could be still justified by the savings in the lower O&M cost as well as the increased reliability throughout the useful 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.

Most of the previous studies are focused on small water discharge and head application but from this study it can be concluded that PV power for water pumping is cost competitive with traditional Diesel energy sources for average water discharge and head of remote applications, if the total system design and time of utilization is carefully considered and organized to use the solar energy as efficiently as possible.

In the future, if the prices of fossil fuel rise more and the economic advantages of mass production reduce the peak watt cost of the photovoltaic cell, the PV pump will be more competitive with conventional supply.

According to the results of the cumulative LCC analysis the years to breakeven between PV and DG system is less than five years.

The research found that the unit water cost of PV system is less than the unit water cost of Diesel system.

According to the sensitivity analysis variation of technical and financial parameters by 10% does not significantly affect the financial indicators. When the variations of technical and financial parameters are extended to 20%, which is a big range, the values of financial indictors is lower than the threshold.

The financial risk analysis done using RETScreen software indicates the impact of the input parameters (initial cost and fuel cost-base case) is higher on the variability of financial indicators (IRR, PBP and NPV). This implies that the two parameters have to be carefully analyzed to minimize the degree of risk in the project.

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 therefore, one has to properly size and optimize the system operation.

Nowadays, the environmental issue becomes one of the main concerns of the world nations. At the stage of power generation, photovoltaic system generally produces no air pollution, hazardous wastes and noise. Thus Photovoltaic systems appear to be promising in view of their environmentally clean nature and the advantage of direct conversion to electrical energy.

8.2 Recommendations

Assessment of PV generators to replace Diesel generators in Borana Zone indicates that the area has a huge potential of solar energy for water pumping. There are, however, some challenges like low purchasing power of the community and lower energy conversion of PV cell, towards the development and adaptation of PV water pumping technologies. It is thus recommended that the government, nongovernmental organizations and the public make concerted efforts to overcome these challenges by using more flexible approaches to improve the current state of PV water pumping system in Ethiopia.

I also recommend that the National Meteorological Agency of Ethiopia (NMAE) to make available the solar data in the form required for researchers of the country and to install direct solar energy measuring instruments at least in some areas of the country which are supposed to have higher potential of solar energy.

Finally, I recommend that, to know the exact solar resource potential of Ethiopia to replace the conventional Diesel energy and to solve the problems of utilizing PV for water pumping in the country more studies should be conducted in the future.

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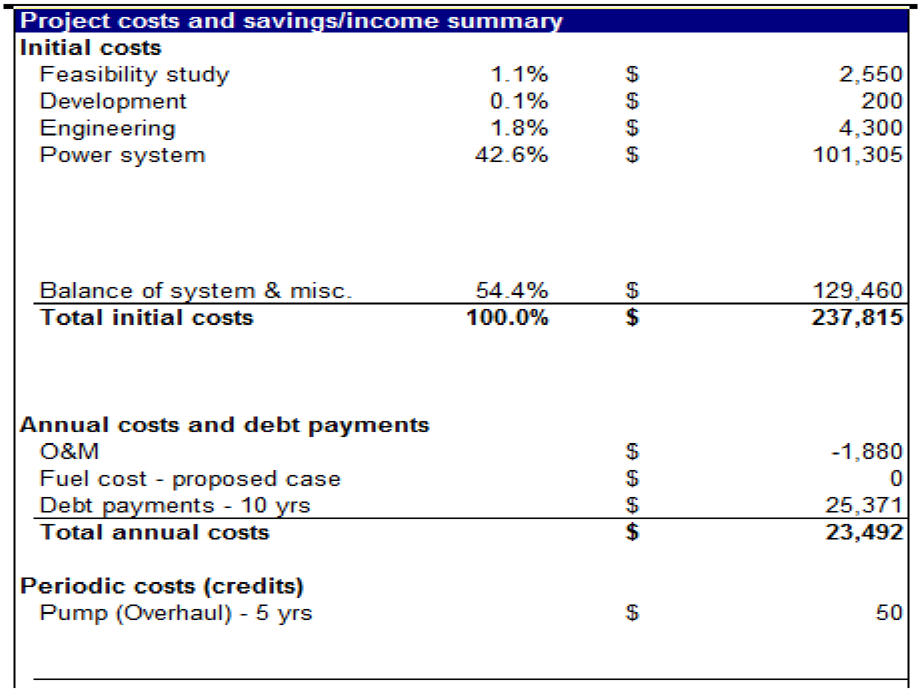
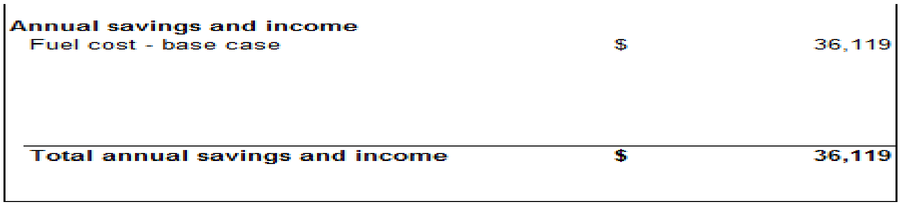
APPENDICES

Appendix A: Results from RETScreen Software

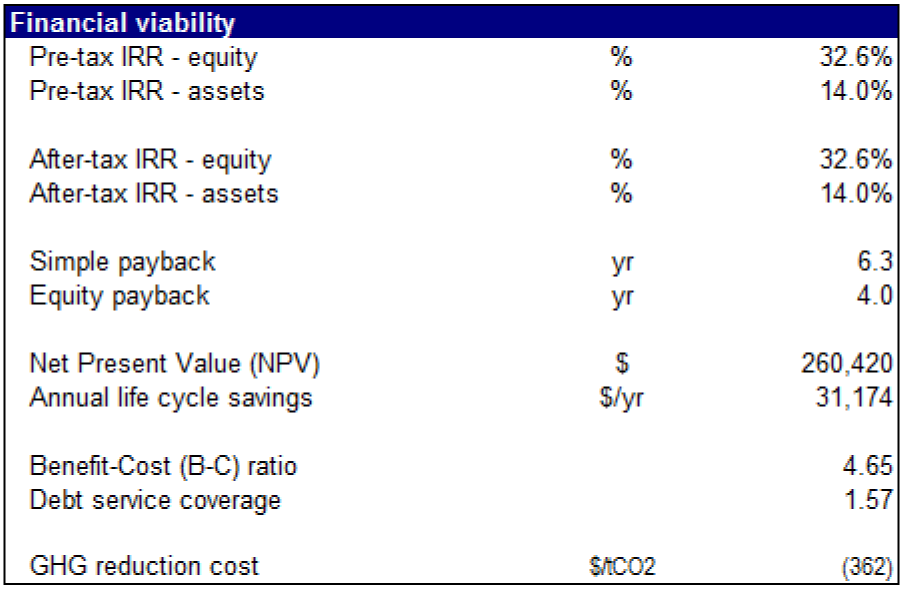
A1.1 Well P1-PW08



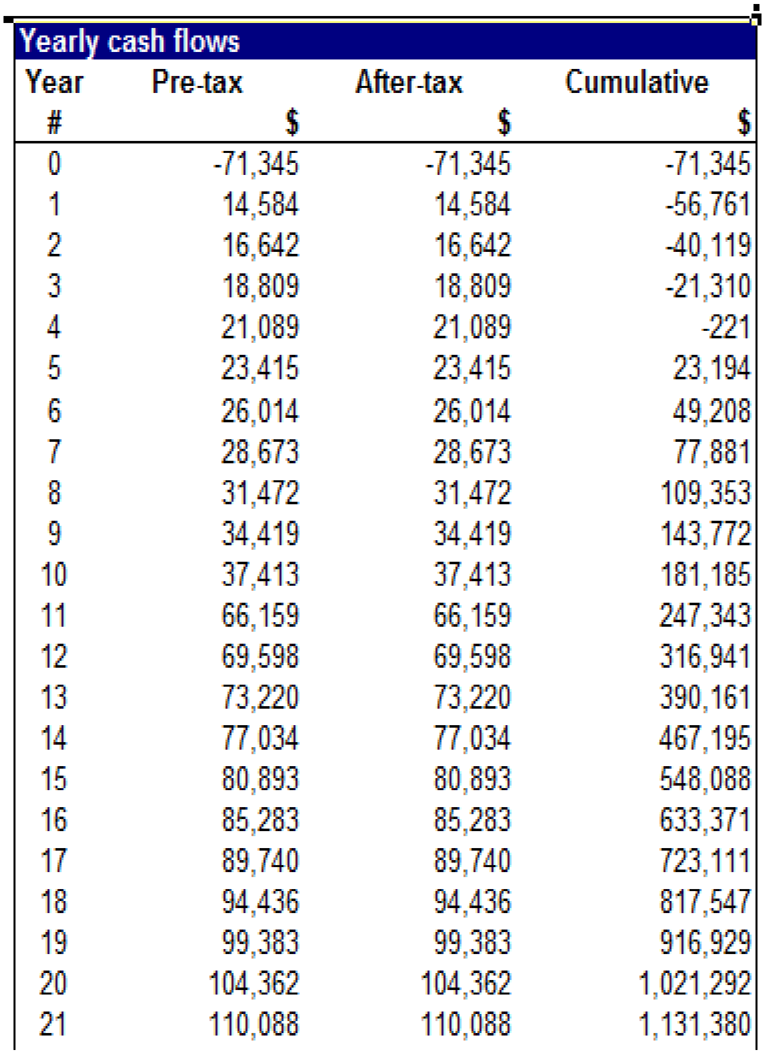
Project costs and savings/income summary			
Initial costs			
Feasibility study	1.1%	$	2,550
Development	0.1%	$	200
Engineering	1.8%	$	4,300
Power system	42.6%	$	101,305
Balance of system & misc.	54.4%	$	129,460
Total initial costs	**100.0%**	**$**	**237,815**
Annual costs and debt payments			
O&M		$	-1,880
Fuel cost - proposed case		$	0
Debt payments - 10 yrs		$	25,371
Total annual costs		**$**	**23,492**
Periodic costs (credits)			
Pump (Overhaul) - 5 yrs		$	50



Annual savings and income		
Fuel cost - base case	$	36,119
Total annual savings and income	**$**	**36,119**



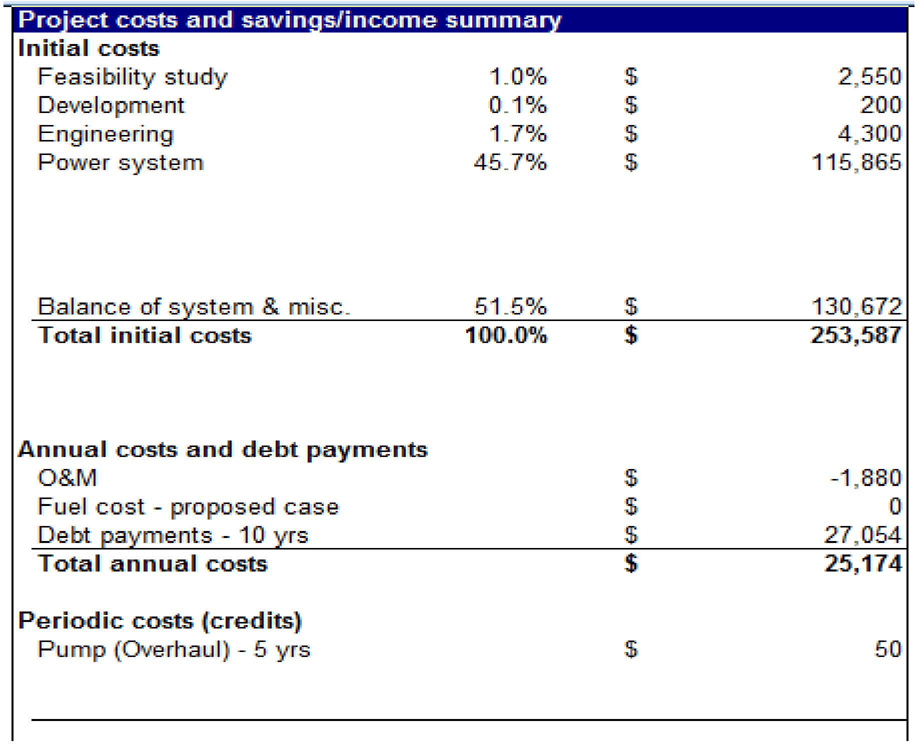
Financial viability		
Pre-tax IRR - equity	%	32.6%
Pre-tax IRR - assets	%	14.0%
After-tax IRR - equity	%	32.6%
After-tax IRR - assets	%	14.0%
Simple payback	yr	6.3
Equity payback	yr	4.0
Net Present Value (NPV)	$	260,420
Annual life cycle savings	$/yr	31,174
Benefit-Cost (B-C) ratio		4.65
Debt service coverage		1.57
GHG reduction cost	$/tCO2	(362)



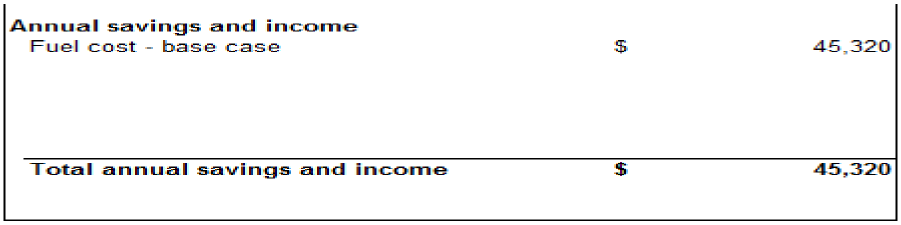
Yearly cash flows

Year #	Pre-tax $	After-tax $	Cumulative $
0	-71,345	-71,345	-71,345
1	14,584	14,584	-56,761
2	16,642	16,642	-40,119
3	18,809	18,809	-21,310
4	21,089	21,089	-221
5	23,415	23,415	23,194
6	26,014	26,014	49,208
7	28,673	28,673	77,881
8	31,472	31,472	109,353
9	34,419	34,419	143,772
10	37,413	37,413	181,185
11	66,159	66,159	247,343
12	69,598	69,598	316,941
13	73,220	73,220	390,161
14	77,034	77,034	467,195
15	80,893	80,893	548,088
16	85,283	85,283	633,371
17	89,740	89,740	723,111
18	94,436	94,436	817,547
19	99,383	99,383	916,929
20	104,362	104,362	1,021,292
21	110,088	110,088	1,131,380

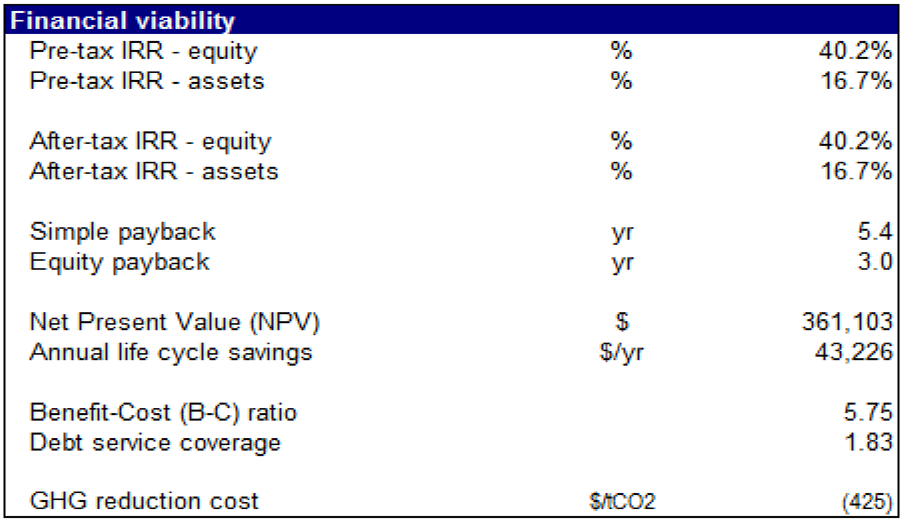
A1.2 Well P1-PW09



Project costs and savings/income summary			
Initial costs			
Feasibility study	1.0%	$	2,550
Development	0.1%	$	200
Engineering	1.7%	$	4,300
Power system	45.7%	$	115,865
Balance of system & misc.	51.5%	$	130,672
Total initial costs	**100.0%**	**$**	**253,587**
Annual costs and debt payments			
O&M		$	-1,880
Fuel cost - proposed case		$	0
Debt payments - 10 yrs		$	27,054
Total annual costs		**$**	**25,174**
Periodic costs (credits)			
Pump (Overhaul) - 5 yrs		$	50

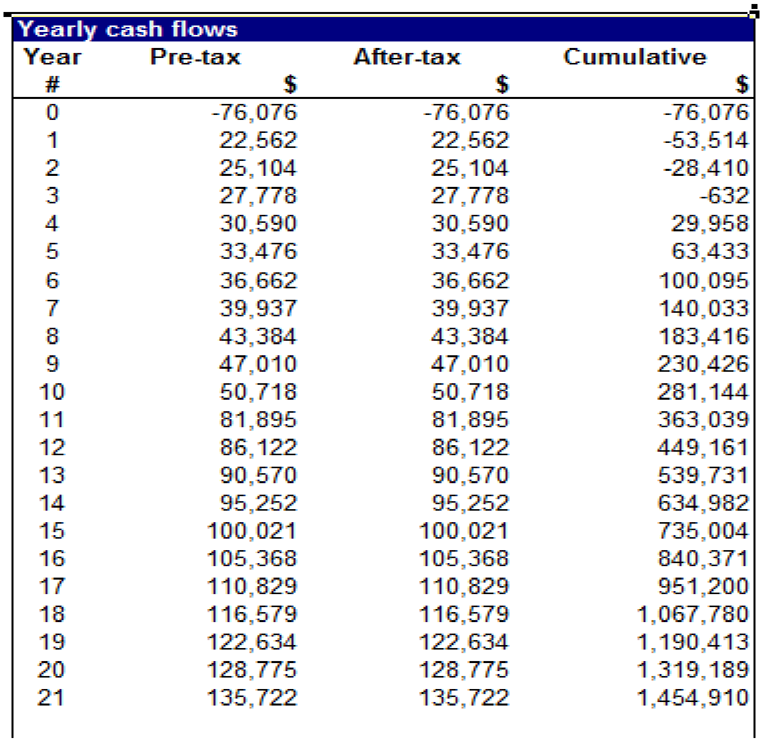


Annual savings and income		
Fuel cost - base case	$	45,320
Total annual savings and income	**$**	**45,320**



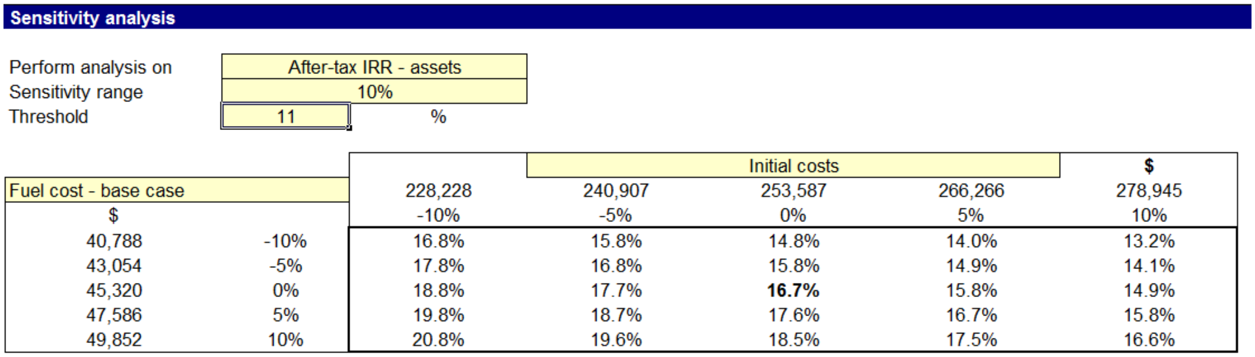
Financial viability

Pre-tax IRR - equity	%	40.2%
Pre-tax IRR - assets	%	16.7%
After-tax IRR - equity	%	40.2%
After-tax IRR - assets	%	16.7%
Simple payback	yr	5.4
Equity payback	yr	3.0
Net Present Value (NPV)	$	361,103
Annual life cycle savings	$/yr	43,226
Benefit-Cost (B-C) ratio		5.75
Debt service coverage		1.83
GHG reduction cost	$/tCO2	(425)



Yearly cash flows

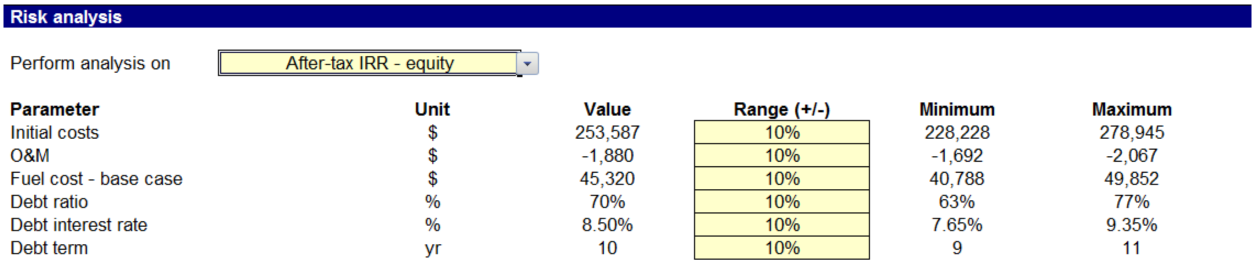
Year \#	Pre-tax $	After-tax $	Cumulative $
0	-76,076	-76,076	-76,076
1	22,562	22,562	-53,514
2	25,104	25,104	-28,410
3	27,778	27,778	-632
4	30,590	30,590	29,958
5	33,476	33,476	63,433
6	36,662	36,662	100,095
7	39,937	39,937	140,033
8	43,384	43,384	183,416
9	47,010	47,010	230,426
10	50,718	50,718	281,144
11	81,895	81,895	363,039
12	86,122	86,122	449,161
13	90,570	90,570	539,731
14	95,252	95,252	634,982
15	100,021	100,021	735,004
16	105,368	105,368	840,371
17	110,829	110,829	951,200
18	116,579	116,579	1,067,780
19	122,634	122,634	1,190,413
20	128,775	128,775	1,319,189
21	135,722	135,722	1,454,910



Sensitivity analysis

Perform analysis on	After-tax IRR - assets	
Sensitivity range	10%	
Threshold	11	%

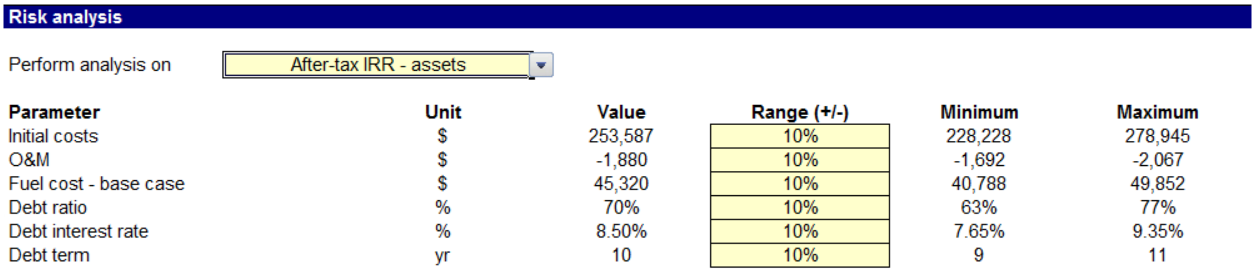
				Initial costs		$
Fuel cost - base case		228,228	240,907	253,587	266,266	278,945
$		-10%	-5%	0%	5%	10%
40,788	-10%	16.8%	15.8%	14.8%	14.0%	13.2%
43,054	-5%	17.8%	16.8%	15.8%	14.9%	14.1%
45,320	0%	18.8%	17.7%	**16.7%**	15.8%	14.9%
47,586	5%	19.8%	18.7%	17.6%	16.7%	15.8%
49,852	10%	20.8%	19.6%	18.5%	17.5%	16.6%



Risk analysis

Perform analysis on After-tax IRR - equity

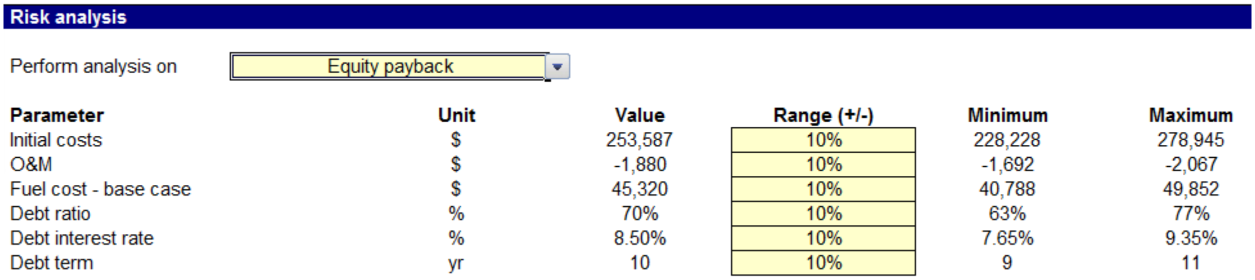
Parameter	Unit	Value	Range (+/-)	Minimum	Maximum
Initial costs	$	253,587	10%	228,228	278,945
O&M	$	-1,880	10%	-1,692	-2,067
Fuel cost - base case	$	45,320	10%	40,788	49,852
Debt ratio	%	70%	10%	63%	77%
Debt interest rate	%	8.50%	10%	7.65%	9.35%
Debt term	yr	10	10%	9	11



Risk analysis

Perform analysis on After-tax IRR - assets

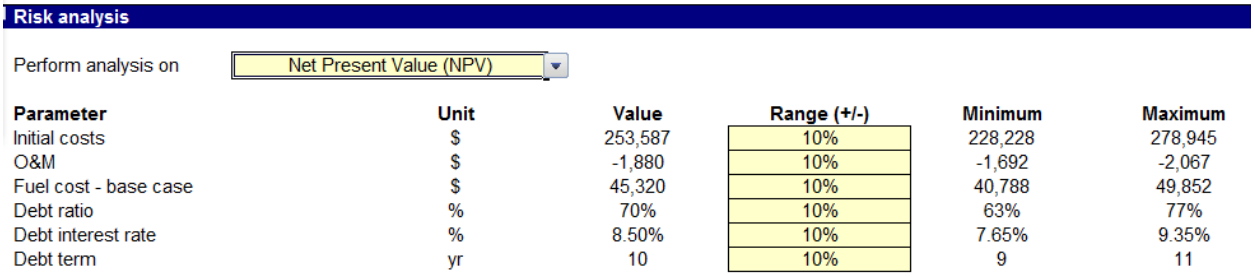
Parameter	Unit	Value	Range (+/-)	Minimum	Maximum
Initial costs	$	253,587	10%	228,228	278,945
O&M	$	-1,880	10%	-1,692	-2,067
Fuel cost - base case	$	45,320	10%	40,788	49,852
Debt ratio	%	70%	10%	63%	77%
Debt interest rate	%	8.50%	10%	7.65%	9.35%
Debt term	yr	10	10%	9	11



Risk analysis

Perform analysis on Equity payback

Parameter	Unit	Value	Range (+/-)	Minimum	Maximum
Initial costs	$	253,587	10%	228,228	278,945
O&M	$	-1,880	10%	-1,692	-2,067
Fuel cost - base case	$	45,320	10%	40,788	49,852
Debt ratio	%	70%	10%	63%	77%
Debt interest rate	%	8.50%	10%	7.65%	9.35%
Debt term	yr	10	10%	9	11

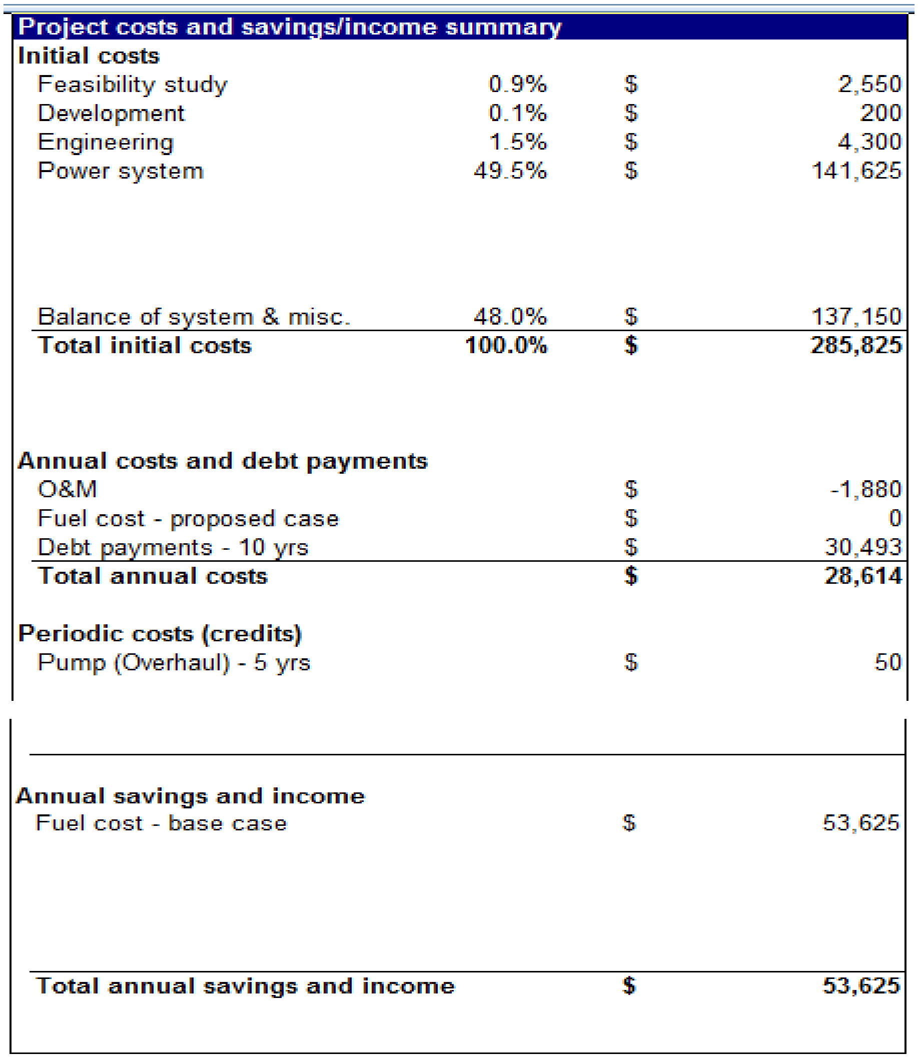


Risk analysis

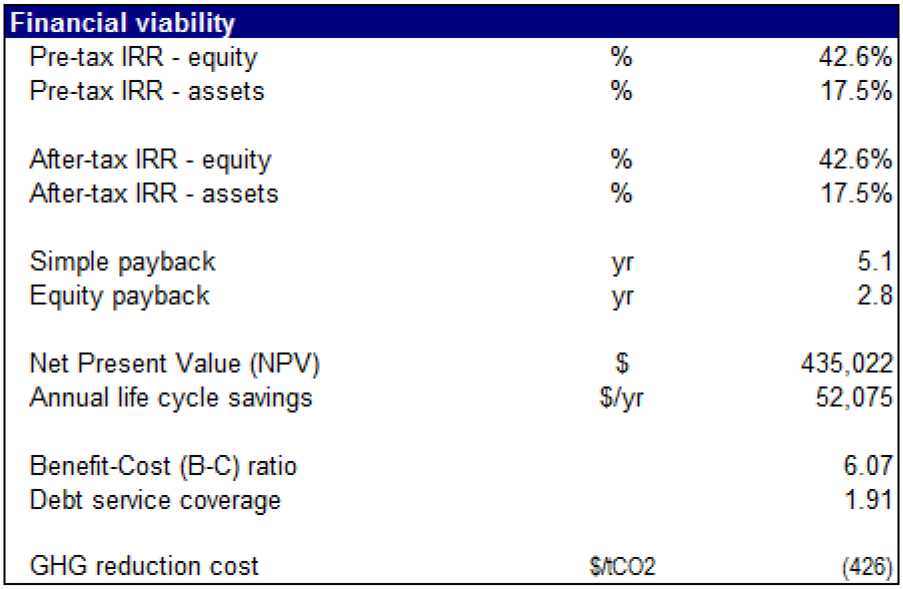
Perform analysis on Net Present Value (NPV)

Parameter	Unit	Value	Range (+/-)	Minimum	Maximum
Initial costs	$	253,587	10%	228,228	278,945
O&M	$	-1,880	10%	-1,692	-2,067
Fuel cost - base case	$	45,320	10%	40,788	49,852
Debt ratio	%	70%	10%	63%	77%
Debt interest rate	%	8.50%	10%	7.65%	9.35%
Debt term	yr	10	10%	9	11

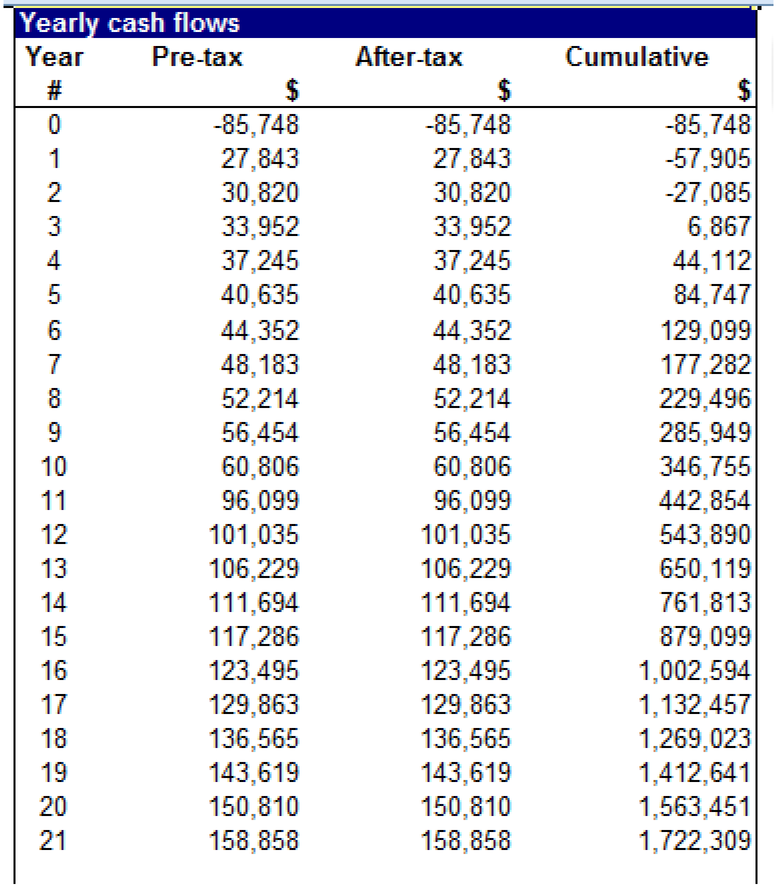
A1.3 Well P1-BTW07



Project costs and savings/income summary			
Initial costs			
Feasibility study	0.9%	$	2,550
Development	0.1%	$	200
Engineering	1.5%	$	4,300
Power system	49.5%	$	141,625
Balance of system & misc.	48.0%	$	137,150
Total initial costs	**100.0%**	**$**	**285,825**
Annual costs and debt payments			
O&M		$	-1,880
Fuel cost - proposed case		$	0
Debt payments - 10 yrs		$	30,493
Total annual costs		**$**	**28,614**
Periodic costs (credits)			
Pump (Overhaul) - 5 yrs		$	50
Annual savings and income			
Fuel cost - base case		$	53,625
Total annual savings and income		**$**	**53,625**



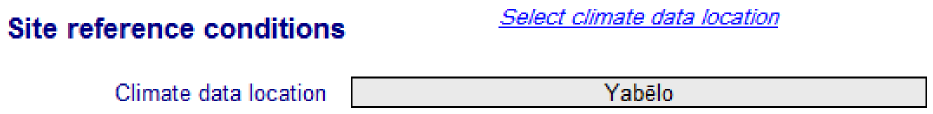
Financial viability		
Pre-tax IRR - equity	%	42.6%
Pre-tax IRR - assets	%	17.5%
After-tax IRR - equity	%	42.6%
After-tax IRR - assets	%	17.5%
Simple payback	yr	5.1
Equity payback	yr	2.8
Net Present Value (NPV)	$	435,022
Annual life cycle savings	$/yr	52,075
Benefit-Cost (B-C) ratio		6.07
Debt service coverage		1.91
GHG reduction cost	$/tCO2	(426)



Yearly cash flows

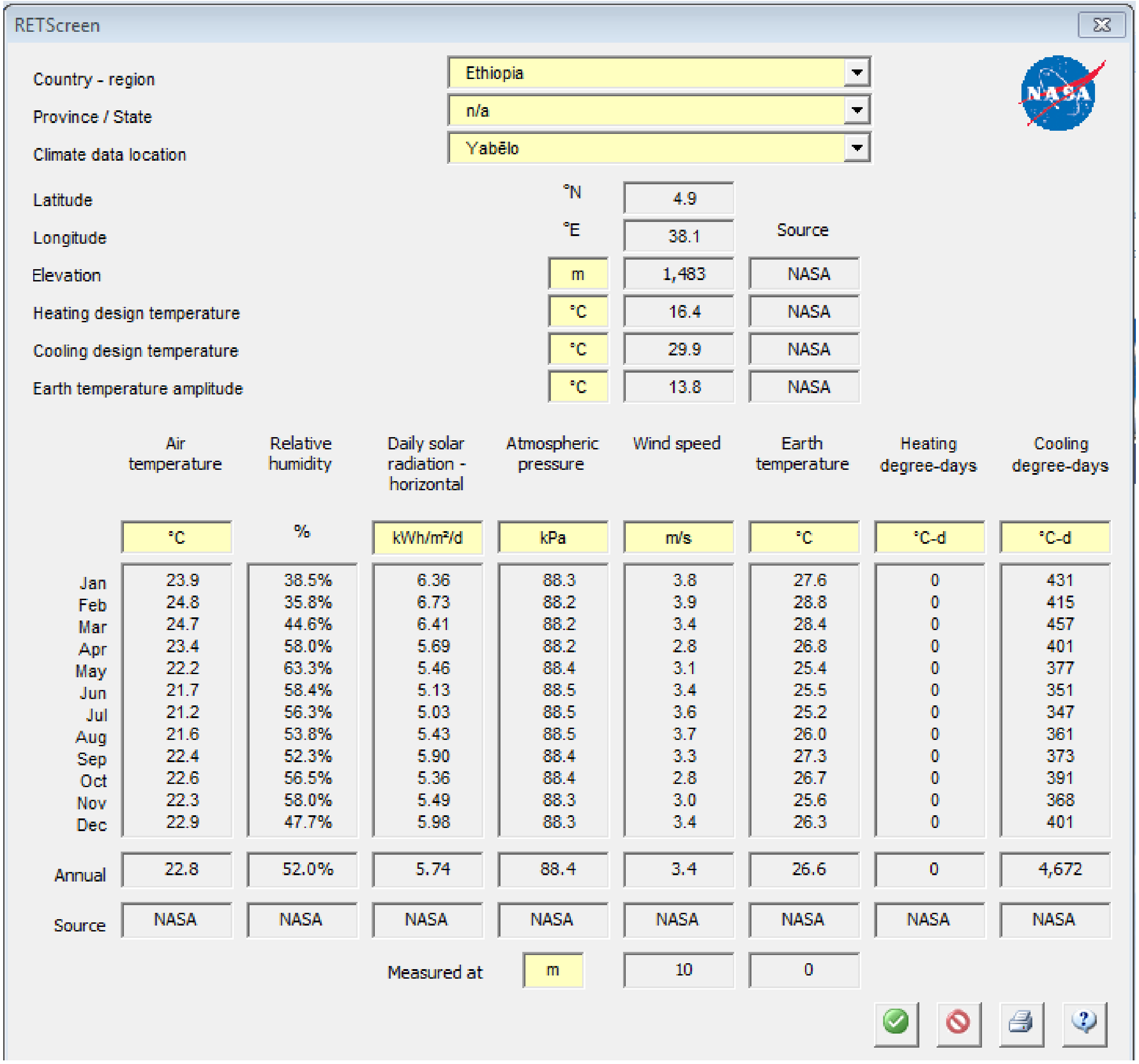
Year #	Pre-tax $	After-tax $	Cumulative $
0	-85,748	-85,748	-85,748
1	27,843	27,843	-57,905
2	30,820	30,820	-27,085
3	33,952	33,952	6,867
4	37,245	37,245	44,112
5	40,635	40,635	84,747
6	44,352	44,352	129,099
7	48,183	48,183	177,282
8	52,214	52,214	229,496
9	56,454	56,454	285,949
10	60,806	60,806	346,755
11	96,099	96,099	442,854
12	101,035	101,035	543,890
13	106,229	106,229	650,119
14	111,694	111,694	761,813
15	117,286	117,286	879,099
16	123,495	123,495	1,002,594
17	129,863	129,863	1,132,457
18	136,565	136,565	1,269,023
19	143,619	143,619	1,412,641
20	150,810	150,810	1,563,451
21	158,858	158,858	1,722,309

Appendix B: Weather Data



Site reference conditions

Climate data location: Yabēlo



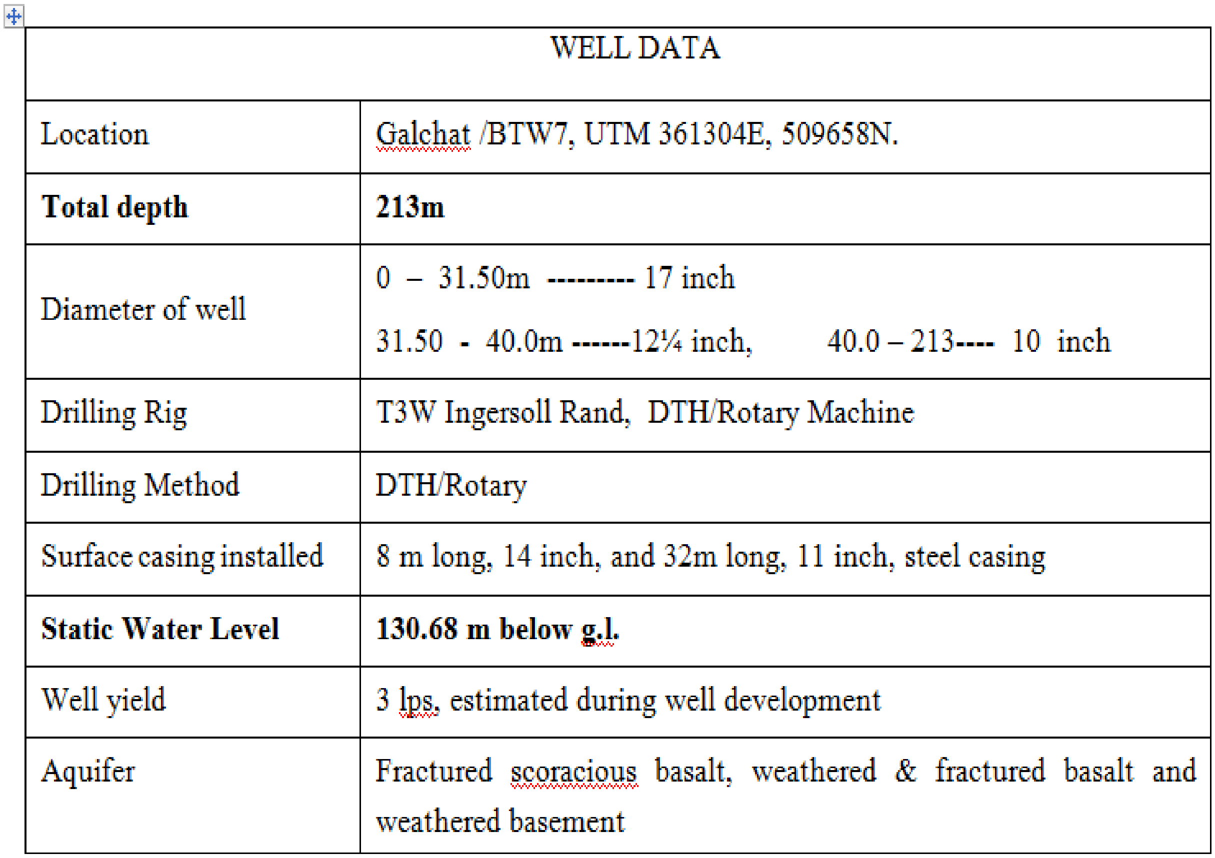
Country - region		Ethiopia		
Province / State		n/a		
Climate data location		Yabēlo		
Latitude	°N		4.9	
Longitude	°E		38.1	Source
Elevation		m	1,483	NASA
Heating design temperature		°C	16.4	NASA
Cooling design temperature		°C	29.9	NASA
Earth temperature amplitude		°C	13.8	NASA

	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
Jan	23.9	38.5%	6.36	88.3	3.8	27.6	0	431
Feb	24.8	35.8%	6.73	88.2	3.9	28.8	0	415
Mar	24.7	44.6%	6.41	88.2	3.4	28.4	0	457
Apr	23.4	58.0%	5.69	88.2	2.8	26.8	0	401
May	22.2	63.3%	5.46	88.4	3.1	25.4	0	377
Jun	21.7	58.4%	5.13	88.5	3.4	25.5	0	351
Jul	21.2	56.3%	5.03	88.5	3.6	25.2	0	347
Aug	21.6	53.8%	5.43	88.5	3.7	26.0	0	361
Sep	22.4	52.3%	5.90	88.4	3.3	27.3	0	373
Oct	22.6	56.5%	5.36	88.4	2.8	26.7	0	391
Nov	22.3	58.0%	5.49	88.3	3.0	25.6	0	368
Dec	22.9	47.7%	5.98	88.3	3.4	26.3	0	401
Annual	22.8	52.0%	5.74	88.4	3.4	26.6	0	4,672
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
Measured at				m	10	0		

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity delivered to load MWh
January	6.36	6.60	5.68
February	6.73	6.89	5.31
March	6.41	6.45	2.76
April	5.69	5.63	2.37
May	5.46	5.34	2.34
June	5.13	4.99	4.25
July	5.03	4.91	4.33
August	5.43	5.35	4.69
September	5.90	5.89	2.48
October	5.36	5.44	2.38
November	5.49	5.65	4.78
December	5.98	6.22	5.40
Annual	**5.74**	**5.77**	**46.76**

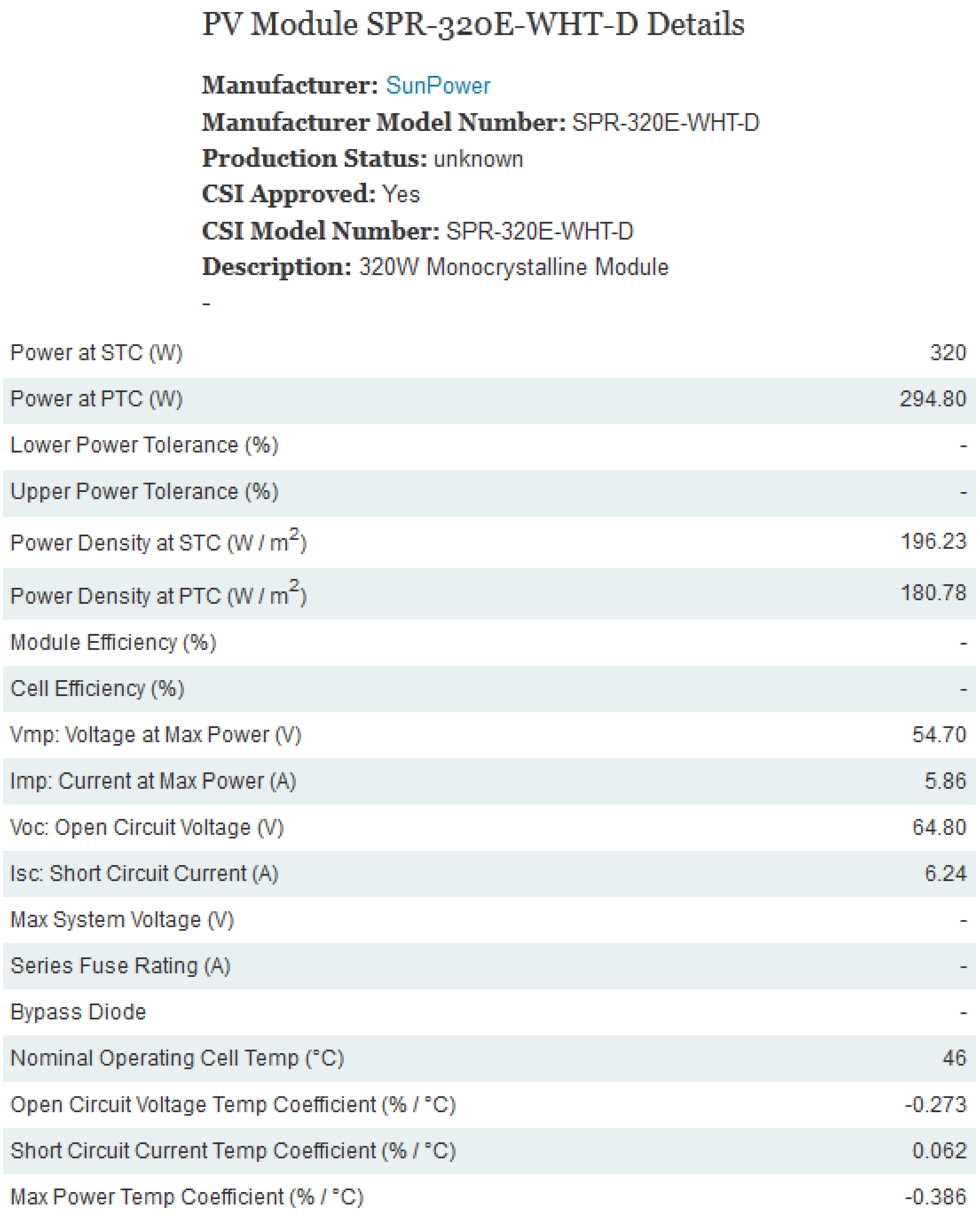
Annual solar radiation - horizontal	MWh/m²	2.10
Annual solar radiation - tilted	MWh/m²	2.11

Appendix C: Well Data



WELL DATA	
Location	Galchat /BTW7, UTM 361304E, 509658N.
Total depth	**213m**
Diameter of well	0 – 31.50m --------- 17 inch 31.50 - 40.0m ------12¼ inch, 40.0 – 213---- 10 inch
Drilling Rig	T3W Ingersoll Rand, DTH/Rotary Machine
Drilling Method	DTH/Rotary
Surface casing installed	8 m long, 14 inch, and 32m long, 11 inch, steel casing
Static Water Level	**130.68 m below g.l.**
Well yield	3 lps, estimated during well development
Aquifer	Fractured scoracious basalt, weathered & fractured basalt and weathered basement

Appendix D: PV Module Specification



PV Module SPR-320E-WHT-D Details

Manufacturer: SunPower
Manufacturer Model Number: SPR-320E-WHT-D
Production Status: unknown
CSI Approved: Yes
CSI Model Number: SPR-320E-WHT-D
Description: 320W Monocrystalline Module
-

Power at STC (W)	320
Power at PTC (W)	294.80
Lower Power Tolerance (%)	-
Upper Power Tolerance (%)	-
Power Density at STC (W / m^2)	196.23
Power Density at PTC (W / m^2)	180.78
Module Efficiency (%)	-
Cell Efficiency (%)	-
Vmp: Voltage at Max Power (V)	54.70
Imp: Current at Max Power (A)	5.86
Voc: Open Circuit Voltage (V)	64.80
Isc: Short Circuit Current (A)	6.24
Max System Voltage (V)	-
Series Fuse Rating (A)	-
Bypass Diode	-
Nominal Operating Cell Temp (°C)	46
Open Circuit Voltage Temp Coefficient (% / °C)	-0.273
Short Circuit Current Temp Coefficient (% / °C)	0.062
Max Power Temp Coefficient (% / °C)	-0.386

Appendix E: Diesel Generator Specification

The generator is Cummins Diesel engine and Faraday alternator and power 75 kW with 8 hours daily fuel tank.

Model	kVA		kWe		Engine				Gen-set
	Standby	Prime	Standby	Prime	Model	Fuel consumption [l/h]	No. of cylinder	B x S mm	Wt. Kg
XD85C	106	98	85	75	6BT5.9-G	24	6	102x120	1100

Appendix F: Submersible Motor Specification

For well P1-PW08

Submersible Motor

Product Details:

Brand Name	**Xingkang**
Model Number	**YQS200-22**
Type	**Asynchronous Motor**
Frequency	**50HZ**
Output Power	**22KW**
Protect Feature	**Waterproof**
Phase	**Three-phase**
Certification	**CCC**
AC Voltage	**380V/480V/660V**
Place of Origin	**Hebei, China (Mainland)**
Efficiency	**IE 2**

Payment & Shipping Terms:

FOB Price:	Get Latest Price
Minimum Order Quantity:	**10 Unit/Units**
Port:	**Tianjin**
Packaging Details:	**Plastic bag first, then wounded by rope and packing by Flywood at last**
Delivery Time:	**10 days**
Payment Terms:	**L/C,T/T**
Supply Ability:	**20000 Unit/Units per Month**

Detailed Product Description

Submersible Motor
1. 380V/ 50Hz
2. Proction stage: IP68
3. Power: 22kw
4. Material: Stailess steel and casr iron

Submersible motor
This motor is AC submersible motor, suit to working in deep well.
Power factor (cosp): 0.84
Rated current: 48.2A
Rated voltage: 380V
Rated power: 22kw
Suitble diameter of borehold: 8"
Eff: 82.5%

For well P1-PW09

Submersible Motor

Product Details:

Brand Name	Xingkang
Model Number	YQS200-25
Type	Asynchronous Motor
Frequency	50HZ
Output Power	25KW
Protect Feature	Waterproof
Phase	Three-phase
Certification	CCC
AC Voltage	380V/480V/660V
Place of Origin	Hebei, China (Mainland)
Efficiency	IE 2

Payment & Shipping Terms:

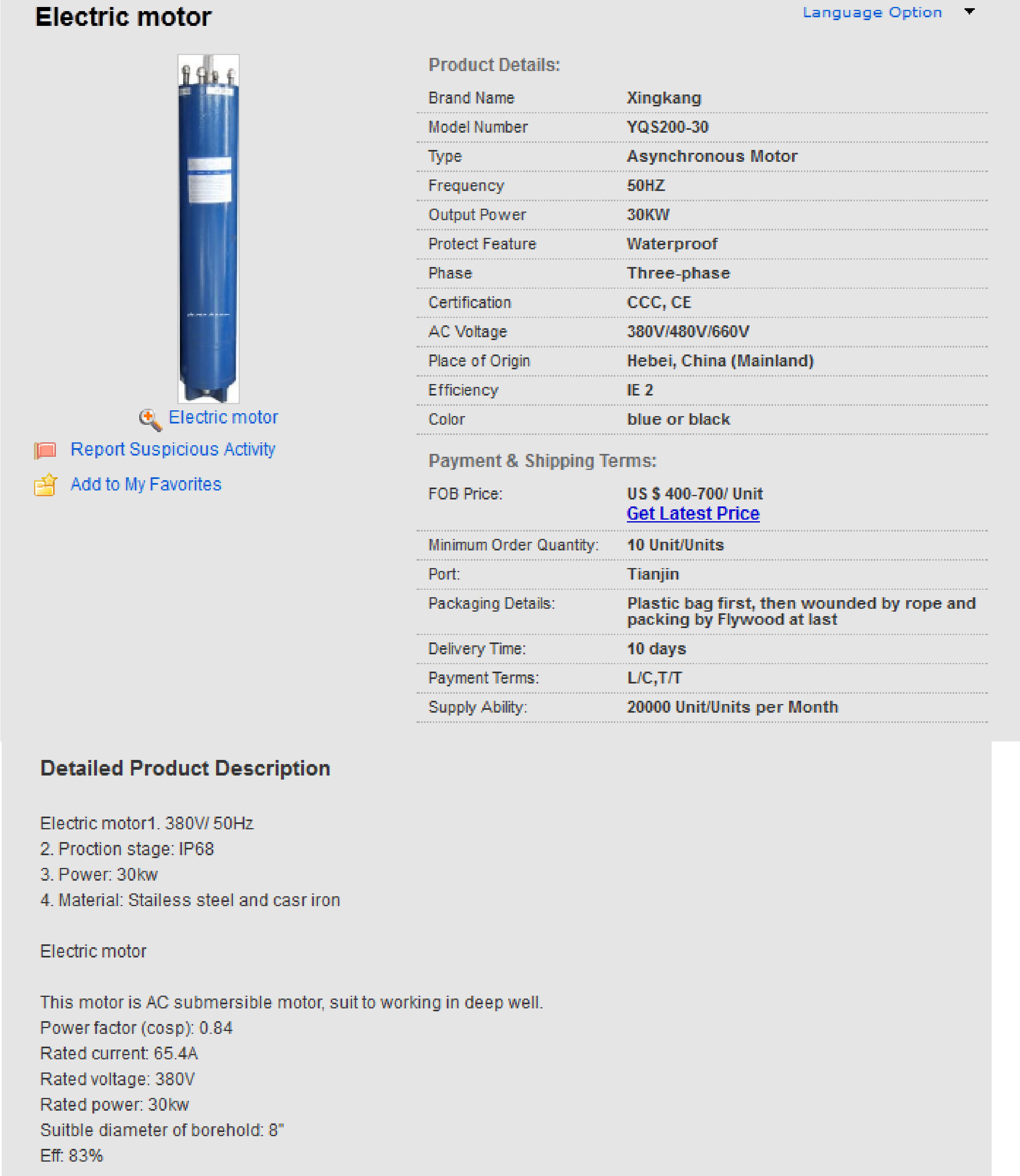
FOB Price:	Get Latest Price
Minimum Order Quantity:	10 Unit/Units
Port:	Tianjin
Packaging Details:	Plastic bag first, then wounded by rope and packing by Flywood at last
Delivery Time:	10 days
Payment Terms:	L/C,T/T
Supply Ability:	20000 Unit/Units per Month

Detailed Product Description

Submersible Motor
1. 380V/ 50Hz
2. Proction stage: IP68
3. Power: 25kw
4. Material: Stailess steel and casr iron

Submersible motor
This motor is AC submersible motor, suit to working in deep well.
Power factor (cosp): 0.84
Rated current: 54.5A
Rated voltage: 380V
Rated power: 25kw
Suitble diameter of borehold: 8"
Eff: 83%

For well P1-BTW07



Electric motor

Product Details:

Brand Name	Xingkang
Model Number	YQS200-30
Type	Asynchronous Motor
Frequency	50HZ
Output Power	30KW
Protect Feature	Waterproof
Phase	Three-phase
Certification	CCC, CE
AC Voltage	380V/480V/660V
Place of Origin	Hebei, China (Mainland)
Efficiency	IE 2
Color	blue or black

Payment & Shipping Terms:

FOB Price:	US $ 400-700/ Unit Get Latest Price
Minimum Order Quantity:	10 Unit/Units
Port:	Tianjin
Packaging Details:	Plastic bag first, then wounded by rope and packing by Flywood at last
Delivery Time:	10 days
Payment Terms:	L/C,T/T
Supply Ability:	20000 Unit/Units per Month

Detailed Product Description

Electric motor1. 380V/ 50Hz
2. Proction stage: IP68
3. Power: 30kw
4. Material: Stailess steel and casr iron

Electric motor

This motor is AC submersible motor, suit to working in deep well.
Power factor (cosp): 0.84
Rated current: 65.4A
Rated voltage: 380V
Rated power: 30kw
Suitble diameter of borehold: 8"
Eff: 83%