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Feasibility Assessment for the Replacement of Diesel Water Pumps with Solar Water Pumps

Prepared by:

emCON Consulting Group

P O Box 1900
Windhoek
Namibia
Tel + 264 - 61 – 224 725
Fax + 264 - 61 – 233 207
Email contact@emcongroup.com

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Abbreviations

CBM	Community Based Management
DP	Diesel Water Pump
DRWS	Directorate of Rural Water Supply
DWA	Department of Water Affairs
GHG	Green House Gases
HDPE	High Density Polyethylene
MET	Ministry of Environment and Tourism
MME	Ministry of Mines and Energy
NAMREP	Namibia Renewable Energy Programme
NamWater	Namibia Water Corporation
PV	Photovoltaic
PVP	Photovoltaic Water Pump
RE	Renewable Energy
SRF	Solar Revolving Fund
UNDP	United Nations Development Programme
WPA	Water Point Association
WPC	Water Point Committee

Executive Summary

A study was commissioned by the Ministry of Mines and Energy (MME) through the Namibian Renewable Energy Programme (NAMREP) to examine the cost effectiveness of solar water pumps compared to diesel water pumps.

Technology

The study provides an overview of water provision technologies for water supplies in rural Namibia where no piped or open water is available and where the water needs are serviced primarily through boreholes.

Current photovoltaic (PV) water pumping (PVP) technologies and diesel water pumping (DP) technologies are discussed in terms of their performance range and their technical features. The study considered the following PVPs:

	Pump type used	Maximum array size	Maximum head	Hydraulic load
Grundfos SQ Flex	Centrifugal & helical rotor	1,400W_{peak}	200m	1,100m^4/day
Lorenz PS	Centrifugal & helical rotor	1,200W_{peak}	230m	1,000m^4/day
Total Energie TSP 1000	Helical rotor	1,280W_{peak}	130m	900m^4/day
Total Energie TSP 2000+	Centrifugal	5,600W_{peak}	120m	4,000m^4/day
Watermax	Diapraghm	300W_{peak}	100m	300m^4/day

The diesel pumps under review are in the power range of 2 to 12kW and the following engine products were considered:

- Kia and Kirloskar of Indian manufacture; and
- Lister of South African manufacture.

The diesel pumping systems is based on a helical rotor, positive displacement pump (Mono and Orbit elements).

Perceptions and experiences

Perceptions and experiences of PV and diesel water pumping systems were gathered through interviews. Issues that were raised are:

- concerns about theft, in particular of PVP systems;
- the perceived inability of PVPs to supply variations in water demand;
- sophisticated technology of PVPs with serviceability mostly provided in Windhoek;
- performance concerns; and
- high cost.

The findings are:

- Theft is a valid concern and users need to consider counter measures where theft is a risk;
- Some PVPs are able to operate in combination with a genset to pump additional water at night or during inclement weather;
- The service infrastructure of PVPs is improving through the training and establishment of solar technicians in the regions;

- Recent developments have seen the introduction of durable, high efficiency, deep well pumps which are improving the performance concerns of the past;
- The cost is discussed in the comparison with diesel pumps below.

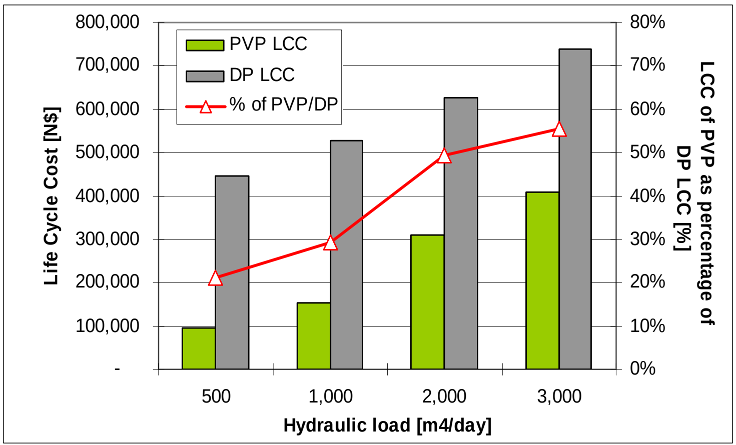
In general the benefits of PVPs are well understood, in terms of their low maintenance needs, automatic operation, the minimal attention that is required and their suitability for low yield boreholes. PVPs provide environmental benefits by offering a clean solution with no carbon emissions and risks of borehole contamination.

Cost comparison

A cost comparison for solar and diesel water pumps was conducted over a range of pumping heads (10m to 200m) and a range of daily flow rates ($3m^3$/day to $50m^3$/day). The life cycle costs (LCC) were calculated over a 20 year period taking into account:

- the initial upfront cost;
- the operating costs (diesel fuel for the operation, inspections of pumping systems);
- maintenance costs; and
- replacement costs.

The graph shows the LCC for PVPs and DPs which has been averaged for different hydraulic loads. The costing results of the diesel pump are highly dependent on the selected pumping schedule (pumping interval and hours per pumping session). In addition the averaged PVP LCC has been divided by the averaged DP LCC for each of the hydraulic load points. This yields the percentage LCC of PVP as a function of the LCC of the DP, measured against the Y-axis on the right.



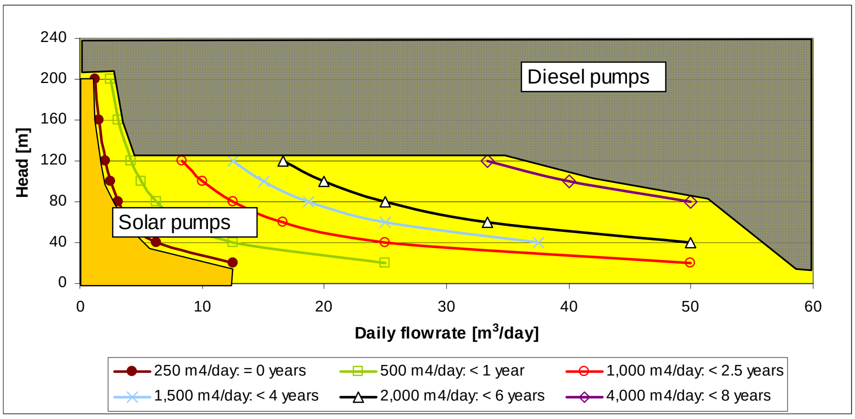
At low hydraulic load the PVP LCC is as low as 20% of the DP LCC. At higher hydraulic loads this value reaches 55% which means that the PVP option still provides a solution at half the life cycle cost of the DP option.

Another measure of comparison is the years-to-breakeven, i.e. After how many years does a solar pump become cheaper to run than a diesel pump? The breakeven point is reached when the cumulative LCC of PVPs become lower than the cumulative LCC of DPs. The shorter the years-to-breakeven, the more attractive the RE solution becomes and the higher the cost savings over the project life. The results for the years-to-breakeven over the operating range considered in this study are shown in the table below.

		Daily water [m³/day]								
		3	4	6	8	13	17	25	33	50
Head [m]	20	0.0	0.0	0.0	0.0	0.2	0.5	1.0	1.3	2.6
	40	0.0	0.0	0.2	0.5	0.8	1.2	2.6	2.8	5.6
	60	0.0	0.1	0.5	1.0	1.2	2.6	3.5	5.9	7.2
	80	0.0	0.3	1.0	1.7	1.8	3.6	6.4	6.7	7.8
	120	0.0	0.9	1.9	2.7	4.1	7.1	8.2	Diesel	Diesel
	160	0.2	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel
	200	0.6	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel

The numbers in the cells represent the years-to-breakeven between PVP and DP. The yellow fields represent years to breakeven for the Grundfos and Lorentz PVPs. The light green fields represent parallel Grundfos systems in the same borehole (assuming borehole suitability) and the blue cells represent the Total Energie TSP 2000+ series of pumps. The grey fields marked "Diesel" indicate that the diesel option is to be selected. This is however not due to the diesel pump solution being more viable but due to the lack of a PVP solution at these operating points.

The figure below shows hydraulic load lines which are used to indicate what the breakeven periods are for PVPs versus DPs. For example, the brown load line (250m^4/day) shows that a PVP operating on that line will breakeven from the start. All PVPs operating to the <u>left</u> and the <u>bottom</u> of that hydraulic load line will also breakeven from the start. Similarly, PVPs operating on the red load line (1,000m^4/day) will breakeven in less than 2.5 years, which decreases to 1 year as the operating point approaches the green load line (500m^4/day).



The orange and the yellow areas indicate the operating range where PVPs are more cost effective than DPs. The orange area indicates where PVPs break even from the start. The grey area indicates where DPs are the technology of choice.

High level market assessment potential

It is estimated that the total number of PVPs installed in Namibia to date is approximately 1,220 units. A survey showed that the uptake over the last five years was about 670 PVPs of which a third (225 units) was installed during 2005.

The borehole statistics[1] for Namibia indicate that 95% of the 51,500 boreholes are less than 200m deep. Taking into account that not all boreholes are operational, that not all boreholes contain water suitable for consumption and that assumptions were made for incomplete borehole statistics, it was estimated that there are approximately 20,000 boreholes with a hydraulic load of less than 1,000m^4/day and another 10,000 boreholes with a hydraulic load between 1,000m^4/day and 3,000m^4/day.

If the take-up of PVPs over the next ten years is 20% of the above number of boreholes then the <u>potential market would constitute an average of approximately 600 PVPs per annum.</u> This would mean that the current installation rate of 225 PVPs (2005) per annum needs to triple.

The high market potential for solar suitable boreholes, the improved technology and the superior financial performance of PVPs coupled with the availability of finance, indicate that there is significant potential to increase the uptake of PVPs.

[1] Information provided by Division of Geohydrology, Department of Water Affairs (DWA), Ministry of Agriculture, Water and Rural Development

1 INTRODUCTION

Namibia as a semi-arid country with very little surface water has to obtain water from wells and boreholes where the population reside in rural areas and are not in the vicinity of one of the perennial rivers at Namibia's borders or near a piped water scheme. It is quite common to find hand-dug wells, in particular in parts of the north where the ground water levels are shallow. However the larger part of water for the above areas is supplied from approximately 51,500[2] boreholes.

1.1 BACKGROUND TO WATER PUMPING IN NAMIBIA

Historically pumping from boreholes in Namibian off-grid areas has been predominantly achieved with wind pumps. Wind pumps have a long service life, are able to deliver water from depths of 300 to 400m, require no non-renewable fuel, require basic skills but are work-intensive to maintain, and have a well developed service infrastructure. Wind pump 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.

Diesel water pumps 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 from boreholes. Diesel pumps have the advantage of pumping water on demand (predictability), also in varying daily capacity, depending on the operating times and over high heads (300m+). Diesel engines have a fairly low capital cost. On the down side the diesel pumping system relies on fuel and is therefore "at the mercy" of fuel cost variations and exchange rate fluctuations. Furthermore diesel engines require regular maintenance, linked to the hours of operation and have a fairly short life expectancy (highly dependent on the level of maintenance, the operating conditions and the quality of the engine and the installation). Most diesel pumps require manual starting making remote pumping installations more costly to operate.

It is quite common to find wind and diesel pumping combinations where either a diesel engine can be used to drive the reciprocating pump or where a diesel generator can be used to drive a submersible pump (fitted underneath the wind pump cylinder) to back up the water supply during low wind period or wind pump maintenance.

Hand pumps are used for pumping from boreholes in particular in the communal areas. These are rugged devices which require no non-renewable fuel, 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 250m^4/day[3]).

Solar photovoltaic (PV) water pumps were first introduced for water provision in off-grid areas about 25 years ago. The technology has developed around many different designs and in some PV water pumps (PVP) the reliability and maintenance requirements have improved over the initial PVPs introduced to the market. PVPs are easy to install, require no non-renewable energy, operate autonomously and are generally "good" for the sustainability of boreholes due to their low extraction volumes spread over eight to ten hours a day. The initial capital cost of PVPs is high due to the cost of the photovoltaic modules. The maintenance requirements of PVPs differ and range between annual and five year maintenance intervals.

[2] Information provided by Division of Geohydrology, Department of Water Affairs (DWA), Ministry of Agriculture, Water and Rural Development

[3] Renewable Energy for Water Pumping Applications in Rural Villages, NREL, July 2003.

PVP technology is sophisticated and maintenance on PVP's does require skilled technicians. The water storage for PVPs needs to incorporate storage for days of low irradiance (inclement weather) but in general irradiation levels for Namibia are more predictable than for example wind resources. The over-sizing of the water storage reservoir is therefore within limits. A perceived limiting factor of PVPs is that they do not easily cater for fluctuating water demands or increased water demand although solutions for this are being offered and will be discussed in this study.

This study, which is assessing the viability of replacing diesel pumps with PV water pumps, will focus on water pumping installations with borehole depths of less than 200m. Many existing installations are fitted with wind pumps, electrical pumps (on grid) and hand pump technologies. These technologies do not form part of the feasibility assessment.

1.2 SCOPE OF WORK

The objective of this study is to analyse the recent trends in the use and costs of PVPs and to conduct a comparative cost benefit analysis between diesel and PVP, based on the life cycle costing approach. With recent technical developments in the PVP sector and with anticipated increase in diesel fuel prices as well as possible shortages, breakeven between the two technologies may be shorter than expected.

In summary the scope of work includes:

1. Installation quantities of solar PV water pumps in commercial, communal and public facilities and price developments of the capital cost of PVPs over the last five years.
2. Conduct a comparative cost benefit analysis between diesel and solar PV water pumps taking into account the current diesel price (including variations of price within the country) as well as anticipated fuel price escalation.
3. Identify the operating and performance conditions under which it is viable to replace diesel pumps with solar PV pumps.
4. Identify the social factors, preferences and satisfaction levels that determine the criteria for selecting a PV pumping or a diesel water pump.
5. Identify the barriers to PVP adoption in the commercial, communal and public sector and make recommendations on how to address these barriers. Review and propose financial incentives as well as government policies that can facilitate the adoption of PVPs.
6. Evaluate the reduction in green house gas emissions for two PVP uptake scenarios.

The report presents the outputs for the above tasks in three sections titled:

- Water pumping in Namibia,
- Life cycle analysis, and
- Facilitation of PV Pumping.

The report summarises the findings in the conclusion and presents recommendations for further activities.

1.3 PREVIOUS WORK

The first in-depth and comprehensive analysis of off-grid water pumping solutions was conducted by Fahlenbock (1996), "Assessment of the Potential of PV Pumping Systems in Namibia". The work includes:

- Ground water resource assessment
- Analysis of existing borehole installations
- Institutional setup at Rural Water Supply
- Economic analysis of solar PV and diesel water pumps
- Technical, economic and social site selection criteria
- PVP suppliers in Namibia
- Assessment of PVP potential

Fahlenbock (1996) is the main document of reference in terms of market and economic analysis from 1996 to 2006.

Hervie (2006) has written a thesis on "Solar water pumping versus diesel pumping in Namibia". The work conducts detailed case studies in two communities and calculates the life cycle cost of solar and diesel pumps, yielding breakeven points between 6 and 11 years. The thesis has been referred to in terms of capital costs and in terms of comparative figures for breakeven points.

2 WATER PUMPING IN NAMIBIA

This section takes a closer look at the PV pumping and diesel pumping technologies traded in Namibia and starts with an overview of the recent trends in installations and pricing of these technologies. This is followed by an overview of the pumping configurations, their features and their performance. The section ends with a summary on the perceptions and motivations for using PVP or DP solutions.

2.1 OVERVIEW OF TECHNOLOGIES

The most common technologies of PVP and diesel pumps are described in this section in terms of technical and performance aspects.

2.1.1 PV pumping technology

A PVP typically consists of the following main components:

1. **Photovoltaic array:** An array of photovoltaic modules connected in series and possibly strings of modules connected in parallel.
2. **Controller:** An electronic device which matches the PV power to the motor and regulates the operation, starting and stopping of the PVP. The controller is mostly installed on the surface although some PVPs have the controller integrated in the submersible motor-pump set:
    a. DC controller: usually based on a DC to DC controller with fixed voltage set-point operation.
    b. AC controller (inverter): converts DC electricity from the array to alternating current electricity often with maximum power point tracking.
3. **Electric motor:** There are a number of motor types: DC brushed, DC brushless, or three phase induction and three phase permanent magnet synchronous motors.
4. **Pump:** The most common pump types are the helical rotor pump (also referred to as progressive cavity), the diaphragm pump, the piston pump and the centrifugal pump.

Some years ago there were PVP models on the market that operated with batteries and a conventional inverter. However it was soon realised that the cost savings on the pump did not make up for the overall substandard efficiency and the higher maintenance cost due to battery replacements. Instead it became clear that it is more economic to rather store water in a reservoir than electricity in a battery bank.

There are currently three pumping configurations commonly utilised in Namibia:

1) **DC drive with positive displacement pumps**. This consists of four pump technologies:
    a. Diaphragm pump driven by brushed DC motor: Submersible motor/pump: Example: Shurflo, DivWatt, All Power Watermax.
    b. Helical rotor pump driven by brushless DC motor: Submersible motor/pump: Example: Total Energie TSP 1000.
    c. Helical rotor pump driven by surface mounted brushed DC motor: Example: Mono/Orbit pump with DC motor

   d. Piston pump driven by surface mounted brushed DC motor: Example: Juwa pump.

2) **AC drive powering a submersible induction motor/centrifugal pump unit**: Example: Total Energie TSP 2000, 4000 & 6000 range; Grundfos SA 1500 and SA 400 which has been utilised extensively in Namibia but may be phased out in the near future.

3) **AC drive powering a three phase permanent magnet synchronous motor**. This category consists of:

   a. Positive displacement helical rotor pump: Example: Grundfos SQ Flex, Lorentz HR range.

   b. Centrifugal pump: Example: Grundfos SQ Flex, Lorentz C range.

The above technologies have specific features which make them suitable for particular applications:

Array voltage: Some of the pumping systems have high array voltages. This has the advantage that the array may be further from the borehole without significant voltage drop (dependant on cable size and current). Array positioning may be important where there is potential for theft.

DC motors: DC motors reach efficiencies of up to 80% and are therefore significantly more efficient than sub-kW three phase motors which have efficiencies in the region of 60% to 65%.

Brushless DC motors: This combines the high efficiency of DC motors with low maintenance as opposed to brushed DC motors which require regular brush replacement (approximately every one to two years – head and quality dependent).

Three phase permanent magnet motors: This similarly combines the high efficiency of permanent magnet motors with low maintenance.

Positive displacement vs. centrifugal pump: Positive displacement pumps have a better daily delivery than centrifugal pumps when driven by a solar PV system with its characteristic variable power supply. This is due to the considerable drop in efficiency of the centrifugal pump when operating away from its design speed. This is the case in the morning and the afternoon of a centrifugal pump driven by a PV array, unless that array tracks the sun (which is why centrifugal PVPs effectiveness improves more with a tracking array than a positive displacement PVP). The efficiency curve of a positive displacement pump is flatter over a range of speeds. However the efficiency of positive displacement pumps decreases with the shallowness of the borehole (the constant fixed friction losses become a more significant part of the power it takes to lift water). Therefore it is not surprising that both Grundfos and Lorentz use centrifugal pumps for applications where the lift is less than 20 to 30m but switch to positive displacement pumps for deeper wells.

Diaphragm pump: The diaphragm pump is used for pumping small volumes of water from 100/120m depth. The pump needs regular maintenance (diaphragm replacements, cleaning). If the diaphragm breaks the motor chamber gets wet. The pump can run dry.

Juwa pump: The Juwa pump is manufactured in Namibia. It consists of a jack pump (reciprocating piston pump) with a DC motor drive. The Juwa is suited for deep well applications with low water requirements/low yield boreholes. The Juwa pump is based on a rugged design and can operate in a hybrid pumping system with the addition of a diesel engine. The Juwa pump is not able to compete on a pricing level with the submersible options that are on the market (e.g. the Lorentz pump) and is therefore only manufactured for special applications.

The PVPs used for analysis in this study are listed in Table 2.1 with their particular performance information.

Table 2.1: PVP performance overview

	Pump type used	Maximum array size [W_{peak}]	Maximum head [m]	Hydraulic load[1)] [m^4/day]	Maintenance interval [years]
Grundfos SQ Flex[2)]	Centrifugal & helical rotor	1,400	200	1,100	5
Lorenz PS	Centrifugal & helical rotor	1,200	230	1,000	3
Total Energie TSP 1000	Helical rotor	1,280	130	900	5
Total Energie TSP 2000+	Centrifugal	5,600	120	~ 4,000	5
Watermax	Diapraghm	300	100[3)]	300	1

1) The hydraulic load is calculated by multiplying the daily delivery [m^3/day] by the head [m] at a fixed array size. This is fairly constant value and a measure of the PVPs performance and operating range. Here the hydraulic load is calculated at an irradiance level of 6kWh/m2/day at the maximum array power of the PVP system.

2) The Grundfos performance is based on the 900W motor. A new motor has been released but the manual sizing information has not been updated by Grundfos yet. The only pump unit added to the Grundfos range is the unit able to pump over a 200m head.

3) The Watermax is supplied in four models: WA: Up to 80m, WB up to 100m, WC up to 150m and WD up to 40m. Only the models up to 100m are considered for this study.

The hydraulic load curves of the above pumps are shown in Figure 2.1. The figures are based in the technical specifications of the PVPs.

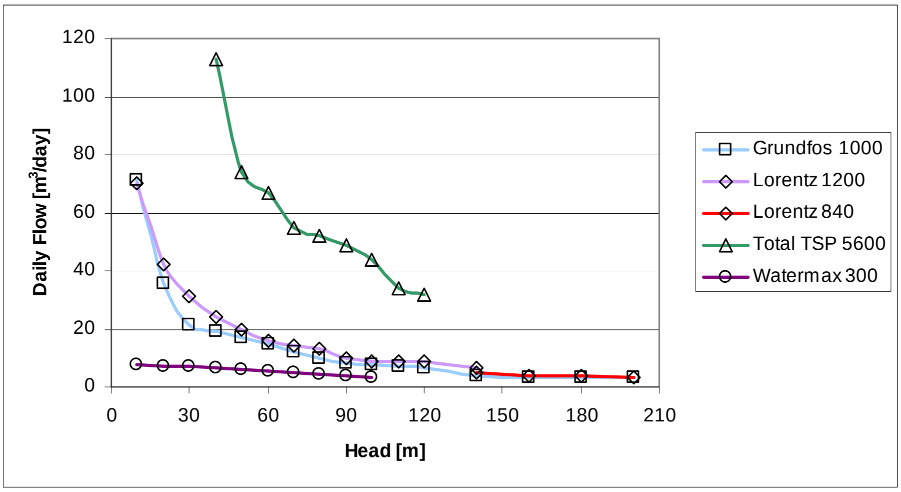


Figure 2.1: Hydraulic load curve of four PVP systems at maximum Watt peak

The operating range of each pump is the area below each of the data series. The Grundfos and the Lorentz pump cover a similar area. These PVPs are suitable for water needs at villages, for homesteads and lodges, and for livestock and game watering. The low maintenance requirements make these pumps attractive for remote water supply solutions. PVPs are not a cost effective solution for highly seasonal irrigation needs. A PVP achieves cost effectiveness through full use of the PVP modules. For example, using a PVP for half a year per annum will double the unit cost of water. Depending on conditions, diesel pumps could offer a more cost effective solution.

The Total Energie PVP can deliver much larger water quantities compared to the Grundfos and Lorentz pump. It can therefore be considered for larger scale water supply requirements. The maintenance requirements are similar to the Grundfos and Lorentz, also making this product attractive for reliable remote water supply solutions.

The Watermax is the only PVP based on a diaphragm pump. It has regular maintenance requirements (diaphragm, valves, brushes, bearings) which make it dependent on maintenance service providers. The pump has to be serviced on average once a year (depending on the head, the water quality and hours of operation). It is therefore not suited to remote areas. This particular pump finds application on game lodges as well as cattle farms.

2.1.2 Diesel pumping technologies

A diesel pump typically consists of four main components:

1. **Diesel engine:** For this study single or dual cylinder, air-cooled, hand-started diesel engines with a maximum continuous output power of 15kW are considered.
2. **Pump element:** The most common pump type is the helical rotor pump also referred to as the progressive cavity pump and the piston pump.
3. **Discharge/Pump head:** The discharge head is fitted above the centre of the borehole. The rising main is fitted to the bottom of the discharge head and the engine is coupled to the pulley through belts. The discharge head transfers the power of the engine to the pump via a circular (progressive cavity) or a reciprocating (piston) action.
4. **Rising main:** The rising main consists of 3m galvanised steel pipes (40 or 50 mm diameter) which are coupled together. The rising main pipes either come with a taper thread or parallel thread. The taper is cheaper to manufacture but does not exhibit the strength of the parallel threaded pipe. Taper threaded pipes are recommended for hand pumps but not diesel pumps. However in reality, taper threaded pipes are often installed due to the initial cost savings. A shaft transfers the power down the centre of the column either through a circular action or through a reciprocating action. The shaft is guided either through bobbin bearings or guides.

The most common diesel engine configuration is the progressive cavity pump. The diesel engine in conjunction with a reciprocating pump is a configuration that is used in a hybrid pumping setup with a wind pump, where the diesel acts as a backup for the wind pump during periods of low wind or during maintenance work on the wind tower. A similar configuration is encountered where the wind pump is backed-up with an electric submersible pump (fitted underneath the cylinder) which is powered by a diesel or petrol generator. The submersible pump remains in the borehole and when there is a need for additional water pumping then the diesel/petrol generator is taken to site for pumping.

The diesel pumping configuration which is used as the comparative case to the PV pumping system is the progressive cavity pump which is a standalone single energy source pumping system and presents the most efficient diesel pumping configuration.

The survey on diesel engines in the local market identified four different makes of diesel engines. These are Hatz, Lister (South African manufacture), Kia (India), and Kirloskar (India). The products are all imported and are of different quality levels. This is reflected in the pricing of the units and the experience of the Directorate of Rural Water Supplies is that the cheaper units exhibit shorter operating life. 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. In the case of the diesel pumps administered by DRWS a major service is conducted every half a year and the engine is overhauled if it is in-operational (and providing that the cost does not exceed 75% of the price of a new engine). 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.

The most common progressive cavity pump elements on the market are Mono and Orbit. They manufacture a range of elements which cover the 0 to 200m head adequately.

The diesel engine system is capable of operating anywhere on the hydraulic load graph as shown in Figure 2.1, for example a diesel engine system can be designed to pump over a head of 200m and deliver 6 m^3/h (60 m^3 over ten hours).

Diesel pumps are suitable for remote off-grid pumping applications in excess of 1,500m^4/day[4]. This threshold is dependent on local financial conditions and is likely to be different for Namibia – the study will review this. The ability of a diesel pump to pump large volumes of water against high heads makes a diesel pump suitable for large village supplies. Diesel pumps can also provide cost effective solutions if the water demand is seasonal, as its operating, maintenance and replacement cost will reduce with reduced hours of operation.

2.2 Experience and Perceptions

This section raises general issues related to the solar PV and diesel pumping options, such as social, environmental, perception and satisfaction which have not been covered under the technical section.

A number of stakeholders (refer to Annexure A1) were consulted regarding the perceptions and experiences with their particular pumping solutions. The findings are summarised here.

- Theft: This is a problem for both PVP and diesel pumping but very costly for the PVP systems due to the main portion of the capital cost being vested in the solar PV modules.
- Variable water demand: Diesel pumps can pump water on demand. PVPs do not have that flexibility. A hybrid system such as solar diesel would present an attractive solution, however at a higher cost.
- Supply security: PVP is considered to have less redundancy, is more difficult to repair and is susceptible to lightning strike. Diesel pumping has a more solid service infrastructure and is considered more reliable. The hybrid pumping solutions would improve supply security.
- The diesel system is considered more flexible (flexible in moving a diesel engine to another borehole).
- Diesel fuel is part of an existing infrastructure and the owner is able to do the minor service on the engine himself. PVP technology requires knowledge of mechanics, electrical and electronics thus making the user/operator dependent on specialised service which is often only available in Windhoek.
- Hybrid pumping systems: Wind pumps backed-up by diesel engine or by diesel generator (often portable). Hybrid pumping systems are common in commercial areas. Either a diesel engine can be used in combination with the pump head or an electric submersible pump is fitted underneath the piston pump. In the latter case the

[4] Renewable Energy for Water Pumping Applications in Rural Villages, NREL, July 2003

user is able to pump water with a petrol/diesel generator during times of low wind conditions.

- The Grundfos SQ Flex presents a hybrid solution that will work with solar (and wind) as well as with a small, portable fuel generator (petrol or diesel). This hybrid pumping solution can deliver twice the amount of water per day compared to solar only. Solar/fuel generator hybrid pumping systems can be considered for backup as well as for catering for days of increased demand. However the pumping system needs to be designed to provide the nominal water requirements on solar PV else the systems does not make economic sense. The disadvantage is that such a hybrid system has increased complexity and is dependent on fuel as well as maintenance. Since the installation is not fixed (such as a diesel engine mounted on a frame on top of a concrete block) the fuel generator may easily be stored securely and transported for maintenance.
- PVP are perceived to pump insufficient water.
- Corrosion is a problem for both diesel and solar pumps:
    - Diesel pump: Due to the poor quality of the steel riser pipes the installation does not last as long as in the past and the pipes have to be extracted and partially replaced every five to seven years.
    - PVP: High grade stainless steel pumps are available. Corrosion prevention measures can be installed so that the pump casing is not corroded. The supply pipe is plastic and therefore does not present a problem.
- The quality of steel riser pipes has decreased in recent years (affecting also the JUWA PVP), resulting in problems when installing and operating diesel pumps.
- It is well understood that PVPs require no attention and start automatically.
- It is well understood that PVPs are ideal for weak boreholes.
- The environmental impact of diesel pumps includes carbon emissions, possible borehole contamination, and threat to borehole sustainability. PVPs can be seen as a resource protection if it is designed for the maximum sustainable yield of the borehole.
- The operation of PVPs is quiet.
- PVPs are perceived to be expensive
- Many users on commercial farms combine the need for starting the diesel pump the opportunity for inspecting fences, checking on livestock and other farming activities. However, if a PVP is used then the frequency of these trips over the farm decrease.

Community water supply solutions are driven by the Directorate of Rural Water Supply. The technical water supply option selected for/by a community is done so in agreement with that community after an elaborate consultative process. The water supply system (diesel, wind, hand pump or PVP) is consequently installed and paid for by DRWS. The installation is handed-over for ownership to the Water Point Association (WPA) established within the community with the understanding that the community will pay for the operating costs as well as for the minor service costs. This process is supported through extensive training in terms of operation and administration of water supply points. The Water Point Committee (WPC) collects money based on water usage to pay for diesel fuel and minor maintenance. There are no hard and fast rules in which way the WPC collects but guidelines are provided during the training and it is left to the community to find the solution that works best.

The major service, overhauls and replacements is the responsibility of DRWS who provides that service and pays for it.

It was found that this approach of handing ownership over to the community has increased the life expectancy of water supply systems and reduced the abuse of systems.

The issues raised by the Directorate of Rural Water Supply with regards to community water supply are as follows:

- Communities are familiar with diesel water pumps and are able to service and do minor repairs on the engines locally.
- Communities require the flexibility in water consumption due to large herds of livestock that graze in some areas of the communal areas.
- Diesel pumps installed through DRWS are usually designed for a ten hour pumping day. That still leaves 14 hours for additional pumping if required.
- In the Kunene region people move the diesel engine to another site as they move across the region to various grazing spots. The pipes, pumps and the discharge head remain in the borehole and only the engine is moved. It is perceived that this cannot be done with PVPs. Depending on the size of the installation and assuming no theft prevention measures it would be quite possible to move the solar modules plus the pump (assuming similar depth in other boreholes).
- Livestock herds have become so large in some areas that the water demand has increased to such an extent that the diesel pump operates close to 24 hours a day. The immediate priority is that the livestock receives water. DRWS is aware that the large cattle herds present a long term problem for grazing, desertification and water resources. However, it would be wrong to approach this through a limitation of the water availability and will require a broader approach which addresses social, cultural and economic issues within the community.
- Contractors for diesel pumps offer good support in the regions and make strong efforts in terms of capacity building by providing free-of-charge training courses. This is not perceived to be the case for the PVP sector where the service support seems to revert back to Windhoek and where training of DRWS staff and community operators is charged for by suppliers.
- DRWS is no longer supporting hybrid wind/diesel pumping systems and have phased out these hybrids by converting them to either wind or diesel pumps only. The reason for this is mainly economic/community affordability and reflects a policy of providing one water supply solution. This too streamlines the maintenance support given by DRWS.

In terms of PVP, the comments received from DRWS include:

- PVPs do not utilise boreholes to the full extent – a borehole with a safe yield of $5m^3$/hour will deliver more in 8 hours when pumped with a diesel engine than with a PVP. The PVP delivers less water in the morning and the afternoon when demand is at a peak. It is understood that tracking will provide a better utilisation factor but still not the same capacity as diesel.
- PVPs cannot compete with DPs on boreholes with medium yield (2 to $5m^3$/hour) as they can pump 24 hours a day. It needs to be understood that boreholes are often operated at full safe yield for up to 24hours a day in order to meet the demand.
- DRWS has a limited annual development budget for water supply implementations. The success of the regional heads in DRWS is “judged” by how many communities

have received water supplies rather than by how many PVP systems were installed. The higher upfront cost of PVP and the separate budgets (development/capital and recurring/operational budgets) thus makes it less attractive to install PVPs within this institutional environment.

  - Note that the Ministry of Finance is considering to allow funds to be shifted from one budget line to another so that Ministries making long term investments with high upfront costs and future savings in operational costs will be able to reap the benefits.
  - In the past development organisations have offered to cover the difference in upfront cost between a PVP and a diesel pump. However this has not materialised to date.

- With the implementation of Community Based Management (CBM) the community takes ownership of the water supply installation and becomes responsible for the operational costs. When a PVP system is installed then the community does not collect money as there are no operational costs. This leads to a crisis when the PVP system requires a service or replacement after a few years of operation. In this regard DRWS prefers diesel pumps as this enforces the money collection systems to cover the operational and minor maintenance costs.
- The service for PVPs is perceived as being mainly available in Windhoek.
- As mentioned above, the PVP sector does not seem to invest in building technical skills among DRWS and communities so that regional staff can perform the fault analysis without having to rely on support from Windhoek. Furthermore, DRWS does not have the in-house skills to design PVPs at this stage. This however could also be changed if the PVP sector would be prepared to build that capacity in DRWS.
- Theft of solar modules is a problem if the water pump is not part of the village. DRWS has in the past insisted that a community members lives next to the pump to increase security.
- PVPs are susceptible to lightning strikes although some models do not seem to have that problem, i.e. the Total Energie TSP range. PVP systems are especially vulnerable when the float switch cables are very long.
- DRWS does use PVPs in remote areas where there is difficult access to the community and large distances to the fuel supply infrastructure.
- DRWS does consider PVPs for replacing hand pumps

Recently the Namibian cabinet has decided that communities must take full ownership of their water supplies by 2010. This means that the full operating, maintenance and replacement costs will have to be met by the community. This will change some of the financial realities and possibly create more interest in PVP solutions for certain applications within the DRWS administered water points.

In response to the issues listed in this section:

- Theft is a concern and depends much on local conditions. Section 4.3 lists counter measure that could avoid or reduce the risk of theft.
- It is acknowledged that more capacity building has to take place in the communal sector if PVPs are to find a larger range of applications. In addition the servicing capacity of PVPs needs to extend to the regions.
- It is understood that the water demand for communities cannot be planned in the same way as the water demand on commercial farms since there are many parties

(community members) with different needs (livestock, domestic, agriculture) that have to be satisfied. Flexibility and reliability are therefore of utmost importance.

- The Grundfos and the Lorentz PVPs are able to deliver additional water through the use of a back-up generator.
    - In terms of communal water supply it would however not make for a permanent solution if a PVP is operated on solar during the day and on a diesel genset during the night. In that case a diesel pumping solution operating 24 hours is the preferred system.
    - Should the maximum water delivery have been reached then borehole allowing (diameter and yield), a second PVP can be installed in the same borehole to operate in parallel with the initially installed unit. This requires some lead time.
- Conduct a more in-depth survey to which can guide selection criteria for pumping solutions that finds the acceptance of the community.
- Consider pilots at the villages of local chiefs so that the chiefs can lead the way, if there is an interest.
- It is essential to identify communities where a PVP water supply is of benefit, meeting the water demand reliably, making ongoing financial provision for repairs and replacements, benefiting from the reduced costs, and in-depth training of community PVP operators and of extension officers in the region. Water supply solutions for communal water supply cannot be approached with the aim of increasing the uptake of PVPs - the approach needs to be much broader to have the necessary sustainable impact on water supply provision in communal areas.
- Possibly secure gap financing for PVPs in communal water once a strategy for communal water supply has been formulated and it has been determined that there is a clear role for PVP.

The cost of PVPs in comparison to diesel pumps is addressed in section 3.

2.3 RECENT PVP UPTAKE AND PRICING

The uptake of PVPs over the last few years has generally shown an increasing trend as presented in Table 2.2 below. The average growth in PVP sales over the period 2001 to 2005 is 22% per annum. The year 2003 is marked by a slump in sales. PVP sales from 2004 to 2005 has shown a 46% increase which is most likely due to funding becoming available through Konga Investment and Bank Windhoek as well as the significant increase in diesel fuel cost (an increase of 26% within three quarters of a year).

Table 2.2: PVP uptake during 2001 to 2005

Year	Communal/ Public	Private	Total
2001	14	87	101
2002	30	90	120
2003	5	64	69
2004	10	144	154
2005	24	201	225
TOTAL	83	586	669

The sales into the private sector are about seven times the size of the public/communal sector. The private sector is predominantly represented by commercial farmers, guest farms and game lodges. In terms of the communal/public sector about half the PVPs listed in Table 2.2 (second column) are installed for the Ministry of Environment and Tourism and approximately 10% are installed through the Directorate of Rural Water Supply. The remainder of PVPs are assumed to be installed through the Ministry of Health and Social Services, the Ministry of Education and NGO's.

The water pumping technology usage for DRWS administered water points is shown in Table 2.3. The trends are of interest here. It shows that besides the overall growth of water points administered that the water points driven through diesel engines are increasing steadily whereas the use of solar PV has virtually remained fixed at just below 100 PVP driven water points. It is also clear from the table that hand pumps are being replaced and that combination systems of wind and diesel are converted to either the one or the other technology.

Table 2.3: Technology use at DRWS administered water points

DRWS administered Water Points driven by:	Diesel Engine	Windmill	Diesel engine & windmill	Hand pump	Solar PV power	Electric	Pipeline	Total
Year 2003	**1,842**	1,122	169	931	**94**	-	2,709	6,867
Year 2004	**1,871**	1,295	?	927	**103**	-	2,884	7,080
Year 2005	**1,932**	1,269	19	884	**96**	12	2,986	7,198
Year 2006	**1,974**	1,276	17	872	**95**	18	3,097	7,349

The pricing development of PVP components excluding the PV modules is shown in Figure 2.2.

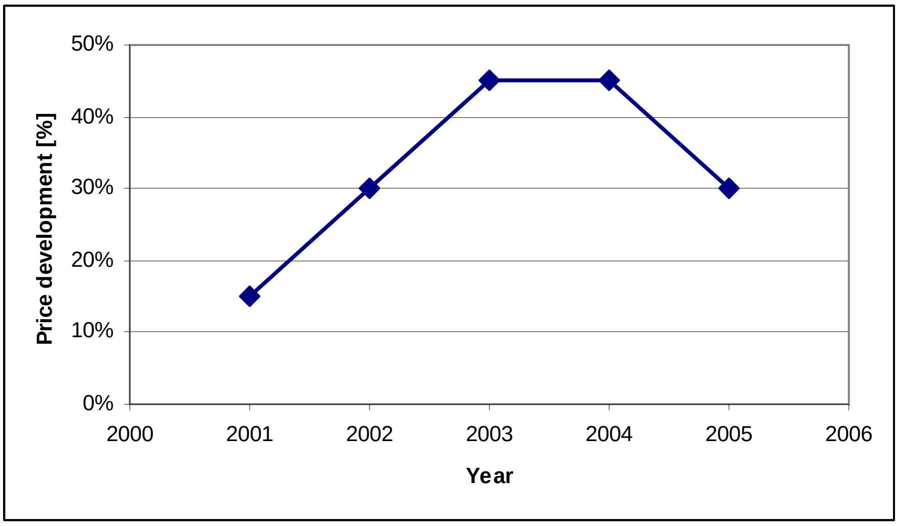


Figure 2.2: Price development for PVP components

On average the prices of the main PV pumping components have increased by about 15% per annum during 2001 to 2003. From 2003 to 2004 prices remained steady and in 2005 price reductions between 10% to 20% were recorded. The above trends are mainly due to the exchange rate variations, with a weak rand during the 2001/2003 period and a strengthening of the rand during 2005. Another reason for the relative improvement of the PVP subcomponent pricing is the recent aggressive pricing policies adopted by some of the manufacturers resulting in lower PVP initial capital costs.

3 COST ANALYSIS

In order to compare different systems offering the same service/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 Life Cycle Cost (LCC) of a system/project. Future costs include operating costs (diesel consumption, transport), maintenance costs (engine oil, filters, brushes, diaphragms, valves, rotor, impellers, labour, transport etc) and replacements (diesel engine, pump, motor, inverter, labour and transport).

In order to calculate all costs in today's Namibian dollar, the future costs are reduced to the present value using a discount rate. The discount rate is equivalent to a bank investment rate.

This approach presents a true reflection of the costs incurred over the project life of a system which provides a particular service and can be used for comparing, for example, a diesel driven car with a petrol driven car. The LCC approach is particularly important when it comes to renewable energy projects which in most cases "frighten" investors in terms of high initial costs. The conventional option, often based on a fossil fuel, appears cheaper due to low initial investment costs but the operating costs more often than not add up to a considerable amount over the project life.

This section describes the approach and details on the life cycle costing of PV pumps and diesel pumps and presents the results of a LCC cost breakdown, the breakeven between the diesel and solar option and the unit water costs.

3.1 INPUTS TO COSTING ANALYSIS

The inputs to the costing model are described here. The number of variables in pumping systems is substantially more than for example in a solar water heater and electric water heater comparison. This is due to the number of components in each system, all of which have a different operating characteristic. For that reason it is important that the inputs to the water pumping cost comparisons are described in detail to avoid significant deviations from the actual costs over system lifetimes.

The diagram in Figure 3.1 gives an overview of how the costing analysis was conducted and structured in the spreadsheet. The elements displayed in the diagram are discussed in more detail in the following subsections.

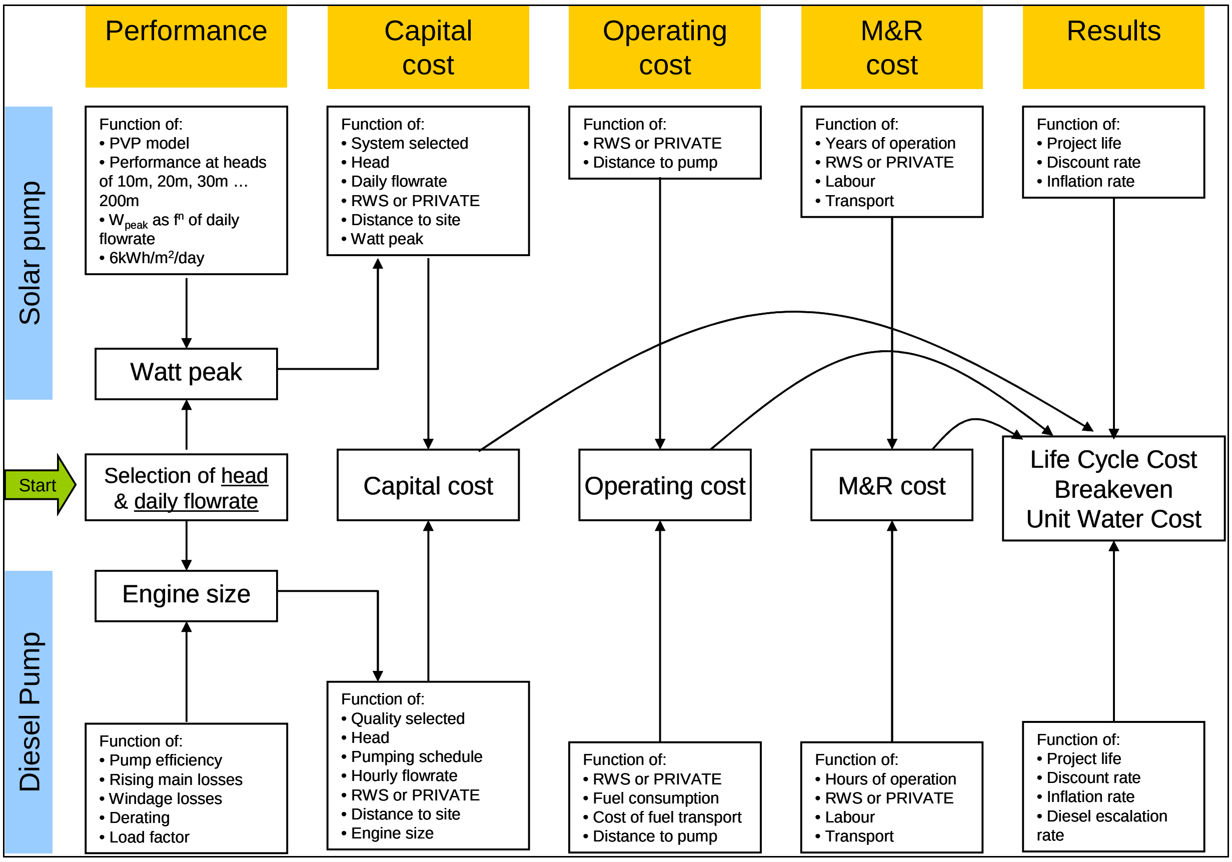


Figure 3.1: Overview of the life cycle costing structure in the spreadsheet

The subsections describe the technology used, the operating range over which the costing comparison is conducted, the cost elements of each system, the financial parameters used and the overall approach taken to the modelling.

3.1.1 Technology range

Based on the findings of the solar PV pumps in the Namibian market, as listed section 2.1.1 the following pumps are modelled in the costing:

- Grundfos SQ Flex range
- Lorentz PS range
- Total Energie TSP 1000 range
- Total Energie TSP 2000+ range
- Watermax

The diesel pumping systems are based on the diesel engines:

- Lister, as the long system life solution
- Kia and Kirloskar, as the short system life solution

while the pumps used are the helical rotor type progressive cavity Mono and Orbit pumps. The pipes used in the calculations are taper threaded pipes, manufactured in China. Parallel threaded pipes were not considered as they do not seem to be available on the Namibian market.

3.1.2 Operating range

The study covers water supply systems that are able to deliver over a head of up to 200m with a maximum daily delivery of 60m^3/day for the PVP option and a maximum hourly delivery of 12m^3/h for the diesel pumping option.

The head used in the calculations refers to the total dynamic head, and therefore includes the possible drawdown in the borehole.

Comparing pumps is slightly more complex than comparing energy systems since a pump delivers a **flowrate** over a **head** depending on the array size whereas an energy system delivers energy (kWh/day) for a particular array size. A pump therefore has two parameters, flowrate and vertical lift. A useful comparison basis for pumps is therefore given by the value referred to as the daily hydraulic load. This is stated as:

Daily hydraulic load [m^4/day] = daily flowrate [m^3/day] x head [m]

In the ideal case this relationship is a constant. For example the hydraulic load at 50m head and 20m^3/day is the same as the hydraulic load at 20m and 50m^3/day, i.e. 1,000m^4/day. Every PV pump reaches a particular hydraulic limit but that value depends on the maximum allowable array size and on the pump's ability to meet the various heads at more or less constant efficiency. Examples of different constant hydraulic load are shown in Figure 3.2.

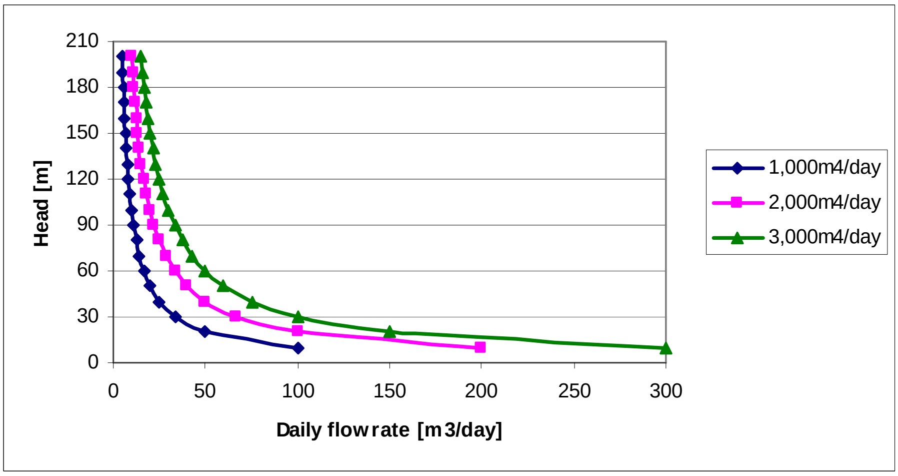


Figure 3.2: Example of hydraulic load graphs

In reality a PVP of fixed array size will not follow the line exactly because of increasing friction head (more losses) with deeper boreholes and due to variations in the characteristics of the specific pump used. Refer to Figure 2.1.

The results of the costing analysis will make use of the constant hydraulic load line to indicate thresholds for different viabilities of PVPs and diesel pumping ranges.

3.1.3 Sizing

In order to create a basis for comparison between PVPs and DPs the performance of the pumping options are linked to dedicated delivery heads. These are:

Table 3.1: Operating heads for pumping comparison

Operating point	Head [m]	Operating point	Head [m]
1	10	8	100
2	20	9	120
3	30	10	140
4	40	11	160
5	50	12	180
6	60	13	200
7	80		

For each of the above heads a water delivery range from 3 to 60 m^3 per day with changing array size is considered.

Throughout the study the delivery of the PV pump system is based on the **daily** delivery whereas the diesel pump system is based on the **hourly** flowrate. To compare PVP and DP at a particular head a daily delivery is used. While PVP delivery is daily, DPs operate at higher delivery rates for less hours so the daily flowrate is converted to an hourly flowrate for DPs (refer to section 3.1.3.2).

3.1.3.1 Solar PV Pump

The sizing of the PVP systems is based on the performance charts provided by the manufacturers. The performance charts for irradiation levels of 6kWh/m^2/day have been selected, which is a representative average of Namibia's solar resource.

For each of the heads listed in Table 3.1 a corresponding list of daily delivery in conjunction with array size (Watt peak) has been compiled. That information has been entered into the spreadsheet costing tool.

It is possible to change the irradiation levels between 5 and 7kWh/m^2/day and to introduce a tracking array for modelling specific locations as well as the use of a passive or active tracking array. The cost model increases/decreases the array size proportionally for decreased/increased irradiance levels. This is therefore a linear adjustment and the error introduced through the non-linear efficiency changes of the PVP is minor since only a 16% variation is allowed. The use of a tracker similarly reduces the required array size to pump the daily water requirements since the tracker has extended operating hours at peak sun conditions. In reality higher irradiance levels and tracking would increase the daily flowrate however, the daily flowrate and the head form the basis of the comparison between PVP and DP and can therefore not be changed.

3.1.3.2 Diesel Pump

The diesel pump is sized by calculating the actual power required to lift water, i.e.:

Hydraulic power [W] = ρ x g x head x flow, where

ρ = density of water [kg/m^3]

g = gravitational acceleration [m/s^2]

head = total dynamic head [meters]

flow = flowrate [m^3/s]

The following losses are added to the hydraulic power to calculate the overall shaft power required:

- Pump element efficiency: Variable as a function of the head
- Friction losses in the rising main: Variable as a function of the flowrate and the pipe diameter
- Rising main losses due to a possibly non-linearity of taper threaded pipes (the quality of taper threaded pipe has become poorer over recent years and there is a good chance that the rising main is not perfectly straight – this "wobble" has efficiency, as well as maintenance implications). This factor can be considerable but is virtually impossible to predict or assess scientifically. It is taken as a fixed 5% value which is considered conservative.
- Windage losses: Fixed at 10%. These are friction losses at the entry and exit of the belts into the pulleys.
- Derating of the diesel engine for altitude and temperature: Fixed: 20% for 1,300 m altitude (4% per 300m above 100m) and 35℃ operatin g temperature (2% for every 5℃ above 25℃).

The engine load factor is selected at 70%, providing the rated nominal power of the engine. The specific fuel consumption per hour of the particular size of diesel engine is used.

The DRWS usually size their diesel engine system for a ten hour pumping day. This still leaves some additional hours in case more water is required and also attempts to use reasonable water abstraction rates for borehole sustainability (instead of pumping the required daily water within two hours, should a borehole have that yield).

The costing model allows the pumping intervals and the pumping hours per pumping session to be defined but limits the abstraction rate to $12m^3$/hour. This allows the modelling of diesel pumping systems where the pump may be remotely located from the operator and is thus only operated every second or third day.

3.1.4 Costing

The costing of a pumping system that has a life expectancy of a number of years is comprised of the capital cost and the future costs, which include operating cost, maintenance cost and replacement cost. In some life cycle costing calculations a residual value is assumed which will provide a small return for the project again, for example the solar modules or the lead of lead acid batteries. However, this is often something that is far in the future and could be quite arbitrary. In this costing no residual values are considered for a PVP or DP system.

Throughout the calculations a differentiation is made between a DRWS installation and a private (commercial farm) installation. The differences are in the capital cost (lower prices for the private system due to owner involvement), the operating costs (more costly for the private system due to a diesel system which can be in the field, away from the home – not applicable to DRWS system) and the maintenance and replacement costs (lower price for the private installation due to more involvement of the owner).

There are three transport rates for different services involving transport. The transport rates listed represent the reference case under current fuel prices (N$6.70/litre) and are adjusted proportionally, based on AA rates with increase or decrease of the fuel price. The rates are listed in Table 3.2.

Table 3.2: Transport rates

Transport type	Rate [N$/km]
Truck	9.00
Contractor bakkie	5.00
Local vehicle	3.00

Furthermore there are three distances that are referred to in the calculations. These are:

1. Installation distance: The distance from a larger centre (e.g. Windhoek) to site. It is assumed that the hardware is stocked at that centre. The default distance is 300km one way.
2. Service distance: The distance from the diesel pump installation to the fuel and diesel engine service infrastructure. The default distance is 100km one way.
3. Operator distance: The distance between the operator (farmer) and a remotely located diesel pump. This distance is only applicable to the commercial farmers as it is assumed that the community is always in the immediate vicinity of the installation. The default distance is 3km one way.

3.1.4.1 Capital cost

The capital costs occur once at the beginning of the project. It comprises the cost of the equipment and accessories, the cost of the installation and the cost of transport. The cost includes all the accessories up to the exit of the borehole. No pipe extensions, reservoirs or pump house structure are included. In the case of PVPs a dual pump solution can be selected for the Grundfos. This assumes that the borehole is able to accommodate such an installation which exceeds the normal 3 to 4 inch installation diameter of PVPs. The capital costs are nearly doubled in this case as there are only savings on transport and some minor savings on piping if the two pumps feed into the same pipe.

It is assumed that the transport vehicle for a PVP installation is a bakkie (N$ 5/km at current fuel prices) whereas the transport vehicle for a diesel installation is a truck (N$ 9/km at current fuel prices) due to the weight of installation materials. It is assumed that the distance to site for the installation trip is 300km.

In terms of the DRWS vs. Private system, the main difference is that the DRWS specifications are fairly high and would thus not be a true cost reflection of a private installation. Therefore certain initial cost items are reduced assuming that the commercial farmer will do some of that work at a lower cost (accessories for installation, foundation costs, belt guard, installation cost, transport cost) when the private installation type is selected.

The capital costs used in the calculations form part of the spreadsheet database and are listed in the Appendix A2.

3.1.4.2 Operating cost

The operating costs for a DRWS installation 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 litres of diesel consumed per annum are calculated from the running time of the diesel pump. A fuel cost escalation of 2% has been assumed but the fact remains that this is a indeterminable parameter as it depends on oil reserves, conflict in oil producing countries and exchange rate.

The transport cost of fuel to site is added to the operating cost of the diesel pump. It is assumed that the average distance to the fuel supply infrastructure is at a 100km distance (service distance) and that six trips for fuel are needed per year. The percentage cost contribution towards the transport costs have been set at 20%. Therefore the other 80% of the transport costs are carried by other activities attended to. The cost rate of the transport is set to N$ 3/km at current fuel prices.

Oil consumption of the engine is provided for under the maintenance costs.

Private installation

It is assumed that the private diesel system has additional costs for driving to a diesel pump which is away from the house (distance assumed is 3km). The transport cost to a remote diesel pumping installation is therefore added to the operating cost of the diesel pump. The interval of the cost is either every day or every second/third day, depending on the pumping interval selected to get an optimal diesel pumping system.

It is assumed that a farmer will visit a PVP installation once a week at the same distance of 3km. This is the only operating costs assumed for a PVP installation.

DRWS installation

There is no additional cost for a “remotely-from-community-located” diesel pump as it is assumed that this is not generally the case, i.e. the pumping system is located in the vicinity of the community.

Refer to Appendix A2 for details.

3.1.4.3 Maintenance and replacement costs

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, acts of God (e.g. lightning), the operating environment (water quality, diesel quality, direct exposure to sunlight, excessive temperature etc) as well as the level of maintenance performed.

PV pumps

PVPs require skilled personnel to carry out the service and this will in most cases mean that the unit to be serviced needs to be shipped to Windhoek. The costs stipulated in the costing analysis are based on product specific parts and include labour as well as a transport fee. The service interval depends on the pump systems used. In most cases the service interval is 5 years. However the service interval for the Watermax is once a year while the Lorentz pump is every three 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. Refer to Table 3.3.

Table 3.3: Replacement schedule for PVPs

PVP make	Maintenance schedule [years]	Maintenance cost [N$]	Replacement schedule [years]
Grundfos SQ Flex	5	3,000	10
Lorentz PS Series	3	3,000	7
Total Energie TSP 1000	5	8,000	10
Total Energie TSP 2000+	5	15,000	10
Watermax	1	1,000	5

The replacement costs for the motor, pump and controller are equivalent to the initial purchase cost. Refer to Annexure A2 for the capital costs used for the calculations.

The transport costs are assumed to be over a larger distance since the service infrastructure for PVPs is not as well developed as that of the diesel pumps. It is therefore assumed that the transport costs are equivalent to the installation distance (300km).

An additional differentiation is made between the DRWS and the Private installation where the transport cost for a DRWS installation is taken at 100% (complete service delivery) and for a Private installation at 50% as the farmer will most likely be involved in the transporting and usually combines trips with other activities.

Diesel pumps

Diesel pumps require minor service, major service and overhauls in regular intervals.

A minor service includes oil change (topping up of oil included here) and air, fuel and oil filters.

A major service includes decarbonisation, adjustments, oil change and filter replacements and requires skilled personnel which is assumed to be in the region (DRWS) or at a close-by service centre (Private systems).

An overhaul includes the tasks of a minor and major service, replacements of parts (e.g. crankshaft) and drilling of cylinders and requires skilled personnel.

The following schedule has been selected for the service and replacement intervals of high quality (e.g. Lister) and low quality diesel engines (e.g. of Indian manufacture):

Table 3.4: Maintenance and replacement intervals for diesel engines: DRWS and Private installations

	Private systems		DRWS systems	
Maintenance & Replacement	Good quality engine [hours]	Low quality engine [hours]	Good quality engine [years]	Low quality engine [years]
Minor service	250	250	4 times per year	4 times per year
Major service	1,000	1,000	2 times per year	2 times per year
Overhaul	10,000	5,000	10,000	5,000
Replacement	35,000	10,000	35,000	10,000

The assumed costs of the service for diesel pumps are listed in Table 3.5.

Table 3.5: Maintenance costs of diesel engines

Maintenance	Low quality engine [N$]	Good quality engine [N$]
Minor service	500	500
Major service	3,000	4,000
Overhaul	60% of new	30% of new

It is assumed that the pump and the rising main steel pipes are lifted and reinstalled every five years. It is assumed that 20% of the pipes need replacement due to rust (corrosion) and wear and tear damage. The costs are modelled on the capital cost of the initial installation. Refer to Appendix A2 for details.

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. Transport costs for overhaul and replacement are therefore doubled to reflect two trips to site.

The transport costs for major service, overhaul and replacement are based on the distance to the fuel supply infrastructure (assumed in the reference case as 100km). Since DRWS often combines trips with service visits to other communities the 100km is taken as a fair assumption.

3.1.5 Financial parameters

The life cycle costing performed here makes use of the constant dollar approach, which therefore excludes inflation. The discount rate, the loan rate and the escalation rates used in this analysis are therefore real rates, exclusive of inflation.

Table 3.6: Financial parameters for the life cycle costing

Parameters	Value	Unit
Project life	20	years
Inflation rate	4.5	%
Real discount rate	4	%
Real loan rate	7	%
Real escalation of diesel	4	%
Cost of time	40	N$/hour
Carbon credits	70	N$/ton
Carbon: On/Off	Off	
Transport: Truck	9.00	N$/km
Transport: Bakkie	5.00	N$/km
Transport: Local	3.00	N$/km

The inflation rates for the last years were 4.5% (2005), 3.9% (2004), 7.3% (2003), 11.3% (2002), and 9.3% (2001). Indications are that the 2006 inflation rate is in the region of 4.5% which is the value selected for the inflation in the calculation of the real rates.

The cost of time has been reflected in the calculation as N$ 40/hour for time spent on operating the pumps. This has been requested in the workshop. However, the impact is minimal. The main cost for fuel transport comes from the vehicle use (90%). The cost distribution for driving to a remote diesel installation assuming a private system is 80% vehicle use and 20% time. The difference is due to the assumptions on the speed of the vehicle, being faster for fuel transport and slower on the farm roads.

The rate for carbon credits is currently about USD 10 per ton per annum of carbon emitted. The spreadsheet LCC tool allows the use of carbon credits. In this evaluation the carbon credits have not been activated due to the anticipated barrier to access although this will hopefully change in the future.

The price of diesel has been more or less fixed in nominal terms during the period beginning 2001 to beginning 2005. However during 2005 the price of diesel rose by 22% in real terms. Indications are that the price rise during 2006 will have a similar magnitude. With the rapid increase of the oil price from USD 30 to above USD 70 a barrel over the last two years and few signs of a return to previous levels it can be expected that the price of diesel will remain high. It is generally assumed that the price of diesel fuel will escalate over and above the inflation rate. This can be attributed to:

- Resource scarcity becoming apparent;
- Political conflict over oil;
- Manipulation of the oil markets to impact on the price of oil;
- Carbon penalties levied on diesel fuel in the future;

Due to many factors impacting on the oil price it recommended not to attempt a prediction of the price of diesel in the future as there is no reasonable case that supports that this can be done or makes sense. The erratic fuel price over the last five years is a case in point. Instead this study will investigate the impact of different diesel prices on the lifecycle cost of diesel pumps.

3.1.6 Life cycle cost modelling

The approach to the LCC is to do all the modelling around a reference case and then allow variations of some of the parameters. The main drivers for the comparison are the range of heads (10 to 200m) and the range of daily flowrates (3 to 50m^3/day) to create a matrix of values providing information on the viability and comparative financial performance of the PVP and the diesel pump.

3.1.6.1 Reference case

A reference case is created from which variations will be calculated. The parameters are as follows:

Table 3.7: Reference case parameters

Parameter	Value
Customer	PRIVATE
Solar irradiation	6 kWh/m^2/day
Tracking	Fixed array
Existing diesel pump installation	No
Type of diesel engine	Short life
Diesel price	6.70 N$/litre
Distance to site	300km
Distance to service	100km
Cost contribution to fuel transport	20%
Number of fuel transport trips per annum	6
Distance to remote pump	3km
Cost contribution to transport to remote pump	50%

The pumping schedule of the diesel pump is varied to allow for a reasonably efficient system. For low daily flowrates of 3 to 10m^3/day the pumping schedule for the DP results in operation on every second day which impacts positively on PRIVATE systems as there will be less driving. For daily flowrate above 10m^3/day the DP is operated every day. In both cases the hours of operation is altered so that the DP reaches a reasonable system efficiency of above 10%.

The financial parameters as listed in Table 3.6 are part of the reference case.

3.1.6.2 Variations

Variations in the parameters listed in Table 3.7 and Table 3.6 can be undertaken for specific cases. The variations which will be considered for this study are as follows:

- Diesel price variations at zero escalation – what is the factor by which the breakeven changes,
- Private installation with tracking,
- Private vs. DRWS installation,
- DRWS design criteria: 10 hours every day.

3.1.6.3 Assumptions and errors

The assumptions for the costing calculations are as follows:

- The boreholes have a sufficiently strong yield to allow for the generally higher flowrates of the diesel pump in comparison to the PVP.
- The water in the borehole is of reasonable quality.
- The sizing of a diesel system which results in under-loading the unit does not negatively impact on the life expectancy of the unit, nor does it change the service intervals (in terms of decarbonisation).
- The “non-linearity” factor of taper thread rising main pipes does not lead to more than 5% losses.

- Site establishment costs are excluded as well as an engine house construction.
- The pumping systems are complete at the exit of the borehole (i.e. the costs of the distribution and reservoirs are excluded from the calculation).
- None of the system components are stolen.
- No insurance of the pumping systems were considered.
- There are no costs for the local operator
- The minor service on diesel pumping systems does not require transport from/to site.
- The road conditions to site are suitable for 4 x 2 vehicles.

The main discrepancies in the calculations are expected from:

- Developments of the diesel price. There may be no escalation for five years and there may be 20% escalation for the next five years. The forecast of the oil price is not feasible.
- The cost reduction between a DRWS and a Private installation is a rough estimate.
- Inaccuracies in the PVP manufacturer's data.
- Poor assessment of the maintenance and replacement costs and intervals.
- The life cycle costing is conducted on an annual basis. When the maintenance and replacement intervals become close to one year then the inaccuracies increase as the interval has to be an integer. This inaccuracy can be remedied by calculating the life cycle cost on a monthly basis. Note that this has not been done.

3.2 RESULTS

The results are presented in this subsection and include the life cycle cost breakdown for an average 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 analysis.

The results focus on the optimal PVP solutions which are the Grundfos, the Lorentz and the TSP 2000+ PVPs. Although the costing spreadsheet also models the financial performance TSP 1000 and the Watermax, these results are not shown here as there are more cost effective alternatives.

Both the Grundfos and the Lorentz PVPs are well known products on the Namibian market. The Total Energie TSP series is less known and currently does not seem to be available on the Namibian market. However in the past a number of TSP units have been installed (DRWS) with good results. The TSP 2000+ series is part of the comparison as it is the only PVP that exceeds 1,400 Wpeak.

Throughout the calculations, the short life diesel engine pumping system is used, primarily because that seems to be the predominant system used in Namibia and secondly because the LCC cost difference between a short and long life diesel engine were found to be negligible with the maintenance and replacement information used. Essentially the savings on the lower capital cost of the short life engine is absorbed by the increased maintenance and replacement intervals while the additional expenditure for the higher capital cost of the long life engine is saved on the maintenance and replacement costs (longer intervals). This finding is certainly debatable and depends on many factors such as the reliability of the minor service, premature engine failure, operating conditions, cost of spare parts, distance to service infrastructure etc.

All comparisons are based on the assumption that the pumping systems are fully utilised, i.e. the solar pump is used every day of the year and the diesel pump is used according to the selected pumping schedule, to meet the average daily delivery of the solar pump.

The study presents some results as a function of the hydraulic load. This is explained in Table 2.1. Since it is not evident how the hydraulic load relates to the Watt peak of different PVPs, this relationship is displayed in Figure 3.3. Note that this is an approximate relationship.

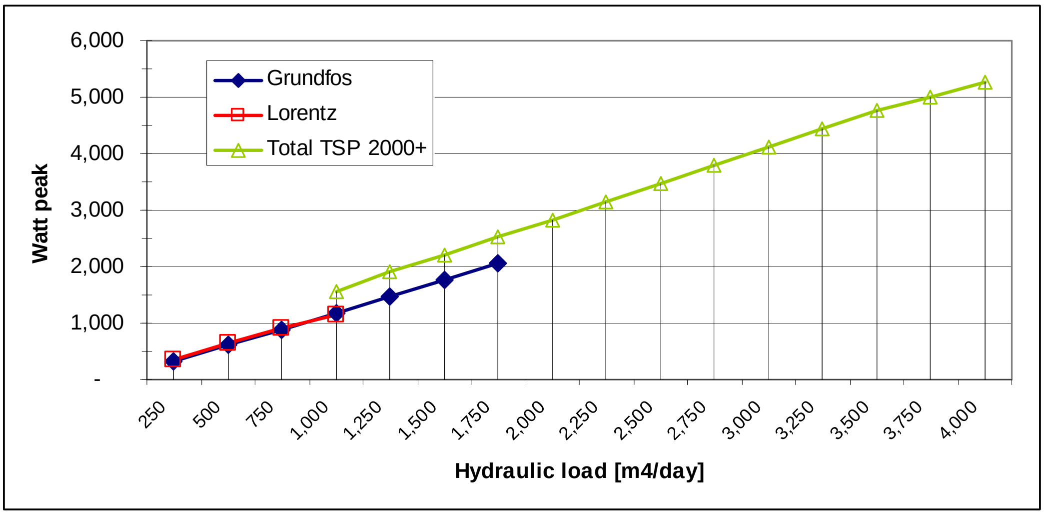


Figure 3.3: Approximate relationship between the hydraulic load and Watt peak

The efficiency of the Lorentz and the Grundfos PVPs are similar and therefore the W_{peak} versus hydraulic load more or less superimpose and have a ratio of 1,200W_{peak} per

1,000m^4/day at 6kWh/m^2/day (or more accurately W_{peak} = 1.16 x [hydraulic load] + 30). The Grundfos PVP reaches a maximum W_{peak} of 2,000 which represents a parallel pumping system (Grundfos Dual).

The Total Energie TSP 2000+ range has a slightly lower efficiency shown by the higher W_{peak} requirements for the same hydraulic load. The relationship between W_{peak} and the hydraulic load is given as Wpeak = 1.25 x [hydraulic load] + 330.

3.2.1 Cost breakdown

The life cycle cost breakdown of two PVPs is shown in Figure 3.4. The first pie chart shows the cost distribution for a Grundfos PVP at a hydraulic load of about 800m^4/day (80m head, 10m^3/day, 970W_{peak}) and the second pie chart shows the LCC breakdown for a Total Energie TSP PVP at a hydraulic load of about 2,500m^4/day (80m head, 32m^3/day 3,400W_{peak}). The breakdown is typical for a renewable energy system showing that the main portion of the cost is the initial capital cost. The portion representing the capital cost increases as the size of the system increases.

The operating cost reflects a weekly inspection drive to the site (default value of 3km) for a commercial farm system. This cost is constant for both systems and therefore becomes less significant in the cost breakdown of the larger PVP. The maintenance and replacement costs increase with the size of the system as the components for the larger PVP are more expensive. The maintenance and replacement intervals are the same for these two PVPs.

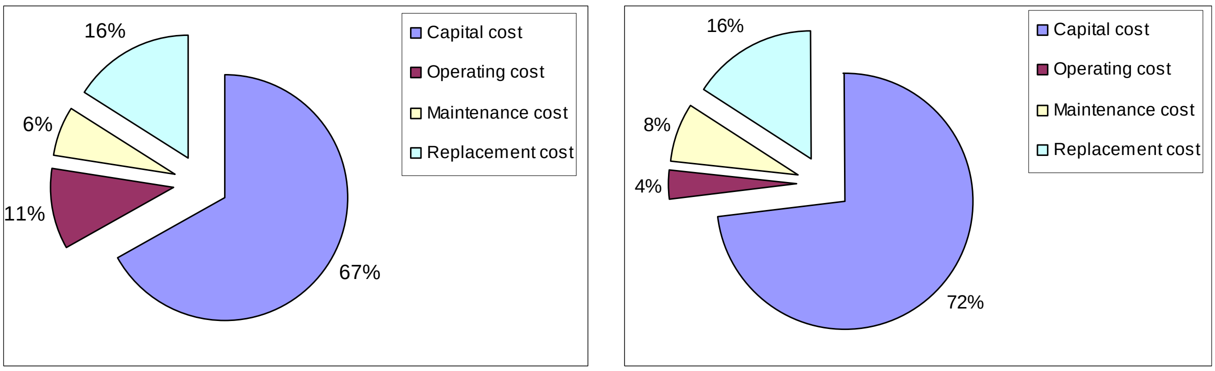
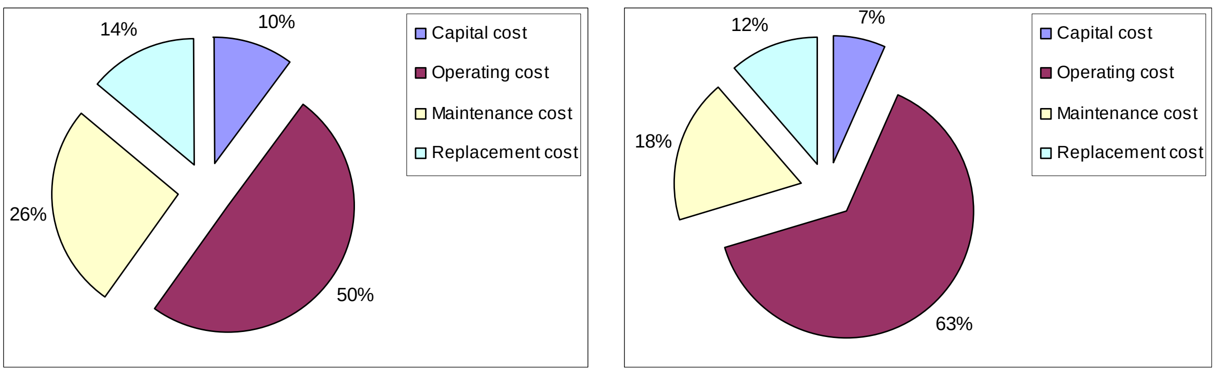


Figure 3.4: Cost breakdown of the LCC for Grundfos and Total Energie TSP 4000

Figure 3.5 shows the LCC breakdowns for diesel pumps delivering 10m^3/day (2.5m^3/h for 8 hours every second day) and 32m^3/day (5m^3/h for 6 hours every day) respectively at an 80m



head.

Figure 3.5: Cost breakdown for diesel pumps delivering an average flow of 10 and 32m^3/day

The bulk of the costs in both cases are the operating costs. As the operating hours increase, the operating costs increase more significantly than the maintenance cost shows that fuel at current cost levels is the main contributor to the LCC of DPs.

3.2.2 Life cycle cost comparison

The life cycle cost of different pumping options shows the true cost incurred over the project lifetime for the same service rendered, i.e. an average of 'x' cubicmeter of water delivered over a fixed head within a fixed period. Since the LCC varies with daily flowrate and head, two daily flowrate examples have been selected. These are shown in Figure 3.6 for three delivery heads each.

It can be seen that the LCC of the PVPs increase with increasing hydraulic load (note that different PVPs have been used, always striving for the most optimal system). The increasing LCC of PVPs is explained by the increasing power requirements.

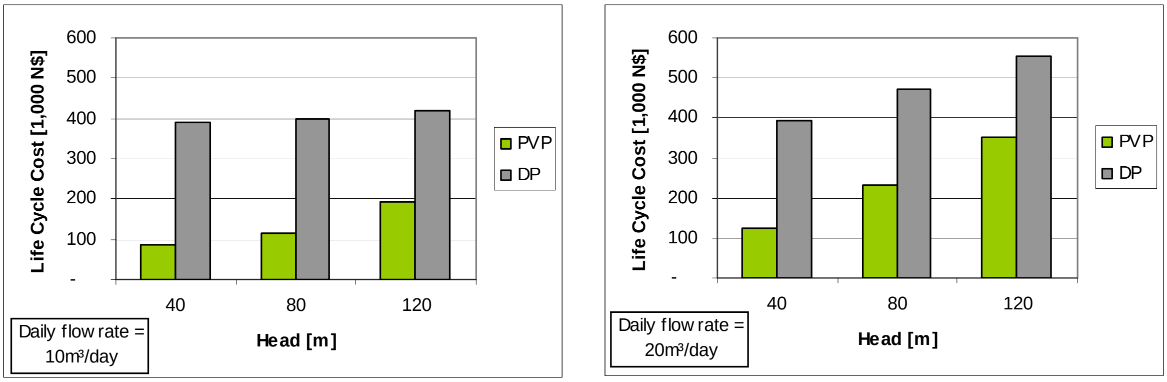


Figure 3.6: Life cycle cost for PVP and DP

The diesel pump hourly flowrates are set to a quarter of the daily flowrates, i.e. 2.5m^3/hour for 8 hours every second day means that the average daily flowrate rate is 10m^3/day. This yields a fairly efficient diesel pumping system and pumping every second day requires less operator travel and time. However this also assumes that the borehole has the necessary capacity to deliver at higher extraction rates since the solar pump would only extract at a rate of a sixth of the daily flowrate, i.e. the maximum flowrate of the solar pump is about 1.7m^3/hour at 10m^3/day.

The LCC of the diesel pump systems remain fairly flat at lower hydraulic load (less than 1,000m^4/day or in terms of hourly hydraulic load less than 200m^4/hour). A diesel pump is not efficient at such low power requirements and the fuel consumption remains more or less fixed at the minimum rate of 0.7litres/hour. Once the hydraulic load increases above 200m^4/hour the fuel consumption rate increases and the operating costs go up. The capital cost also increases but the impact on the overall LCC is minimal.

The LCC is summarised in Figure 3.7 where the LCC for PVPs and DPs has been averaged for different hydraulic loads. This is highly dependent on the selected pumping schedule which is as follows:

- If the daily flowrate is less than 10m^3/day, then the diesel pump will pump every 2nd day. If the daily flowrate is more than 10m^3/day then it will pump every day.
    - If the daily flowrate is less than 10m^3/day, then the duration of the pumping session will be 8 hours (pumping every second day).
    - If the daily flowrate is less than 20m^3/day but more than 10m^3/day, then the duration of the pumping session will be 6 hours (pumping every day).

- o If the daily flowrate is more than 20m^3/day then the duration of the pumping session will be 8 hours (pumping every day).
- The pumping intervals and the pumping hours per session are interlinked.

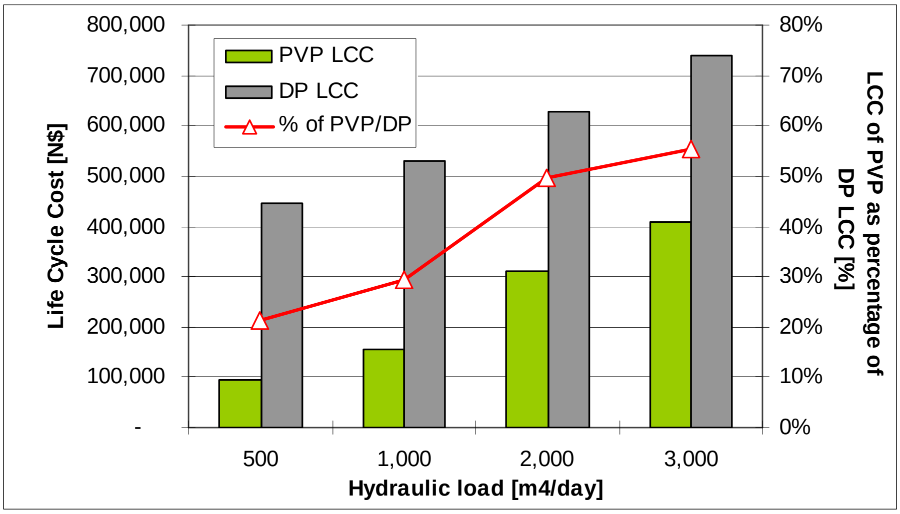


Figure 3.7: Life Cycle Costing as a function of the hydraulic load

The resulting LCC values are shown in Figure 3.7. In addition the averaged PVP LCC has been divided by the averaged DP LCC for each of the hydraulic load lines. This yields the percentage cost of PVP as a function of the cost of the DP. At low hydraulic load the PVP LCC is as low as 20% of the DP LCC. At higher hydraulic loads this value reaches 55% which means that the PVP option still provides a solution at half the life cycle cost of the DP option.

3.2.3 Breakeven between PV pumps and diesel pumps

The choice between PVP and DP 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 years to breakeven which is when the cumulative LCC of PVPs become lower than the cumulative LCC of DPs. The shorter the years to breakeven, the more attractive the RE solution becomes and the higher the cost savings over the project life.

3.2.3.1 Single case breakeven analysis

Figure 3.8 shows a typical graph presenting the years to breakeven. In this case a Grundfos pump delivering 10m^3/day over 80m head is compared with a short life diesel engine, pumping for eight hours every second day (assuming that the necessary reservoirs are in place). The breakeven occurs after two years.

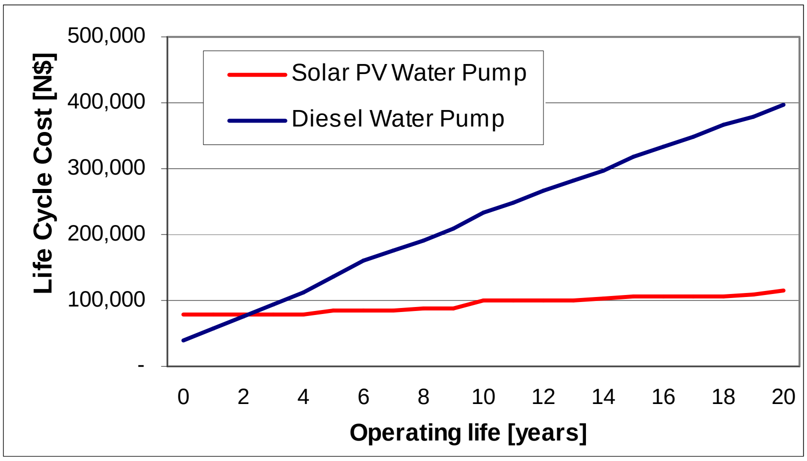


Figure 3.8: Typical years to breakeven graph for PV pump vs. a diesel pump

Figure 3.9 shows the impact of changes in the fuel price on the overall LCC and the years to breakeven. This particular example is based on a water pumping system delivering 15m^3/day over a 100m head with a diesel pump delivering at 3.75m^3/h. The calculations were repeated for three fuel prices: 6.00, 9.00 and 12.00 N$ per litre. All calculations were done with a zero diesel price escalation rate.

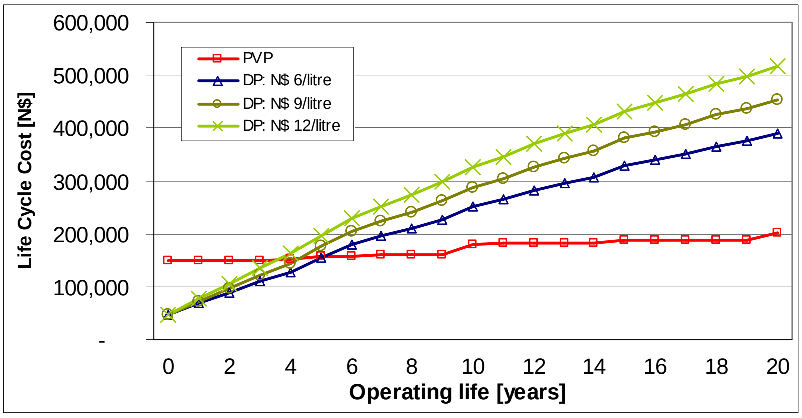


Figure 3.9: The impact of fuel price on the LCC and breakeven

The impact of the fuel price on the overall LCC is evident through the increased final costs. The relationship between the LCC and the fuel price is approximately <u>3% increase in LCC for every 10% increase in fuel price</u>.

The impact of increased fuel prices is cumulative over the project life. In cases where the years-to-breakeven is already fairly short, a fuel price increase will not impact significantly. However where the years to breakeven is longer (three years plus) the higher fuel prices will bring the breakeven point forward. The indicative relationship between the fuel price and the breakeven point is shown in the following graph.

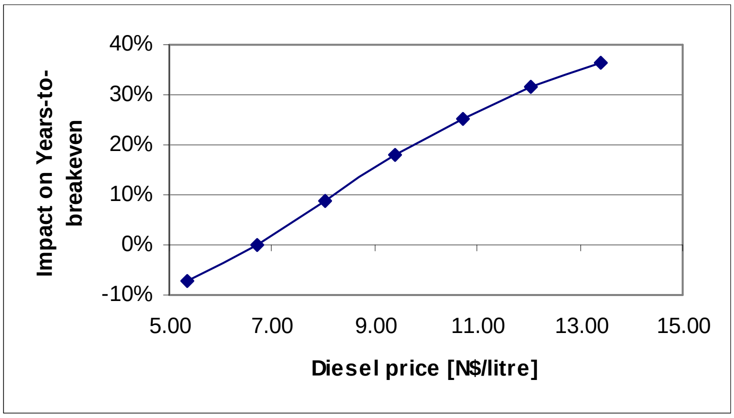


Figure 3.10: Indicative relationship between fuel price and breakeven

The calculation is based on the current diesel price of 6.70N$/litre (0% impact) and represents an average impact of fuel price variations on the years to breakeven. For different operating points the impact is different since the pumping schedule, the capital cost and the replacement costs vary over the range of operating points. The relationship indicates a <u>5% reduction in the years to breakeven for every 10% increase in the fuel cost</u>. This holds true for up to 50% fuel increases where after the impact of an increase in fuel price lessens.

The use of tracking arrays to increase the daily output of the PVP is a popular option with PVP systems. Tracking arrays can be passive or active, single or double axis, all of which determines the increase of the daily energy harnessed. The increase can be in the region of 10% to 15% for a passive, single axis tracker and to 25% to 30% for an active, dual axis tracker. If the pump is a centrifugal pump (pump efficiency sensitive to operating point) then the daily efficiency of the pump will improve more than the daily efficiency of a helical rotor pump, which has a flatter efficiency curve.

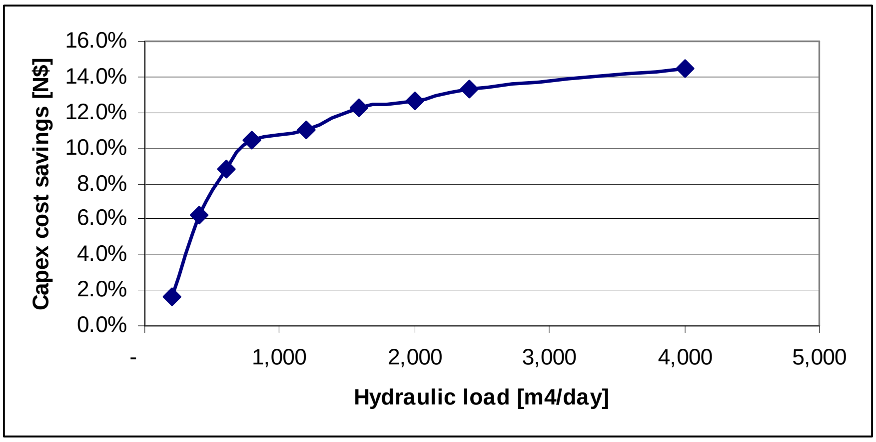


Figure 3.11: PVP capital cost reduction when using a tracking array with 20% increase in solar irradiation

For the cost comparison it is assumed that the tracking does not increase the water delivery but allows a reduction in the size of the solar PV array (this is a practical approach adopted here since the average daily flowrate between the PVP and DP need to remain the same for comparison sake).

Figure 3.11 shows that the cost savings at low hydraulic load and consequently low PV array size is small and increases as the size of the hydraulic load and therefore the PV array size increase. For example, the PV array size needed for a PVP to deliver at a hydraulic load of 1,000m^4/day is about 1,200Wpeak. The capital cost of the system decreases by about 10% if tracking arrays are used to decrease the PV array size for the same amount of water per day. This cost savings includes the additional cost of trackers and the reduced cost of the PV array.

3.2.3.2 Summary breakeven analysis

The comparison of PVPs and DPs over the whole operating range (10m to 200m and 3m^3/day to 50m^3/day) yields are multitude of results which will be presented in this section. It is important that a sensible pumping system is selected for each of the operating points. This refers mainly to the PVP selected (choosing the optimal PVP at each operating point) and to the pumping schedule selected for the diesel pump which seeks to optimise system efficiency without exceeding the borehole capacity through an excessive extraction rate.

The years to breakeven has been calculated for the Grundfos, Lorentz and the TSP 2000+ PVPs in comparison to the short life diesel engine pumping system over the operating range being studied here. All results are based on the reference case listed in Table 3.7. Any deviation from the reference case is stated.

Table 3.8 presents the summary years-to-breakeven results. The numbers in the cells represent the years to breakeven between PVP and DP. The yellow fields represent years to breakeven for the Grundfos and Lorentz PVPs (the two pumping models have similar life cycle costing results). The light green fields represent parallel Grundfos systems in the same borehole and the blue cells represent the Total Energie TSP 2000+ series of pumps.

The diesel pumping schedule, which has a significant impact on the operating costs and the maintenance and replacement intervals, has been selected as follows:

- If the daily flowrate is less than 10m^3/day, then the diesel pump will pump every 2nd day. If the daily flowrate is more than 10m^3/day then it will pump every day.
    - o If the daily flowrate is less than 10m^3/day, then the duration of the pumping session will be 8 hours (pumping every second day).
    - o If the daily flowrate is less than 20m^3/day but more than 10m^3/day, then the duration of the pumping session will be 6 hours (pumping every day).
    - o If the daily flowrate is more than 20m^3/day then the duration of the pumping session will be 8 hours (pumping every day).
- The pumping intervals and the pumping hours per session are interlinked.

The underlying criterion for the DP pumping schedule was that the diesel pump hourly flowrate does not exceed a quarter of the average daily flowrate selected for the PVP. This still requires a borehole with a stronger yield than would be required for a PVP delivering the same average amount of water.

Table 3.8: Years to breakeven for PVP vs. DP over the operating range

		Daily water [m³/day]							
		3	6	8	13	17	25	33	50
Head [m]	20	0.0	0.0	0.0	0.2	0.5	1.0	1.3	2.6
	40	0.0	0.2	0.5	0.8	1.2	2.6	2.8	5.6
	60	0.0	0.5	1.0	1.2	2.6	3.5	5.9	7.2
	80	0.0	1.0	1.7	1.8	3.6	6.4	6.7	7.8
	120	0.0	1.9	2.7	4.1	7.1	8.2	Diesel	Diesel
	160	0.2	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel
	200	0.6	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel

As the hydraulic load increases the years to breakeven between PVPs and DPs increase! The grey fields marked "Diesel" indicate that the diesel option is to be selected. This is however not due to the diesel pump solution being more viable but due to the lack of a PVP option at these operating points. It is unlikely that the PVPs will develop much into the higher heads (120 to 200m) in combination with a hydraulic load of more than 1,500m^4/day due to the lower anticipated volume of PVP sales for these particular borehole requirements. It is expected though that PVPs will be developed which can pump up to a 200m head and deliver up to 7.5m^3/day (i.e. up to 1,500m^4/day). However beyond that operating point the diesel pump will remain the pumping system of choice.

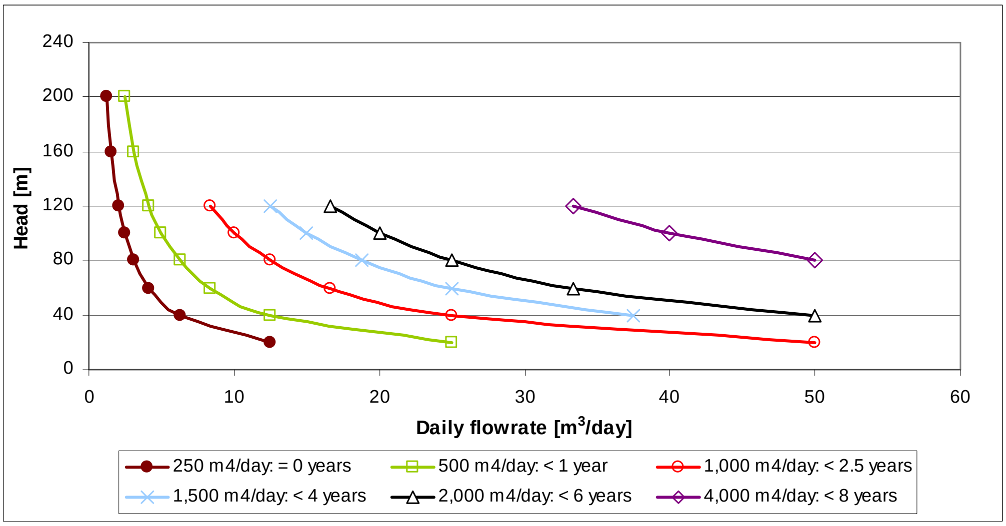


Figure 3.12: Hydraulic load lines with years to breakeven

In Figure 3.12 hydraulic load lines are used to indicate what the breakeven periods are for PVP vs. DP. For example, the brown load line (250m^4/day) shows that a PVP operating on that line will breakeven from the start. All PVPs operating to the left and the bottom of that hydraulic load line will also breakeven from the start. Similarly, PVPs operating on the red load line (1,000m^4/day) will breakeven in less than 2.5 years, which decreases to 1 year as the operating point approaches the green load line (500m^4/day).

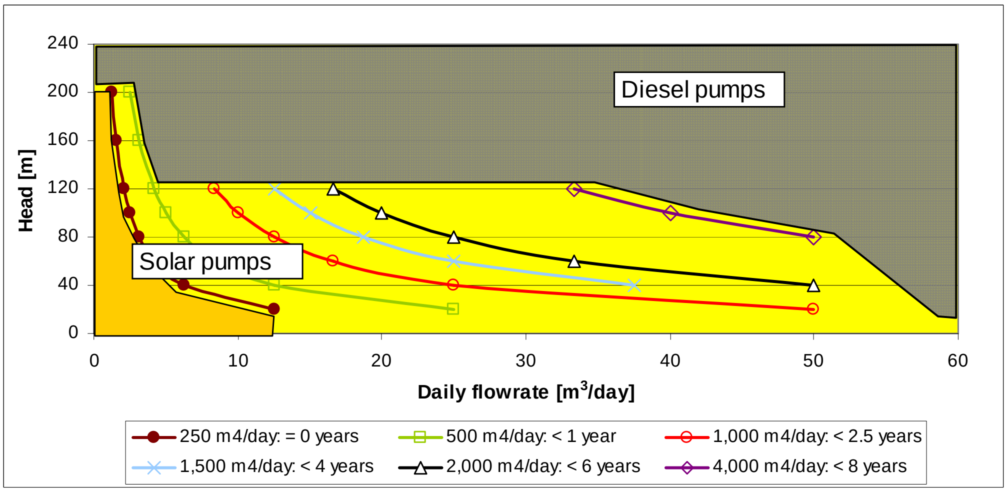


Figure 3.13: Cost effective areas for pumping technologies

Figure 3.13 shows the same graph as in Figure 3.12 but with coloured areas indicating the pumping technologies of choice. This assumes that pumping systems are fully utilised throughout the year.

The orange and the yellow areas indicate the operating range where PVPs are more cost effective (lower LCC) than DPs. The orange area shows where PVPs break even from the start. The grey area indicates where DPs are the technology of choice. As stated before, the grey area also indicates the operating range where no PVPs are available.

Figure 3.14 shows another method of presenting the summary results of years-to-breakeven versus hydraulic load for the three PVP systems analysed. The parameter settings are as per reference case in Table 3.7.

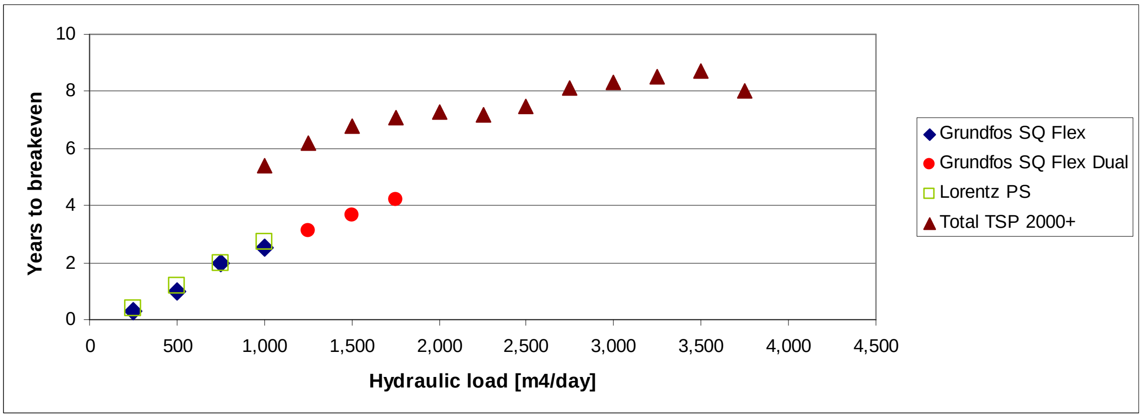


Figure 3.14: Years to breakeven as a function of hydraulic load

The graph shows the similar financial performance of the Grundfos and the Lorentz PVPs. The Grundfos is also modelled with parallel systems in the same borehole (red, circular markers). The jump between the Grundfos/Lorentz PVP and the Total Energie TSP 2000+ Series is mainly due to the lower efficiency of the Total TSP range, which is based on a induction motor and a centrifugal pump element (refer to section 2.1.1) as well as the higher per kW cost of the subsystem components (inverter, motor and pump).

In Figure 3.15 the graph of Figure 3.14 has been presented as a function of Watt peak. This makes it simpler to relate the results to existing PVP system sizes as opposed to the hydraulic load. Example: A Lorentz PVP with 350W_{peak} array power presents a cheaper option right from the start when compared to a DP. A Lorentz/Grundfos PVP with a 900W_{peak} array breaks even with a DP after about two years.

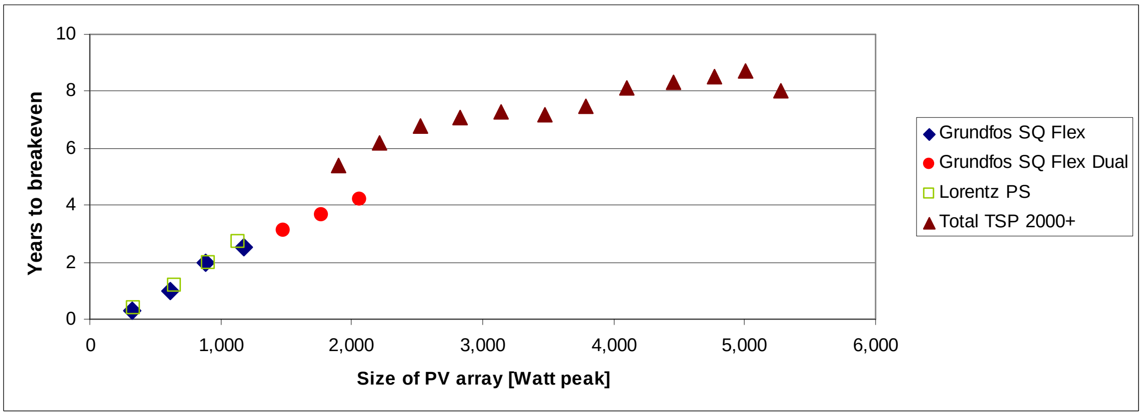


Figure 3.15: Years to breakeven as a function of Watt peak

Figure 3.16 presents an example for the DRWS case. This example differs from the PRIVATE pumping system example as follows:

- Higher upfront cost due to full outsourcing of the diesel pumping installation.

- No transport cost to a remote pumping system as it is assumed that the operator stays at the water point.
- The pumping schedule has been selected as per DRWS design: 10 hours of pumping everyday.

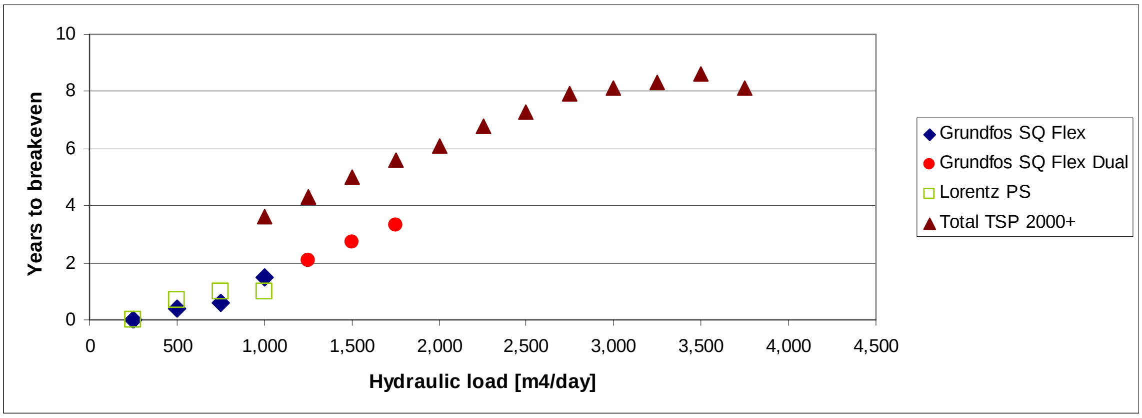


Figure 3.16: Years to breakeven for a DRWS installation pumping 10hours everyday

This results in the years to breakeven decreasing by approximately one year for Grundfos and Lorentz PVPs and two years for the Total Energie TSP series at lower hydraulic loads. The main reason for this decrease is that the DPs are operating less efficiently at lower hydraulic load due to the long pumping hours and low hourly pump rates. The higher capital cost of an installation meeting the DRWS specifications is countered by the savings of transport costs to a remote pumping installation as assumed for the PRIVATE installation.

In summary, the results for the PRIVATE installation show that:

- PVPs operating below 250m^4/day are more cost effective from the start,
- PVPs operating below 500m^4/day break even after less than one year.
- PVPs operating below 1,000m^4/day break even after less than 2.5 years.
- PVPs operating below 2,000m^4/day and below 120m head break even after less than 6 years.
- PVPs operating below 4,000m^4/day and below 120m head break even in less then 8 years.
- Diesel pumps are the pumping solution of choice when operating:
  - Above 4,000m^4/day.
  - Above 120m head and 500m^4/day.
  - Above 200m head.

3.2.3.3 Comparison to previous work

Hervie (2005) conducted detailed case studies for two DRWS administered water points and found the following breakeven results:

- 6 years to breakeven at 70m head and 17m^3/day.
- 11 years to breakeven at 130m head and 12m^3/day.

It is not clear which PVPs were used to make this comparison other than that these were Grundfos pumps. It is therefore assumed that this comparison is conducted with the previous Grundfos SA 1500 range, which is based on an induction motor with a centrifugal pump.

Comparing the above results to the modelling conducted in this study yields the following results:

- 3 years to breakeven at 70m head and 17m^3/day (Grundfos SQ Flex Dual).
- 6 years to breakeven at 120m head and 12m^3/day (Total Energie TSP 2000).

The lower results can be due to many factors, which include:

- Lower capital cost of PVPs due to stronger currency and lower Wpeak prices. There is no capital cost breakdown to conduct a more in depth analysis as Hervie was using the prices which were paid for these system in order to model the actual situation as close as possible.
- Lower efficiency of the Grundfos SA 1500 (only applies to case 1).
- Modelling of diesel pumps conducted on actual hours of operation in this study.
- Higher fuel transport costs assumed.
- Possible inaccuracies in converting costs of the case study installation into todays currency.
- Lower discount rate (2% as opposed to 4%).
- No escalation for diesel fuel used by Hervie.
- Different pumping schedules.

During a presentation Hervie made another comparison at an operating point of 100m and 7m^3/day which has a breakeven between one to two years. Figure 3.13 shows similar results for a hydraulic load of 700m^4/day.

<u>In 1996 Fahlenbock found that the breakeven between PVP and DP at 1,000m^4/day and 2,000m^4/day were about 13 and 18 years. This has reduced to 2.5 and 6 years respectively!</u>

3.2.4 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.

The UWC is calculated from the life cycle cost based on the assumption that the capital for the implementation of the water supply system is borrowed from the bank against the real loan rate. The LCC is therefore amortised into equal annual payments over the project life. The resulting annual payments are divided by the annual water delivery to yield the UWC.

Table 3.9 lists the calculated UWC for a range of heads and daily flowrates based on the pumping schedule as described in section 3.2.3.2 and the reference case parameters described in Table 3.7. From the UWC figures it is evident that the cost of water increases with increasing head (more solar PV required) and decreases with increasing water volume pumped (higher efficiency).

The yellow fields represent single PVP solutions, the orange fields represent parallel Grundfos systems in the same borehole and the blue fields represent Total Energie TSP 2000+ PVPs. The UWC reflect these changes in systems through a discontinuity in the trends.

Table 3.9: Unit water cost for PVPs

		Daily volume flow [m³/day]							
	[m]	3	6	8	13	17	25	33	50
Head [m]	20	6.33	3.38	2.09	1.54	1.27	0.99	0.85	0.87
	40	5.64	3.15	2.53	1.90	1.59	1.65	1.40	1.57
	60	6.09	3.51	2.86	2.21	2.49	1.97	2.38	2.08
	80	6.49	3.96	3.33	2.93	2.98	3.18	2.75	2.43
	120	7.59	4.82	4.50	4.38	5.04	4.31	No PVP	No PVP
	160	7.78	No PVP	No PVP	No PVP	No PVP	No PVP	No PVP	No PVP
	200	8.77	No PVP	No PVP	No PVP	No PVP	No PVP	No PVP	No PVP

The UWCs of DPs are listed in Table 3.10. The same pricing trends are observed as for the UWCs of PVPs, i.e. the UWC at high head and low volume has the highest value and the UWC at lowest head and highest daily flowrate has the lowest value.

Table 3.10: Unit water costs for DPs

		Daily volume flow [m³/day]								
	[m]	3	4	6	8	13	17	25	33	50
Head [m]	20	31.72	23.81	15.89	11.92	10.98	8.23	5.50	4.77	3.18
	40	32.09	24.09	16.07	12.06	11.07	8.30	5.56	4.81	3.47
	60	32.47	24.37	16.26	12.20	11.17	8.37	5.74	4.97	3.99
	80	32.84	24.65	16.44	12.34	11.26	8.44	6.24	5.45	4.57
	120	33.58	25.20	16.82	12.62	11.45	9.24	7.28	6.49	5.81
	160	34.32	25.76	17.19	13.44	12.17	10.19	8.55	7.83	7.15
	200	35.07	26.32	17.69	14.48	13.13	11.26	9.43	8.68	8.02

Figure 3.17 graphically presents selected heads and daily flowrates for PVPs. The trends show that:

- The cost of water increases with increasing head.
- The UWCs are high for low volume applications.
- The UWCs at daily flowrates above 8m^3/day are similar.

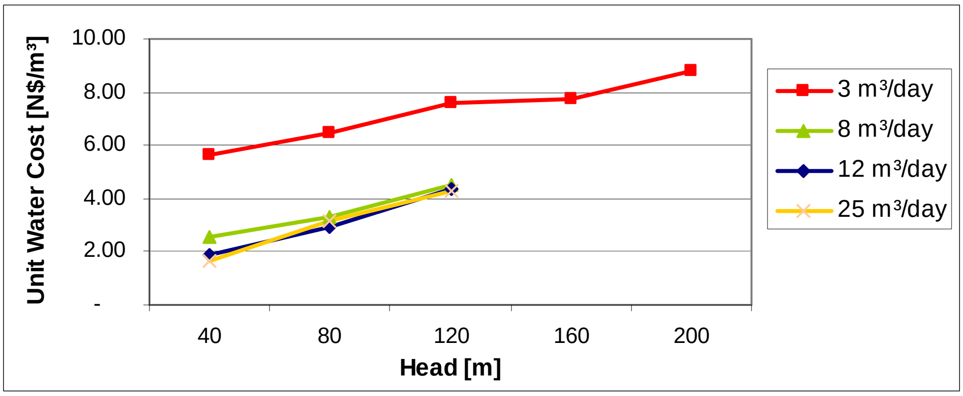


Figure 3.17: Unit Water Cost of PVPs at selected heads

Figure 3.18 graphically presents selected heads and daily flowrates for DPs. The trends show that:

- The cost of water is relatively insensitive to head.
- The UWCs are high for low volume applications.
- The UWCs decrease as the flowrates increase.

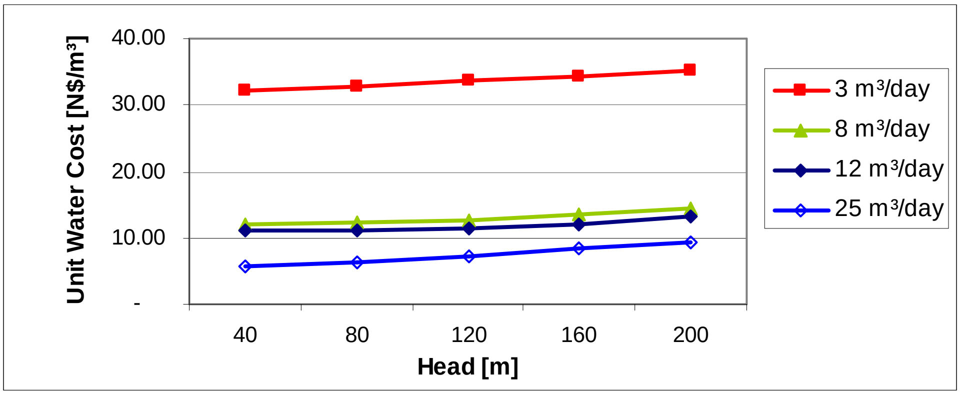


Figure 3.18: Unit Water Cost of DPs at selected heads

In order to compare the differences between the UWC for PVP and DPs, the UWC of PVPs has been divided into the UWC of the equivalent DP. The result is shown in Figure 3.19. For example, the UWC of a PVP is about 21% of the UWC of a DP at 40m head and 8m^3/day flowrate. With increasing head and daily flowrate the UWC of a PVP moves closer to the UWC of the DP, however, in the example shown, the UWC of a PVP still remains below 60% of the UWC of a DP.

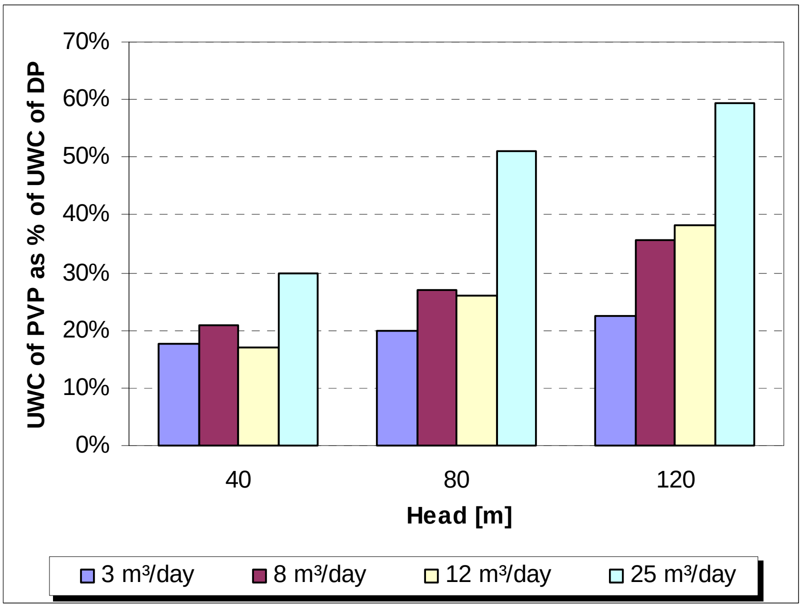


Figure 3.19: Percentage UWC of PVPs as a function of UWC of DPs

This reiterates the findings that the DP does not present a viable solution at low hydraulic loads.

3.2.5 Sensitivity analysis

The sensitivity analysis is conducted to identify parameters which have a major impact on the results presented in section 3 and therefore qualify the results shown accordingly.

The sensitivity analysis assesses the impact on variations of the following parameters:

- Discount rate: 2%, 4% (reference case), 6%.
- Project life: 15, 20 (reference case) & 25 years.
- Diesel escalation rate: 0%, 4% (reference case) and 8%.
- Change in fuel consumption: -15%, no change, 15%.
- Transport: All distances at zero, reference case and double all the distances.

The output indicator for variations in above parameters is the percentage change in LCC. Three pumping scenarios were selected for the sensitivity analysis. The changes on the LCC were observed for these three scenarios and recorded if there were deviations between the three scenarios then these are reported here. The scenarios were:

- 120m, 7m^3/day
- 40m, 30m^3/day
- 80m, 20m^3/day

This covers a range of hydraulic loads and also makes use of the three different PVP systems. All calculations were based on the reference case as listed in Table 3.7.

3.2.5.1 Discount rate

The sensitivity to changes in discount rate is shown in Figure 3.20. A lowering of the discount rate results in higher LCC as future values are reduced to a lesser extent. The DP shows a higher sensitivity to changes in discount rate. This is to be expected since most of the costs of a diesel pumping system are the future cost components which are therefore more affected by the discount rate then the PVP option with higher upfront costs. Actual changes in the discount rate over the project will therefore impact more significantly on the LCC of the DP than on the LCC of the PVP.

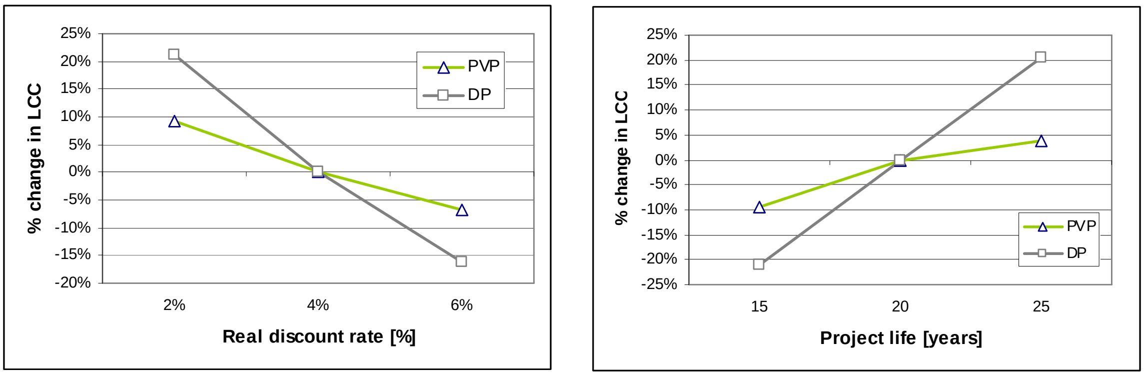


Figure 3.20: Sensitivity analysis: Discount rate & project life

The sensitivity to project life follows the same reasoning. A shorter project life will reduce the costs of a diesel pumping system more significantly due to lower accumulated operating, maintenance and replacement costs. The PVP however is less affected by changes in the project life than the DP system.

The sensitivity analysis for fuel escalation and possible errors in the diesel engine fuel consumption are shown in Figure 3.21. As expected the LCC of the DP is highly sensitive to variations in the diesel price. The LCC of the PVP is slightly affected due to the costs associated with weekly inspection trips. The transport rates are all linked to the diesel price and therefore the changes in diesel cost will impact on the transport costs.

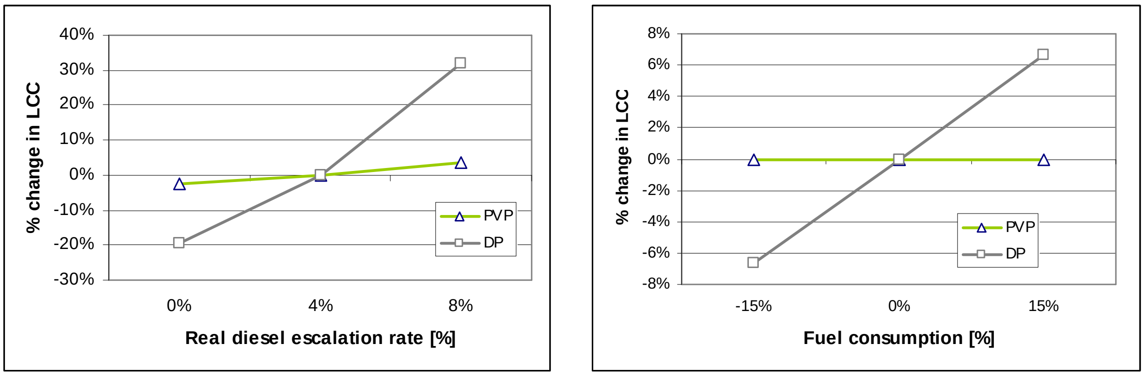


Figure 3.21: Sensitivity analysis: Fuel escalation and fuel consumption

Errors in the fuel consumption are not that critical as shown in the graph. With a 15% error the LCC changes by about 7%.

The transport sensitivity was tested with the figures listed in Table 3.11.

Table 3.11: Sensitivity values for transport distances

Distances	Reference case	Scenario 1	Scenario 2
Distance to site	300km	0km	600km
Distance to fuel	100km	0km	200km
Distance between operator and pump	3km	0km	6km

Figure 3.22 shows the sensitivity to transport distances. The LCC of the DP is significantly affected by transport distances and their associated costs. The LCC cost of a small PVP system is similarly affected due to the lower overall cost of the system. It is assumed that the PVP system is inspected weekly and is at a distance of 3km from the operator. As the PVP system size increases, the transport cost portion reduces as part of the overall cost.

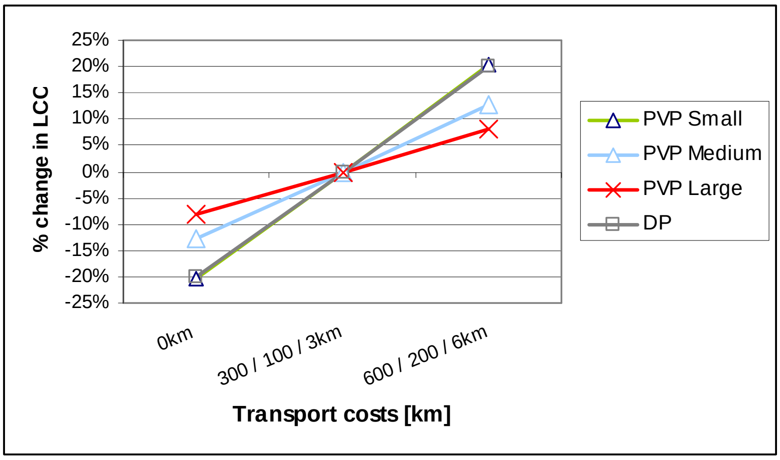


Figure 3.22: Sensitivity analysis: Transport costs

Transport therefore has a significant impact on the LCC of DPs and of small PVPs. Knowledge of local conditions for modelling PVP and DP financial performance will therefore be beneficial to avoid unrealistic assumptions on distances.

4 FACILITATION OF PV PUMPING

This section looks at what will facilitate the use of PV pumping beyond the financial case which was demonstrated in section 3 and commences with a high level analysis of the approximate number of boreholes which are suitable for Namibia

4.1 HIGH LEVEL MARKET POTENTIAL ASSESSMENT[5]

This section explores the potential for PVPs through looking at the number of boreholes which are suitable for PVP operation.

The Division of Geohydrology operating under the Department of Water Affairs (DWA) within the Ministry of Agriculture, Water and Rural Development maintains a record of boreholes in Namibia. Although it is mandatory that all boreholes are registered with the DWA, in reality some of the boreholes drilled have not been registered. With the borehole survey of 2003 a database of 51,500 boreholes was established.

The Resource Management Unit at the Department of Water Affairs determines sustainable abstraction rates for the boreholes based on a holistic resource management approach which takes into consideration the overall groundwater resources, the different types of aquifers and the recharging of the groundwater resources, among others. The unit advises the Directorate of Rural Water Supply (DRWS) on the appropriate abstraction rates for boreholes in the communal areas.

Table 4.1 shows that 71% of the recorded boreholes are on freehold, privately owned land. The communal areas hold 24% of the recorded boreholes and these are administered by the Directorate of Rural Water Supply. The remaining 5% of boreholes are located on state controlled land.

Table 4.1: Number of recorded boreholes in Namibia

Sector	No of boreholes	Percentage of total
Communal	12,233	24%
Freehold	36,653	71%
State	2,642	5%
TOTAL	**51,528**	**100%**

Not all of the boreholes drilled are usable. The quality measure of water is gauged by the amount of total dissolved solids (TDS) contained in the water. Potable water has a TDS of up to 2,000 mg/l, while the range from 2,000 mg/l to 5,000 mg/l can be used for livestock, and greater than 5,000 mg/l is unusable[6].

About half of the boreholes listed in the database have water quality records. The records show that about 80% of the boreholes have water quality fit for human consumption, 10% is suitable for livestock use only while another 10% is unusable. The chemical analysis of the other boreholes is not known and it is not possible to extrapolate from the above data to the overall water quality breakdown. However for the purposes of estimating the potential for

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[5] Information provided by Division of Geohydrology, Department of Water Affairs (DWA), Ministry of Agriculture, Water and Rural Development

[6] Atlas of Namibia, A Portrait of the Land and its People, Mendelsohn. J, Jarvis. A, Robert. C and Robertson. T, Ministry of Environment and Tourism, 2002.

PVPs in Namibia after concluding the cost benefit analysis, the existing data will be extrapolated to the recorded 51,500 boreholes in Namibia since that is the most reasonable approach available.

Figure 4.1 presents the number of boreholes which are in use and which have an acceptable chemical composition for livestock. The total number of boreholes of use are therefore 41,760 (81% of 51,500). The data shows that about 95% of the boreholes in Namibia have a depth of between 0m and 200m. The remaining 5% of boreholes are deeper than 200m.

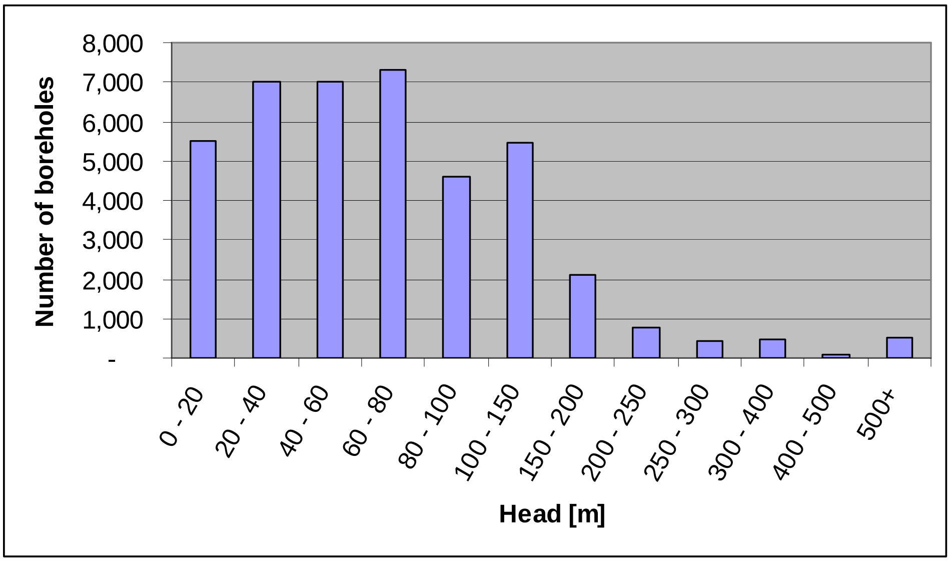

Figure 4.1: Number of boreholes in use at different borehole depths

In order to determine how many of these boreholes can be serviced with PVPs the number of boreholes falling within the hydraulic load curve of 1,000m^4/day and 3,000 m^4/day are established. This is approached as follows:

1. The total number of boreholes on the database is 51,500. There are more boreholes as some have not been registered. No estimates on the number of additional boreholes are made here.
2. It is assumed that 10% of the boreholes are no longer in use (overuse, collapsed etc).
3. The chemical analysis is extrapolated to the total number of boreholes (realising that this will potentially contain a large error). It is therefore assumed that 90% of all boreholes in use are suitable for livestock consumption.
4. It is assumed that the rest water level is 20m above the bottom of the boreholes.
5. The number of boreholes within each head range is queried by assuming that the abstraction rate is 66% of the borehole yield (safe yield).
6. About 60% of the database information contains head and borehole yield. The analysis is conducted with 60% of the data and then extrapolated to the total number of boreholes.

This yields the total number of boreholes that fall to the “bottom and the left” of the constant hydraulic load curve (refer to Figure 3.2). These boreholes would be fully and sustainably utilised through PVPs at 66% of the borehole’s capacity, based on the Division of Geohydrology’s abstraction rate design principles. Therefore boreholes with yields in excess of what a PVP at a particular head is able to deliver are not taken into account and would require other pumping technology to utilise fully (e.g. diesel or electrical pumps).

Table 4.2 lists the number of boreholes for two ranges of constant hydraulic loads. The potential number of boreholes suitable for PVP figures indicates the long term market potential for PVP, assuming that wind pumps, which probably account for 80% of the technology used on these boreholes, will in future be replaced by PVPs.

Table 4.2: Potential number of boreholes suitable for PVP

Hydraulic load [m^4/day]	Number of boreholes	Suitable for
1,000	20,700	Grundfos SQ Flex (1400) Lorentz Eta Total Energie TSP 1000
1,000 to 3,000	9,400	Dual Grundfos SQ Flex (1400) borehole allowing Total Energie TSP 2000+

During the last five years approximately 670 PVPs were installed (refer to Table 2.2). Fahlenbock (1996) established that approximately 250 PVPs were installed by 1995. Assuming that another 400 PVPs were installed between 1996 and 2000 (average of 80 PVPs per year) then the overall number of PVPs installed to date is 1,220.

Although it is unrealistic to assume the figures in Table 4.2 to be the potential market for PVPs, it nevertheless indicates that there is significant potential for PVPs to replace diesel pumps and aging wind pumps.

Due to the financial realities as described in section 3 it would be a reasonable scenario to estimate that the take-up of PVPs over the next ten years will be 20% of the above number of boreholes. That would result in approximately 6,000 PVPs, which translates to a potential market of 600 PVPs per annum and would mean that the current installation rate of 225 PVPs (2005) needs to be tripled.

4.2 FINANCING

Financing of renewable energy systems has historically been a challenge as many main stream banking institutions did not consider RETs as an asset and insurance, a prerequisite for financing, was often not simple to arrange. This picture has however changed recently with the activities of the NAMREP programme. At present there are three financing possibilities, these being:

- Solar Revolving fund (SRF)
- Bank Windhoek
- AgriBank

The Solar Revolving Fund was set up by the MME in 1996 for the purpose of facilitating off-grid rural electrification through the use of Solar Home Systems. Since 2004 the SRF is offering loans for PVPs and Solar Water Heaters too. The SRF, currently administered by Konga Investments provides a five year loan repayment period with a 5% deposit against an attractive interest rate of 5%. At current inflation rates of 4.5% this means that the real interest rate of the loan is about 0.5%! The SRF has ceiling amounts for each of its loan categories, which are SHS N$ 30,000, PVP N$ 50,000 and Solar Water Heaters N$ 30,000.

A 500W_{peak} PVP (400m^4/day) cost approximately N$50,000 including transport, installation and VAT. A 1,000W_{peak} PVP (900m^4/day) costs approximately N$80,000 including transport, installation and VAT.

Bank Windhoek offers loans for SHS, PVP and SWH at an interest rate of prime less 5%. The loan period is a maximum of 5 years and the deposit is 5%. The maximum loan amount for these conditions is N$ 80,000 per individual. Should the loan amount exceed the N$ 80,000 than the loan is split and the portion above N$ 80,000 is loaned at commercial rates.

The AgriBank provides loans for both diesel as well as solar PV water pumping installations with a repayment period up to 15 years. Loans are provided at bank rates less a negotiated percentage. This makes the AgriBank loan for a PVP less cost effective than the other two loan schemes but represents more affordable monthly payments.

The First National Bank has indicated that it is interested in funding RETs and is in the process of setting up a system for facilitating loans.

With the above financing mechanisms being available, one of the major barriers, i.e. the initial capital cost, has been removed and with a necessary amount of advertising the availability of the financing mechanisms will become common knowledge to potential customers.

4.3 MEASURES FOR THEFT PREVENTION

The theft of solar photovoltaic modules are experienced as one of the main barriers to widespread adoption of solar energy technologies and have certainly halted some ideal applications such as remote telecommunication stations and pumping systems.

Theft ought to be a concern where there is a lack of ownership, where there is a lack of correct application (e.g. institutional PV installations where the users have not been consulted in terms of their needs and the energy systems that are installed do not provide the services needed), where systems fall into disrepair (and the energy service ceases) and where the systems are installed at remote locations and near public places. What follows is a list of ideas for minimising the occurrence of theft:

- For new boreholes: Try to find a drilling location which is close to the users/beneficiaries or remote from roads,
- For community water supply, ensure that there is ownership of the water supply system,
- Mark the modules with the owners name in non-removable paint,
- Engrave the name of the owner on the frame,
- Note the serial numbers of all the modules,
- Inform the police of the installation if sensible,
- Make use of high voltage modules and put up a sign at the installation in the local languages that these modules are not usable in other installations,
- Put up a sign anyway, even if not high voltage modules,
- Put a fence around the PV installation,
- Electrify the fence if sensible (large installation),
- Electrify the fence with interrupt/shorting alarm if sensible,
- Use a siren if feasible,
- Telemetric radio contact to owner and/or Police,

- Take out insurance on the installation,
- If sensible have somebody live at that water supply point,
- Organise for security personnel in large applications,
- Pad-lock the base-plate to the borehole casing to protect the motor/pump unit in the borehole,
- Place the modules into the centre of the reservoir if near borehole and feasible,
- Use one-way bolts to fix the modules on the frame,
- Install the modules on six meter steel poles with a large concrete block as foundation,
- Fit razor wire underneath the modules,
- Fill the inside of a steel pole with cement and or construction steel.

These measures may not be a guarantee but may help in reducing theft.

This list of measures will be made available to users of PVPs to assist them to reduce the risk of theft.

4.4 DISSEMINATION OF LATEST INFORMATION

As a result of technological advances, the reduced years to breakeven, the availability of finance and the recent escalation in fuel price the case for PVP has improved substantially. This information needs to be shared with the following sectors:

- Commercial farmers
- Communities in the communal areas and communal conservancies
- Public sector

The approximately 7,000 commercial farmers in Namibia represent the largest market for PVPs through converting from diesel pumping to PVP as well as in the future from old and more difficult to maintain wind pumps. The commercial farmers can best be reached through the National Agricultural Union (NAU) and the Namibian National Farmers Union (NNFU) and its media channels such as the AgriForum, the Landbou Mikrofoon and general radio stations.

Discussions with the Directorate of Rural Water Supply clearly indicated that the switching from diesel water pumps to PVPs will not take place under current conditions. In fact, if anything, the current number of existing PVPs under DRWS administration will most likely be reduced. With the impending implementation of the Cabinet decision that communities will have to pay the full operating, maintenance and replacement cost by 2010 as well as concerns around sustainable water supply provision it may in future become a necessity to consider PVPs more seriously. However this requires a clear understanding of the needs and it is suggested that a survey is conducted into the needs, challenges, finances and social realities of diesel/wind/solar driven community water supplies. Following this, a strategy can be formulated that will see an implementation plan for PVPs for communal water supply, where appropriate.

Communal conservancies will benefit from PVPs due to the low operating costs and low maintenance requirements. In addition, PVPs fit into the tourism activities conducted by many of the communal conservancies. The conservancies need to be presented with the latest information, including the financing options. It is envisaged that the information is disseminated through an umbrella organisation for community based organisations (e.g. NACOBTA).

In terms of the public sector such as the Ministry of Health and Social Services (remote clinics) and Ministry of Education (remote schools) it is suggested that the best strategy will be to approach consulting engineers and share the latest findings so that the engineers can take this information to their client when they are requested to design water supplies for off-grid institutions. The Ministry of Environment and Tourism as well as the Ministry of Home Affairs and Immigration (remote Police Stations) make use of PVPs for their off-grid water supply requirements and where the water needs can be met through PVP.

4.5 GREENHOUSE GAS REDUCTION

There is virtually no consolidated data on the use and size of diesel pumps in Namibia. In order to conduct the greenhouse gas (GHG) reduction analysis, it will be assumed that PVPs can replace diesel pumps which operate at an average hydraulic load of 1,000m^4/day. It will further be assumed that there is a potential to replace 1,000 to 2,000 diesel pumps with PVPs on commercial farms. This figure is motivated as follows:

- There are 36,600 boreholes on commercial farm land (refer to Table 4.1). It was previously assumed that 10% are no longer in use and another 10% are not suitable for livestock (Total Dissolved Solids are too high).
- This leaves approximately 30,000 boreholes. It was also previously assumed that 80% of the boreholes on commercial farm land are equipped with wind pumps.
- That leaves approximately 6,000 boreholes of which about 1,000 are operated with PVPs (refer to Table 2.2 – 80% of PVPs are on commercial farms - and refer to section 4.1 for the total estimate of installed PVPs).
- It is therefore assumed that there are about 5,000 boreholes on commercial land which operated with diesel pumps.
- It is feasible that 20% to 40% of these are replaced through PVP, which is equivalent to 1,000 to 2,000 PVPs.
- It is assumed that the average size diesel pump that is being replaced was operating at a hydraulic load of 1,000m^4/day.

Diesel contains 0.73kg of carbon per litre. Carbon combines with oxygen to from carbon dioxide (CO_2) with an oxidation factor of 99%. Using the molecular weight of carbon (12) in relation to CO_2 (44) it is calculated (0.73*(44÷12)) that the content of CO_2 in one litre of diesel is equivalent to 2.67kg[7].

A diesel pump using a 3kW engine to provide power for 1,000m^4/day (assume 2.8m^3/h at 100m head) will consume approximately 0.77lit/hour. This results in an annual fuel consumption of 984litres per annum which is equivalent to 2.6tons of CO_2 per annum.

Table 4.3: GHG reduction potential

Number of PVPs replacing DPs	GHG reduction
1,000 units	2,600tons pa
2,000 units	5,200tons pa

Table 4.3 summarises the potential GHG reduction if 1,000/2,000 diesel pumps can be replaced with an average hydraulic load of 1,000m^4/day.

7 Information from: US Environmental Protection Agency: Overview of Pollutants and Programs: Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel. EPA420-F-05-001, February 2005.

5 CONCLUSION

The study shows that Namibian water supply needs stand to benefit from converting to solar PV water pumping in cases where:

- Water depth is less than 120m and the hydraulic load is less than 4,000m^4/day.
- Water depth is less than 200m and the hydraulic load is less than 500m^4/day.

The years to breakeven between PVP and DP systems are:

- With immediate effect for PVPs operating below 250m^4/day,
- Less than one year for PVPs operating below 500m^4/day,
- Less than 2.5 years for PVPs operating below 1,000m^4/day,
- Less than 6 years for PVPs operating below 2,000m^4/day, and
- Less than 8 years for PVPs operating below 4,000m^4/day and below 120m head.

General application issues result in exceptions such as, for example:

- where the water requirements are seasonal or
- where the diesel engine/generator has a multifunction use, e.g. at a farming homestead or
- where the diesel engine must be moved to other boreholes at various intervals or
- where a fully operational wind pump is backed-up by a diesel engine/generator, it is unlikely that the PVP option will present a viable alternative.

The main barriers identified are:

- Theft is probably the single largest barrier to widespread use of PVPs. The bulk of the capital cost of a PVP system rests in the photovoltaic modules which are often difficult to protect. In a diesel water pumping system the majority of the cost goes into infrastructure development and heavy materials (foundations, rising main pipes, element).
- The second major barriers to use of PVPs are perceptions that the cost of solar PV water pumping is higher than diesel water pumps.
- Dependence on specialised services which are possibly only available in Windhoek - or discomfort with the technology (high tech). Support for the diesel engine is either locally available or in the vicinity – that gives users a higher water supply security.
- Many users perceive the PVP option to be inflexible to fluctuating water demands and seasonal variations and are therefore not aware of hybrid options for PVP (users are aware of the hybrid option between wind and diesel).

The key findings of this study are:

- Technology developments have now provided products which can be described as the optimal system for the average borehole conditions:

    - Low maintenance requirements (3 to 5 years),
    - Reliable operation,
    - Simple installation,
    - Efficient pumping component combinations, such as brushless permanent magnet motors in conjunction with helical rotor pumps,

- The capital cost of commercially installed PVP is similar to the capital cost of commercially installed DP up to the pumping limit of 250 m^4/day. The higher capital cost of the renewable energy option is therefore not applicable under these conditions.
- The is a technology gap between 120m and 200m for PVPs. PVPs do not exceed hydraulic loads of more than 500m^4/day in that range.
- The future regarding diesel is full of possibilities in terms of bio-fuel developments, but it is important to consider the following in terms of fossil sourced diesel:
    - The cost of diesel will most likely rise due to growing demand, peak oil (whether fear or reality), war over oil and possible future carbon levies/penalties. Transporting diesel fuel to a remote site and using diesel/petrol in the process will represents a double impact from increased fuel prices.
    - Diesel supply insecurities are likely to increase due to growing world demand, supply chain bottlenecks and limited refinery capacity among others. The year 2006 is a case in point where energy shortages were experienced in the SADC region simultaneously (electricity, diesel and LP Gas).
- The Directorate of Rural Water Supply has very real issues which make the use of PVPs less attractive. These include:
    - Communities are familiar with diesel water pumps and are able to service and do minor repairs on the engines locally.
    - Communities require the flexibility in water consumption due to large herds of livestock that graze in some areas of the communal areas.
    - Diesel pumps installed through DRWS are usually designed for a ten hour pumping day. That still leaves 14 hours for additional pumping if required.
    - Diesel pumps are often preferred as it is a familiar technology and mechanical skills are more common than electrical/electronic skills.
    - PVPs do not utilise boreholes to the full extent – a borehole with a safe yield of 5m^3/hour will deliver more in 8 hours when pumped with a diesel engine than with a PVP.
    - PVPs cannot compete with DPs on boreholes with medium yield (2 to 5m^3/hour) as they can pump 24 hours a day.
        - DRWS has a limited annual development budget for water supply implementations. The success of the regional heads in DRWS is "judged" by how many communities have received water supplies rather than by how many PVP systems were installed.
    - When a PVP system is installed then the community does not collect money as there are no operational costs. This leads to a crisis when the PVP system requires a service or replacement after a few years of operation. In this regard DRWS prefers diesel pumps as this enforces the money collection systems to cover the operational and minor maintenance costs.

- The infrastructure for diesel pumping is much more developed and widespread than the PVP infrastructure (maintenance and spare parts), with the PVP support based mainly in Windhoek.
- The PVP option is the more sustainable solution in terms of preserving borehole life which presents excellent financial value due to the costs associated with drilling new boreholes.
- The policy of PVP usage differs between government departments:
    - Directorate of Rural Water Supply, who determine in collaboration with the community which water supply option to choose.
    - Ministry of Environment and Tourism, which has a strong PVP policy.
    - Health and Education are advised by consultants.
- Financing for water pumping systems is available for both PVP and DP systems. The Solar Revolving Fund and the AgriBank of Namibia finance PVPs while the AgriBank also finances diesel pumping systems

The market for PVPs is expected to increase significantly with recent improvement in technology, the lower cost, the shorter time to breakeven and the availability of finance. The market potential for PVPs in Namibia is huge due to relatively low yields from boreholes. It is estimated that there are approximately 20,700 boreholes which fall below the 1,000m^4/day hydraulic load line. Most of these are currently serviced by wind pumps. PVPs present a financially attractive option and can be expected to service the market for wind pump and diesel pump replacements.

6 RECOMMENDATION

The lobbying activities that follow this study need to focus on the following stakeholders which have been identified as those which will have the broadest impact on the uptake of PVP in the Namibian market:

- Commercial farmers: As shown most of the boreholes in Namibia are on commercial land. This is therefore the sector that can make the most significant impact. The identified media for lobbying the commercial farmers are through the monthly/bi-monthly publications, the radio as for example the Landbou Mikrofoon and Farmers Info, as well as through the electronic media of the farmers unions and the hospitality association.
- Consultants Engineers designing water pumping systems for Ministries such as MOHSS, Ministry of Education and Ministry of Home Affairs (Police Stations).
- Suppliers: Although the service infrastructure for PVPs outside the capital has improved, it will be beneficial to further increase the turn-around times for PVPs to become operational after breakdown in order to further alleviate water supply security concerns of users.
- Suppliers: Investigate warehousing options for RETs, as to be better prepared for increased demand in PVPs. The experience with Solar Water Heaters has been that delivery times for SWH systems have become a few months due to increased demand and the sector has not been responding rapidly enough.
- Theft prevention measures: Inform potential and existing users of PVPs what measures can be employed for avoiding or reducing the risk of theft. Make use of existing information channels such as the Agricultural Unions, the radio and the internet.

The key messages that need to be shared with selected stakeholders is that for average pumping applications:

- The capital cost of PVPs in the sub 300 Wpeak range is similar or lower than diesel pumps.
- The cheaper operating costs of PVP leads to significantly lower life cycle costing of the PVP option up to a hydraulic load of 4,000m^4/day below 120m head.
- Diesel pumps which deliver low volumes at low head are costly due to poor load factor and higher per kW fuel consumption. A PVP of the same daily delivery will have a lower initial capital cost than the diesel pumping system.
- Flexible hybrid pumping options are available to allow for higher daily water requirements, which are able to operate on solar as well as diesel/petrol generators.
- The sector needs to utilise robust technology which is not always the case. This applies to both PVP and DP, both of which offer a range of quality of products. The poorer quality products require more frequent maintenance intervals and have shorter life expectancy.
- Using PVP for critical water supplies (noting that almost all water supplies are critical) requires higher levels of redundancy. Considering that the PVP has a life cycle cost which is always less than the equivalent diesel pumping option for the systems modelled here there are sufficient “funds” to provide spare parts as well as critical

components such as the controller, motor/pump unit and a few solar PV modules and still retain lower costs compared to a diesel pump. These components, although potentially never utilised, will provide security of water supply.

- Loans are available for funding the upfront costs of a solar pump!

The communal water supply market cannot be approached without a better understanding of the barriers and strategies which will truly enhance service delivery at reduced cost. In order to increase the uptake of PVPs in the service of the community and lessen the financial burden with regards to the full cost recovery for operation, maintenance and replacement as planned for 2010 the following activities are recommended:

- Conduct an in depth survey of communal water supplies operated on diesel and solar in three regions: Omaheke, Otjiozondjupa and Kunene.
- Conduct interviews with the Water Point Committee members as well as extension officers for DRWS in the region determining water needs, current pumping solutions, problems (fuel supply, reliability, water shortages, human capacity) and financial realities. Establish what the impact will be on community affordability when the full cost recovery (excluding capital cost) is implemented as per cabinet decision.
- Determine the training requirements of water point operators and extension officers for PVP systems.
- Determine the service infrastructure requirement for PVP systems, including full component replacement kits (controller, motor and pump) which would still provide a significantly lower all-inclusive cost as compared to diesel pump solutions.
- Understand the institutional setup which is supporting the current wind and diesel systems. Determine the current level of standardisation. Determine the capacity building needs for the potential addition of PVPs into the support infrastructure.
- Identify PVP selection criteria which take cognisance of the water requirement characteristics for communities and implement three pilot schemes in communities that can serve as a demonstration to other communities. The demonstration should consider PVPs with a back-up generator and tracking arrays.
- Follow-up with a monitoring exercise to determine impact and lessons.

7 REFERENCES

Atlas of Namibia – A Portrait of the Land and its People, John Mendelsohn, Alice Jarvis, Carole Roberts and Tony Robertson, Published for the Ministry of Environment and Tourism of Namibia by David Philip, 2002.

Solar Pumping for Communities – Technical Manual, Energy for Development Group for Department of Water Affairs and Forestry, Cape Town, South Africa, April 2001.

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Solar Water Pumping versus diesel pumping in Namibia, Evans, Hervie, Dissertation. 2006.

Baseline study of renewable energy resources and technology in Namibia, Consulting Services Africa, for NAMREP. 2005.

Evaluation of two prototype three phase photovoltaic water pumping systems, Scholle, Axel, MSc, University of Cape Town. 1994.

Renewable Energy for Water Pumping Applications in Rural Villages, N Argaw, R Foster and A Ellis, New Mexico State University, Las Cruces, New Mexico, under subcontract for National Renewable Energy Laboratory, July 2003.

Solar (Photovoltaic) Water Pumping, Intermediate Technology Development Group, Technical brief.

Annexure

A1 Stakeholders

Information collection and interviews were held with the following stakeholders:

- Directorate of Rural Water Supplies
- Department of Works
- Ministry of Environment and Tourism
- Namibia Wildlife Resorts
- Ministry of Agriculture, Water and Rural Development, Division of Geohydrology
- AgriBank
- Namibia Agricultural Union
- Namibia National Farmers Union
- NamWater
- Consulting Engineers (GS Fainsinger and Associates, Lund Consulting Engineers, WML Consulting)
- Rössing Uranium Mine
- Terrasol
- NEC
- ConServ
- Solar Age
- SolTec
- Elwiwa
- Denorco
- Auas Wholesalers
- Afro Pumps
- Commercial farmers

A2 Cost modelling inputs

User information

Comparative PV Pumping and Diesel Pumping Costing Tool for Namibia

Commissioned by Ministry of Mines and Energy
for the
Barrier Removal to Namibian Renewable Energy Programme (NAMREP)
with acknowledgements to
UNDP/GEF

developed by Emcon Consulting Group
[Email: axel@emcongroup.com]
Costing Tool for Solar & Diesel water pumping Ver 2006 Rev 0

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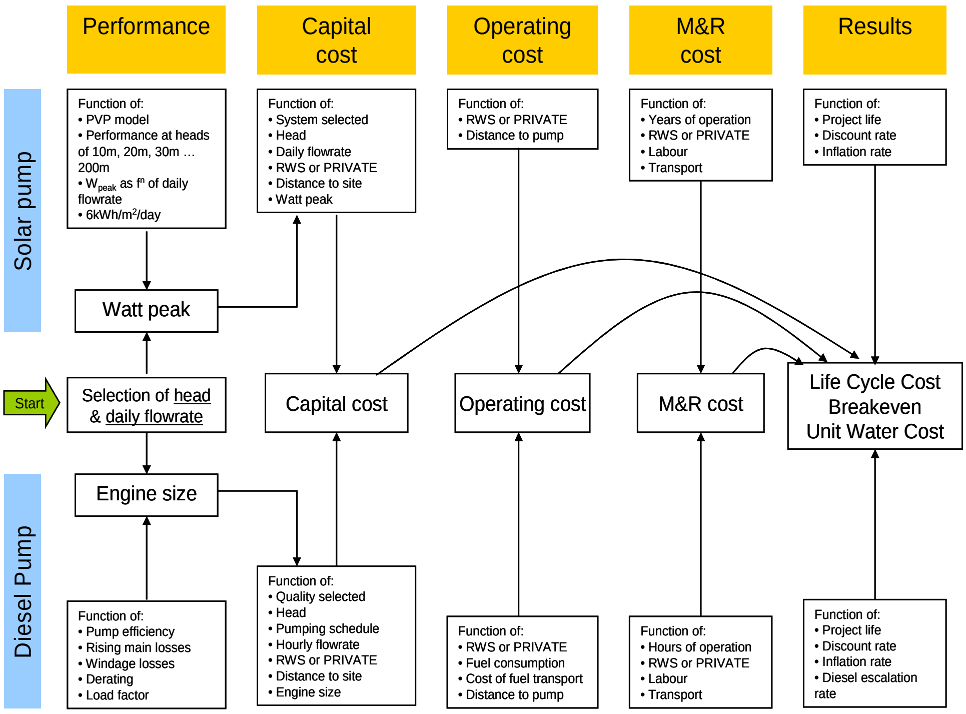
ERRORS AND DISCREPANCIES

ISSUES TO ADDRESS ONE FINE DAY

COLOUR CODES

Diagramtic overview of spreadsheet



Comparative PV Pumping and Diesel Pumping Costing Tool for Namibia

USER INFORMATION

OUTPUT OF THE COSTING TOOL

The function of the spreadsheet is to calculate the **life cycle costing** of a solar and a diesel water pumping system. The Life Cycle Cost includes all future costs incurred over the project life of the system such as operation, maintenance and replacements cost which are reduced to their present value and added to the initial capital cost in order to provide a fair basis for comparison between renewable and non-renewable options. This cost is also referred to as the all-inclusive cost. The all-inclusive cost of the solar and the diesel pump is compared in order to evaluate **overall project cost** and a **breakeven** between the solar option (higer start-up cost) and the diesel option (higher operating and maintenance costs). For more detailed information, consult the final report on this study which can be found on Emcons webpage.

USING THE COSTING SPREADSHEET

General inputs

The key inputs for the costing spreadsheet are driven from the **MAIN** spreadsheet page. All blue cells can be manipulated. The main comparison case is selected through the **daily flowrate** (3 to 50m^3/day) and the operating

Select whether the comparision is based on a Rural Water Supply (**RWS**) or a privately (**PRIVATE**) owned pumping system. The main difference is that the RWS supply system has to adhere to more stringent specifications and is completely outsourced to a contractor. That is not the case for the Private system, where the owner will make own preparations and contributions. These contributions reduce the cost of the concrete work, the accessories, the labour and the transport. A cost item which will increase the PRIVATE installation is the distance to a remote diesel pump - these costs are entered further down on the MAIN page.

The **distance to site** is used for installation purposes and is the distance between the supplier and the site.

PVP inputs

Select the PVP system. The PVP systems have different operating ranges. If there is no system able to operate at the selected daily flowrate and head then the calculated array size will show that there is "No valid system".

The PVP systems which are modelled are:

Grundfos SQ Flex: 1,000 Wpeak, 10 to 200m, (new data is awaited for the 1,400 Wpeak systems).
Lorentz PS range: 1,200 Wpeak, 10 to 230m head
Total Energie TSP 1000: 1,300 Wpeak, 10 to 130m
Total Energie TSP 2000, 4000 and 6000: 5,600 Wpeak, 0 to 120m
Watermax: 300Wpeak, 10 to 100m

Select the **number of multiple PVP** systems operating in parallel in the borehole. This only works for the Grundfos and the Lorentz pump. The number has no effect with the other PVPs. This variable needs to be used with care. The boreholes need to allow for it and a deep well installation may have its own problems. Although three pumps can be selected for parallel installation all the modelling was done with single and dual solar pumping system.

The **irradiation level** and the **tracking factor** can be set for the particular circumstances. In order to be used in comparison with diesel the size of the PV array is reduced for higher irradiation levels and the use of a tracking array rather than increasing the daily flowrate which would not enable a one for one comparison anymore.

Diesel pump inputs

Select whether the diesel pump is an **existing** installation.

Select whether the diesel engine is a **short life** (Indian manufacture) or a **long life** engine (South African Lister

Select the **pumping schedule**: How often is the pump started (every day, every second day etc) and how many hours per pump session. The hourly flowrate is calculated from that. The flowrate needs to be less than the safe yield of the borehole and less than 12m^3/hour (maximum modelled here). Select these values so that the efficiency of the diesel pump is as high as possible within the above constraints. RWS designs for 10hours of pumping per day, which can lead to very poor efficiencies with high operating costs for low water requirements. A rule of thumb is a maximum hourly flowrate of a quarter of the daily flowrate which will for the record still result in higher abstraction rates than the

Set the current **diesel price** per litre.

Set a real **diesel escalation rate** (0 to ?%). This is a difficult parameter. The user needs to take care - the escalation rate is valid for the complete operating life and setting it very high may seriously impact on the validity of the comparison. Either set the escalation to zero and try different diesel prices or set the escalation to somewhere below

Transport cost of fuel to site from nearest service centre (assumed to be less than distance to site). The **number of trips per annum** are set and the **percentage cost contribution** to these trips (0% to 100%; Default value = 20%) as well as the **cost of time** is entered. The local transport rate is taken as the cost per km (default N$3/litre).

Transport cost for a remote diesel engine (distance between operator and diesel pump - only applicable for commercial farmer system - not applicable for RWS diesel pumping systems). The **distance** (default = 3km) is entered and the annual costs for travelling and cost of time is calculated from the pumping schedule and multiplied times the **percentage cost contribution** (0% to 100%; Default is 50%).

Comparative PV Pumping and Diesel Pumping Costing Tool for Namibia

USER INFORMATION

RESULTS

Numerical results are shown on the MAIN page.
Graphical and summary results are shown on the **OUTPUT** page.

MAINTENANCE AND REPLACEMENT

Maintenance and replacement costs per pumping systems are entered with the relevant interval at which these costs occur. For solar the interval is in years and for diesel pumps it is in hours of operation.
Refer to main report for more information.

GLOBAL PARAMETERS

Financial

The **project life**, the **interest rate**, the **loan rate** and the **inflation rate** are entered here.
The cost reduction factor for RWS and PRIVATE is defined here (Default = 50% for selected items - not affecting compo

Transport

Three **transport rates** are used: Truck (Default = N$9/km), contractor vehicle (Default = N$5/km) and local transport (Default = N$3/km). These are entered here.

Technical

Constants are entered here.
The **flowrate threshold** for switching between 40mm and 50mm diameter rising main column for diesel pumps is set (Default = 40mm < 3m3/h < 50mm <12m3/h.
Rising main steel pipe service and **replacement factors** are entered here.
Multiple PVPs are evaluated here to be only applicable to SQ Flex.
If the stated performance of a PVP is not correct, than a correction factor can be applied here.

Carbon credits

Carbon emission parameters are defined.
Carbon credits are activated/deactivated for the carbon credit calculation.

VARIABLES

This page summarises all the parameters which are used in the calculations and which need to be considered. The location of where the parameter is defined is stated.

DATA LOCATION

Many of the spreadsheet pages are hidden to allow a less "busy" spreadsheet interface. There pages can be unhidden: Menu > Format > Sheet > Unhide.

The **LCC** calculation sheets perform the life cycle costing calculation up to a maximum of 25 years. Escalation of diesel price is included in the operating cost line, general escalation is included in the next line and the remaining rows are for
The **BREAKEVEN** sheet calculates the breakeven point by finding the intersection between the cumulative LCC cost of the PVP and the diesel pump selected. Through calculating the gradient between each year, the year where the curves intersect is selected to provide an accurate breakeven year.
The **performance data for each of the PVPs** is entered on a seperate spredsheet page. The data is entered for a list of dedicated heads 10, 20, 30 ... 100, 120, 140, 160 and 200m). The Wpeak required for each PVP is entered as a function of the daily flowrate at 6kWh/m^2/day. The information is summarised in the **PVP SUMMARY** sheet.
The **WPEAK** sheet calculates the required Wp for the operating point (flow and head) and PVP selected.
The **PVP COST** sheet calculates the cost of the complete systems, including installation and transport based on fixed and linear costs (e.g. array structure as function of Wpeak, cable length as function of head + 15m etc).
The **DP SIZE & FUEL** sheet calculates the size of the diesel engine required, including all losses in the pump (logarythmic function), the rising main (exponential function), the windage losses, the derating (altitude and temperature) and the load factor. The fuel consumption is calculated based on a lookup table.
The **DP ENGINE COST** sheet contains the prices of the diesel engines and based on the kW engine size calculated, selects the correct price.
The **DP COST** sheet calculates the price for the complete system based on rates for pipes (multiplied times the head), and fixed costs where appropriate.
The **VALIDATION** sheet contains all the lists of items which are selected by lists, such as the head, the PVP makes

Comparative PV Pumping and Diesel Pumping Costing Tool for Namibia

USER INFORMATION

NOTES ON FORMULAE'S USED

The LOOKUP formula was initially used to draw information out of the tables. However, this formula requires that the information is sorted in alphabetical order, which is not always the case. In that case it is safer to use the combination

MATCH - Looks up a value in an array and returns the row number. Note that the '0' as the last parameter defines that an exact match needs to be found, instead of the closest match ('1' or '-1'). This is what also solves the issue of non

INDEX - Returns the value from a single cell in an array, where the row (from MATCH above) and the column (fixed)

The formulae's are interlinked to replace the standard Lookup formulae.

Linear and exponential regression formulae

LINEST: Fits a linear regression curve. There must be more x values than y values. The arrays may not contain '0' values. There may not be any empty cells in the x value array

TREND: Linear forecast to extend a series of x and y values

LOGEST: Fits an exponential curve to a row of x and y values.

GROWTH: Exponential forecast, similar to TREND.

FINANCIAL DEFINITIONS

All costs are in **Namibian dollars inclusive of VAT**.

All **Life Cycle Costing** calculations are done in **constant 2006 dollars** (exclusive of inflation).

Escalation is defined as the percentage price increase (positive) / decrease (negative) over and above the inflation/deflation rate. The nominal escalation rate includes the inflation rate, while the real escalation rate exlcudes the

Real rate and inflation

The real discount rate, real loan rate and the real escalation rate are calculated by subtracting the inflation rate from the current rates. This is not quite correct. For the record: For example, the real discount rate is equal to ((1 + nominal discount rate)/(1 + inflation rate) - 1). The difference however is so small and the interest ranges quite "large" that a

ASSUMPTIONS

The boreholes have a sufficiently strong yield to allow for generally higher flowrates of the diesel pump in comparison to

The water in the borehole is of reasonable quality.

The sizing of a diesel system which results in under-loading the unit does not negatively impact on the life expectancy of the unit, nor does it change the service intervals (in terms of decarbonisation).

The “non-linearity” factor of taper thread rising main pipes does not lead to more than 5% losses.

Site establishment costs are excluded as well as engine house construction.

The pumping systems are complete at the exit of the borehole (i.e. the costs of the distribution and reservoirs are excluded from the calculation).

None of the system components are stolen.

No insurance of the pumping systems were considered.

There are no costs for the local operator.

The minor service on diesel pumping systems does not require transport from/to site.

The road conditions to site are suitable for 4 x 2 vehicles.

ERRORS AND DISCREPANCIES

Developments of the diesel price. There may be no escalation for five years and there may be 20% escalation for the next five years. The forecast of the oil price is not a feasible exercise.

The cost reduction between a DRWS and a Private installation is a rough estimate.

Inaccuracies in the PVP manufacturers data.

Poor assessment of the maintenance and replacement costs and intervals.

The life cycle costing is conducted on an annual basis. When the maintenance and replacement intervals become close to one year then the inaccuracies increase as the interval in years has to be an integer. This inaccuracy can be remedied by calculating the life cycle cost on a monthly basis but that has not been implemented.

COLOUR CODES

User can enter data in these cells: Contain numerical values
Highlighted cells to indicate essential information
Contain either empirical or system sizing data
These cells form named ranges (one dimesional)
These cells form named arrays (two dimesional)
EMCON: Areas under construction, uncertainties about the selected values, are highlighted in yellow
EMCON: Marked for deletion

Main Input Page

MAIN INPUTS	Values	Units
Pumping head: Select	100	m
Daily pump volume	8.0	m³/day
Installation distance (adds to capital cost)	300	km
Toggle for DRWS/PRIVATE system	Private installation	

PVP Inputs

PVP make: Select	Lorentz PS series [230m]	
Multiple PVPs	1	
Irradiance and tracking inputs	6kWh/m²/day with 0% tracking	
Daily solar irradiation	6.0	kWh/m²/day
Tracking array	0%	

PVP RESULTS

Calculated array size	1,006	Wpeak
Sub-system efficiency	48%	
PVP capex	80,535	N$
PVP opex	624	N$/annum
PVP Life Cycle Cost	**135,688**	N$/project
PVP: Unit water cost	**4.39**	N$/m³

Diesel Pump Inputs

Existing diesel installation?	No	
DP engine: Select	Short life engine	
Pumping interval: Every	2	day(s)
Pumping hours per pump cycle	7	hours
Cost per litre of diesel	6.70	N$/litre
Diesel price real escalation	4%	

Diesel Transport Inputs and Results

Cost of fuel transport	816	N$/pa
Distance to next nearest fuel depot	100	km
Number of trips per year	6	Trips pa
% contribution to trip costs for fuel transport	20%	
Cost of time	40	N$/hour
Cost of transport to remote pump site	2,190	N$/pa
Distance of operator to diesel pump	3	km
% contribution to trip costs for starting of DP	50%	
Cost of time	40	N$/hour

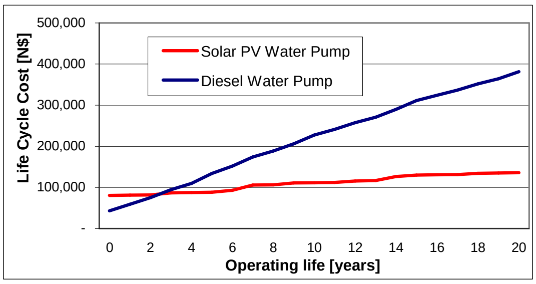
DIESEL PUMP RESULTS

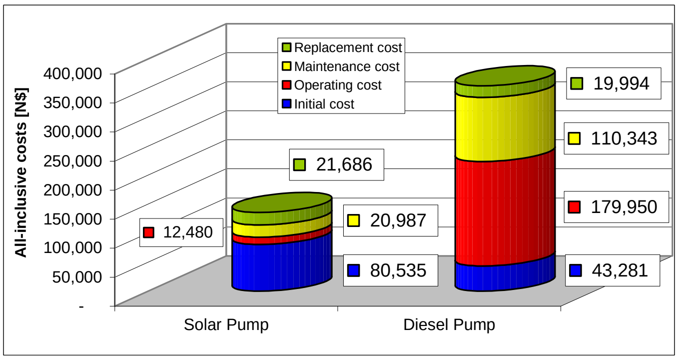
Resulting flowrate	2.29	m³/hour
Engine size required	2.3	kW
Engine size selected	2.6	kW
Resulting fuel consumption	0.70	litres/hour
System efficiency	10.7%	
Annual diesel consumption	894	litres/ann
Annual diesel cost	5,991	N$/pa
Diesel pump capex	43,281	N$
Diesel annual opex cost	8,997	N$/pa
Diesel pump Life Cycle Cost	**381,596**	N$/project
DP: Unit water cost	**12.34**	N$/m³
Carbon emission per annum	**2.4**	tons/pa

Breakeven	**2.5**	years

Key results page

Life Cycle Cost Comparison: Current result





Breakeven occurs after 2.5 years

Scenario:

Head	100 m
Daily flow	8.0 m³/day
RWS/PRIVATE	Private installation
PVP selected	Lorentz PS series [230m]
PVP quantity	Single
Irradiance	6 kWh/m²/day
Tracking	0%
DP selected	Short life engine
DP interval	2 days
DP hours	7 hours

Main outputs

	LCC [N$]	UWC [N$/m³]	Power		Efficiency [%]	
Solar Pump	135,688	4.39	1,006	W_{peak}	48.2%	subsystem
Diesel Pump	381,596	12.34	2.6	kW	10.7%	overall

Savings	245,908	N$
Factor: DP/PVP	2.8	

Maintenance and Replacement Costs

Prices: VAT inclusive

Recurring costs: PVP	Active	Cost [N$]	Interval [Years]
RC2: Replacement of main components	1	16,215	7
RC3: Recurring cost: Service of PVP	1	5,175	3

Click '+' to unhide

Recurring costs: DP	Active	Cost [N$]	Interval [Years]
RC2: Replacement of engine	1	14,950	7
RC3: Recurring cost: Minor service	1	2,300	1
RC4: Recurring cost: Major service	1	4,982	1
RC5: Recurring cost: Overhaul	1	9,430	3
RC6: Recurring cost: Pump and pipes	1	11,170	5

Click '+' to unhide

Determine position in array

Transport related to M&R

PVP transport cost	1,500
DP transport cost	500

Maintenance and Replacement Costs & Intervals: Database

Range: pvp_m&r

	Grundfos	**Labour & BOS**	**Cost [N$]**	**Interval [years]**
1	Replacement of motor/pump/controller unit	1,800	11,570	10
2	Service		3,000	5
3				1
4	**Lorentz**			
5	Replacement of motor/pump & contoller unit	1,800	11,100	7
6	Service		3,000	3
7				1
8				
9	**Total TSP 1000**			
10	Replacement of motor/pump & contoller unit	1,800	26,800	10
11	Service		8,000	5
12				1
13				
14	**Total TSP 2000+**			
15	Replacement of motor/pump & contoller unit	2,300	36,300	10
16	Service		15,000	5
17				1
18				
19	**Watermax**			
20	Replacement of motor/pump & contoller unit	1,600	10,500	5
21	Service		1,000	1
22				1
23				

Range: dp_m_r

	Short life engine		**Cost [N$]**	**Interval [years]**	**Interval [hours]**
1	Replacement	3,000	12,000	7.0	10,000
2	Minor service		2,000	1.0	
3	Major service	3,000	3,833	1.0	1,000
4	Overhaul		7,200	3.0	5,000
5	Pump and pipes		9,213	5.0	
6					
7	**Long life engine**				
8	Replacement	3,000	12,000	27.0	35,000
9	Minor service		2,000	1.0	
10	Major service	4,000	5,110	1.0	1,000
11	Overhaul		3,600	7.0	10,000
12	Pump and pipes		9,213	5.0	
13					
14					

GLOBAL VARIABLES

FINANCIAL PARAMETERS		
Project life	20	years
Nominal rates		
nominal discount rate = investment rate	8.5%	
nominal loan rate	11.5%	
inflation rate	4.5%	
VAT	15%	
nominal escalation rate: general	4.5%	
nominal escalation rate: diesel	8.5%	
Escalation trend: SELECT	Linear	SELECT
Real rates		
real discount rate = investment rate	4.0%	
real loan rate	7.0%	
real escalation rate: general	0.0%	
real escalation rate: diesel	4.0%	
RWS/Private installation		
Factor of price reduction: Private as opposed to RWS	50%	

TRANSPORT COST		
DIESEL		
Price of diesel: Base price 2006	6.70	N$/litre
Installation, Operation & Transport		
Transport: Installation of diesel pump: Truck	9.00	N$/km
Transport rate for outsourced services	5.00	N$/km
Local transport rate to start diesel pump	3.00	N$/km
Rates adjusted by diesel price increases		
Transport: Installation of diesel pump: Truck	9.00	N$/km
Transport rate for outsourced services	5.00	N$/km
Local transport rate to start diesel pump	3.00	N$/km
Maintenance		
% contribution to trip costs: RWS	100%	
% contribution to trip costs: PVP: Private	50%	
% contribution to trip costs: DP: Private	50%	

TECHNICAL		
Constants		
ρ (roh)	1,000	kg/m³
g (gravitational)	9.81	m/s²
Diesel: Ratio of litres per kg	1.187	l/kg
Diesel: Energy per litre [MJ]	30	MJ/litre
Diesel: Energy per litre [kWh]	8.3	kWh/litre
Specific fuel consumption	0.24	kg/kWh
Diesel Weight		
Carbon content in diesel		
DP: Rising main flowrates		
Pipe diameter: 40mm up to a flowrate of	3	m³/hour
Pipe diameter: 50mm up to a flowrate of	12	m³/hour
DP: Rising main: Maintenance & Replacement		
Percentage of pipes replaced	20%	
Extra cost % for extracting & reinstalling pipes	50%	
Maintenance interval	5	years
Multiple PVPs	1	
PVP factors		
Lorentz PVP	0%	
Grundfos PVP	0%	
Total PVP	0%	
Watermax PVP	0%	

Carbon credits (click '+' to view)	None	
Activate after	0	years
Carbon per litre of diesel	2.65	kg/litre
Carbon credits	70	N$/ton

Summary of variables in tool

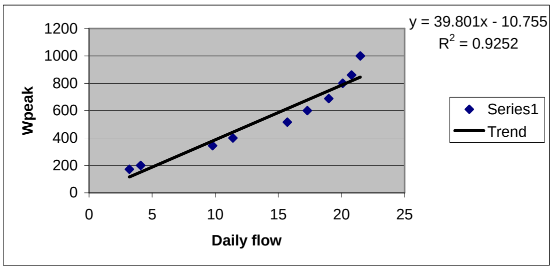
	Value	Impact	Sheetname
Head	100	na	MAIN
Daily flowrate	8	na	MAIN
RWS or Private installation	Private installation	High	MAIN
Distance to site (install_distance)	300	Small	MAIN
PVP			
PVP make	Lorentz PS series [230m]	Medium	MAIN
Multiple PVPs	1	High	MAIN
Irradiance levels	6	High	MAIN
Tracking factor	0%	Medium	MAIN
DP			
New or exisiting diesel installation	No	High	MAIN
Diesel engine	Short life engine	Medium	MAIN
Diesel pumping schedule	2	High	MAIN
Diesel pumping schedule	7	High	MAIN
Diesel price	6.70	Medium	MAIN
Distance to next nearest fuel depot (service_distance)	100	Medium	MAIN
Number of trips per year	6	Medium	MAIN
Cost contribution towards fuel transport	20%	Medium	MAIN
Cost of time	40	Small	MAIN
Distance of operator to diesel pump (operator_distance)	3	High	MAIN
% contribution to trip costs for starting of DP	50%	High	MAIN
Cost of time	40	Small	MAIN
Capital cost			
PVP component cost	Various	Various	PVP cost
DP component cost	Various	Various	DP cost
Maintenance and replacement			
PVP maintenance costs: Parts	Various	Various	M&R
PVP maintenance costs: Labour	Various	Various	M&R
PVP maintenance interval	Various	Various	M&R
PVP replacement cost: Components	fixed thru PVP prices	Various	M&R
PVP replacement cost: Labour	Various	Various	M&R
PVP replacement interval	Various	Various	M&R
			M&R
DP maintenance costs	Various	Various	M&R
DP maintenance intervals	Various	Various	M&R
Diesel pumping sizing			
Specific fuel consumption	0.24	Not used	GLOBAL
Fuel consumtption	Fitted curve	Medium	DP size & fuel
Pump element efficiency curve	Fitted curve	Small	DP size & fuel
Rising main loss curve	Fitted curve	Small	DP size & fuel
Rising main losses - non-linearity	5%	Medium	DP size & fuel
Windage losses	10%	Small	DP size & fuel
Derating	20%	Small	DP size & fuel
Load factor	70%	Small	DP size & fuel
Minimum diesel engine size	2.6	Small	DP size & fuel
Maximum diesel engine size	16.8	Small	DP size & fuel
GLOBAL			
Financial			
Project life	20	Medium	GLOBAL
Discount rate	8.5%	Small	GLOBAL
Loan rate	11.5%	Small	GLOBAL
Inflation rate	4.5%	Medium	GLOBAL
Diesel escalation rate	8.5%	Medium	GLOBAL
Percentage cost reduction between RWS & Private installation	50%	Medium	GLOBAL
Transport			
Transport: Installation of diesel pump: Truck	9.00	Small	GLOBAL
Transport rate for outsourced services	5.00	Medium	GLOBAL
Local transport rate to start diesel pump	3.00	Medium	GLOBAL
Percentage trip costs for maintenance: RWS	100%	Medium	GLOBAL
Percentage trip costs for maintenance: PVP: Private	50%	Medium	GLOBAL
Percentage trip costs for maintenance: PVP: RWS	50%	Medium	GLOBAL
Technical			
Rising main: 40mm: Maximum flowrate	3	Small	GLOBAL
Rising main: 50mm: Maximum flowrate	12	Small	GLOBAL
Rising main: Percentage replacement	20%	Medium	GLOBAL
Rising main: Additional % cost for lifting/reinstalling pipes	50%	Medium	GLOBAL
Maintenance interval for steel pipes	5	Medium	GLOBAL
PVP factors			
Lorentz PVP	0%	Medium	GLOBAL
Grundfos PVP	0%	Medium	GLOBAL
Total PVP	0%	Medium	GLOBAL
Watermax PVP	0%	Medium	GLOBAL

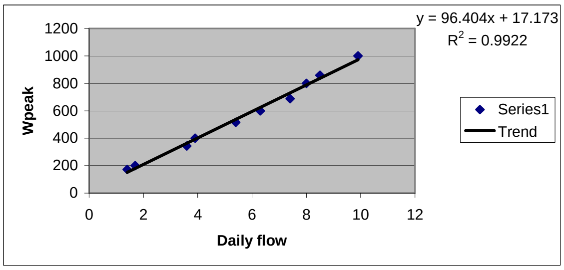
Performance curves of the PVPs

PVP performance: Grundfos SQ Flex

Head			1	2	3	4	5	6	7	8	9	10	
[m]	PV array	[Wpeak]	172	200	344	400	516	600	688	800	860	1000	y
10	Daily flow	[m³/day]	10.1	11.5	20.1	24.0	33.7	38.5	46.7	55.5	62.8	71.5	x
20	Daily flow	[m³/day]	6.8	8.0	15.0	16.8	20.2	21.3	23.3	27.4	30.9	35.7	
30	Daily flow	[m³/day]	3.2	4.1	9.8	11.4	15.7	17.3	19.0	20.1	20.8	21.5	
40	Daily flow	[m³/day]	2.4	2.9	6.6	7.9	11.5	13.4	15.9	17.3	18.1	19.2	
50	Daily flow	[m³/day]	2.2	2.5	5.3	6.0	8.8	10.4	12.7	14.7	15.9	17.1	
60	Daily flow	[m³/day]	2.0	2.3	4.5	5.2	7.3	8.0	10.2	11.9	13.4	14.8	
70	Daily flow	[m³/day]	1.7	2.0	3.9	4.3	6.3	7.2	8.1	9.0	10.5	12.3	
80	Daily flow	[m³/day]	1.4	1.7	3.6	3.9	5.4	6.3	7.4	8.0	8.5	9.9	
90	Daily flow	[m³/day]	1.2	1.5	3.2	3.7	4.5	5.4	6.6	7.3	7.7	8.3	
100	Daily flow	[m³/day]	1.0	1.3	3.0	3.4	4.2	4.7	5.9	6.7	7.1	7.7	
110	Daily flow	[m³/day]	0.7	1.0	2.6	3.0	3.9	4.2	5.1	6.0	6.6	7.1	
120	Daily flow	[m³/day]	0.5	0.7	2.3	2.7	3.6	3.9	4.3	5.3	6.0	6.6	
140	Daily flow	[m³/day]	0.9	1.1	2.4	3.1	3.8						
160	Daily flow	[m³/day]	0.6	0.7	2.0	2.6	3.4						
180	Daily flow	[m³/day]		0.4	1.4	2.2	2.9	3.3					
200	Daily flow	[m³/day]			0.9	1.9	2.3	3.3	3.5				

1	2	3	4	5	6
Head	**Factor**	**Intercept**	**Min**	**Max**	**R²**
[m]	[Wp]	[Wp]	[m³/day]	[m³/day]	
	m	b			0.925
10	13.11	67.22	10.1	71.5	0.995
20	29.96	- 57.33	6.8	35.7	0.985
30	39.80	- 10.75	3.2	21.5	0.925
40	44.34	47.20	2.4	19.2	0.973
50	51.25	68.04	2.2	17.1	0.992
60	62.02	64.29	2.0	14.8	0.995
70	78.96	42.41	1.7	12.3	0.995
80	96.40	17.17	1.4	9.9	0.992
90	110.07	14.25	1.2	8.3	0.985
100	118.81	23.34	1.0	7.7	0.987
110	125.92	51.80	0.7	7.1	0.988
120	134.74	74.29	0.5	6.6	0.986
140	113.30	70.34	0.9	3.8	0.991
160	117.52	107.81	0.6	3.4	0.995
180	131.25	144.24	0.4	3.3	0.980
200	128.13	204.66	0.9	3.5	0.935

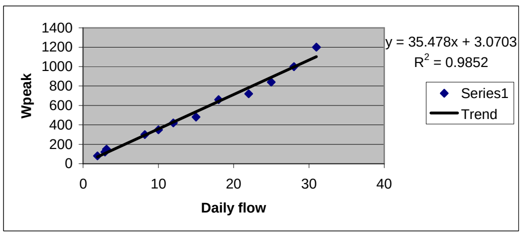


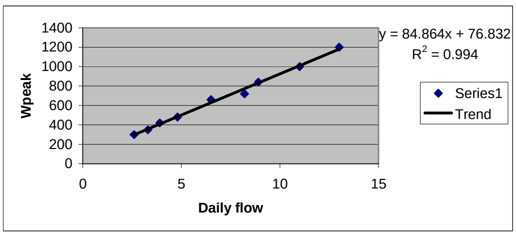


PVP performance: Lorentz PS 200, PS 600 & PS 1200

Head			1	2	3	4	5	6	7	8	9	10	11	12	
[m]	PV array	[Wpeak]	80	120	150	300	350	420	480	660	720	840	1000	1200	y
10	Daily flow	[m³/day]	3.9	5.2	5.4	12	19	22	24	36	43	49	60	70	x
20	Daily flow	[m³/day]	2.5	3.8	4.9	11	15	17	19	23	26	30	36	42	
30	Daily flow	[m³/day]	1.9	2.9	3.1	8.2	10	12	15	18	22	25	28	31	
40	Daily flow	[m³/day]		2	2.5	5.4	6.5	7.5	10	13.5	18	21	22	24	
50	Daily flow	[m³/day]				4.8	5.5	6	8.5	10.7	14	16	18	20	
60	Daily flow	[m³/day]				3.7	4.8	5.4	7	8.5	10	12	14	16	
70	Daily flow	[m³/day]				3	4.1	4.8	5.5	7.3	9	10	12	14	
80	Daily flow	[m³/day]				2.6	3.3	3.9	4.8	6.5	8.2	8.9	11	13	
90	Daily flow	[m³/day]				2.1	3	3.7	4.4	5.5	7.4	8.4	9	10	
100	Daily flow	[m³/day]				1.8	2.7	3.2	3.8	4.9	5.8	7.3	8	9	
120	Daily flow	[m³/day]				1.6	2.5	3	3.4	4	5	6.5	7.6	8.5	
140	Daily flow	[m³/day]				1.3	2	2.5	3	3.5	4.4	5.2	5.8	6.4	
160	Daily flow	[m³/day]						2	2.4	3	3.5	3.9			
180	Daily flow	[m³/day]						1.4	1.9	2.8	3.3	3.6			
200	Daily flow	[m³/day]							1.6	2.5	3	3.4			
230	Daily flow	[m³/day]							1.3	1.8	2.5	3.1			

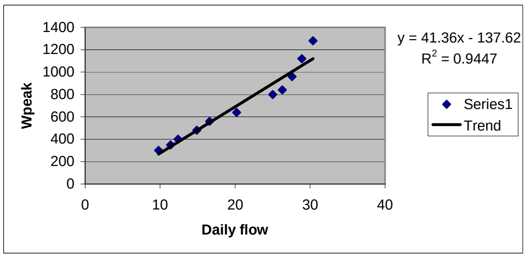
1	2	3	4	5	6
Head	**Factor**	**Intercept**	**Min**	**Max**	**R²**
[m]	[Wp]	[Wp]	[m³/day]	[m³/day]	
	m	b			0.936
10	16.09	57.94	3.9	70.0	0.994
20	28.20	-14.23	2.5	42.0	0.992
30	35.48	3.07	1.9	31.0	0.985
40	42.46	56.24	2.0	24.0	0.966
50	53.07	53.06	4.8	20.0	0.972
60	71.55	16.18	3.7	16.0	0.991
70	81.47	32.43	3.0	14.0	0.994
80	84.86	76.83	2.6	13.0	0.994
90	105.71	34.92	2.1	10.0	0.957
100	120.83	39.07	1.8	9.0	0.979
120	127.38	67.48	1.6	8.5	0.977
140	171.53	13.43	1.3	6.4	0.969
160	220.90	-29.85	2.0	3.9	0.985
180	183.82	146.08	1.4	3.6	0.978
200	191.70	171.78	1.6	3.4	0.984
230	183.94	274.94	1.3	3.1	0.936

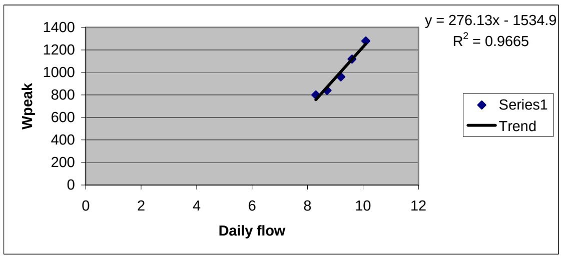




PVP performance: Total Energie TSP 1000

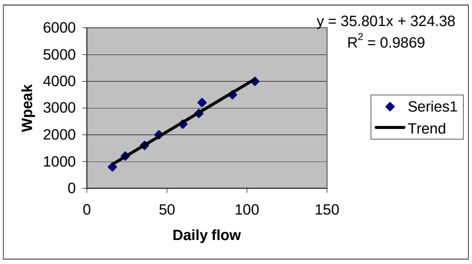
Head			1	2	3	4	5	6	7	8	9	10	11		1 Head [m]	2 Factor [Wp]	3 Intercept [Wp]	4 Min [m³/day]	5 Max [m³/day]	6 R²
[m]	PV array	[Wpeak]	300	350	400	480	560	640	800	840	960	1120	1280	y		m	b			0.940
10	Daily flow	[m³/day]												x	10	#VALUE!	#DIV/0!	0.0	0.0	
20	Daily flow	[m³/day]	12.9	15.5	18.6	20.2	24.3	27.4	35.0	36.8	38.6	40.5	42.5		20	29.40	-131.92	12.9	42.5	0.944
30	Daily flow	[m³/day]	9.8	11.4	12.4	14.9	16.6	20.2	25.0	26.3	27.6	28.9	30.4		30	41.36	-137.62	9.8	30.4	0.945
40	Daily flow	[m³/day]	7.2	8.5	9.8	11.2	13.0	15.0	18.5	19.4	20.4	21.4	22.5		40	57.06	-163.07	7.2	22.5	0.946
50	Daily flow	[m³/day]	5.4	6.4	7.0	8.3	10.0	12.0	15.0	15.8	16.5	17.4	18.2		50	65.79	-86.79	5.4	18.2	0.940
60	Daily flow	[m³/day]	4.3	5.2	6.0	7.0	7.8	9.3	12.7	13.3	14.0	14.7	15.4		60	76.18	-57.03	4.3	15.4	0.943
70	Daily flow	[m³/day]	3.2	4.1	4.7	5.5	6.3	7.3	10.7	11.2	11.8	12.4	13.0		70	85.79	-0.78	3.2	13.0	0.940
80	Daily flow	[m³/day]							9.4	9.8	10.3	10.8	11.4		80	250.00	-1,585.00	9.4	11.4	0.981
90	Daily flow	[m³/day]							8.3	8.7	9.2	9.6	10.1		90	276.13	-1,534.91	8.3	10.1	0.966
100	Daily flow	[m³/day]							7.5	7.9	8.3	8.7	9.1		100	310.00	-1,573.00	7.5	9.1	0.961
110	Daily flow	[m³/day]									7.5	7.8	8.3		110	391.84	-1,962.45	7.5	8.3	0.980
120	Daily flow	[m³/day]									6.9	7.2	7.6		120	454.05	-2,164.32	6.9	7.6	0.993
130	Daily flow	[m³/day]									6.4	6.6	7.0		130	514.29	-2,308.57	6.4	7.0	0.964

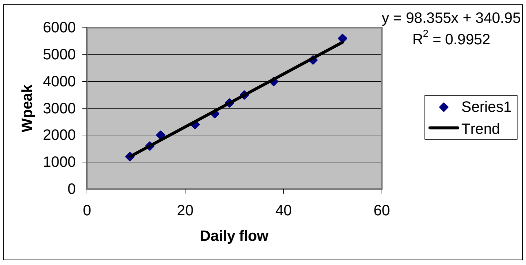




PVP performance: Total Energie TSP 2000, TSP 4000 & TSP 6000

Head			1	2	3	4	5	6	7	8	9	10	11		1 Head [m]	2 Factor [Wp]	3 Intercept [Wp]	4 Min [m³/day]	5 Max [m³/day]	6 R²
[m]	PV array	[Wpeak]	800	1200	1600	2000	2400	2800	3200	3500	4000	4800	5600	y		m	b			0.979
10	Daily flow	[m³/day]	56	86	109									x	10	15.01	-55.59	56.0	109.0	0.994
20	Daily flow	[m³/day]	22	37	57	73	89	108	121						20	23.74	280.49	22.0	121.0	0.998
30	Daily flow	[m³/day]	16	24	36	45	60	70	72	91	105				30	35.80	324.38	16.0	105.0	0.987
40	Daily flow	[m³/day]	10	18	27	37	40	50	53	59	69	93	113		40	48.04	414.91	10.0	113.0	0.985
50	Daily flow	[m³/day]	11	14	21	27	36	41	46	49	52	68	74		50	72.34	13.86	10.9	74.0	0.988
60	Daily flow	[m³/day]	7	12	16	22	28	34	39	43	49	58	67		60	78.39	221.66	7.4	67.0	0.997
70	Daily flow	[m³/day]	7	11	13	18	26	28	32	34	39	47	55		70	97.94	144.56	6.7	55.0	0.993
80	Daily flow	[m³/day]		9	13	15	22	26	29	32	32	38	46	52		80	98.36	340.95	8.7	52.0	0.995
90	Daily flow	[m³/day]		6	10	13	19	23	26	27	33	41	49		90	103.37	552.74	6.3	49.0	0.996
100	Daily flow	[m³/day]		5	9	11	17	20	23	24	28	37	44		100	113.15	652.06	4.8	44.0	0.994
110	Daily flow	[m³/day]		4	8	10	14	17	21	22	25	30	34		110	143.84	448.92	4.0	34.0	0.988
120	Daily flow	[m³/day]		3	7	9	13	17	20	21	24	28	32		120	147.99	535.05	3.0	32.0	0.979





PVP costing

PVP system cost	**Unit**	**Price**
PV array		41,982
PV array structure		2,811
PVP subsystem		9,300
Pipe, cable & rope		4,906
Accessories		4,720
Installation		3,311
Transport for installation		3,000
Total PVP installation cost	pvp_capex	**80,535**

PVP subsystem pricing
Array name: pvp_subsystem_cost_array

Grundfos SQFlex [200m]	9,770
Lorentz PS series [230m]	9,300
Total TSP 1000 [120m]	25,000
Total TSP 2000+ [120m]	34,000
Watermax [150m]	8,900

PVP retail price database	**Unit**	**Price/ Factor**	**Intercept**
Solar PV array; per Wpeak	N$/Wpeak	42	
Fixed array; per Wpeak	N$/Wpeak	2.0	800
Tracking array; per Wpeak	N$/Wpeak	2.0	2,000
Grundfos pump-motor with controller unit: 900W	per unit	8,960	
Control unit IO100	per unit	810	
Lorentz controller, H200, H600 & H1200	per unit	3,100	
Lorentz pump-motor unit	per unit	6,200	
Shurflo controller, 10A	per unit	1,600	
Shurflo pump, Series 9300	per unit	4,600	
Total Energie TSP 1000 inverter & pump/motor	per unit	25,000	
Total Energie TSP 2000 inverter & pump/motor	per unit	34,000	
Total Energie TSP 4000 inverter & pump/motor	per unit	36,000	
Total Energie TSP 6000 inverter & pump/motor	per unit	44,000	
Watermax controller	per unit	1,500	
Watermax WA motor pump unit	per unit	7,200	
Watermax WB motor pump unit	per unit	7,400	
Watermax WC motor pump unit	per unit	7,800	
Watermax WD motor pump unit	per unit	8,500	
Hose pipe	N$/m	2.00	
HDPE pipe, per meter	N$/m	7.00	
Submersible cable	N$/m	35.06	
Steel rope, 4mm	N$/m	6.00	
Steel rope, 5mm	N$/m	7.00	
Accessories (Array wiring, juncitons, smalls, concrete)		8%	
Installation (function of Wpeak & depth)	N$/m	3,311	

Price averaging

PV modules	Price	Wpeak	N$/Wp
Supplier 1			
Module 1	2,056	50	41.12
Module 2	2,530	65	38.92
Module 3	3,423	80	42.79
Module 4	3,329	85	39.16
Supplier 2			
Module 1	2,580	60	43.00
Module 2	2,770	65	42.62
Module 3	3,370	80	42.13
Module 4	3,660	85	43.06
Module 5	5,150	120	42.92
Average price per Watt peak			**41.75**

DP performance and fuel consumption calculation

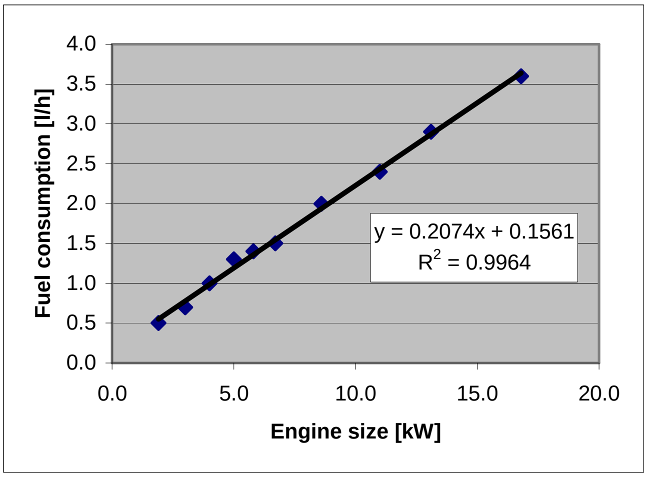
MONITOR	**Value**	**Units**
Specific fuel consumption	0.24	kg/kWh
Head	100	m
Flowrate	2.3	m³/h

Factors & Functions	**Factor**	**Functions**
Pump	0.125	0.024
Pipe: 40mm	2.220	1.270
Pipe: 50mm	0.472	1.666
Pipe: 65mm	0.431	1.100

Efficiencies & Losses	**Value**	**Units**
Pout (pump)	623	W
Efficiency (pump)	60%	
Friction losses (pipe)	6%	
Rising main losses - non-linearity	5%	
Windage losses	10%	
Derating	20%	
Shaft output power	1.6	kW
Load factor	70%	

Design checks		
Pre-liminary engine power	2.3	kW
Minimum diesel engine size	2.6	kW
Maximum diesel engine size	16.8	kW
Check if above minimum size	2.6	kW
Check if below maximum size	2.6	kW

OUTPUTS			
Diesel engine size	engine_power	**2.6**	**kW**
Engine fuel consumption	diesel_consumption	**0.70**	**l/h**



kW	L/h
1.9	0.5
3.0	0.7
4.0	1.0
5.0	1.3
5.8	1.4
6.7	1.5
8.6	2.0
11.0	2.4
13.1	2.9
16.8	3.6

Coefficient	Offset
0.2073667	0.15608706

Diesel pump costing

DP system cost:		Price
Engine cost		9,000
Rising main		12,067
Fixed costs:		12,669
Installation costs:		1,200
Transport for installation		2,700
Total diesel pump plus installation cost	dp_capex	**43,281**

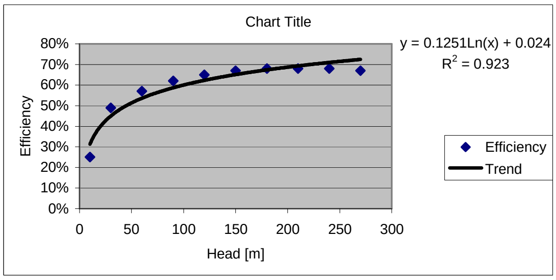
Prices scaling for DRWS vs private DIY installation

Diesel pump specifications	Private installation
Factor	50%

DP retail price database	Unit	Price/ Factor	Intercept
Long life engine	N$	15,468	
	N$		
Short life engine	N$	9,000	
Diesel engine BOS	per unit	6,575	
Diesel engine foundation	per unit	3,250	
Borehole top	per unit	5,513	
Rising main: 40mm, taper thread	per m	121	
Rising main: 50mm, taper thread	per m	160	
Rising main: 65mm, taper thread	per m	235	
Pump element	per unit	3,000	
Rising main accessories	per unit	4,000	
Installation: Borehole	per unit	6	1,800
Transport: Installation of diesel pump: Truck	per km	9	

Pump element efficiency curve (Orbit 0202)

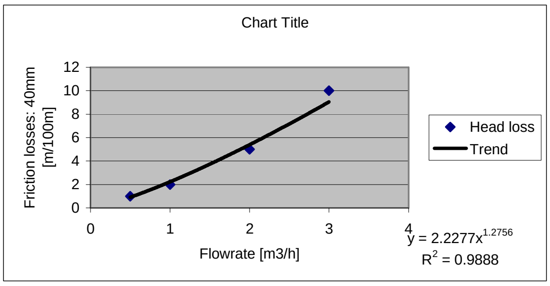
Total Head	Efficiency (%)	Factor	Offset
10	25%	0.125	0.024
30	49%		
60	57%		
90	62%		
120	65%		
150	67%		
180	68%		
210	68%		
240	68%		
270	67%		



Losses in rising main

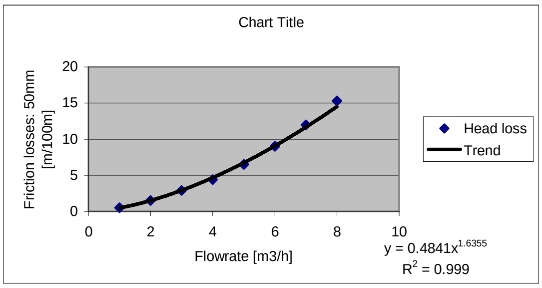
40mm column

Flow rate [m3/h]	FH losses [m/100 Head]	Factor	Power
0.5	1	2.22	1.27
1	2		
2	5		
3	10		
4	17		
5	26		
6	37.5		



50mm column

Flow rate [m3/h]	FH losses [m/100 Head]	Factor	Power
1	0.5	0.4715	1.666
2	1.5		
3	2.9		
4	4.4		
5	6.5		
6	9		
7	12		
8	15.3		



A3 Workshop proceedings

Workshop

for

Feasibility Assessment for the Replacement of Diesel Water Pumps with Solar Water Pumps

held

11 August 2006

Windhoek

WORKSHOP PROCEEDINGS

1. Presentations

The workshop was opened by Mr Hamutwe, who provided the background to the NAMREP programme and referred to one of the barriers, "Public awareness and social acceptability", with regards to the PVP study stating that this study means to shed light where there is a lack of factual information preventing general acceptance and usage of this particular RET.

The workshop was facilitated by Mr Martin Heita. Mr Heita gave a perspective on some international developments in the renewable energy and energy efficiency sector stating that the time has come globally and locally to take renewable energy into serious consideration.

Mr Axel Scholle presented the findings of the Feasibility assessment for the replacement of diesel water pumps with solar water pumps.

2. Discussion

The workshop was conducted interactively and participants made comments and raised questions during the presentation. These comments and queries are documented here:

- The Grundfos SQ Flex range has been extended to 1,400Wpeak and 200m head.
- The combination (hybrid) of wind/diesel administered by DRWS is mostly used in Karas and Hardap. Why is DRWS phasing out hybrid pump systems?
    - The delegates from DRWS were not completely certain but offered the explanation that the hybrid systems are more complex and costly to maintain (two technologies) and are therefore being converted to either the one or the other technology.
- The combination of solar and diesel presents an efficient and flexible option, in particular with a small petrol generator (1.5kVA). For communal water supply it would not be considered due to the single energy source policy. However the community could decide to buy their own petrol generator. Do the participants consider the solar plus genset option a viable solution? The suppliers considered this to be the case.
- Diesel pumps for larger number of livestock and people. This flexibility is considered an advantage by rural communities. However this may cause overexploitation of water resources and land in the vicinity of the water supply. In this regard water resource management is vital and is inherently part of a PVP.
- Communal livestock keeping should take a more commercial approach by selling more rather than ending with large herds of cattle which become difficult to sustain in the communal areas.
- The diesel fuel to rural communities used to be subsidised but that is no longer the case.
- The diesel section in the report is to mention the supply risks explicitly. Also, the future of the diesel price is completely unpredicatable as it is not governed by local circumstance but by interantional events which are completely beyond Namibias control.
- The diesel price will go up next week and the study should update the results with these prices.
- Of the 7,000 DRWS administered water points, only 100 make use of PVP technology.

- Presenter: An advantage of a diesel engine is that it is moveable.
- Suppliers felt that a PVP is also moveable, where in fact the whole installation can be moved (in the diesel engine case only the engine is moved – the head, rising main and pump stay in the borehole). However, a PVP is only completely moveable if the borehole specifications are similar. Furthermore, the diesel installation is considered to be overcapitalised in terms of the below ground installation (also concern about rusting pipes).
- A comment was made to incorporate PVP with rural electrification as a more comprehensive service delivery.
- PVP replacement include the controller, motor and pump – not the PV modules.
- The time factor for dealing with the fuel purchase and the refuelling, operations etc, needs to be taken into consideration – the operator has to dedicate time to these issues and that needs to be reflected in the costing tool as an option to be activated.
- The report should present the breakeven vs hydraulic load on a graph with head vs daily flowrate as well indicating the years to breakeven on the constant power lines.
- It was suggested that the study runs a number of scenarios for the cost of diesel (best at a real escalation of 0%) where the diesel price is for example 6, 8, 10 and N$12 per litre. If possible, a factor should be stated which can be used to recalculate the years to breakeven.
- The suppliers should improve the service delivery in the outlying areas.
  - This was felt to already be the case through the solar technicians which are able to locate the problems and also effect repairs.
  - It was suggested that more on-the-job training would be made available through the solar suppliers so that VTC students can learn the ropes in PVP technologies.
- The study should be more concrete on theft prevention issues if theft is such an issue by providing a list of mitigatory actions. It was also raised that the amount of theft that is being anticipated is actully a myth and that the percentage of theft of installed PVPs is possibly very small – nobody could make a statement of the percentage of theft experienced.
- It was recommended to the suppliers to be present and exhibit at auctions as this was where money was being traded.
- It was mentioned that it is important to get influential people (chiefs) to lead the way in terms of PVP as other potential users may follow suite.
- Will the PVP sector be ready to service an increased demand for PVPs? The response was positive.

The presentation and discussion ended at 13:30.

1. Participants

NAMREP: Feasibility of replacing diesel pumps with solar PV pumps
Workshop, 11 August 2006, 10:00 to 13:00, Habitat Centre
List of participants

	Stakeholder	Sector	Email	Tel
1	Aring, H	Elwiwa	haring@elwiwa.com.na	061-218600
2	Chatta L	Adra Namibia	adra-nam@mweb.com	061-228146
3	Genis W	NEC	nbrueckner@namencor.com.na	061-236720
4	Grobler, Adriaan	Lithon Project Consultants	groblera@iway.na	065-224203
5	Hamutwe-Jr, Shimweefeleni G	NAMREP	ghamutwe@mme.gov.na	(061) 284 8169
6	Hasheela, Raimo	NAMREP	rhasheela@mme.gov.na	(061) 284 8170
7	Heita, Martin	Polytechnic of Namibia	tindaesi@iway.na	061-271941
8	Hibbert N	Ministry of Education	tnghiyoonanye@mec.gov.na	293 3341
9	Hipangelwa, Noddy	MME	nhipangelwa@mme.gov.na	(061) 284 8205
10	Hoffmann, Kerstin	Solar Age Namibia	kerstin@solarage.com	(061) 215 809
11	Howard, Glenn	Emcon Consulting Group	glenn@emcon.com.na	224 725
12	Kaizemi A	DRWS - Minisitry of Agriculture - Otjiwarongo		067-303020
13	Kandjavera P	Farmer	pkandjavera@agribank	061-2074111
14	Kaperu A	Ministry of Education	tnghiyoonanye@mec.gov.na	293 3341
15	Kauaria TJ	energy.omaheke elect.		812536188
16	Kaulinge Seve	SK Holdings (Pty) Ltd	skholdings@mweb.com.na	061-230459
17	Keeja B	DRWS - Ministry of Agriculture - Karibib		064-550057
18	Nakatana, Levy	Windhoek Vocational Training Centre	lnakatana@wvtc.edu.na	061-211742
19	Muhinda I.M	Ministry of Environment & Tourism	imuhinda@met.gov.na	061-2842111
20	Mushaandje David	Ministry of Education	dmushaandja@mec	061-2933329
21	Nepaya, Leokadia	Independent	ndeapo19@yahoo.com	081 230 5378
22	Nuukongo Paulin	MEC Technology		811221711
23	Ooshysten F	DRWS - Minisitry of Agriculture	oosthysten@mawrd.gov.na	062-564436
24	Rhiemer, Mark	ConServ	mriehmer@conservcc.com	(061) 236 336
25	Rusch, Holger	CMB (NAMIBIA) (Pty) Ltd.	cmbwo@namibnet.com	237253/4
26	Rust B	WML Consulting Engineers (Pty) Ltd	wmleng@mweb.com.na	220285
27	Scholle, Axel	Emcon Consulting Group	axel@emcongroup.com	224 725
28	Schultz Robert	DRFN	r3e@iway.na	
29	Schultz, Werner	TerraSol	terrasol@iafrica.com.na	(061) 239 454
30	Schütt Harald	Amusha cc	haralds@namibnet.com	061-232333
31	Singo A	Adra Namibia	adra-nam@mweb.com	061-228146
32	Steuber, Heinrich	SolTec	h.steuber@soltec.com.na	(061) 235 646
33	Taylor J	JTCE	jtce@mweb.com.na	061-224088
34	Tjamburo, Prescott	Solar Technician		081 128 7168
35	Tjijenda K	DRWS - Minisitry of Agriculture	tjijenda@mawrd.gov.na	208 7288
36	Truebenbach, Volker	E-Power	volker@e-power.com.na	254 813
37	Uunona, Catherine	Consulting Services Africa	catherinem@csa.com.na	237427
38	van de Heuvel, Marco	WML Consulting Engineers (Pty) Ltd	marco@wmleng.com	061-220285
39	van Schalwyk, Mr	Africon Namibia	ojvs@africon.com.na	297 7000
40	von Leipzig, Holger	Bicon Namibia	bicon@bicon.com.na	275120

End of Document

A4 Terms of Reference

BARRIER REMOVAL TO NAMIBIAN RENEWABLE ENERGY PROGRAMME - NAMREP
NAMREP/TOR-PVP STUDY-10-05

Terms of Reference for the Assessment of the Technical and Economic Feasibility for the Replacement of Diesel Water Pumps with Solar Water Pumps (PVP)

1. INTRODUCTION

The **development objective** of the project is to increase affordable access to sustainable energy services through the further development of a market for Renewable Energy Technologies (RETs) in Namibia that contribute to climate stabilization by reducing CO_2 emissions through the removal of technical, financial, social, institutional, capacity, public awareness and social acceptability barriers.

The **immediate objective** is to remove barriers to the delivery of commercially, institutionally, and technically sustainable RES including electricity production (for off-grid lighting, radio, TV, water pumping, and refrigeration), and water heating to the household, institutional, commercial, and agro-industrial sectors and to demonstrate the enabled environment through affirming demonstrations of the applications of the technologies. The Project has the following six components as focus areas barrier removal:

- **Component 1: Capacity building:** the capacity building component will focus amongst others on the training of Private Sector (PV industry), the NGOs staff, the Government and the PMU to create technical capacity in dealing with renewable energy issues.
- **Component 2: Removal of institutional barriers:** the primary objective of this component is to influence GRN institutional policies so as to make them more favourable/equitable to RETs. This will be achieved through removing budgeting, subsidies, information and other institutional barriers to the appropriate use of RESs in planning processes at inter-sectoral levels.
- **Component 3: Public awareness and social acceptability:** the overriding cross technology awareness building and social acceptability objective is to create awareness throughout Namibia of RETs, addressing the particular needs of the stakeholders.
- **Component 4: Financial barriers:** the primary objective of this component is to reduce/overcome the financial barriers to the supply, installation, purchase and maintenance of RETs including reduction of the price and ready availability of finance for the purchase and maintenance of systems.
- **Component 5: Technical barrier removal/reduction:** the main objective of the reduction of technological barriers is to facilitate, support and strengthen the introduction of the Renewable Energy and Energy Efficiency Institute in Namibia, which will provide detailed technical information and develop and apply appropriate norms, standards and codes of practice as required by the RET industry and their market.

- **Component 6: Demonstrations and pilots:** the objectives of the demonstration component of this Project are two fold: to test the transformed market for RESs and refine project activities to successfully complete the market transformation; and tangibly/visibly raising the profile of RETs through affirming demonstrations of their appropriate applications throughout Namibia.

2. OBJECTIVE OF THE CONSULTANCY:

The main purpose of this consultancy is to determine the current status of solar water pumping (PVP) utilization in Namibia and to conduct an assessment of the potential for using PVP in place of diesel water pumps on commercial and communal farms and at public facilities.

3. TERMS OF REFERENCE TOWARDS ATTAINING THE CONSULTANCY

The activities to be undertaken will result in four major outputs:

1. Review and analysis of the current ownership, use and distribution of diesel and solar water pumps across the country.
2. Recommendations on possible mechanism to be applied for implementing an economic and socially beneficial benefit program to facilitate the use of PVP in Namibia; and
3. Guide a graduate student in the completion of a master's degree thesis using the data and information generated from this study. The student will be part of the investigating team and will conduct research required for the fulfillment of the requirements for a thesis.
4. Plan, develop and conduct a comprehensive promotional campaign targeted to select stakeholders.

The selected consultant, institution or consortium will do the following:

1. Determine the extent and distribution of diesel and water pump use in commercial, communal farms and in public facilities. This should include data on number of installations done annually over the last five years.
2. Review the possible types of PVP based on efficiency, cost, pumping depth, discharge etc. that could replace existing diesel water pumps on commercial, communal farms and public facilities. Suppliers and dealers should be identified and consulted.
3. Consult with key stakeholders such as commercial and communal farmers, Ministry of Works Transport/Department of Works, private sector businesses, entrepreneurs, financial institutions i.e. AgriBank.
4. Determine the potential for adoption and the conditions under which adoption will be enhanced among commercial, communal farmers and public facilities. This should also include determination of present levels of satisfaction by current PVP users.
5. Conduct a comparative cost benefit analysis (life-cycle-cost) of diesel vs solar water pumps taking into account the current pump price of diesel applicable to different locations across Namibia. Also conduct an analysis for a projected diesel price for the year 2010.

1. Review the financial and economic incentives, government policies such as use of PVP at public facilities, and financing models that could facilitate adoption of PVP.
2. Indicate how and by how much the application of PVP vs diesel water pumps will decrease GHG emissions.
3. Writing articles on PVP in the media for public consumption.
4. Prepare, design and print 1000 copies of a one page brochure highlighting key points about the PVP.
5. Plan, prepare and conduct a comprehensive promotional campaign based on the findings of the study.
6. Submit electronic copy for reproduction and distribution to various stakeholders.
7. The consultant should suggest other innovative and effective means of promotion with details.
8. Based on the above, make recommendations that decision makers and others could use.

6. REQUREMENTS OF THE TRAINING TEAM:

The team leader shall be an energy expert having a tertiary qualification, as well as technical and economical understanding of PVP applications. The other core members that make up the study team must demonstrate a thorough understanding of and familiarity with the subject matter as well as practical experience in the field. They must also demonstrate capabilities and experience in the alternate energy systems, solar water pumps as well as economic analysis.

7. BUDGET

The selected consultant, institution or consortium must submit a budget detailing estimated cost of the expected implementation of this activity. This budget must be in the form of a complete breakdown detailing costs of key personnel and the amount of time allocated to each key person, transportation, materials and other items. The costing should also include the cost for the preparations, facilitating, conducting and reporting on the stakeholder’s workshop in to be held in Windhoek. A payment schedule should also be submitted in the form of a financial proposal separately from the two copies of the technical proposal and in different envelopes. A fixed contract will be entered into with the selected contractor.

8. IMPLEMENTATION ARRANGEMENTS

The consultant will be commissioned by NAMREP in consultation with the Ministry of Mines and Energy. The consultancy for the study, including review of draft(s) and presentation of the findings should be completed not later than 28 February 2006 and for the promotional campaign no later then 30 April 2006.

The selected consultant, institution or consortium will be responsible for the preparation and delivery of a comprehensive report on the activities undertaken and completed within the terms of this consultancy. The report will include but is not limited to information on the geographic areas covered, institutions, data collected, findings and recommendations arising from the work. The report will include an executive summary, the body of the report and annexes.

Thirty (30) copies of a draft report will be presented for use by NAMREP for use at the workshop to be facilitated by the contractor. The draft report will be presented at least 10 working days before the workshop. The contractor will incorporate the comments from interested parties, NAMREP into the final report. Ten (10) bounded hard copies of the final report and one copy of the electronic version using appropriate software (preferably Microsoft Office or Acrobat) must be delivered to NAMREP upon completion of this assignment. The LCC tool should also be submitted in electronic format using Microsoft Excel.

The consultant shall prepare a report of the promotional campaign and submit 10 hardcopies and one (1) electronic copy of the Final Report. The report should include the stakeholders, attendees, aspects covered in the presentation, discussions and any positive concrete outcomes.

9. SUBMISSION PROCEDURE

Interested consultants, institutions or consortia should submit a technical and financial proposal in separate envelopes indicating their interests and capability to implement the above work in sealed envelopes marked **TECHNICAL PROPOSAL FOR THE REVIEW OF POTENTIAL FOR SOLAR WATER PUMPING** and **FINANCIAL PROPOSAL FOR THE REVIEW OF POTENTIAL FOR SOLAR WATER PUMPING** respectively to the following address by **27 October 2005**

The National Project Director
UNDP/GEF/MME Namibia Renewable Energy Programme – NAMREP
Ministry of Mines and Energy
Attention: Veiko Nangolo
1st Floor Ministry of Mines and Energy Building
Private Bag 13297
1 Aviation Road
Windhoek

E-mail: vnangolo@mme.gov.na or weah_veiko@hotmail.com

Enquiries: Veiko Nangolo: Tel: +264 61 284 8170 or Cell: +264 811 244 172

DEADLINE FOR SUBMISSIONS: 27 October 2005 @ 16h00