A COST AND RELIABILITY COMPARISON BETWEEN SOLAR AND DIESEL POWERED PUMPS

Solar Electric Light Fund (SELF)
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Introduction

In rural and/or undeveloped areas where there is no power grid and more water is needed than what hand or foot pumps can deliver, the choices for powering pumps are usually solar or a fuel driven engine, usually diesel.

There are very distinct differences between the two power sources in terms of cost and reliability. Diesel pumps are typically characterized by a lower first cost but a very high operation and maintenance cost. Solar is the opposite, with a higher first cost but very low ongoing operation and maintenance costs.

In terms of reliability, it is much easier (and cheaper) to keep a solar-powered system going than it is a diesel engine. This is evident in field where diesel engines lie rusting and unused by the thousands and solar pumps sometimes run for years without anyone touching them.

The first cost of solar is often daunting to donors and project implementers who are tempted to stretch their budgets as far as possible to reach the greatest number of beneficiaries by using a low first-cost option. But most would probably agree that "quantity over quality" is not a good value if the higher quantity option is not likely to be giving good service five years down the road and if beneficiaries are going to be stuck with interventions they cannot afford to sustain over time.

Solar pumping has had clear advantages for a number of years but the differences are becoming more striking in a world of rapidly escalating fuel costs. Not only will some of the world's poorest people not be able to afford fuel for their pumps, but living at the end of remote supply chains, they may not even be able to get it in the first place as world demand overtakes supply. (Rwanda has already had at least 3 nation-wide fuel shortages in the last 18 months).

In this paper, we offer evidence accumulated by others as well as from our own experience showing that solar pumping is the most reliable and cost-effective option for many water pumping applications in developing countries.

Solar powered village water supply - SELF- Nigeria

<u>Cost Comparisons – HOMER Simulations</u>

The U.S. National Renewable Energy Laboratory (NREL) has developed a sophisticated simulation program that optimizes the most economic energy choices per specific project inputs. In this example, SELF has used HOMER (Hybrid Optimization Model for Electric Renewables) to model choices for a pumping system that is designed to pump 5,000 gallons per day from a total depth (head) of around 100 feet. It compares a solar array of 1900 watts against a 4 kW diesel generator. Both power an equivalent pump of approximately 1 horsepower. Several simulations were performed to gauge the effect of the price of fuel and the fuel efficiency of the diesel generators. These and other parameters are listed below:

Fuel cost:
Case 1: $1.20 per liter
Case 2: $1.50 per liter (current approximate cost in Namibia, Rwanda and Benin)
Case 3: $1.70 per liter

Fuel efficiency (consumption) of diesel generator:
Case 1: .3 liters per kilowatt generated
Case 2: .5 liters per kilowatt generated
Case 3: .7 liters per kilowatt generated

Solar resource: Annual average of 4.6 peak sun hours per day (This figure is low for most African countries and represents a conservative approach)

Real annual interest rate: 5%
System life: 20 years

Key program outputs:
Initial capital cost: "first cost" for each option – assumes same pump costs

Operation cost/year: Average O&M costs per year. Does not include pump replacement costs which would be same for both

Net Present Cost: The present value of the cost of installing and operating the system over the lifetime of the project (also referred to as lifecycle cost).

$ per kilowatt: The cost per kilowatt of electricity per each option.

Simulation 1: "Worst case" for solar: Fuel cost: $1.20 per liter. Consumption rate: .3 liters per kilowatt

	Initial Capital	**Operating cost/year**	**Total NPC**	**$ per kWH**
PVP Option	**$12,300**	**$335**	**$16,472**	**$0.66**
DP Option	**$2,000**	**$4,854**	**$62,494**	**$2.48**

Simulation 2: "Best case" for solar: Fuel cost: $1.70 per liter. Consumption rate: .7 liters per kilowatt

	Initial Capital	**Operating cost/year**	**Total NPC**	**$ per kWH**
PVP Option	**$12,300**	**$335**	**$16,472**	**$0.66**
DP Option	**$2,000**	**$12,525**	**$158,094**	**$6.27**

We can see from these simulations that solar ranges from one tenth to one fourth the Net Present Cost of the diesel option.

Solar vs. Diesel Cost Comparisons – Recent Studies by Others

One of the most comprehensive recent studies comparing solar to diesel powered pumps is the 2006 report "*Feasibility Assessment for the Replacement of Diesel Water Pumps with Solar Water Pumps",* issued by the Ministry of Mines and Energy of Namibia, prepared by EmCon Consulting Group and sponsored by UNDP, Global Environmental Facility (GEF) and the Government of Namibia.

Namibia is an ideal location for a pumping study. Because Namibia has very little surface water, it relies on over 50,000 bore-hole wells for its water supply. Many of these wells are off the grid and are powered by diesel pumps. Solar energy has been used for pumping in Namibia for over 25 years and from 2001 to 2006, 669 solar-powered wells were installed – creating a large field for study.

This report furnishes overwhelming evidence that for small to medium sized wells, solar (PVP, or photovoltaic pump) is much cheaper on a life cycle cost basis than diesel-powered (DP) pumps. When looking beyond the original purchase price, PVP pumping systems cost anywhere from 22-56% of what diesel pumps cost and can achieve a payback over DPs in as little as 2 years.

Though called "small to medium", most village water supply pumps (and SELF pumps used for drip irrigation), fall into this range. The daily output of these pumps range from 800 to 13,000 gallons per day (3,000 – 50,000 liters). Fifty thousand liters is enough to supply 2,500 people with their daily water needs when using UNDP standards of 20 liters per person per day. The effective depth (head) for these pumps is up to 400 feet or more (120 meters).

DEFINITION OF TERMS AND CONVERSIONS:

- Cubic meter = 1,000 liters
- Gallon = 3.79 liters
- Meter = 3.28 feet
- Hydraulic load: the daily output (cubic meters) x the head (total vertical pumping distance). A typical hydraulic load would be 18 cubic meters from a depth of 40 meters = 720
- $1.00 U.S. = 7.49 Namibian Dollars in Sept, 2006 (date of report)
- $1.00 U.S. = 7.66 Namibian Dollars on July 23, 2008

Life Cycle Costs

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

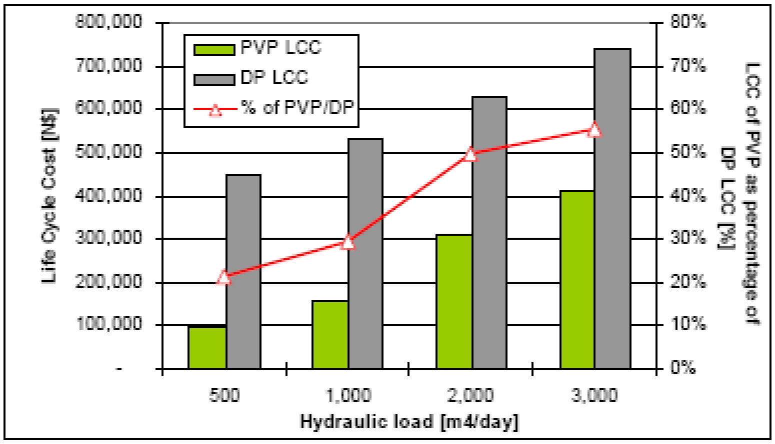


Figure 3.7: Life Cycle Costing as a function of the hydraulic load

Breakeven point

As previously stated, PVPs have a high up-front capital cost but very low operation and maintenance cost when compared to DPs. It is useful to know when the solar pump becomes cheaper to run than a diesel pump. The chart below compares three classes of PVPs to diesel. The systems in yellow are the smallest pumps of around 1 horsepower. (As commonly used by SELF). The green systems are double yellow systems (2 pumps in the same hole). And the blue system is a large 4 horsepower solar pump.

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

The following figure shows the breakeven point for a single case – a pumping system with an output of 10,000 liters per day from a head of 80 meters. The study also states that for pumping systems having a hydraulic load of 1,000 or less, the break even point is less than 2.5 years. Most pumps that SELF has used for agriculture or village water supply fall in this range.

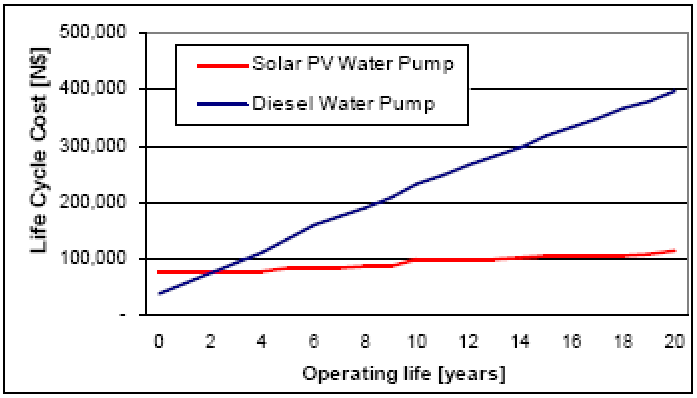


Figure 3.8: Typical years to breakeven graph for PV pump vs. a diesel pump

The effects of diesel fuel price increases.

The rapidly increasing price of petroleum products is of course changing economic calculations everywhere and these increases greatly impact both LCC and break even points for diesel pumps. At the time of the 2006 Namibia study, the price of diesel was 6.70 $N per Liter. At this writing, it is 10.64 $N per liter – almost a 60% increase.

According to sensitivity studies done for the Namibia report, every 10% increase in fuel costs results in a 3% increase in LCC. Accordingly, the present day LCC of the DP option is 18% higher than what is shown in these figures. It was also found that for every 10% increase in fuel costs, the there is a 5% reduction in the years to breakeven. So a PVP that broke even in 2.5 years in 2006 now breaks even in 1.75 years. During this period (2006-2008) the price of solar has been stable so the LCC for PVPs stay essentially the same. As we project into the future, the price of PV is surely to come down, while the price of oil is likely to go up.

Drip irrigation for market gardens – supplied by SELF solar pumps in Benin

Solar Water Pumping Cost Comparisons – Older Studies.

The following studies are older and therefore are based on fuel costs that are not realistic today. As we demonstrate above, the comparison between solar and diesel is heavily dependent on the price of fuel. All of the studies cited below were favorable to solar at the time of writing and would be even more favorable if written today with current fuel prices.

- A Sandia National Lab study of 3 different sized solar pumping systems (106 Wp, 848 Wp, 1530 Wp) in Mexico showed that all had lower life-cycle costs than diesel-powered pumps. The PV systems vs. diesel had paybacks of 2, 2.5 and 15 years respectively when replacing fueled pumps (gas or diesel). [1]
  Note: At the time of this study, 1998, crude oil prices were $11/barrel vs. $137 today (Source: Energy Information Agency, U.S. Government)

- In a comparison of fueled pumps vs. PV, a German study showed PV-powered pumps to have the lowest life-cycle costs for PV array sizes of 1kWp and 2kWp and the same cost as fuel pumps for power ratings of 4kWp. (The largest PV pump SELF has installed to date for village water supply is 1.9kWp)[2]
  Note: The date of this study is unknown, but it was before 2006, when the price per barrel of crude oil was $68 compared to the $137 price of today.

- A study by GTZ (Posorski, Haars, 1995) in seven countries concluded that PV pumping systems for drinking water are economically competitive in the range of small diesel pumps (1-4 kWp solar systems).
  Note: At the time of this study, the price of crude oil was $17 per barrel, compared to $137 per barrel today.

Solar pumping array for Benin Agricultural Project - Benin

[1] Foster R., Cisneros G., New Mexico State University and Hanley C., Sandia National Laboratory, " Life Cycle Cost Analysis for Photovoltaic Water Pumping Systems in Mexico," as presented at the 2nd World conference on Photovoltaic solar Energy Conversion, 6-10 July, 1998, Vienna, Austria.
[2] Bucher W., "Renewable Energies in Rural Areas." German Aerospace Research Establishment.

Comparison of Reliability between Solar and Diesel

1. Reliability of diesels.

Unfortunately, we have not found quantitative studies dealing with the reliability of diesel engines used in developing countries. However, experiential and anecdotal information abound. The following quotes are indicative of what SELF and others have found during extensive experience in the field:

> " *Maintenance and high fuel costs have been long-standing problems with diesel generators. The systems are often in remote locations, and the difficulties of purchasing imported spare parts and fuel have often made them unreliable."*
>
> ESMAP (Energy Sector Management Assistance Programme)– World Bank/UNDP, "Best Practice Manual Promoting Decentralized Electrification Investment" Report 248/01, 2001

> " *Quite often the cost (of operating a generator) can be very much higher than expected because of the need for maintenance personnel and the difficulties encountered in obtaining fuel and spare parts."*
>
> Intermediate Technology Design Group, "Technical Brief – Diesel"

> " *Diesel generators can be used in remote areas, but this requires a constant supply of diesel and mechanical parts. The cost of the Kwh produced is therefore always considerably higher than with connection to the grid. There also tend to be many disruptions, owing to the difficulties that many people experience getting generators repaired promptly."*
>
> Renewable Energy and Energy Efficiency Partnership (REEEP). "CASE STUDY: Concession for rural electrification with solar home systems in Kwazulu-Natal (South Africa)." Dr. Xavier Lemaire, Centre for Management under Regulation, Warwick Business School.

> "*Conventional diesel generators are not a real alternative solution, as they don't meet the demand of rural population and have other negative side effects:*
>
> - *High cost of operation a susceptibility to break down*
> - *Maintenance servicing is poor and expensive*
> - *Not environmentally friendly*
>
> *Thus, seeking to reach remote villages with conventional systems is prone to fail, as the supply to these locations incurs costs and risks that are too high for users to bear."*
>
> Bremen Overseas Research and Development Association. "Decentralized Energy Supply: Energy supply for household and small scale home industries in rural and mountainous areas."

With our extensive experience working in developing countries for over 17 years, SELF has seen first hand, over and over, the inability of poor rural populations to keep diesel engines running.

In one project we visited in Nigeria, 30 water pumping systems had been distributed to villages. Most were driven by diesel pumps and a handful were solar. After 5-7 years of operation, none of the diesel pumps were still working. Although we weren't able to find out the status of all solar pumps, we were able to visit a village with a working PVP system. When asked when the last time someone had come out to maintain the system, village elders looked at each other quizzically and then replied that no one could recall anyone coming out to look at the system – ever - it had been working away virtually untouched for over 5 years. (We later confirmed this with the Government agency that installed the system – they said they never had money for maintenance of any kind)

Another village in Nigeria has a large working diesel pump for a central water supply system. But they can only run it every few weeks, as it takes that long to collect enough money from the villagers to purchase fuel.

More recently, one of SELF's health partners in Rwanda, Partners In Health, had installed brand new European-built generators at 5 sites to back-up SELF's PV systems. These new generators even came with a one-year maintenance contract provided by a local supplier. Nevertheless, within the first year of operation, at least 2 of the 5 generators experienced serious problems resulting in a loss of service and during the first year of operation most of the sites were unable to obtain diesel fuel at least once due to shortages in the country.

Besides economic and reliability concerns, diesel generators create noise and air pollution and contribute to climate change.

2. PVP: reliability and maintenance requirements.

Water pumping has long been the most reliable and economic application of solar-electric (photovoltaic, or PV) systems. Most PV systems rely on battery storage for powering lights and other appliances at night or when the sun isn't shining. Most PV pumping systems do not use batteries – the PV modules power the pump directly. Instead of storing energy in batteries, water is pumped into storage reservoirs for use when the sun isn't shining. Eliminating batteries from the system eliminates about 1/3 of the system cost and most of the maintenance.

Without batteries, the PVP system is very simple. It consists of just 3 components: the solar array, a pump controller and the pump. The only moving part is the pump. The solar modules are warranted to produce for 20-25 years. The expected life of most controllers is 5-10 years. Pump life can vary from 5 - 10+ years (and many are designed to be repaired in the field). **Unless the pump or controller fails, the only maintenance normally required is cleaning the solar modules every 2- 4 weeks!** This task obviously can be done cheaply by non-skilled local labor.

3. Maintenance requirements for diesel generators.

In contrast to the minimal needs for PVPs, the operation and maintenance needs for diesel engines are both extensive and expensive.

Diesel engines require minor service, major service, and major overhauls at regular time intervals. The following is an excerpt from the Namibian study quoted above:

> " A minor service includes oil change (topping up of oil included) 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 or at a close-by service center.
>
> An overhaul includes the tasks of a minor and major service, replacement of parts (e.g. crankshaft) and drilling of cylinders and requires skilled personnel.
>
> The following schedule has been selected for the replacement intervals of high quality (Lister) and low quality engines (e.g. of Indian manufacture):"
> (Note: units are in hours of operation)

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

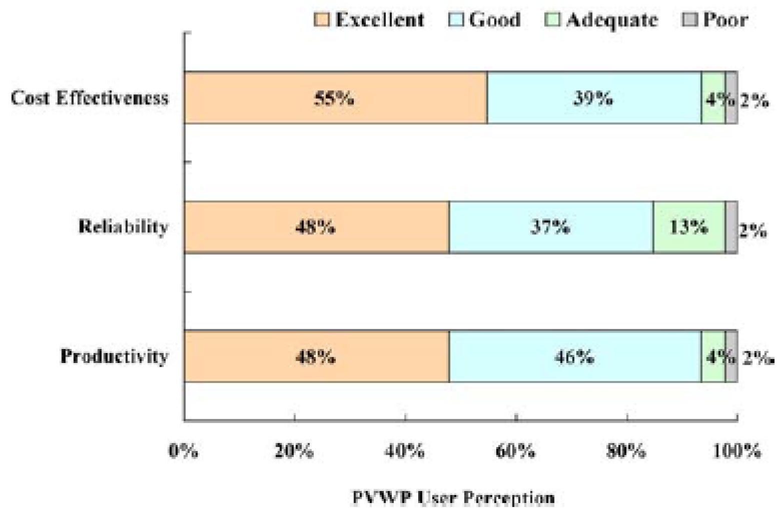
The following chart is based from the same Namibian study where the typical costs (in Namibia) for the various service operations were calculated. In our chart we have converted the costs to U.S. dollars. (1$ = 7.55 $N)

Typical diesel maintenance costs - Namibia

Maintenance	**Low quality engine**	**Good quality engine**
Minor service	**$67**	**$67**
Major service	**$397**	**$530**
Overhaul	**60% of new**	**30% of new**

4. PV reliability assessments from the field.

We can talk all day long in our offices about reliability in the field, but the satisfaction of the user and the service they receive are what really matters. The following study goes back and looks at the performance of PVPs in Mexico 10 years after 206 systems were installed. The study is from a paper presented at the American Solar Energy Society Conference in Portland, Oregon in July, 2004. It is entitled "*Ten-year Reliability Assessment of Photovoltaic Water Pumping systems in Mexico",* by Robert Foster, New Mexico State University; M. Ross, C. Hanley and V. Gupta, Sandia National Laboratories and several other authors from Mexico. The following chart illustrates a high degree of user satisfaction with pumps.



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The study summary states that after 10 years 60% of the systems were still operating appropriately. The most common cause of failure was pump failure, which could also have happened if the system was powered by diesel generators. There were no failed solar modules. The report offers no information on how the systems were sustained, but suggests that the pumps were all used by private farmers and ranchers and that they were each responsible for maintaining their own systems.

We have experienced the reliability of solar pumping systems in the field and have seen that they have a high "survivability factor", even with little or no care at all. However, SELF is a firm believer that there must be sustainability measures developed for each project to ensure maximum life and service. SELF takes great care with each project to make sure there are financial, technical, re-supply and organizational systems in place for sustaining the pumping systems.

Sun + water + seeds + hard work = better nutrition, income for women and hope for a bright future. SELF solar irrigation project - Benin

Summary

Solar pumping systems are inherently more reliable than diesel powered systems. They are simpler, have fewer moving parts and require mostly unskilled labor to keep them running. In the worst case, with no care at all, they will likely run for months or years unattended. They do not require a trained operator on site, as do diesel systems.

Solar pumps require a substantial up-front investment when compared to diesel pumps. In effect, when purchasing a PV system you are buying many years of electricity up-front. At the time of purchase, you know to a large extent what your energy and pumping costs are going to be for the next 20 plus years (the life of the PV power generators).

In contrast, the cost of diesel is already prohibitive to the world's poorest people. No one knows what the price will be next year or 5 years from now but all indications suggest that oil-derived fuels will only continue to increase in cost as global oil production slips over the top of the curve and heads downward in the face of rapidly increasing demand. Biofuels may provide an answer and perhaps the best answer for internal combustion engines if they can be grown and produced locally, but those solutions are not yet ready in most parts of the developing world and presently, many countries struggle to cultivate enough land just to feed themselves.

In terms of energy security, it is highly possible that there will be continuing periods of fuel shortages as richer countries compete for dwindling supplies – leaving the most disadvantaged without the ability to obtain fuel at any price.

Finally, the poorest of the poor should not have to suffer for the environmental sins of developed countries and be limited in their options by only using the cleanest energy sources for development. But by the same token, the poor may suffer more than most in the face of climate change and increasingly scarce resources. It's in everyone's interest that development and care for the climate and environment happen at the same time – especially when long-term cost and reliability favor the cleaner option.