WASH Guidance Note - Solar Pumps

Figure 1: Image courtesy of Concern Pakistan team

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Contents

Glossary

Alternating Current (AC)	An electric current that reverses its direction many times a second at regular intervals. It is widely used in power supplies as you can step the voltage up and down easily without losing too much energy (unlike with Direct Current). It is therefore the most common way of powering electrical devices.
Direct Current (DC)	An electric current flowing in one direction only. It is produced by solar panels (amongst other things) and can be used to charge batteries, but generally needs to be converted to alternating current (using an inverter) in order to power devices like pumps.
Hybrid System	A system that uses an alternative power-source as a back-up, generally a diesel generator, for when it is not possible to obtain solar power, e.g. cloudy days, maintenance.
Inverter	A device that converts direct current into alternating current.
Joule (J)	A unit of energy which is defined as the energy transferred to (or work done on) an object when a force of one Newton acts on that object in the direction of its motion through a distance of one metre.
Kilowatt Hour (kWh)	A unit of energy which is defined as 1000 Watt-hours (or 3.6 million Joules)
Photovoltaic (PV) Cell	The basic components of a PV panel. PV cells are electrical devices that convert the energy of light directly into electricity by the photovoltaic effect. Many PV cells make up a PV panel/module.
Photovoltaic (PV) Panels/Modules	Solar panels that turn the power of the sun into electricity using the photovoltaic effect. These are made up of multiple connected PV cells.
Solar Irradiance	The power per unit area received from the Sun in the form of electromagnetic radiation (usually defined as watt per square metre, W/m^2 or kilowatt-hour per square metre kWh/m^2). There are several measurements of solar irradiance, but 'Horizontal Solar Irradiance' is generally how it is described for a particular location.
Watt (W)	A unit of power defined as 1 joule per second.

Introduction

Solar power is fast becoming a cheap energy source across the world, especially in Sub-Saharan Africa and the Middle East. This is due to the high levels of solar irradiance (the power per unit area of the sun) in these countries and its consistency throughout the year (see Figure 2).

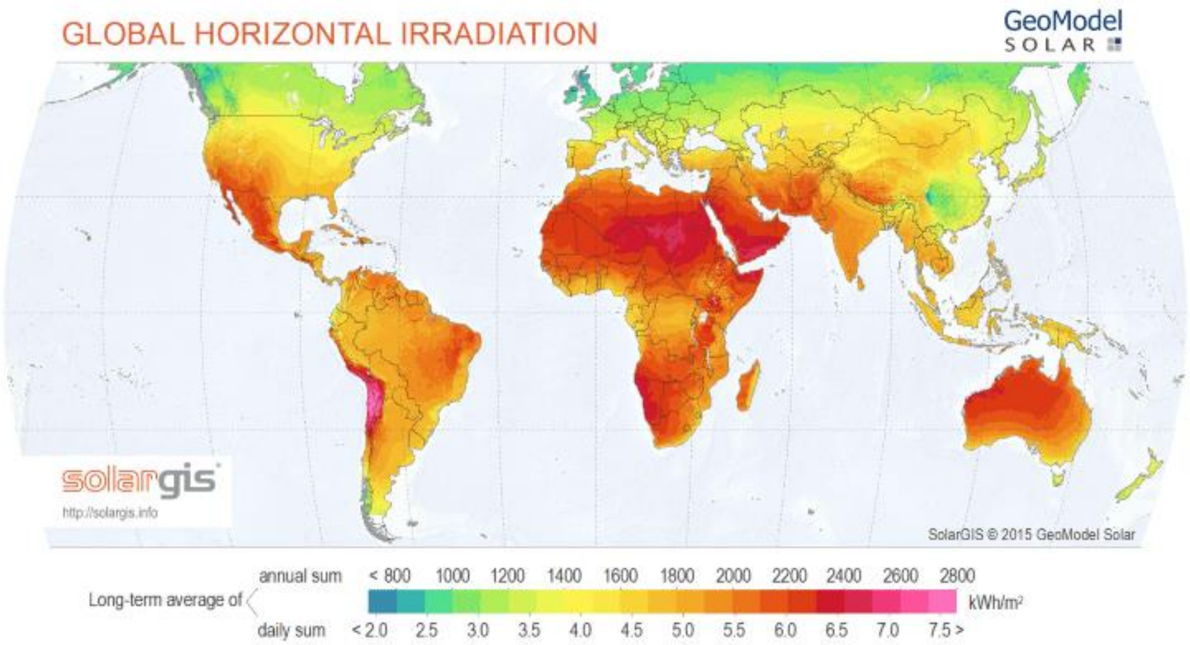

Figure 2: Global Horizontal Irradiation, in kWh/m ^{2} across the world from low (blue) to high (pink)[1]

In parts of the world where there is a limited conventional supply of power, decentralised systems are often the only option, which in the past, have mainly taken the form of diesel generators.

Some benefits of solar systems over conventional diesel generators are that:

- There are minimal operational costs associated with solar (especially important given that a number of countries Concern works in regularly experience fuel shortages or sudden price hikes).
- It is a renewable source of energy and so there is no pollution or carbon emissions from running the system.
- The lifecycle costs of solar energy are actually below that of diesel generators in many countries and are forecast to continue dropping[2]
- Solar pumping systems are more durable and reliable than diesel systems, due to them having less moving parts. For instance, solar panels, also known as Photovoltaic (PV) panels, generally have a design life of 25 years.

[1] World Bank, 2016. *Global Solar Atlas.* [Online]
[2] World Bank, 2018. *Solar Pumping: The Basics,* Washington: World Bank.

Solar has many benefits, but like all relatively new technologies, it has its challenges, such as:

- Underdeveloped supply chains that can make sourcing spare parts difficult
- Expensive spare parts
- Lack of capacity in-country for installation and operation and maintenance (O&M)
- Reliability of power supply, which can vary drastically when it is cloudy compared to when it is clear and sunny
- Vandalism and theft (although this is less of a problem than it used to be due to the cost of solar panels having decreased in recent years)
- Aquifer depletion due to increased ability to pump and poor design

These challenges can be managed through careful project design.

This guidance note will go through the process of designing a solar powered water system from undertaking a life cycle cost assessment, through the technical design and into the operational and maintenance stage. It also includes a basic checklist that can be used by the country programme team to assess the design of a solar system. This guidance note should be read in conjunction with Section 2.1 of Concern's Engineering Standards[3], which explains the process of developing a borehole and Concern's Health and Safety Procedures for Country Programmes[4].

[3] Concern Worldwide, 2016. *WASH Minimum Engineering Requirements & Standards, London*: Concern Worldwide.https://concern2com.sharepoint.com/sites/KExchange/Publications/Concern%20Water,%20Sanitation%20and%20Hygiene%20Engineering%20Standards.pdf

[4] Concern Worldwide, 2019. *Health and Safety Procedures,* London: Concern Worldwide. https://concern2com.sharepoint.com/sites/KExchange/Publications/Health%20and%20Safety%20Procedures%20First%20Issue.pdf

Checklist for Solar Powered Systems

The following can be used as a quick checklist for the programme team to ensure that the main aspects of designing a solar system have been considered. Appendix A, courtesy of the Global Solar Working Group, gives a more detailed checklist for what to look out for during the installation and maintenance of a solar system, which can be undertaken by a non-specialist, alongside the installer.

The checklist for the design phase is as follows:

- Has the siting assessment taken into account shading from any tall buildings/mountains to ensure that a sufficient amount of sunlight will hit the solar panels during the day?
- Has the water demand of the community been established and extrapolated to take into account the full lifecycle of the project? (i.e. has the solar system been sized for expected population growth over the design life of the project?)
- Has a hydrogeological survey and pump test/yield test of the source been undertaken following Concern's engineering standards?
- Has a Life cycle Cost Analysis been undertaken to ensure that solar is the most cost-effective solution in this context and that the community can afford the basic Operation and Maintenance (O&M) of the scheme?
- Is there a reputable distributor (i.e. Grundfos, Lorentz or similar) in the country that we are working in?
- Has a design been undertaken using industry-standard software (i.e. the Grundfos or Lorentz calculators) in order to specify the components of the system?
- In the design/specifications, is it clearly stated that the solar panels should be facing south (in the northern hemisphere) or north (in the southern hemisphere)?
- In the design/specifications, is the angle of inclination of the solar panels clearly defined?
- Does the design secure the area from theft/vandalism (i.e. with a secure fence)?
- Will the cables and pipes be well protected? (i.e. Are all pipes/cables buried at least 50cm underground? If cables are crossing any roads are they encased in PVC ducts 1m below ground level? If pipes are crossing roads are they made of GI?)
- Is there a diesel back-up/alternative source for when the solar panels will not function to their full capacity? (i.e. during cloudy days)
- Is there a clear O&M plan? (i.e. will the community be trained in how to operate and maintain the system themselves? Or will a service contract with the installer be used for maintenance?)
- Are there spare parts available in country? And is it clearly stated how to access these spare parts in the O&M documentation?
- Is it clearly stated in the O&M documents that solar panels should be cleaned regularly? (the regularity of this will depend on how arid the region is)
- Is the proposed area for the solar panels clear of trees or else is it clearly stated in the O&M documents that all trees in the area should be cut back to ensure that there is no shading over the solar panels?
- Do the proposed distributors offer a guarantee/warranty for the after-sales service?

Life-cycle Cost Analysis (LCCA)

Before a solar system is chosen as the solution for a community's water needs, a basic life-cycle cost analysis should be undertaken to assess the approximate costs over the lifetime of a solar project (including operation and maintenance) to see if solar technology is the most cost-effective solution for a community. Special attention should be taken of the ability to pay for operation and maintenance by the operator (local water authority or community), as well as the likely repair costs of certain elements breaking over the lifetime of the project.

A systems strengthening approach should be undertaken here if there are any parts of the supply chain that are weak (i.e. lack of access to spare parts or lack of capacity for O&M repairs). It is preferable to work with the local authorities for projects of this scale, but remote communities can sometimes prove that they are able to support the O&M of a scheme if they have the finances, the technical skills and are cohesive as a community.

Lorentz have a simple Lifecycle Cost Analysis tool which compares the cost of a Lorentz solar system with a diesel generator[5]. This takes into account the capital and operational costs of both systems. Costs need to be adjusted depending on the specific context in-country, but once this has been done, this tool can be used as a basis for an LCCA.

LCCAs are iterative and so they should be updated once new information is available. Once the initial LCCA has been undertaken and the scheme has been given the go-ahead, the technical design can begin. Once that has been completed, more detailed costs will be available and so a more detailed LCCA will then be needed to assess exactly how much money will be required for O&M over the lifetime of the project and to set a more realistic expectation of the fees that will need to be collected.

The operators of the scheme (local authority/community) should be involved in the LCCA process as much as possible in order for them to feel an ownership of the scheme and provide accurate data about their capacity for paying regular fees and in undertaking/managing the O&M.

The data required for an economic appraisal of a solar system includes[6]:

- Period of analysis (taken as the longest lifespan of any of the components – i.e. normally 25 years for solar systems)
- Country-specific discount rate (this is the nominal interest rate minus the inflation rate) – see appendix B
- The capital cost of each component, including transport and installation costs
- The annual operation and maintenance costs, including labour costs
- The lifespan of each component

[5] Lorentz, N.D. . *Solar v Diesel Calculator.* [Online]. Available at: https://partnernet.lorentz.de/svd

[6] IOM, 2018. *Global Solar and Water Initiative,* s.l.: International Organisation for Migration.

These costs can then be compared to the costs of a diesel generator or other possible solutions within the context that you are working.

The design life of various parts of a solar system should be checked with the manufacturer that you plan to use, however some approximate timescales are shown below for indicative designs[7]:

- Solar panels: 25 years
- Pump/motor: 10 years
- Inverter/control box: 6-8 years
- Support structure: 25 years
- Accessories: 10 years
- Diesel generator: 35,000 hours of running time

Although the operational costs of a solar scheme are generally much cheaper than for a diesel generator, if new parts are needed, these can be expensive (approximately USD2,000 for a new pump and USD300 for a solar panel not counting taxes or transportation costs[8]). It is therefore imperative that a proper financial model is in place to fund the O&M of a solar powered system.

If a hybrid system is planned, then the costs of solar and diesel will have to be assessed together.

Attached in Appendix B are two LCCA tools which have been used in South Sudan for solar-only systems and hybrid solar systems, courtesy of the Global Solar Working Group. Again, costs will need to be changed depending on the specific contexts in-country. A technical briefing on how to undertake economic assessments is also included in Appendix B.

[7] IOM, 2018. *Global Solar and Water Initiative,* s.l.: International Organisation for Migration.
[8] Lorentz, N.D. . *Solar v Diesel Calculator.* [Online]. Available at: https://partnernet.lorentz.de/svd

Technical Design

Once the initial LCCA has been undertaken, the technical design can begin. Once the borehole location has been sited, the main technical design work is focussed on sizing the pump and solar array. Submersible pumps should be used if possible.

It should be noted that pumps can either be DC or AC powered. DC pumps are usually more efficient for shallow boreholes, however AC pumps can often be more economical for deep boreholes. In these cases, an inverter will be required to change the DC power generated by the solar panels to AC power to run the pump.

The power of a pump is dictated by:

- The water demand (and therefore required flow rate of the pump). This should include the peak hour demand and a percentage for wastage.
- The safe yield of the aquifer
- The total head (initial groundwater level + drawdown + height above ground level)
- The length of the riser pipe and distance to the storage tank or in the case of direct pumping frictional losses in pipes and other accessories

The parameters of a pump are expressed in terms of a pump performance graph like the one in Figure 3. In this example, the flow is 4.3m³/hr and the total head is 43.5m.

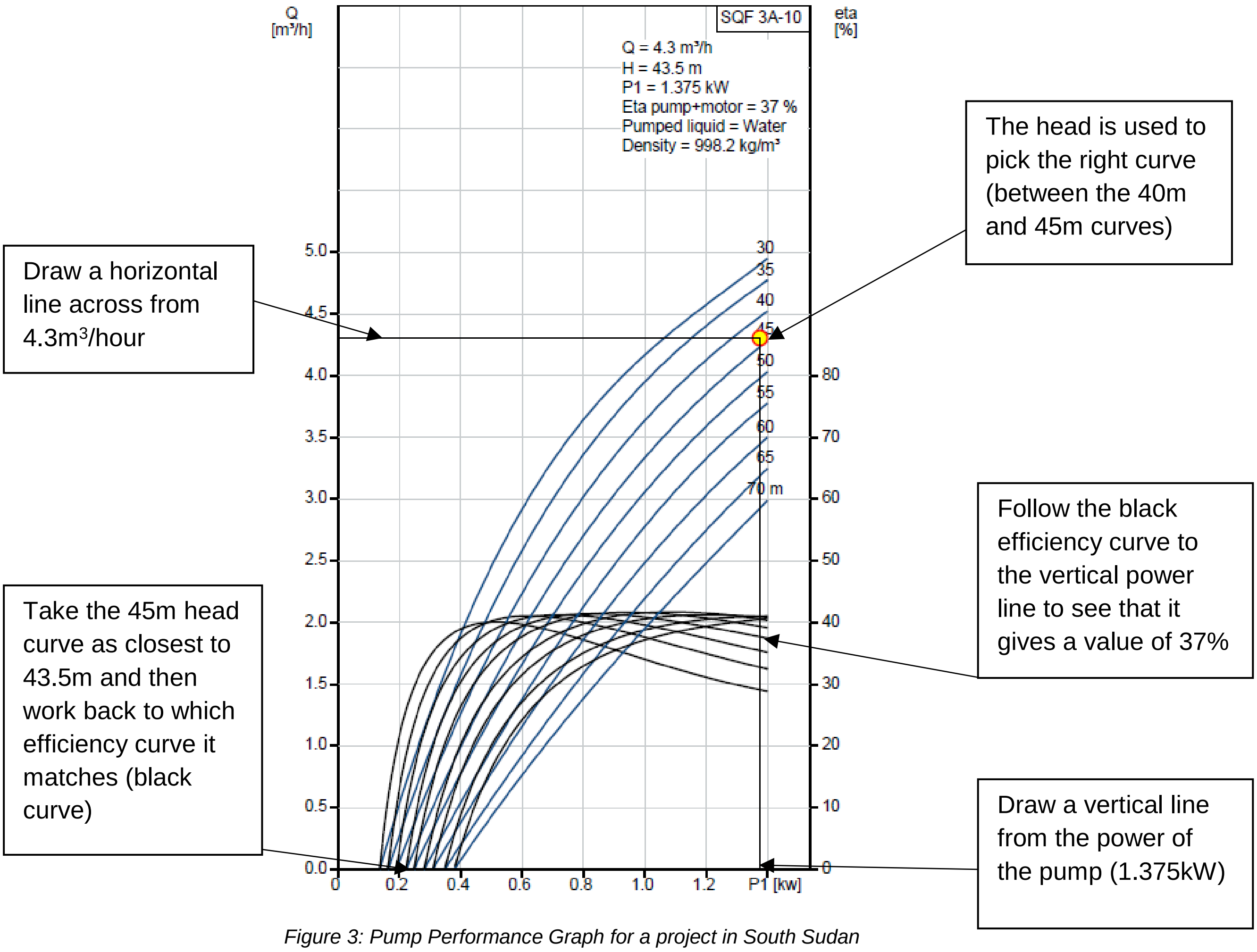

Figure 3: Pump Performance Graph for a project in South Sudan

The efficiency of the pump under the above conditions is 37%, meaning that it will require approximately 3 times as much energy to power the pump as that stated in the installed capacity of the pump. The efficiency of a submersible pump is generally in the region of 30-50%.

It is a common mistake to think that the power of the pump will be equal to the power of the solar array, however due to the pump efficiency and other losses associated with the system, this is not correct and will result in a significantly undersized system.

Amongst other parameters, the size of the pump and the efficiency of the pump dictates the number of solar panels that will be needed to power it for the expected flow rate. Solar panels convert the power of the sun (solar irradiance) into electricity. This is usually expressed in terms of Watts per square metre (W/m^2) or kilowatt-hours per metre squared (kWh/m^2). The irradiance changes according to the time of day (with zero irradiance at night and the maximum irradiance when the sun is at its highest point). It also changes according to the seasons. This makes manual calculations very difficult to undertake.

The installed capacity of a solar panel is related to how much energy it will generate at 'peak capacity'. This means that a 200W solar panel will only generate 200 Watts of energy if the conditions are perfect, i.e. the irradiance of the sun is at its maximum, the angle of direction towards the sun is optimal, there are no clouds in the sky or dust on the panels etc.

As the peak conditions cannot be met at all times (especially with panels that do not move to track the sun) there will be losses in how much power will be generated by the panels and so how much water can be pumped. This can clearly be seen by the below figure which shows the amount of water being pumped is lower at the beginning and the end of the day, compared to during the middle of the day (which is closer to optimal conditions).

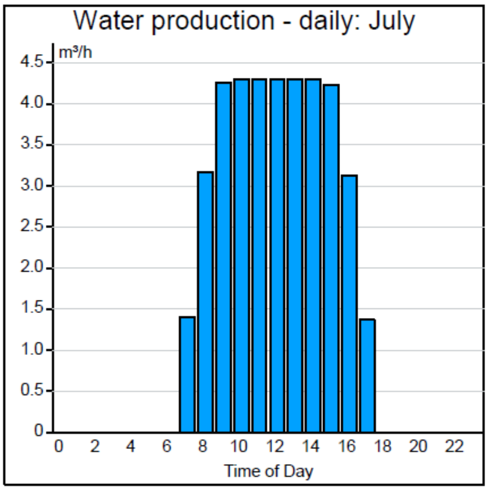

Figure 4: An example profile of how much water is pumped per hour over the course of one day, based on a project in South Sudan

The amount of water produced each month will also differ as the intensity of the sun changes throughout the year as the Earth tilts on its axis (effectively moving closer to or further away from the sun). Near the equator this does not change much, but at the extremes of the northern and southern hemisphere, this changes drastically.

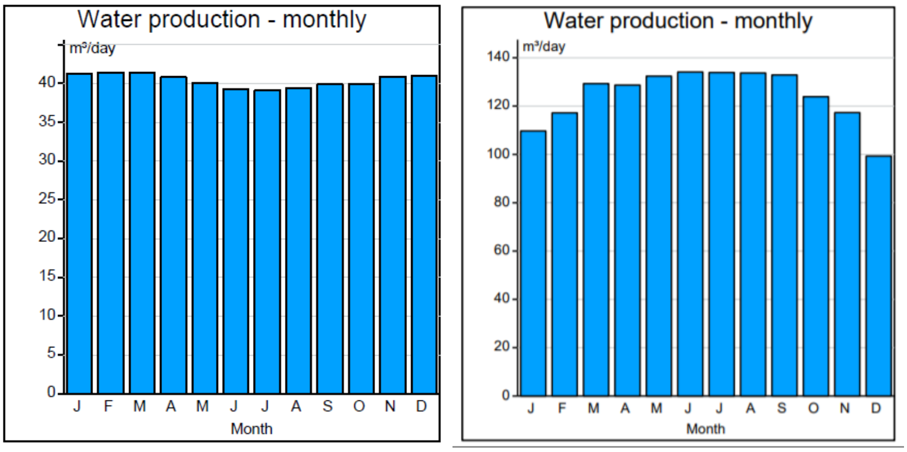

Figure 5: The profile of monthly water production at a location in South Sudan (left), which is close to the equator and Lebanon (right) which is further from the equator

It should be noted that the peak capacity figure includes the efficiency of the solar panel to convert the sun's energy to usable electricity, so this does not need to be taken into account in any calculations. Solar panels are generally only 10-20% efficient, as they only convert certain frequencies of light into electricity and some of the right frequencies of light are reflected, rather than absorbed (see Figure 6). For instance, a 200W solar panel with 20% efficiency will generate 200W of power when the power from the sun hitting the panel is 1000W. Also a 200W solar panel which only has an efficiency of 15% will be 1.25 times larger than a 200W solar panel which has an efficiency of 20%.

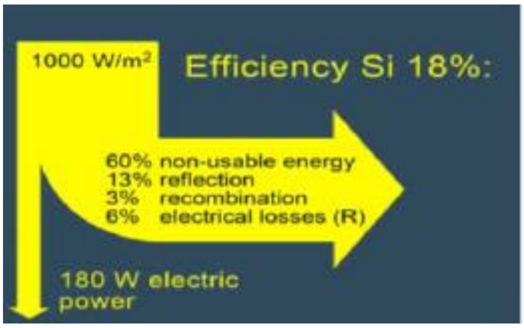

Figure 6: The efficiency of a 180W solar panel with an 18% efficiency rating[9]

If space is a constraint, then more efficient Solar PV panels should be chosen over less efficient PV panels. However, it should be noted that more efficient Solar PV Panels are generally more expensive, so if space is not a constraint, but budgets are, then less efficient but cheaper PV panels should be chosen.

[9] IOM, 2018. *Global Solar and Water Initiative,* s.l.: International Organisation for Migration.

Hybrid Systems

As a solar system can only generate electricity when the sun is shining, another system will be needed in order to ensure a constant supply of water all year round, even during cloudy days.

There are several alternatives:

- Size the system to cater for 2-3 days' worth of water. This is often impractical, as the pump and storage tank would need to be very large in order to store enough water to supply a community for 3 days.
- Size the solar array to provide some redundancy and install a battery to store the extra power generated from the solar panels. Battery technology on this scale is still quite underdeveloped, so the cost of this option is generally prohibitive in the context in which we work.
- Install a back-up diesel generator that can be used to pump water on cloudy days. This is generally the most practical and cost-effective option.

Solar Calculators

As previously stated, manual sizing of solar arrays is complicated and often inaccurate due to changes in solar irradiance throughout the day and year. It is therefore strongly recommended that software-based applications to size solar pumping schemes are used.

Grundfos and Lorentz both provide calculators that can be used to size solar systems. Other dealers should also have their own software to size their particular systems.

The Lorentz calculator is slightly more detailed, but the Grundfos calculator works just as well for most applications. Step-by-step guides for using both calculators are shown in Appendix C.

If you choose to go with another reputable distributor other than Grundfos or Lorentz, then the specific distributor's calculator should be used. If this does not exist, then the Grundfos or Lorentz calculators can be used to size the pumps and solar arrays and then pumps and solar panels with the same specifications can be sourced from the alternative provider. It should be stressed that is essential that the same specifications are used, or else the system will not function as intended (or in the worst case scenario, not at all). The essential specifications are:

- The total head (m)
- The flow rate per hour (m^3/hr)
- The power of the pump (kW)
- The required efficiency (%)

Quality of products:

It is imperative that good quality parts are procured, as the market is flooded with cheap, faulty products that fail to function as stated or break very quickly and are not covered under warranty.

As a result, solar modules must be approved to IEC/EN 61215 and 61730 or UL 1703 certified and listed. Control equipment must meet EN 61800-1, EN 61800-3, EN 60204-1 or internationally recognized equivalent standards[10].

[10] IOM, 2018. *Global Solar and Water Initiative,* s.l.: International Organisation for Migration.

Installation

It is important that a pump system is installed correctly. It is imperative that the solar panels face due south (if you are in the northern hemisphere) or due north (if you are in the southern hemisphere). It is also essential that they are installed at the correct angle (which is approximately the same as the latitude of the location that you are in, but never less than 15^{o} for self-cleaning to occur).

A solar system is made-up of the following essential parts:

• Water Pump  *Figure 7: Image courtesy of Lorentz*	• Borehole housing, pipes and cables  *Figure 8: Image courtesy of John Heelham*
• A liquid level sensor, to monitor the water levels in the borehole so that it will be known whether the flow of water from the borehole is sustainable or whether you are over-exploiting the aquifer (which will eventually lead to the borehole drying up)  *Figure 9: Image courtesy of Lorentz*	• A well probe to ensure that the pump stops if the water in the well runs dry, thereby avoiding irreparable damage to the pump  *Figure 10: Image courtesy of Lorentz*
• Generator House to keep the technology safe from damage/theft  *Figure 11: Image courtesy of Martin Findlay*	• Inverter and control panel to operate the solar system and change the power generated from DC to AC, if the pump runs on AC power  *Figure 12: Image courtesy of Martin Findlay*

• A water meter to monitor how much water is being pumped out of the well  *Figure 13: Image courtesy of Lorentz*	• Solar Panels to harness the sun's energy to produce electricity  *Figure 14: Image courtesy of Concern Pakistan team*
• A sun switch to switch the pump off if solar irradiation levels are too low and stop the premature wearing down of the pump  *Figure 15: Image courtesy of Lorentz*	• A storage tank  *Figure 16: Image courtesy of Martin Findlay*
• Tap stands or distribution system  *Figure 17: Image courtesy of John Heelham*	• A secure fence to limit the chance of theft  *Figure 18: Image courtesy of [Pixabay]*

There are also the following optional parts that might be required for a particular system

• Diesel back-up generator (when supply needs to be guaranteed even on cloudy days)  *Figure 19: Image courtesy of Martin Findlay*	• The manufacturer might also recommend some other accessories depending on the context of the system

Operation and Maintenance

Operation and maintenance is essential to the correct functioning of a solar system and its ability to function well throughout its design life.

The community should be as involved in the O&M as much as possible in order for them to be able to quickly respond to issues and feel an ownership of the scheme. Depending on their technical capacity, this can either be in the management of a maintenance contractor or in certain aspects of the physical O&M itself.

One of the most important aspects of O&M is the cleaning of the solar panels. Dirt/sand on the panels can reduce the system's efficiency by up to 50%[11]. It is therefore very important to clean the panels regularly (especially in arid environments which generate a lot of dust). This should be done with a cloth only. Soap should not be used as it can damage the panels.

Figure 20: A solar array in Somaliland that has only been partially cleaned and so will not be operating at full capacity

Another important aspect is ensuring that the panels are not in the shade. As such, panels should be sited in a clear area and any surrounding trees/foliage should be cut back if it starts to create a shadow over any part of the panels.

Other operational requirements involve ensuring that there are no open wires and that the inverter is regularly cleaned of dust.

A useful example pictorial checklist is shown in Appendix D. It is recommended that this is used as an example, translated into the local language, printed out, laminated and stuck to the wall of the generator house where it can be seen in order to act as a reminder of what regular O&M needs to be done. There is also a more detailed O&M checklist as part of Appendix A.

It is imperative that the installer of the scheme provides in-depth training to the operator (i.e. local authority or community) about how to best operate the system.

Although solar systems are generally quite robust, when something breaks it can be complicated to fix, so it is generally best to contract a maintenance contractor (or purchase an after-sale service scheme) in order to ensure that the system will function throughout its design life. This doesn't mean that the local authority/community shouldn't be involved in maintenance. The operation and preventative maintenance outlined above should be done by the operator and also whatever else they have the capacity to do (i.e. some cabling/pipe works if they have the experience). However changing an inverter/the pump or installing more solar panels should be done by a professional.

[11] Sulaiman, S. A., Hussain, H. H., H., N. L. N. S. & Razali, M. S. I., 2011. Effects of Dust on the Performance of PV Panels. *World Academy of Science, Engineering and Technology,* pp. 2021-2026.

It should be noted that most failures occur during or shortly after the pump system's installation and tend to originate from faulty controller or PV wiring. If this occurs, it will be covered under warranty and so the installer should come back and fix it free of charge. If a scheme lasts 1-2 years without any serious issues, it is more likely to fulfil its whole design life; therefore, schemes should be closely monitored in the first 2 years[12].

There have been cases in the past of thieves masquerading as technicians to steal solar panels. If a maintenance contract is in place, the community should be well aware of the dates of maintenance, should have a number to ring if they are suspicious of any technicians that come to visit and should ensure that functional solar panels are never removed from the site to be 'fixed'.

As stressed in earlier sections, a comprehensive financial system needs to be in place to collect enough fees to pay for maintenance, as this can be expensive and often comes in spikes rather than at regular intervals (for instance a new pump costs approximately USD2,000 and a new solar panel costs roughly USD300, not counting taxes or transportation costs).

Lessons learnt from previous Concern solar projects

The following are a list of useful lessons learnt from previous solar projects undertaking by Concern

- Inclusion of the community in the planning of the project provides a sense of ownership. In Tanzania, this resulted in the majority of repairs being done by the community itself.
- For high cost investments like solar and diesel pump projects, a durable fence, security guard house and a small office are needed to ease management of the system.
- In Mozambique, the money that was being collected by the community was being spent on the guard's wages, so they were not able to afford repairs if any breakdown occurred. This shows that a comprehensive LCCA had either not been completed or had not been followed.
- In one project in Uganda, the pump had not been sized correctly, so the community preferred using a diesel generator because it had a higher pumping rate.
- The capital costs of solar parts are more expensive than diesel, so a full LCCA should be undertaken to ensure that the funds are available for capital costs and that the community can ensure the sustainability of the system throughout its design life.
- In one context, solar panels were in the shade and so were functioning below their full capacity.
- In previous designs, people have specified the solar array to have the same installed capacity (power) as the pump. This greatly reduces the amount of water that can be pumped and meant that the water demand of the community was not met.
- Land ownership and allocation needs to be clearly defined.
- In Pakistan, they found that warranties/after sale services etc. must be clearly mentioned in the supplier's agreement and an MOU between the supplier and the operator signed.
- In certain regions of Pakistan, hail was reported to damage the panels. Wire mesh can be put in place to protect against hail to some extent, but it is recommended that solar panels are not installed in areas with a high risk of heavy hailstorms.
- A lot of training on how to operate the scheme needs to be given to the operators. This is especially important around turning the pump off when water does not need to be pumped.
- In situations where mains power is available, an inverter is necessary to switch between D.C Power (from the solar panels) and AC Power (from the national grid power).
- In previous designs, solar panels have been designed on the roof of a 9m high storage tank, which makes O&M (especially regular cleaning of the panels) very difficult and dangerous.

[12] IOM, 2018. *Global Solar and Water Initiative,* s.l.: International Organisation for Migration.

Appendices

All appendices can be found on Knowledge Exchange at the following link:

https://concern2com.sharepoint.com/sites/KExchange/Publications/WASH%20Guidance%20Note%202019%20-%20Solar%20Pumps%20-%20Appendices.zip

The file is about 4mb and will automatically download when you click on the link.

Concern worldwide

ENDING EXTREME POVERTY WHATEVER IT TAKES

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