2015

# SOLAR-POWERED PUMPING IN LEBANON

## A Comprehensive Guide on Solar Water Pumping Solutions


Empowered lives.
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Federal Department of Foreign Affairs FDFA
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## BACKGROUND

Following the Syrian Crisis, the majority of refugees are being hosted in communities that are among the poorest in the country, including the North of Lebanon and the Bekaa. These communities suffer from poor water services due to lack of adequate infrastructure and have limited means to expand local sources of livelihood including agriculture.

As such UNDP is supporting host-communities in different areas including the development and construction of water networks and the improvement of livelihoods, particularly in the agricultural sector. For example, within the umbrella of the Lebanese Center for Water Management and Conservation (LCWMC) at the Ministry of Energy and Water, a project funded by the Swiss Agency for Development and Cooperation is targeting to improve the water supply services in North Lebanon specifically in Wadi Khaled and Akroum Area. This new project is managed and implemented by the United Nations Development Programme (UNDP), the Energy and Environment Programme. Furthermore, through the CEDRO project, support is being provided through funding from the Government of Germany and UNHCR, to install renewable energy systems to light households and streets in vulnerable host-communities.

Given the opportunities available to use renewable energy for water pumping for both water distribution networks and for the extraction of water for irrigation, an assessment of the viability of solar pumps needs to be assessed.

The assessment presented in this report includes the following tasks:

- Review the types of PV systems that could be used to run the pump taking into consideration the efficiency and cost. Suppliers and Dealers of such systems should be identified and consulted.
- Distinguish the appropriate type, model, and number of solar panels needed for different uses, with particular focus on pumping capacity for potable water distribution networks and agriculture, to always ensure the highest performance and efficiency.

- Identify all required electronic device (the controller unit) which matches the PV power needed to regulate the operation, starting and stopping the pump.
- Describe and highlight on the efficiency of such PV system especially in bad weather and in low light conditions such as cloud cover and storm.
- Outline the general maintenance needed for such system, including financial and technical resource requirements

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**Disclaimer**

# LIST OF ACRONYMS & ABBREVIATIONS

| | |
|---|---|
| $ | US Dollar |
| A | Ampere |
| AC | Alternating Current |
| API | American Petroleum Institute |
| BOQ | Bill of Quantities |
| Capex | Capital Expense |
| CEDRO | Community Energy Efficiency & Renewable Energy Demonstration Project for Lebanon |
| DC | Direct Current |
| DOE | Department of Energy |
| G | gravity |
| gal | Gallon |
| gpm | gallons per minute |
| ha | Hectare |
| hp | horsepower |
| hr | Hour |
| J | Joules |
| kg | Kilogram |
| km | Kilometer |
| kW | KiloWatt |
| kWh | KiloWatt-hour |
| LCB | Linear Current Booster |
| LCEC | Lebanese Center for Energy Conservation |
| MDG | Millennium Development Goals |
| min | Minute |
| MPPT | Maximum Power Point Tracking |
| NEEREA | National Energy Efficiency and Renewable Energy Action |
| Opex | Operating Expense |
| pc | Piece |
| PDP | Positive Displacement Pump |
| PSH | Peak Sun Hour |
| PV | Photovoltaics |
| PVGIS | Photovoltaic Geographical Information System |
| TDH | Total Dynamic Head |
| UN | United Nations |
| UNDP | United Nations Development Programme |
| UNHCR | United Nations High Commissioner for Refugees |
| US | United States |
| V | Volt |
| W | Watt |
| ρ | Density |

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# INTRODUCTION

Water is a basic necessity of life. Be it for drinking, irrigation, livestock, or domestic use, there is nothing of such a crucial importance to human health and well-being. This puts water as one of the major issues in the UN's Millennium Development Goals (MDG). Seven out of the eight MDGs rely on the water and sanitation target to be achieved, namely eradicating extreme poverty and hunger; achieving universal primary education; promoting gender equality and empowering women; reducing child mortality; improving maternal health; combating HIV, AIDS, malaria and other diseases; and ensuring environmental sustainability.

Potable water is usually moved from sources at lower levels such as rivers, ponds, wells, and other ground sources to higher levels for irrigation, domestic use, and other needs. Whether being moved vertically from deep to surface levels, or horizontally from one location to another, water requires energy as a major component linked to water availability and consumption.

Pulling up a rope with a bucket at its end, manually pushing a hand-pump to bring up water to surface levels, putting domestic animals to move in a loop to do the job, and connecting an electrically-driven water pump to move water around are all means of energy applications used to supply water to communities and individuals. The rope and bucket is history now; the hand-pump is way impractical; cattle of these days are too lazy for water pumping; leaving us with electrically-driven pumping systems as the most reliable and practical solution. While most pumping systems rely on the electric utility's power for its affordability and reliability to a certain extent, it remains more feasible for some applications located in remote and non-electrified regions to have their own independent power supply. This is achieved through the use of independent diesel generators or other renewable energy technologies such as wind and solar power.

## *Why Solar pumping?*

Of all the benefits solar energy has brought and keeps bringing to humans, none makes as much difference to humanity and people's daily lives as pumping water does. Through providing water for potable use, irrigation, and livestock, solar water pumping brings obvious benefits to rural areas and remote communities.

Available abundantly and free, offering a financially feasible and technically practical solution, solar water pumping is becoming very common in agricultural applications to be regarded as an emerging solution providing water to disadvantaged and unfortunate communities.

Using sophisticated yet well-established technologies, solar energy empowers a water pump that moves water from wells, ponds, and other water sources to ground levels and to end use locations. Thus, as long as the sun is shining, water is being pumped and moved around either to a water storage location or directly to consumers. This avoids the hassle of batteries for power storage that makes solar PV applications disfavored in many cases.

Solar pumping is considered a more economically feasible solution due to the lower operating expenses (Opex) related to fuel supply and maintenance costs and reduced carbon footprint as compared to diesel generators. Tens of thousands of solar water pumps are in operation all over the world, meeting consumption needs especially in regions beyond power lines and producing best during sunny seasons when the demand on water reaches its peak.

## Basic Definitions

| | |
|---|---|
| **Alternating Current** | An electric current that reverses its direction at regularly recurring intervals. Commonly used in most household appliances. |
| **Centrifugal Pump** | A type of pump that uses an impeller to spin water and push it out by centrifugal force. |
| **Diaphragm Pump** | A type of pump in which water is drawn in and forced out of one or more chambers, by a flexible diaphragm. |
| **Direct Current** | An electric current flowing in one direction only and substantially constant in value. |
| **Flowrate** | The amount of fluid that flows in a given time, normally expressed in units of cubic meters per hour or gallons per minute in the US. |
| **Foot Valve** | A check valve that prevents water from flowing back down the pipe. It is placed in the water source below a surface pump. |
| **Friction Loss** | The loss of pressure due to flow of water in pipe due to distance covered, fittings, and other factors. |
| **Inverter** | An electronic control device that produces AC output from DC input. |
| **kWh** | A unit of energy that is the multiplication of power in kilowatts (kW) and time in hours. |
| **Linear Current Booster** | An electronic device that conditions the voltage and current of a PV array to match the needs of a DC-powered pump, especially a positive displacement pump. It allows the pump to start and run under low sun conditions without stalling. It is also called a pump controller. |
| **Peak sun hours** | The equivalent number of hours available in a certain location per day when the intensity is enough to produce 1 kW of energy. Usually in the range of an annual average of 3 to 7 hours per day. |

| | |
|---|---|
| **Solar Insolation** | The amount of sunlight falling on a specific area for a given period of time. Also known as solar irradiance and given in $kWh/m^2$ /day. |
| **Suction Lift** | The vertical distance from the surface of the water in the source, to a pump located above surface pump located above. |
| **Surface Pump** | A pump that is not located on ground level to suck out water from lower level sources. |
| **Dynamic Head** | The summation of vertical lift and friction loss in piping. |
| **Watt Peak** | The maximum capacity of the PV panel(s), also known as the rated power of the panel. It is the maximum amount that can be produced under standard test conditions. |

## WATER PUMPING APPLICATIONS & TECHNOLOGIES

Distribution of water through networks and in piping channels is driven by a properly designed pumping system that uses an electrically or mechanically driven pump to do the job. The pump is mainly used for dewatering purpose to reduce downtime from large rain events and to continuously transfer water from one point to another.

There are two major types of water pumps currently available in the market; the first is the centrifugal pump, which uses a rotating impeller to move water into the pump and pressurize the discharge flow. Centrifugal pumps are able to pump fluids with various specifications regardless of the viscosity levels, but are specialized with thin liquids and high flow rates.

Centrifugal pumps are used in buildings and fire protection for water supply. Also used in wells and boost applications for water supply and pressure boost.

The second is positive displacement pump (rotary pump) that delivers a fixed amount of flow through the use of a flexible diagram undergoing mechanical contraction and expansion. This kind of pump is perfect for high viscosity fluids, and specialized for low flow and high pressure combination. The fact that positive displacement pumps remove air from the lines and eliminate the need to bleed the air makes them very efficient.

### *Water Pumping Applications*

There are tens of applications for water pumps, each requiring a different type of pump and a special design to perfectly meet the water pumping requirements. Different types of pumps currently exist, each for a specific use as reported by ScoutHub, LLC [[1]

*Table 1: Different types of pumps and applications [1]*

| Application | Pump Type | Application |
|---|---|---|
| **Boiler Feed** | Centrifugal (multistage) | Control amount of water entering a boiler |
| **Borehole** | Submersible | Pump liquid from a borehole |
| **Chemical** | Centrifugal or PDP | Handle abrasive and corrosive industrial materials |
| **Circulator** | Centrifugal or PDP | Circulate fluid through a closed or looped system |
| **Dewatering** | Centrifugal (submersible or vertical) | Remove water from a construction site, pond, mine shaft, etc... |
| **Drill** | | Powered by attaching an electric power drill |
| **Drum** | Centrifugal for thin, Piston for viscous | Empty fluid from barrels or drums |
| **Fire** | Centrifugal (horizontal, end suction, vertical) | Used for firefighting |
| **Flooded Suction** | | With a suctioned chamber that is always full of the fluid being pumped |
| **High Pressure** | PDP, Rotary, Reciprocating, or Centrifugal | Used in water blast, hydro-mining, and jet cutting |
| **Industrial** | Centrifugal or PDP | Industrial applications (slurry, wastewater, chemicals, oil & gas etc…) |
| **Irrigation** | Centrifugal | Agriculture application where water is moved to dry land |
| **Marine** | | In large salt water tanks to pump sea water |
| **Mud** | | Transfer heavy sludge or mud. Pressurize and circulate fluid on oil rigs |
| **Paint** | | Dispense paint, for direct application or into separate containers |
| **Petrochemical** | Magnetic Drive, Diaphragm, Piston | Transfer petroleum products that are often very viscous and corrosive |
| **Pneumatic** | | Pressurize liquid using compressed air through the piping system. |
| **Pond** | Submersible and External | Gardens, ponds, and fountains to prevent water from being stagnant |
| **Pool** | | Circulate water in a pool |
| **Pressure** | Metering, and sometimes Booster | Used to create either high or low pressure |
| **Process** | Centrifugal or PDP | In process applications |

| | | |
|---|---|---|
| **Sanitary** | | Transport fluids that must be processed for sanitary standards |
| **Sewage** | Submersible | Mostly used to pump sewage to a waste treatment facility |
| **Sludge** | Centrifugal or PDP (progressive cavity) | Pump waste fluids with high solids content |
| **Slurry** | | Heavy duty pump made to handle thick, abrasive slurries |
| **Sprinkler** | | Creating pressure to move the water through an irrigation system |
| **Transfer** | | Move fluid from one receptacle to another |
| **Trash** | | Fluids with solid content such as mud, trash, fish, or waste products |
| **Utility** | Submersible | Remove water from an area, often times after a flood |
| **Wastewater** | | Move wastewater toward or within a waste treatment facility |
| **Well** | Jet, Centrifugal, or Submersible | Draw water to the surface from an underground water source |

## Water Pumping Technologies

The majority of water pumps in operation worldwide are electrically-driven, with only a small share of other types of pumps such as hand pumps, wind-mills, animal-driven, and hydraulic pumps.

Wherever the electric grid is available, it is mainly used as the primary source of power. For remote applications, onsite diesel generators have been used for a long period of time to power irrigation and water distribution pumps in un-electrified regions. Renewable energy started to become more and more of a feasible solution especially with the increasing insecurity of electricity supply and the unstable fuel prices, offering farmers and rural residents environmentally friendly power sources to pump water. Technologies utilizing solar energy for electrically powering the water pump are becoming more common, offering competitive advantages over traditional fuel-driven generators.

### Hand Pumps

This is probably the most ancient and trivial method for water pumping. All it needs is a human pumping water by hand, able to transfer water from an underground source to surface level. Advancements have been made over time to construct a similar foot pump or a bicycle pump, applying the same concept but can be run by kids instead.


### Animal-driven Pumps

Donkeys, cows, camels, and sometimes sheep are used to pump water for irrigation and domestic use. The animals are connected to a water wheel and planned to keep walking in a tight circle to turn an axle which in turn powers the waterwheel. This way water is pumped into ground level and made available for use mainly for irrigation applications.

### *Wind Pumps*


Traditional wind mills have been used for centuries, pumping water directly from underground sources to end use which is mainly irrigation. The wind turbine is coupled directly to a water pump, so as long as the wind blows, there is water being pumped and made ready for use. It consists of a wind turbine, a pump, and a piping system.

### *Hydraulic Pumps (Hydraulic Ram)*


A hydraulic ram (aka hydram) is a pump powered by water to pump water. It uses stream water pressure to move a fraction of the stream to the desired location. It consists of a cyclic water pump that uses the water hammer effect to develop pressure increasing the hydraulic head and lowering the flow rate of the fluid.

### *Diesel Electrical Pumps*


These pumps are powered by an onsite diesel generator that works as a normal electricity generator to simply the pump with electricity to operate. This is the most polluting technology and relies heavily on the availability and affordability of oil. It has a low Capex, but a very high Opex for fuel supply and maintenance requirements.

### *Solar Pumps*


Solar pumps are the most feasible non-fossil-based technology for water pumping. It is even more feasible than the traditional wind mills due to their ability to pump water as long as the sun is there. It consists of solar panels, a pump controller, a DC pump, or an AC pump with an inverter. Some pumps use a linear current booster (LCB) that allows having an extra current to start up the pump through voltage modification. This allows the pump to start and run even on cloudy days.

*Table 2: Pros and cons of different water pumping technologies*

| Technology | Pros | Cons |
|---|---|---|
| **Hand** | + Can be locally manufactured | – Loss of human productivity |
| | + Low Capex | – Low flow rate |
| | + Low Opex | – Inefficient with boreholes |
| **Animal-driven** | + Low Opex (only maintenance) | – Animal feeding cost |
| | + A place to collect animal manure | – Animals not always available |
| **Wind** | + Can be locally manufactured | – Some applications require storage |
| | + Unattended operation | – Difficult to install |
| | + Low Opex | – Requires project planning |
| | + Long life | – High maintenance cost |
| **Hydraulic** | + Unattended operation | – Low output |
| | + Low Opex | – Not suitable for all sites |
| | + Long life | – Difficult to maintain |
| **Diesel** | + Easy installation | – High Opex |
| | + Low Capex | – Dependent on fuel prices |
| | + Widely used | – Noise and environmental pollution |
| | + Portable and modular | – Short life |
| **Solar** | + Unattended operation | – High Capex |
| | + Low Opex | – Some applications require storage |
| | + Modular | – Dependent on solar radiation levels |
| | + Long life | – Requires skilled technicians |

## SOLAR WATER PUMPING

### *How it Works*

Solar pumps utilize the photovoltaic effect to produce free electricity used for water pumping. Photons of light hit a collection of solar cell, exciting electrons into a higher state of energy, making them act as charge carriers an electric current. This is how Photovoltaic (PV) cells produce electricity.

The photovoltaic effect was first observed in 1839 by Alexadre-Edmond Becquerel, and is now used to produce electricity from one of the most dominant renewable energy resource.

The method is simple! DC electricity is produced in a set of silicon solar cells gathered in modules and put together into arrays. Connected to a pump that can be either surface or submersible. Surface pumps are mounted at ground level its inlet linked to the well and its outlet to the water delivery point, while submersible pumps are completely lowered into the water (best applicability for deep wells). Both DC and AC pumps can be used; in the case of AC, an inverter is needed to convert DC to AC. The operation of the pump is controlled by a pump controller that assess the voltage output of the panels.

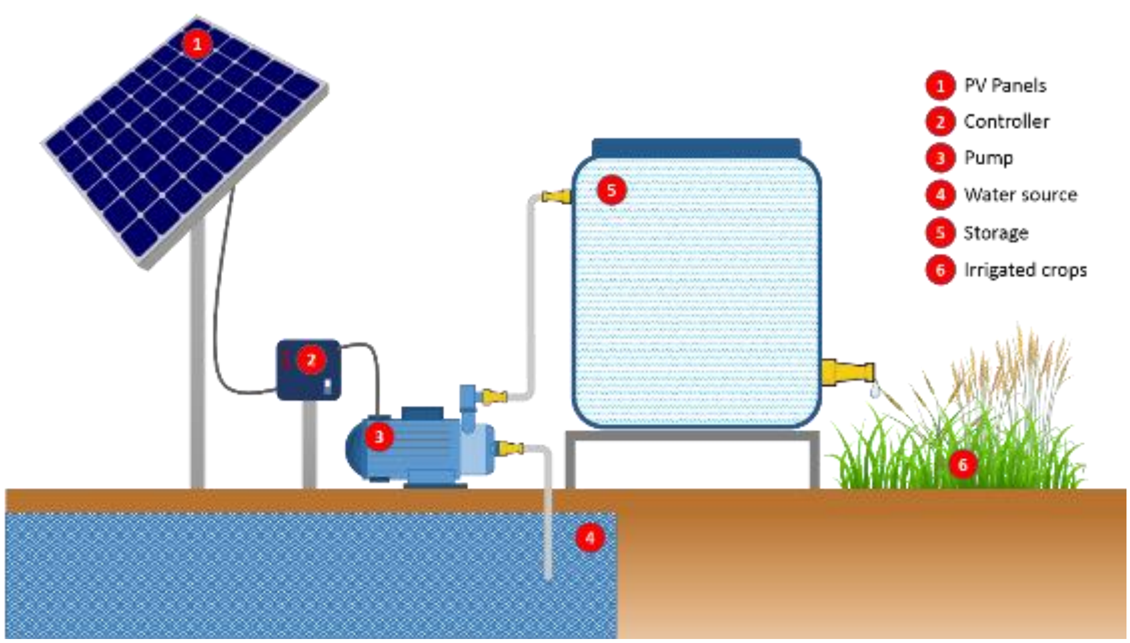



*Figure 1: Typical off-grid surface solar pumping system sketch*

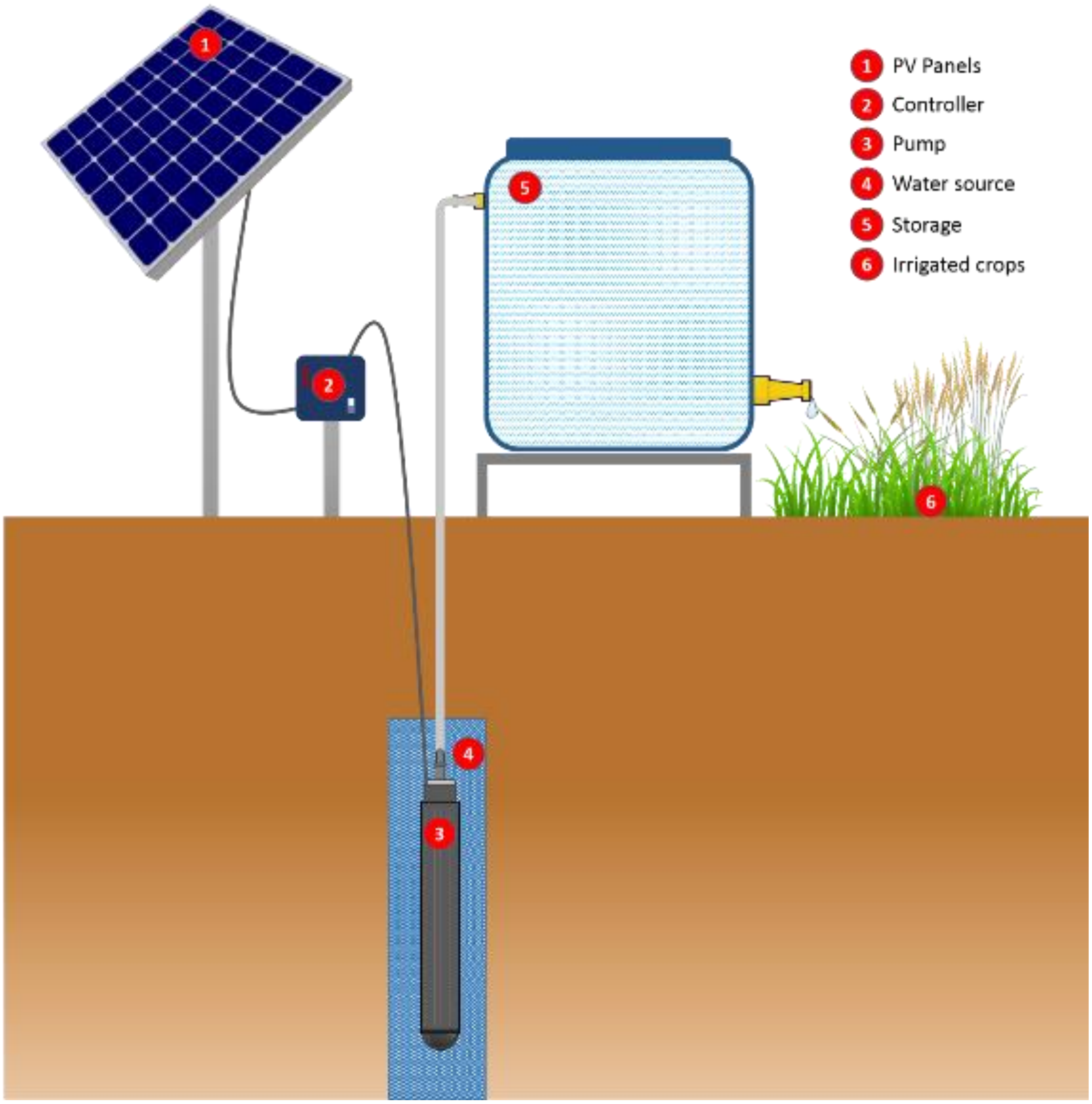



*Figure 2: Typical off-grid submersible solar pumping system sketch*

Storage can be done by the use of elevated water tanks or storage ponds where water is stored until it is demanded and delivered to end-users, or through the use of batteries that store electricity and save it until there is demand for water. The first is apparently more feasible and less maintenance-demanding as compared to battery storage systems.

Some solar pumping applications use tracking systems to maximize power production and increase daily gain, through single axis or dual axis tracking solar collectors. This is applied in case of high volume demand but requires large water storage volumes.


*Figure 3: Solar tracking options [2]*

## *Why Go Solar?*

Solar energy has been widely utilized for its positive impact on the environment and its ability to replace oil-based electricity generators. Yet, there is more into solar energy when it comes to water pumping, making it a more feasible and technically reliable solution for agricultural and domestic applications.

There are many reasons to consider solar pumping as an alternative to conventional fuel-based techniques. Table 3 shows the main advantages of solar water pumping over other technologies

*Table 3: Differentiating advantages of solar pumping*

| Category | Advantage |
|---|---|
| **Maintenance** | + Low maintenance requirements |
| **Running Cost** | + Almost no running cost |
| **Independence** | + No fuel dependence |
| **Operation** | + Unattended operation |
| **Pollution** | + Zero pollution (no emissions, no spills, no waste) |
| **Production** | + Produce best during sunny weather, when water is needed most |
| **Noise** | + No noise produced |
| **Lifetime** | + Long lifetime (more than twice that of conventional technologies) |
| **Flexibility** | + Easily relocated, moved, or expanded |

## Applications

Solar water pumping is primarily used in irrigation applications in remote areas and rural regions where these applications are mainly demanded. Yet, solar water pumping is also used for a variety of other applications such as domestic water supply, livestock watering, and irrigation.

### Domestic Water Supply

Private homes, camps, villages, rural medical centers and other facilities use solar energy to pump water from underground sources. The pump may be powered by a series of fully dedicated solar panels or can just be part of an electrical load connected to a series of solar panels used to empower the home, clinic, camp, etc… there are two major applications that are commonly used. The first is centralized solar pumping where a large pump is used to supply water to a village or a set of villages, or a neighborhood, the second is decentralized where each home or facility has its own solar pumping system powering a small water pump sufficient to supply domestic water needs.

A lot of decentralized applications use batteries for electricity storage as they tend to use the solar panels for their own domestic electricity consumption, which requires storage for consumption during off-sun hours.

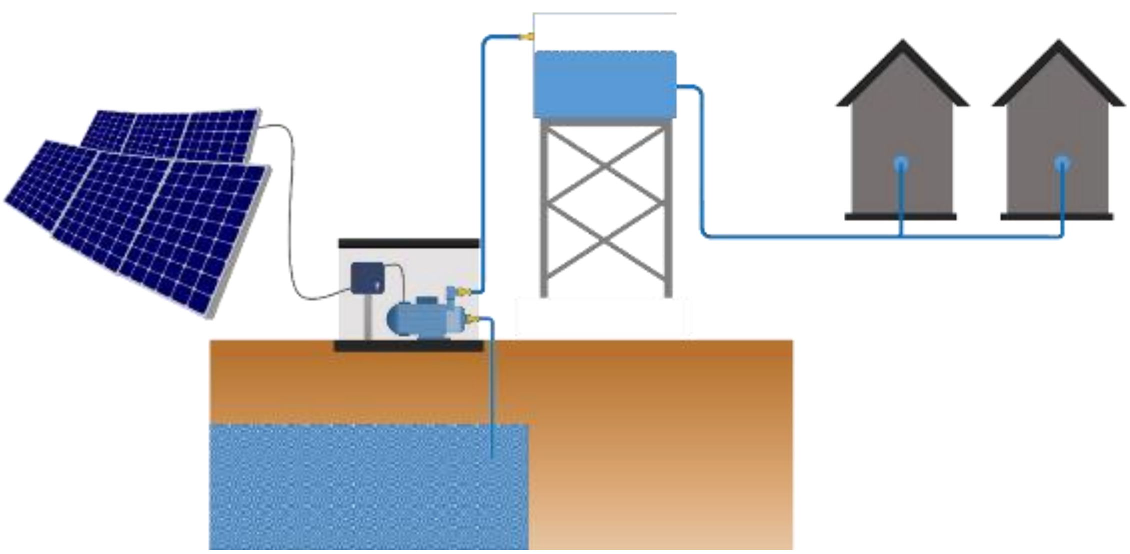


*Figure 4: Typical domestic water supply solar pumping system*

### *Irrigation and Livestock Watering*

Farms, orchards, vineyards, and domestic gardens use solar pumps for irrigation and cattle watering purposes, especially those located in remote and off-grid areas. Water is usually pumped whenever the sun is shining and delivered to the irrigated area or cattle raising location. Some applications store water in elevated tanks that can keep water from season to another.

Solar pumping is most suitable with application requiring low flow and pressure, which keeps open channels and drip irrigation as the most suitable methods when coupled with solar PV pumping.

*Table 4: Suitability of solar pumping with common irrigation methods*

| Irrigation Method | Application Efficiency | Typical Head | Suitability with Solar |
|---|---|---|---|
| **Open Channels** | 50 – 60% | 0.5 – 1 m | ✓ |
| **Sprinklers** | 70% | 10 – 20 m | ✗ |
| **Drip** | 85% | 1 – 2 m | ✓ |
| **Flood** | 40 – 50% | 0.5 m | ✗ |

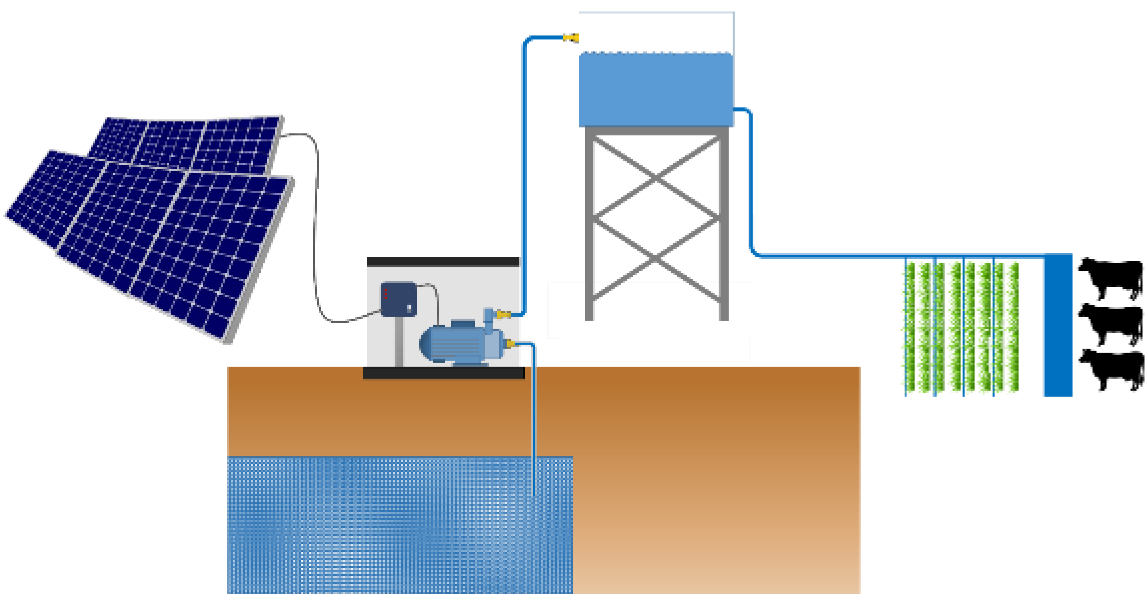


*Figure 5: Typical irrigation and livestock watering solar pumping system*

## System Design

A good solar pumping system is the one properly designed and sized to fit the job requirements. Various designs exist for a variety of applications, requiring research and technical design to avoid system insufficient performance or unnecessary cost incurrence.

Unlike traditional utility or private generator powered systems, where large pumps are normally installed to pump water in large volumes whenever power is available, solar PV pumping requires more austerity as system components are really expensive and efforts need to be done to bring system set up cost to a minimum.

During the design phase, system designers need to decide on whether the system is to be on-grid or off-grid, with storage or without it and whether storage is in batteries or in elevated water tanks. They need to decide on the type of pump being used and whether the application requires a submersible or a surface pump, using AC or DC power. These all are factors that affect the system performance and feasibility of the proposed solution.

### Grid and Storage

#### On-Grid vs Off-grid

Typical PV systems are grid-connected, allowing feeding produced electricity into the utility mains and thus using it as a storage volume. The concept behind on-grid systems is to reduce the additional expenses of batteries and avoid lost excess energy that is being produced but unused due to low demand.

In solar pumping applications, when the grid is available, some systems are hooked into the grid allowing for a two-way exchange of power, working as such:

(1) When solar energy is available, and there is demand for water, water is directly pumped to end use using solar power

(2) When solar energy is available, and there is demand for water but not consuming all the electricity produced, excess electricity is fed into the grid

(3) When solar energy is available, and there is demand for water but requiring more power than what is produced by the solar PV system, extra electricity provided from the grid

(4) When solar energy is available, and there is no demand for water, electricity is fed into the grid

(5) When solar energy is not available, and there is demand for water, water is directly pumped to end use using grid power

For applications where the utility grid is not available, mainly remote and not electrified regions, the PV system is installed as a stand-alone system, sometimes connected to a private generator and sometimes just left as a stand-alone unit.

The private generator plays the roles (1), (3), and (5) of the grid mentioned above. It provides electricity when needed unless there is a storage system in place. This storage system allows to store electricity or water to offer availability during night times and winter seasons.

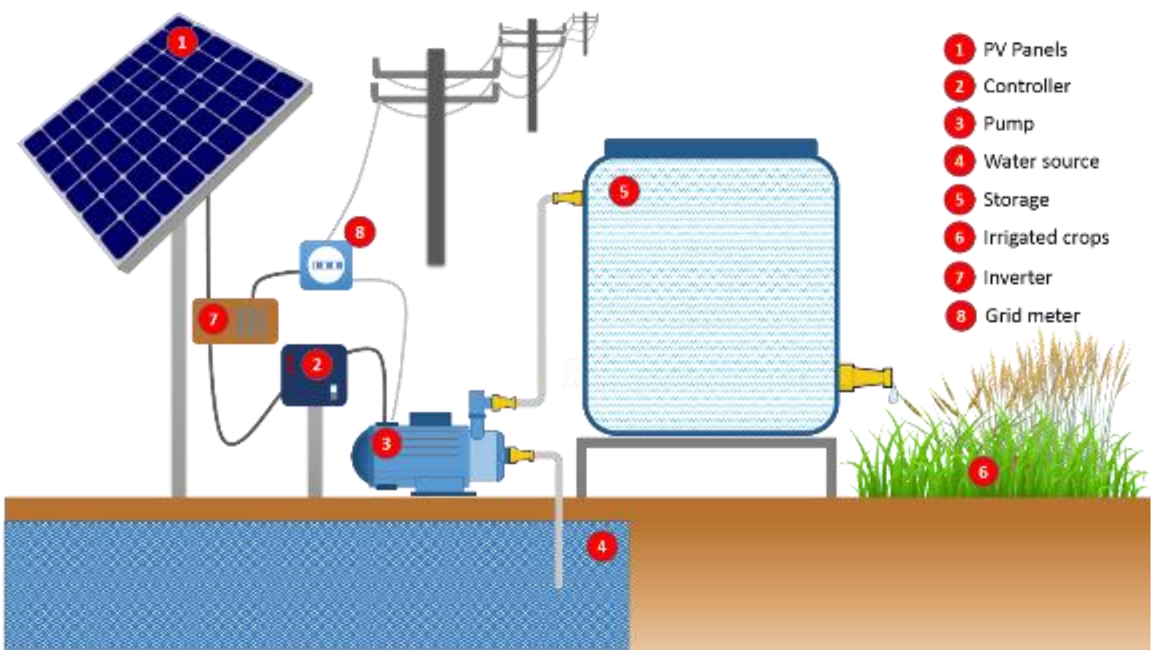



*Figure 6: On-grid solar pumping system*

***Water Storage vs Battery Storage***

Solar energy is only available during the day, and can sometimes be absent during heavy winter days, which would require storage for some applications. In principle, batteries are the most commonly used storage method for electricity, but it is a major burden due to its increased cost and high maintenance requirements. For this reason, a lot of solar pumping applications favor the use of water storage instead, here water is pumped whenever sufficient solar power is available and stored in an elevated tanks, form which water can be withdrawn whenever required.

Water storage is very practical when the system is properly sized. During sunny days, the system provides enough water more than the daily requirements, since pumping is free, this water can be stored in water tanks that should be sized to ensure sufficient storage volume depending on climatic conditions and water consumption patterns. This is also called the direct drive system design.

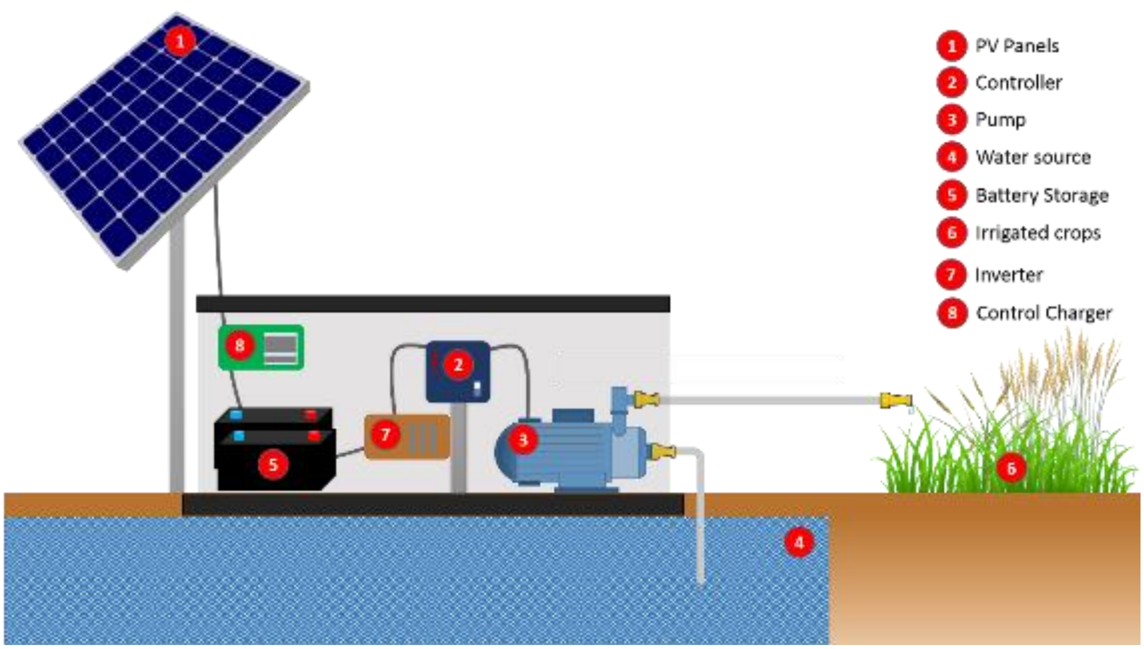



*Figure 7: Solar pumping system with battery storage*

## *Pump Type*

### *Submersible vs Surface*

There are two major types of pumps used in water pumping, the selection process depends on the type of water source, the flow requirements, and the site conditions.

Surface pumps are used in shallow wells ad surface water sources such as streams and ponds. It can only pump water from around 7 meters below ground level with the ability to push far uphill but with a limited total dynamic head of 14 meters. Yet, to maintain pump efficiency and increase system reliability it is recommended to keep the suction lift to a minimum.

There are three main types of surface pumps:

(1) **Delivery pump:** Moves water from a location to another, at both high or low pressure

(2) **Pressure pump:** Pressurize small water systems in homes and small buildings

(3) **Booster pump:** Maintain pressure or flow for towns and communities

Surface pumps are less costly than submersible pumps, and offered at larger variety, but submersible pumps are mainly used for deeper wells although they are also suitable for surface applications.

A submersible pump is usually positioned inside the underground well, normally located more than 7 meters below ground level. Some pumps can go as deep as 450 meters below ground level, with high durability characteristics and ability to tolerate water with relatively high levels of salinity. Recent technologies are developing floating submersible pumps where the pump is positing in a floating unit on the top of the water.

There are two major categories of submersible pump, the most common is centrifugal used for low head and high water volume and the other is positive displacement including helical rotor pumps and diaphragm pumps used for high head and low volume.

*Table 5: Types of submerssible pumps and their operating characteristics*

| Pump Type | Head (m) | Flowrate ($m^3$/day) | Remarks |
|---|---|---|---|
| **Centrifugal** | 0 to 80 | 6 to 20 | Similar to conventional pump |
| **Helical Rotor** | 50 to 150 | > 20 | Robust; one turning part |
| **Diaphragm** | 0 to 150 | 2 to 5 | Complex; many moving parts; requires lubricants |

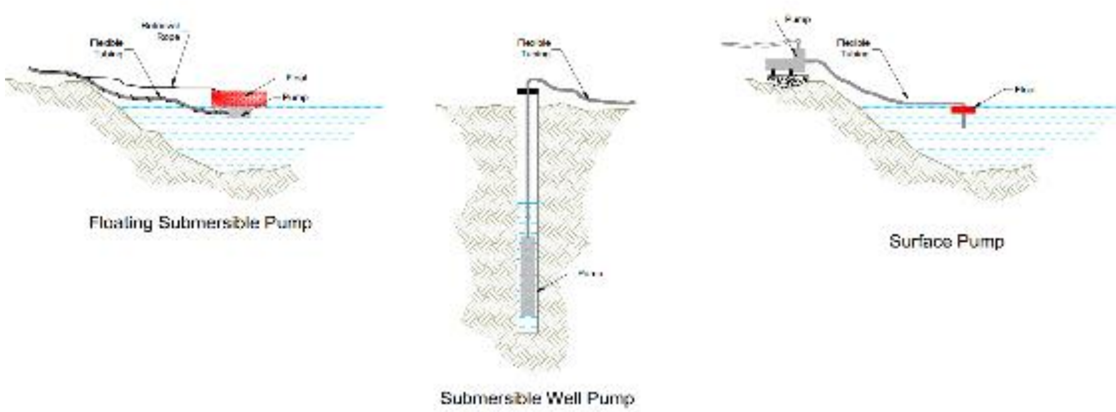



*Figure 8: Major types of water pumps that can be used with solar energy [3]*

### *AC vs DC*

PV produces electricity in DC form, thus giving DC pumps an advantage over AC pumps due to the avoidance of additional costs for the use of an inverter and the reduced efficiency caused. But DC pumps are only suitable for small applications where the required flow is relatively low.

## *Layout Design*

### *Structure*

Solar panels can be ground-mounted, roof-mounted, or post-mounted depending on the site conditions. Metallic structures are normally used to hold the panels, these structures are designed to withstand high winds and stormy weather.

The structure itself needs to be properly coated and protected against environmental factors such as rain, humidity, and other conditions.

### *Orientation*

In order to maximize the performance of solar panels, it is essential to install them facing true south, with an acceptable tolerance of 15 degrees towards east or west that doesn't significantly affect the performance. For applications needing solar energy in the morning more than it does in the afternoon, a shift towards the east is practical to receive the solar rays as early as possible.

In some situations there could be some shade caused by trees or other obstacles at one of the sides, which requires shifting the panels slighting to the opposite sides to avoid shading as much as possible.

### *Tilt*

The panel can get the best out of the solar radiation when its surface receives the solar rays at a perpendicular angle, allowing for a maximum solar ray density per unit area. But since the sun path varies from day to another, being at higher levels during the summer and lower in relation to the horizon.

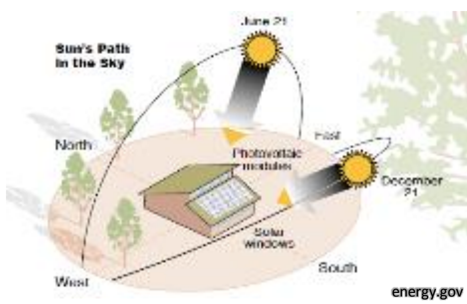



*Figure 9: Sun path in summer and winter*

According to the sun path and the latitude of Lebanon, the best tilt angle has been shown to be around 55 degrees in winter and 15 degrees in summer, with 35 being an average value.

Rule of thumb says that the tilt angle needs to be almost as much as the latitude of the location with a 5 degrees tolerance.

The optimal solution would be changing the tilt angle on daily basis to match the solar radiation angle, but since this is not a practical solution, the application decides on the tilt angle. In applications demanding maximum production in winter for example, there is a tendency to go above average to guarantee best performance in higher demand seasons.

For solar water pumping, water demand is at its highest during summer season, thus solar panels are best when tilted at an angle of 30 or 25 degrees relative to horizontal ground level.

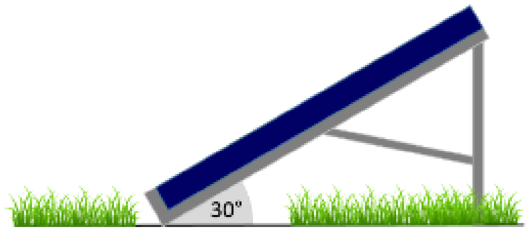



*Figure 10: Optimum tilt angle for solar pumping applications*

### Sun Tracking

Although not very practical for solar water pumping applications, it is worth mentioning that some applications do require sun tracking. This is done either by daily tracking, or seasonal tracking, and sometimes both together known as dual tracking as shown in Figure 3 earlier.

Tracking systems can increase the output by as much as 35%, but also incur additional costs and require more maintenance over the lifetime of the system.

### Pump Location

The pump should be located in an enclosed room called a pump pit or a pump house. Surface pumps are not water proof and need to be kept away from water and protected from environmental conditions to prolong their lifetime and reduce maintenance requirements. If a submersible pump is used, the pump will be inserted in the borehole, but should not be too close to the bottom of the borehole or else it will stuck in dirt and lead to pump damage.

Distance between the pump and the PV panels should be kept to a minimum to reduce voltage drop in the cables. Increased distance causes harmonics and would require a harmonics filter to avoid damages to the pump and the inverter/controller.

### Other Considerations

In order to make solar PV pumping a viable solution, several considerations need to be made especially in the case of irrigation. These considerations make PV water pumping a competitive and practical solution as compared to conventional diesel and grid-tied systems.

(1) The irrigation system needs to be designed in a water-conserving manner to reduce water demand

(2) It is recommended that the plot size for solar irrigation doesn't exceed 4 ha.

(3) High rates of system utilization are recommended to achieve economic viability, making permanent crops and continuous crop rotation in arid climates the best option for solar irrigation

## System Components

A typical system consists of four major components that together make up a solar water pumping unit capable of providing large capacities of water during summer and winter times. The major components are the PV panels, the solar pump, the controller, and the storage volume. Some systems use batteries as a storage volume while others use water tanks.

There are other minor components that are also used such as the mounting structure, wiring, piping, float switch and others.

### PV Panels

The photovoltaic panel is the energy collector that receives solar radiations and converts them to electrical energy. This conversion process loses as much as 80% of the energy thus leaving us with an efficiency of 20% at best cases.

PV panels are considered the most important and effective items in the PV system, making up almost 80% of the overall system cost (assuming no battery storage needed). How many modules and how much collection area is a topic that will be studied under the system sizing section.

PV panels produce DC electricity, they are interconnected together in series and parallel to achieve the desired voltage and current.

*Table 6: Different types of solar PV cells and their reported efficiencies*

| Type of Cell | Reported efficiency range | Cost |
|---|---|---|
| **Monocrystalline** | 14 – 16% | **$ $ $** |
| **Polycrystalline** | 12 – 14% | **$ $** $ |
| **Amorphous Silicon** | 8 – 9% | **$** $ $ |

## *Solar Pump*

The choice of pump type, size, and capacity depends on the application and its requirements. In principle, submersible pumps are used in wells deeper than 7 meters and surface are used for shallow wells.

Regardless of that, DC motors are widely applied in small applications with capacity not exceeding 3 kW, mainly applicable for small water demand such as gardening, landscaping, small volume livestock watering, etc. DC pumps are more efficient and more practical as they do not require an additional component to convert current to Ac for instance. This reduces costs and avoids additional efficiency drops.

Ac pumps are used for larger applications with capacities exceeding 3 kW, requiring an inverter to change the current that the solar panels produce (DC) to a current that is suitable for the pump (AC).

Latest 3-phase pumps use a variable frequency AC motor and a three-phase AC pump controller that enables them to be powered directly by DC power produced by the solar modules.

## *Controller*

The controller plays a vital role in the system performance due to its ability to regulate the power production to match that produced by the panels with that required by the pump. It also plays a critical role in protecting the system by turning it off when the voltage is at inappropriate level, meaning too low or too high compared to the operating voltage range of the pump. This voltage protection role helps extend the lifetime of the pump and reduce maintenance requirements.

### *Storage Volume*

The sun is not always there, and even when it is there the flow rate doesn't always meet the daily water demand. This requires the use of a storage volume that can benefit from the solar energy available all day long and store it either in electrical energy form in batteries or as potential energy form in storage tanks.

Batteries are only used when there is no possibility to have a water storage volume or when the volume is not sufficient. They increase the set up invoice by almost double and require frequent maintenance and replacement at least every 4 years. This makes water storage a more practical and efficient solution.

The storage volume and capacity requirements depends on the application and the pattern of water demand, but in principle the tank is sized with a capacity that is 3 times the daily demand on average . In some applications storage volume can go to a capacity of 10 times the daily water demand.

### *Other components*

Other components include the support structure that provides stability to mounted solar panels, electrical interconnections including cables, junction boxes, connectors and switches, earthing kit for safety in case of lightning or short circuit, and plumbing requirements from pipes and fittings required to connect the pump come as part of the installation.

In addition, a harmonics filter might be required to avoid inverter and pump damage. Whether a filter is required or not should be mentioned in the inverter datasheet.

## *Sizing Methods*

Oversizing would incur unnecessary costs, and undersizing would lead to insufficient performance. This is why each component needs to be properly designed and sized to meet the specific requirements of the project. It is the only way to guarantee reliability and system durability, and achieve the desired performance.

The steps that need to be followed in the sizing process of a new water pumping system powered by solar are presented in Table 7.

*Table 7: Steps and their outputs in the sizing process of a solar pumping system*

| Assessment | Variables | Output |
|---|---|---|
| (1) Water source | (a) Water depth<br>(b) Water level<br>(c) Delivery capacity | - Pump type<br>- Capacity of water available |
| (2) Water demand | (a) Consumption profile<br>(b) Storage capacity | - Storage size |
| (3) Total head | (a) Static head<br>(b) Dynamic head | - Pump size |
| (4) Solar resources | (a) Solar radiation<br>(b) Sun peak hours per day | - PV size |
| (5) Flowrate | | - Pump size |
| **Sizing** | **Input Data** | |
| (6) Pump | (a) Flowrate<br>(b) Total head | |
| (7) Solar array | (a) Pump size | |

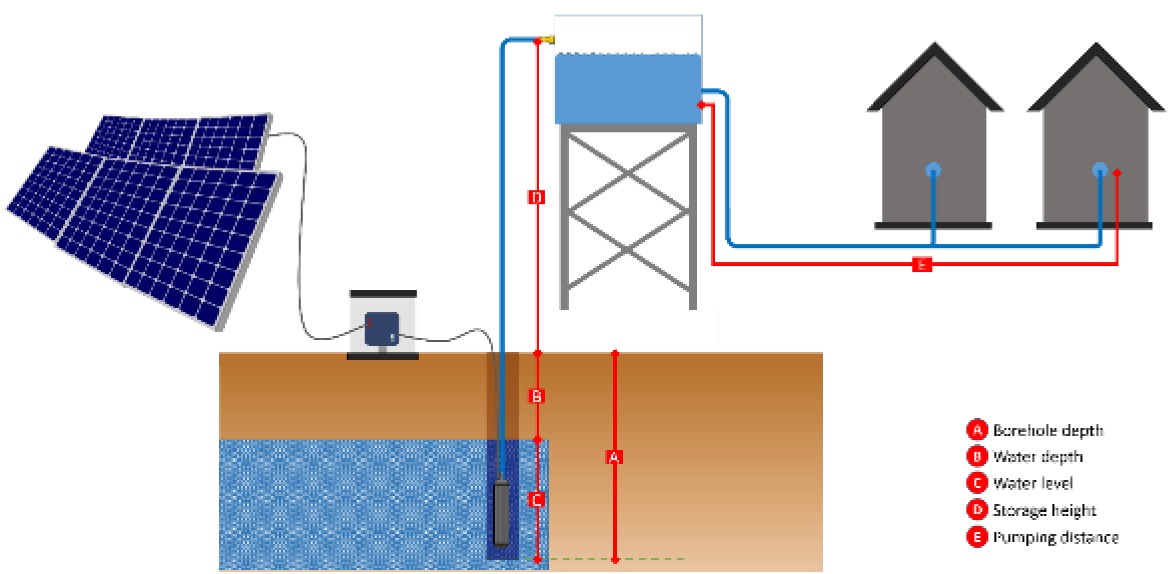



*Figure 11: Dimensions figure of a typical solar water pumping system*

## (1) Water source

(a) The depth of the well ***(A)*** decides on whether a surface pump can be used or not. For wells deeper than 7 meters below ground level, it is demanded to use a submersible pump instead even though it costs more.

(b) The water level ***(C)*** decides on the position of the submersible pump. Clearance needs to be kept between the bottom of the borehole and the pump.

(c) Delivery capacity (Tested delivery capacity) measures the capacity of water source to provide water in a sustainable manner. Withdrawing more than the tested delivery capacity leads the borehole to become a dry well as the discharge rate exceeds the water resource replacement rate.

**(2) Water demand**

(a) Water demand is the major factor affecting the size of the pumping system. It is calculated as a daily consumption rate and in some times as an hourly rate in case the consumption pattern requires that.

Table 8 shows the average values used as international benchmarks for the daily consumption rate in various applications such as residential, livestock, and irrigation.

*Table 8: Daily consumption rate average values for different applications [4][6][7]*

| Application | Unit | Daily consumption rate (Lit/day) |
|---|---|---|
| **Residential** | Inhabitant | 50 - 275 |
| **Livestock** | Milking Cow | 95 |
| | Horse or Dry cow | 76 |
| | Sheep or Goat | 7.6 |
| | Chicken | 1.5 |
| **Irrigation** | Rice (1 ha) | 100 |
| | Cereals (1 ha) | 45 |
| | Vegetables (1 ha) | 50 |
| | Sugar cane (1 ha) | 66 |

(b) The storage capacity is the volume of water that need to be stored to ensure sufficient and continuous supply of water to end users. Storage tanks usually range in capacity between a storage of 2 to 10 days depending on the location and the usage patterns. For example, if the daily demand is 2,000 liters the storage volume should be at least 6,000 liters, and could go up to 20,000 liters in some applications.

In order to ensure sufficient storage, the pumping system needs to be sized with additional water volume demand of between 10% and 40% based on the application.

### (3) Total head

The total head is the distance between the storage delivery points to the submerged depth of the pump in addition head losses through the piping system. It is the summation of elevation head, major losses head, and minor losses head.

(a) The static head ***(D)*** is the height between ground level and the storage volume. It should be kept to a minimum to reduce the lift requirements of the pump, but needs also to take into consideration the suitability of the storage location. Every meter of height accounts for one meter of dynamic head.

(b) In order to compute the dynamic head, an approximate value is used measuring the distance covered by pipes from ground level to the storage volume in the horizontal direction. For a perfectly horizontal path only 5% of the covered distance is accounted for, meaning that if the pipe runs for 100 meters in the horizontal direction with no inclination, 5 meters are added to the dynamic head. In case of inclination, the height difference should be accounted for in the storage height value.

*Example:*

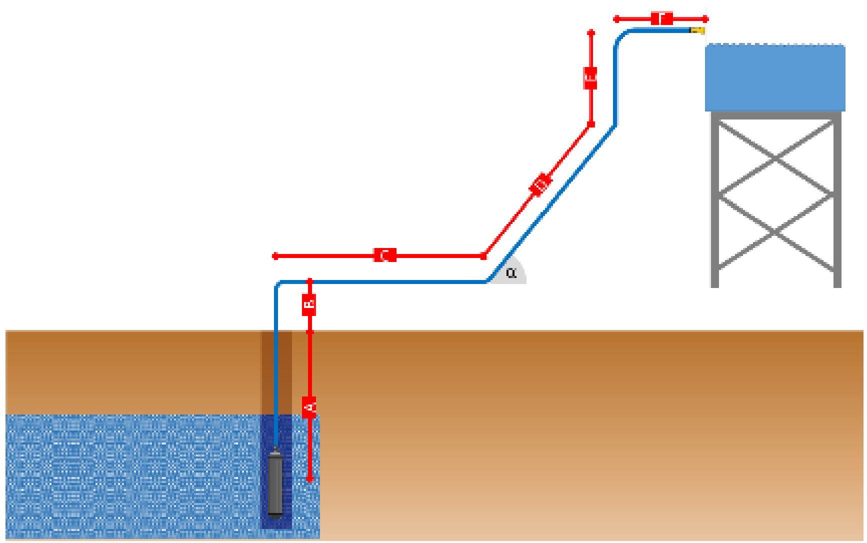


*Figure 12: Head calculation example application*

*Total Head =* *A* + *B* + *(C* x *5%)* + *(D* x *cos α)* + *E* + *(F* x *5%)*

It is recommended to use a safety factor of 20% going up to 30% if the water condition is unstable. For this purpose, it is imperative to keep the pump head higher than the total head calculated by at least 20%.

**(4) Solar Resources**

(a) Lebanon is blessed with good solar radiation levels, varying from a yearly average of 1,700 kWh/m² in the least irradiated regions to 2,500 kWh/m² in those regions with best solar irradiance. Irradiance reaches highest levels during the months of May, June, July, and August, peaking in July at more than 300 kWh/m² per month.

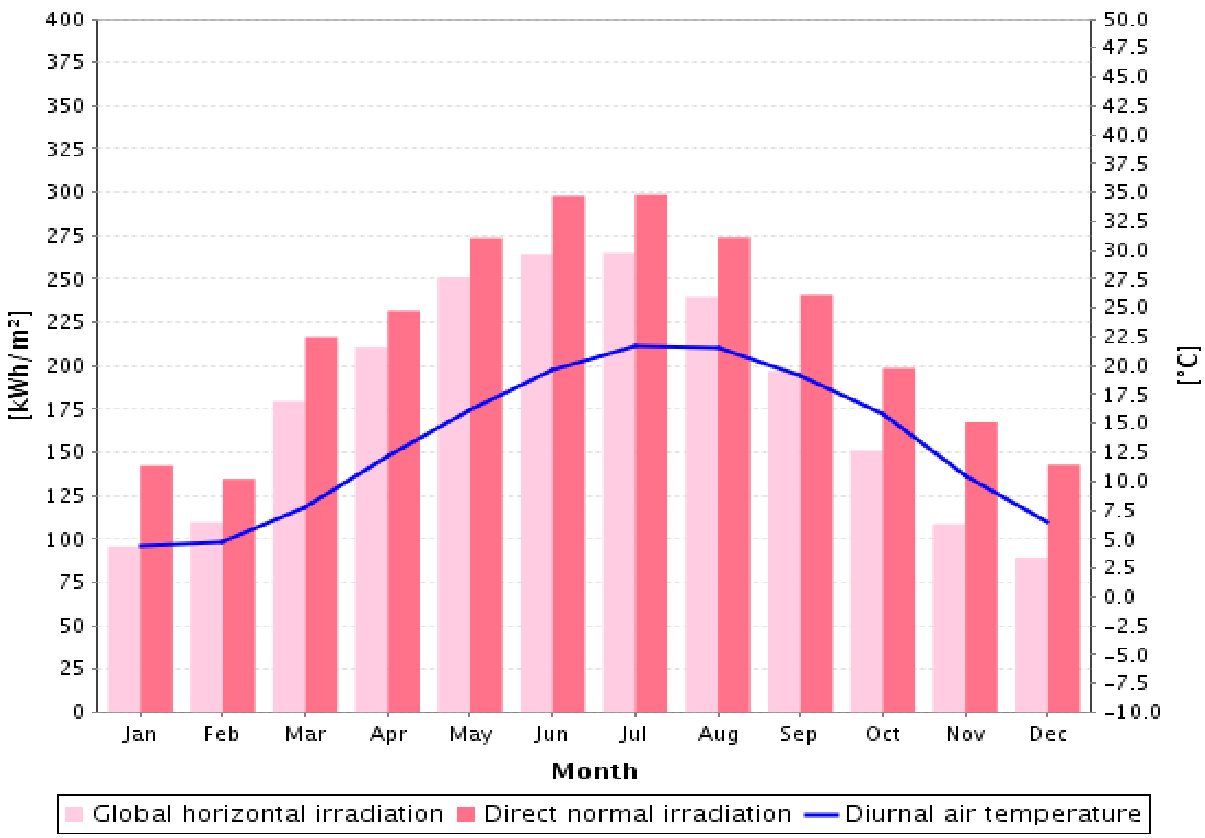



*Figure 13: Solar irradiance data for the city Zahle in Bekaa [4]*

(b) Peak sun hours (PSH) indicates the average equivalent hours of full sun energy received per day, this varies based on the location and the tilt angle, with 1 PSH equals to 1 kWh/m²/day.

According to CEDRO in their publication on PV Plants in Lebanon published in 2013, on average Lebanon has a solar Global Horizontal Irradiation of 5.3 peak sun hours, which yearly stands for about 1,934 peak sun hours [10].

*Table 9: Global irradiation at different tilts in Beirut [9][10]*

| Month | $H_h$ | H (23°) | G (30°) | G (45°) |
|---|---|---|---|---|
| **January** | 2,610 | 3,610 | 3,830 | 4,140 |
| **February** | 3,470 | 4,400 | 4,590 | 4,790 |
| **March** | 4,680 | 5,380 | 5,470 | 5,450 |
| **April** | 5,870 | 6,160 | 6,110 | 5,770 |
| **May** | 7,270 | 7,130 | 6,930 | 6,240 |
| **June** | 8,150 | 7,730 | 7,430 | 6,520 |
| **July** | 7,900 | 7,610 | 7,360 | 6,530 |
| **August** | 7,200 | 7,380 | 7,260 | 6,720 |
| **September** | 6,130 | 6,880 | 6,950 | 6,810 |
| **October** | 4,590 | 5,690 | 5,890 | 6,080 |
| **November** | 3,200 | 4,370 | 4,620 | 4,970 |
| **December** | 2,390 | 4,490 | 3,620 | 3,960 |
| **Daily Avg. (Wh/m²)** | 5,300 | 5,820 | 5,840 | 5,670 |
| **Sun Peak Hours / day** | 5.30 | 5.82 | 5.84 | 5.67 |

### (5) Required flowrate

The flow rate can be calculated from the water demand and the peak sun hours per day. Calculated in $m^3$ per hour, the flow rate is the result of the demand in cubic meters divided by the peak sun hours in hours.

| **Flowrate** | = | **Demand** | ÷ | **PSH** |
|---|---|---|---|---|
| *m³/h* | | *m³/day* | | *h/day* |

### (6) Pump size

The pump power required can be computed in one of two main methods. The first method is using the pump sizing chart provided by the pump manufacturer and requiring two variables only that are the total head (3) and the flowrate (5).

Flow rate and TDH are plotted on the sizing chart as shown in Figure 14 in red and green respectively, with the blue curves being pump performance curves. The point of intersection between flow and TDH is the point of reference. The selected pump needs to have its curve encompassing the reference point, preferably the closet one to guarantee best efficiency.

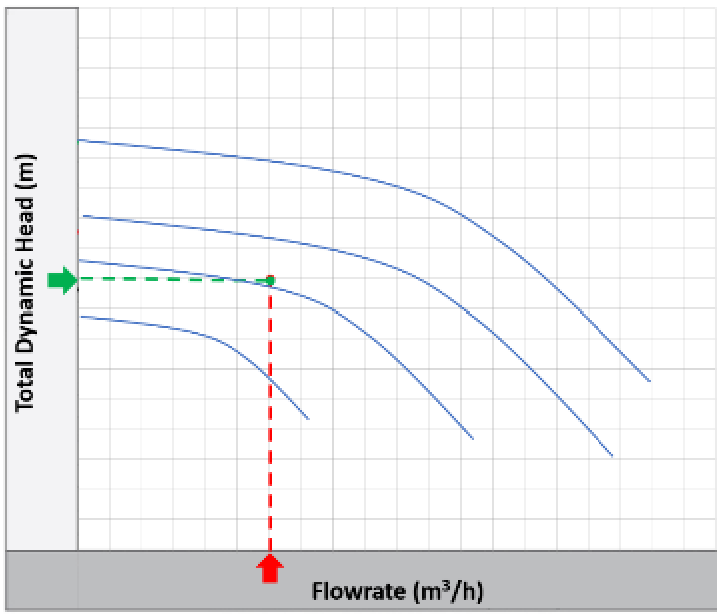



*Figure 14: Example of a pump sizing chart*

Other type of pump performance charts are also common and will be used in the rest of this document, which allows matching the pump flow with the pump head curve and match it with the required peak power. Example curves for positive displacement and centrifugal pumps are shown in Figure 15 and Figure 16.

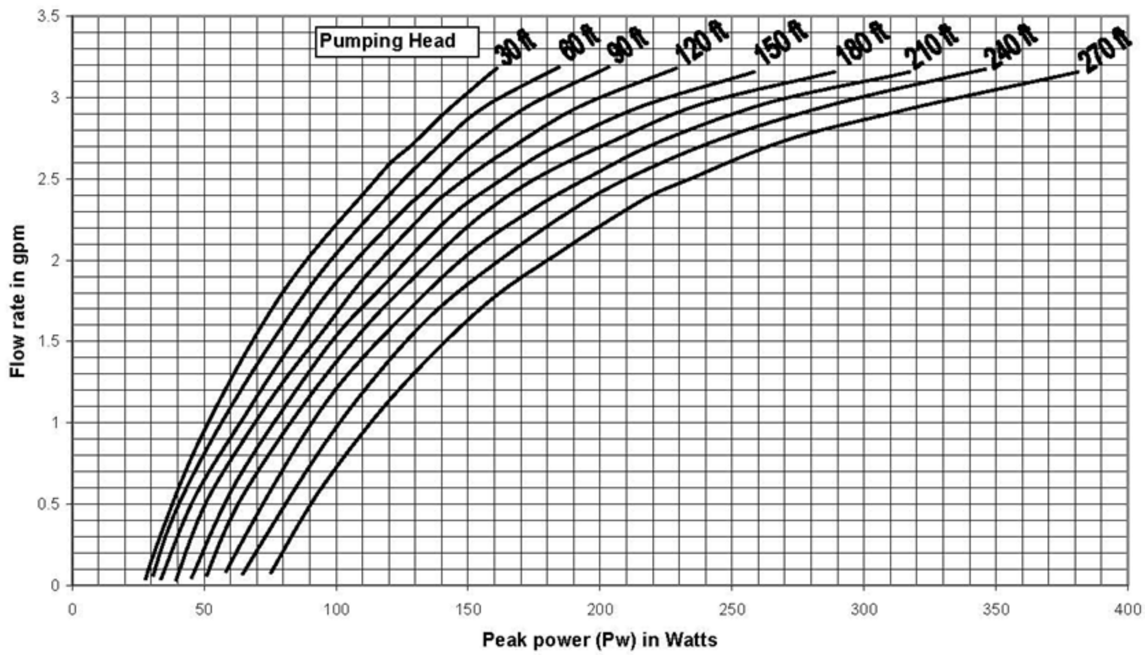



*Figure 15 Example positive displacement pump curve [7]*

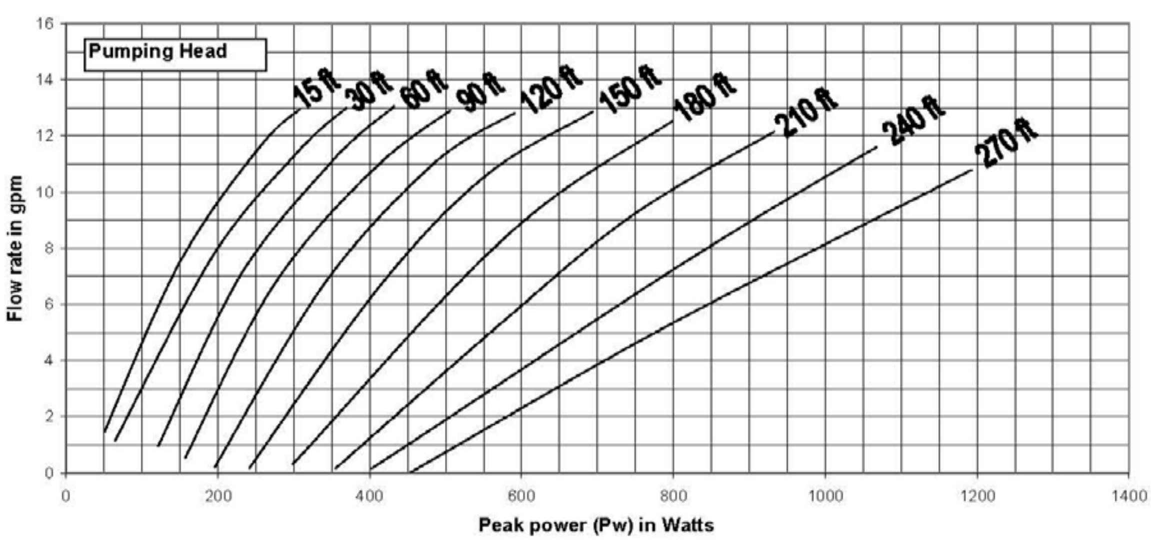



*Figure 16: Example centrifugal pump curve [7]*

The second method uses a formula that calculates pump power from the total head (3) and the flowrate (5), water density, and gravity. It is not recommended to use this method as it sometimes return inaccurate data. It is better to refer to official datasheets published by manufacturer to avoid being too theoretical in the sizing process.

| **Hydraulic Power** | = | **Flowrate** | × | **TDH** | × | **ρ** | × | **G** | ÷ | **3,600** |
|---|---|---|---|---|---|---|---|---|---|---|
| *W* | | *$m^3/h$* | | *m* | | *$kg/m^3$* | | *$m/s^2$* | | *s/h* |

*With: $\rho = 999.97\ kg/m^3$ (for water at average temperature)*

*$G = 9.8\ m/s^2$*

| **Shaft Power** | = | **Hydraulic Power** | ÷ | **Pump Efficiency** |
|---|---|---|---|---|
| *W* | | *W* | | - |

**(7) Solar array**

| **PV Power** | = | **Pump Power** | ÷ | **Efficiency Factor** | × | **Inverter Efficiency** |
|---|---|---|---|---|---|---|
| *Wp* | | *W* | | - | | - |

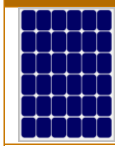
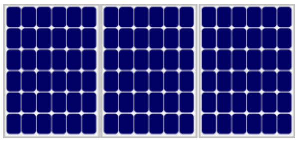
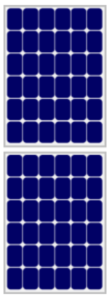
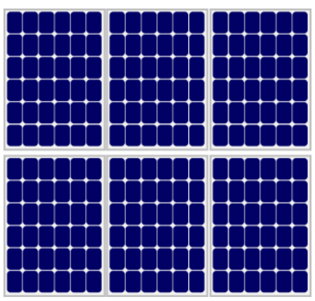
The efficiency factor is normally take 80%, and the inverter efficiency taken around 85%. The inverter efficiency is only applied if there is a need to convert from DC to AC and an inverter is being used.

The final stage is deciding on the solar array connections and how to make the interconnections in order to achieve the desired voltage and current.

Connecting the panels in series adds up the voltages of the panels while keeping the current fixed. While parallel connections add up the current while keeping the voltage fixed.

Table 10 shows the effect of parallel and series connections on the voltage and current of PV modules. Each module is assumed to have a voltage of 40V and current of 3A.

*Table 10: PV modules connections in parallel and series*

| Panel Connection | Connection | Voltage | Current |
|---|---|---|---|
|  | None | 40 | 3 |
|  | Series | 120 | 3 |
|  | Parallel | 40 | 6 |
|  | Series & Parallel | 120 | 6 |

## *Cost*

Solar pumping is most practical and financially feasible when the power line is more than 1 km away from the pump location. The investment that would be made to have a solar-powered water pump makes more sense than that made to extend power lines.

On average, extending the power lines costs somewhere between 18 and 36 USD per meter, in Lebanon there is no official data published by EDL as each case is studied on its own. But there is no doubt that the numbers wouldn't be any lower than 18 USD per meter of lines.

The cost of a solar PV pump depends on the requirements and the site conditions. The availability of the pump also plays a major role and the security levels in the area do have an influence on the investment value.

International benchmarks are available from previous experiences in the developing world, especially in India. Data published by Energypedia showed an average investment rate of $5.93 USD per Wp for a 1 kWp PV drinking water supply system and $11.85 for a ready-to-operate system including pumping system, logistics, set-up, reservoir, construction, water distribution. This rate drops as the capacity increases to reach $4.63 and $7.59 respectively as shown in Figure 17. Nowadays, these rates are expected to have dropped by at least 20% due to the latest advancements in PV cells technologies and the drop in prices.

A comparative chart for diesel water pumping and PV water pumping is presented in Figure 18 where methods are compared in terms of $m^4$ delivered, with $m^4$ equals volume in cubic meters multiplied by the total dynamic head in meters.

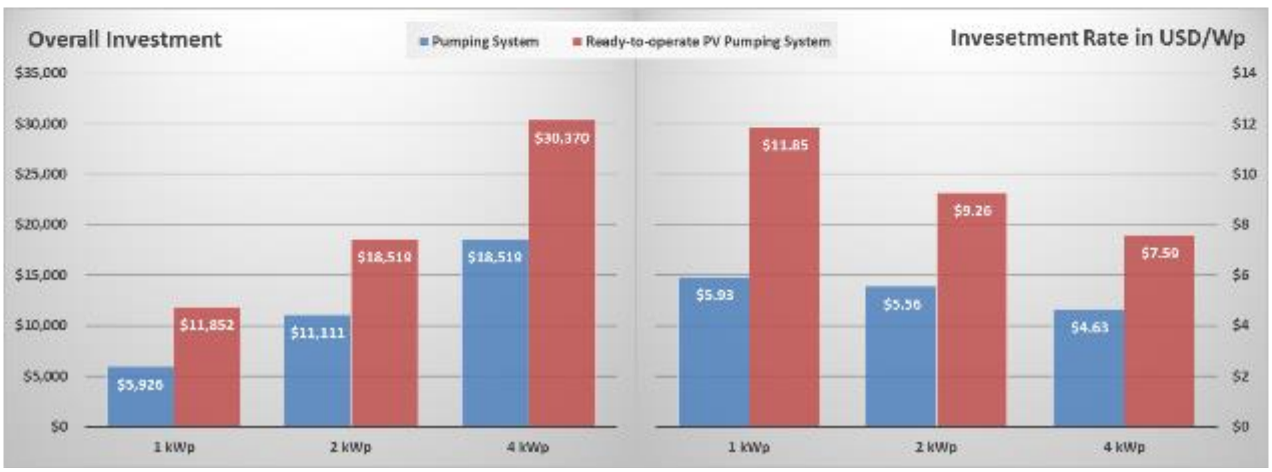



*Figure 17: Investment cost of PV pumping systems for drinking water supply [11]*

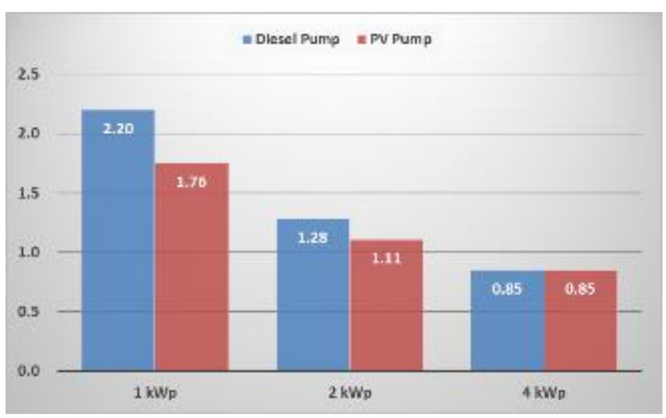



*Figure 18: Water pumping cost of diesel compared to PV per $m^4$ [11]*

In Lebanon, A typical 10 kW solar pumping system for domestic water use delivering 13,000 liters per day would cost around 20,000 USD, assuming that the pump is already available, making an average of $2 per Watt. Smaller systems tend to have a higher USD per watt rate but normally not exceeding $4 per watt.

Table 11 shows the cost range of major components of a solar pumping system and presents the case of a typical 10 kW pumping system, and Table 12 shows the price variation as compared to the size range considering economies of scale.

*Table 11: Average cost range of a solar water pumping system*

| Component | Unit | Price Range per Unit |
|---|---|---|
| **Solar Modules** | Watt | $1 – $1.5 |
| **Mounting Track** | Watt | $0.1 – $0.4 |
| **Water Pump** | hp | $500 – $1,500 |
| **Controller** | Watt | $0.05 – $0.3 |
| **Floating Switch** | Pc | $20 – $70 |
| **Inverter** | Watt | $0.05 – $0.3 |
| **Other material** | Watt | $0.01 – $0.1 |
| **Installation** | Watt | $0.1 – $0.3 |
| **Average Price per Wp** | | $1.5 – $2.5 |

*Table 12: Average cost by range*

| Size Range | Average Price per Wp |
|---|---|
| **3 – 10 kW** | $2.0 - $2.5 |
| **11 – 50 kW** | $1.8 - $2.3 |
| **> 50 kW** | $1.5 - $2.1 |

## *Economic Analysis*

Solar pumping makes more sense in applications not demanding very high water supply, so the solar powered pump can operate slowly based on the solar radiation availability. When compared to conventional diesel generator pumps, it appears that solar pumping pays back the investment in an average of 2 years.

According to a study performed by Emcon Consulting Group for the UNDP in Namibia, aiming at assessing solar pumping as compared to diesel pumping, a medium size solar pumping system with a head of 80 meters and flowrate of 12 $m^3$/day would break even in 2 years with diesel at an average price of $0.86 per liter and 2.6 years with diesel at $0.57 per liter. The results of the assessment is shown in Figure 19.

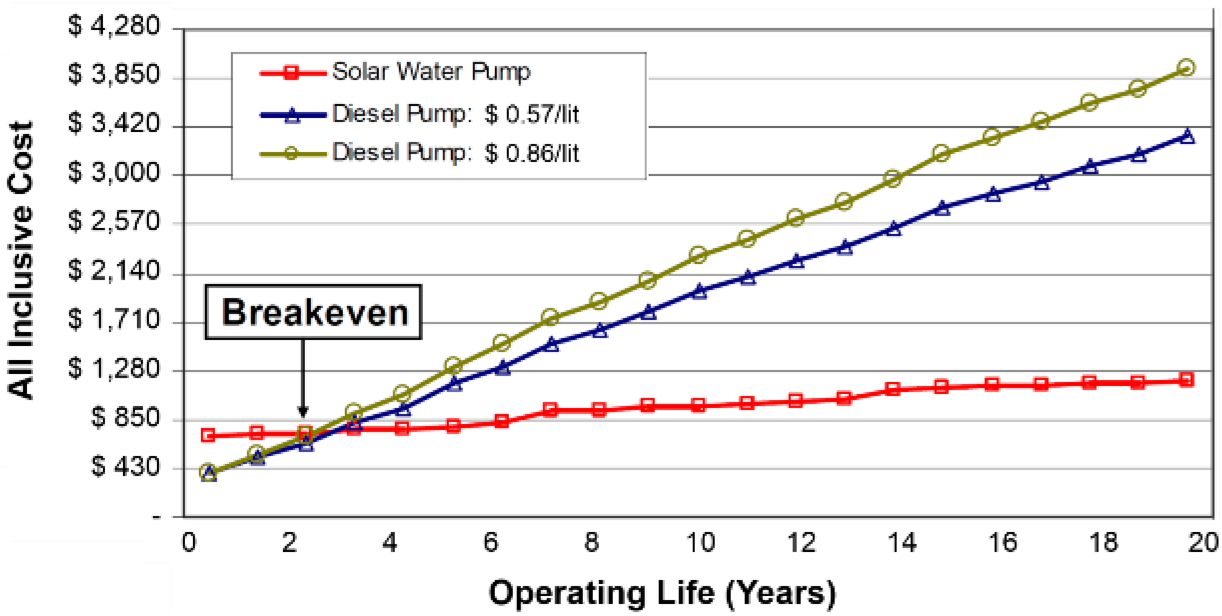



*Figure 19: Diesel vs solar water pumping breakeven point case study [12]*

For other flowrate and head values, Table 13 shows the breakeven for different values, highlighting in yellow the cases where solar pumping would make sense. The blocks in grey identify cases where there is no alternative pump to be used for solar pumping, in such a case diesel still needs to be used or the solar PV system will be designed to provide electricity to the existing AC pump.

*Table 13: Years to breakeven – when solar becomes cheaper than the diesel option [12]*

| | | Daily water [m³/day] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 3 | 5 | 8 | 10 | 13 | 17 | 25 | 50 |
| Head [m] | 20 | 0.0 | 0.0 | 0.0 | 0.2 | 0.2 | 0.6 | 1.3 | 2.8 |
| | 40 | 0.0 | 0.0 | 0.4 | 0.9 | 1.0 | 1.1 | 2.6 | 4.1 |
| | 60 | 0.0 | 0.0 | 0.9 | 1.2 | 1.7 | 2.6 | 3.5 | 5.1 |
| | 80 | 0.0 | 0.0 | 1.3 | 1.6 | 2.3 | 3.7 | 4.6 | 7.1 |
| | 100 | 0.0 | 0.1 | 2.3 | 3.1 | 3.7 | 4.6 | 6.1 | Diesel |
| | 120 | 0.0 | 1.1 | 2.4 | 3.9 | 4.4 | 5.7 | 6.5 | Diesel |
| | 160 | 0.0 | Diesel | Diesel | Diesel | Diesel | Diesel | Diesel | Diesel |
| | 200 | 0.0 | Diesel | Diesel | Diesel | Diesel | Diesel | Diesel | Diesel |

## *System Performance*

The output of the solar pump varies by season, all depending on the solar insolation level and the power of the pump. A simplified way to estimate the water pumped volume is presented based on the formulas used in the sizing process but going in reverse.

| **Shaft Power** | = | **PV Power** | × | **Efficiency Factor** | × | **Inverter Efficiency** |
|---|---|---|---|---|---|---|
| *W* | | *Wp* | | - | | - |

| **Hydraulic Power** | = | **PV Power** | × | **Eff. Factor** | × | **Inverter Eff.** | × | **Pump Eff.** |
|---|---|---|---|---|---|---|---|---|
| *W* | | *Wp* | | - | | - | | - |

Also

| **Hydraulic Power** | = | **Water Volume** | ÷ | **PSH** | × | **TDH** | × | **2.722** |
|---|---|---|---|---|---|---|---|---|
| *W* | | $m^3/day$ | | *h/day* | | *m* | | $Kg.h/s^2.m^2$ |

*Using* $\rho = 999.97\ kg/m^3$ *and* $G = 9.8\ m/s^2$

Conclusion:

| **Water Volume** | = | **PV Power** | × | **η** | × | **PSH** | ÷ | **TDH** | × | **2.722** |
|---|---|---|---|---|---|---|---|---|---|---|
| $m^3/day$ | | *Wp* | | - | | *h/day* | | *m* | | $Kg.h/s^2.m^2$ |

*η is the product of PV efficiency factor, Inverter efficiency, and Pump efficiency.*

With the solar insolation varying by month, the water volume pumped will also vary based on those values.

## Example 1: Rice Farm

***Given data:***

- Plot Area: 38 ha rice
- Well depth: 6 meters
- TDH: 16 m
- Location: Bekaa
- Tilt angle: 20°
- PSH (20°): 5.5 hrs/day
- PV Panel: 117 W; 35.5 V; 3.3 A

| Month | PSH | Month | PSH |
|---|---|---|---|
| January | 4.213 | July | 8.096 |
| February | 5.049 | August | 7.986 |
| March | 6.017 | September | 7.645 |
| April | 6.721 | October | 6.479 |
| May | 7.623 | November | 5.082 |
| June | 8.173 | December | 3.982 |

### Sizing

With a water depth being less than 7 meters, a surface pump will be used.

| | | | | | | |
|---|---|---|---|---|---|---|
| **Demand** | = | **38** | × | **0.1** | = | **3.8** |
| *m³/day* | | - | | *m³/day* | | *m³/day* |
| **Flowrate** | = | **3.8** | ÷ | **5.5** | = | **0.69** |
| *m³/h* | | *m³/day* | | *h/day* | | *m³/h* |
| **Storage** | = | **3.8** | × | **3** | = | **11.4** |
| *m³* | | *m³/day* | | *day* | | *m³* |

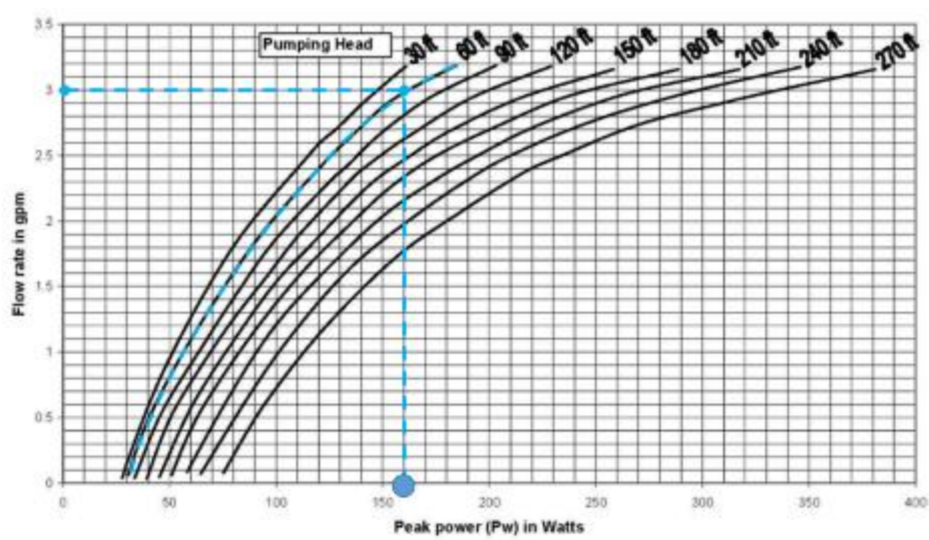



*Figure 20 Pump sizing for example 1*

With a THD of 16 meters (52.5 ft) and a flow of 0.69 $m^3/h$ (3 gpm), using the pump sizing chart for positive displacement pumps, the water pump and its relative power is identified

| PV Power | = | 160 | ÷ | 80% | × | 100% | = | 200 |
|---|---|---|---|---|---|---|---|---|
| Wp | | W | | - | | - | | W |

The pump operating voltage and technical specification are determined from the datasheets. Assuming that the minimum operating voltage of the pump is 60V.

In order to supply the power of 200 W, two panels will be used each with a power rating of 117 W at 35.5 V and 3.3 A. the panels will be connected in series to reach the 60V voltage requirement of the pump.

The final designed system now utilizes 234 Watt solar panels at 71 V and 3.3A.

## *Cost Estimation*

*Table 14: Cost estimation for example 1*

| Component | Unit | Qty | Unit Price | Total Price |
|---|---|---|---|---|
| **Solar Modules** | Watt | 234 | $1.50 | $350 |
| **Mounting Track** | Watt | 234 | $0.20 | $47 |
| **Water Pump** | hp | 0.2 | $1,200 | $240 |
| **Controller** | Watt | 234 | $0.43 | $100 |
| **Floating Switch** | Pc | 1 | $50 | $50 |
| **Inverter** | Watt | - | - | $0 |
| **Other material** | Watt | 234 | $0.09 | $20 |
| **Installation** | Watt | 234 | $0.30 | $70 |
| **Total Price** | | | | $877 |

### *Performance*

| Water Volume | = | 234 | × | 38% | × | PSH | ÷ | 16 | × | 2.722 |
|---|---|---|---|---|---|---|---|---|---|---|
| *$m^3$/day* | | *Wp* | | *-* | | *h/day* | | *m* | | *Kg.h/ $s^2$.$m^2$* |
| | = | 2.04 | × | PSH | | | | | | |
| | | *$m^3$/h* | | *h/day* | | | | | | |

*Table 15: Estimated water pumping by month for example 1*

| Month | PSH *hrs* | Volume pumped *$m^3$* | Demand *$m^3$* | Balance *$m^3$* |
|---|---|---|---|---|
| **January** | 4,213 | 266.4 | 117.8 | + 148.6 |
| **February** | 5,049 | 288.4 | 106.4 | + 182.0 |
| **March** | 6,017 | 380.5 | 117.8 | + 262.7 |
| **April** | 6,721 | 411.3 | 114.0 | + 297.3 |
| **May** | 7,623 | 482.1 | 117.8 | + 364.3 |
| **June** | 8,173 | 500.2 | 114.0 | + 386.2 |
| **July** | 8,096 | 512.0 | 117.8 | + 394.2 |
| **August** | 7,986 | 505.0 | 117.8 | + 387.2 |
| **September** | 7,645 | 467.9 | 114.0 | + 353.9 |
| **October** | 6,479 | 409.7 | 117.8 | + 291.9 |
| **November** | 5,082 | 311.0 | 114.0 | + 197.0 |
| **December** | 3,982 | 251.8 | 117.8 | + 134.0 |
| **Total Annual** | | 4,786.4 | 1,387.0 | + 3,399.4 |

## *Example 2: Cow Farm*

***Given data:***

- Cattle: 150 milking cows
- Well depth: 16 meters
- TDH: 50 m
- Location: Bekaa
- Tilt angle: 30°
- PSH (20°): 6 hrs/day
- PV Panel: 117 W; 35.5 V; 3.3 A
-

| Month | PSH | Month | PSH |
|---|---|---|---|
| January | 4.213 | July | 8.096 |
| February | 5.049 | August | 7.986 |
| March | 6.017 | September | 7.645 |
| April | 6.721 | October | 6.479 |
| May | 7.623 | November | 5.082 |
| June | 8.173 | December | 3.982 |

### *Sizing*

With a water depth being more than 7 meters, a submersible pump will be used.

| | | | | | | |
|---|---|---|---|---|---|---|
| **Demand** | = | **140** | × | **0.095** | = | **13.3** |
| *m³/day* | | - | | *m³/day* | | *m³/day* |
| **Flowrate** | = | **13.3** | ÷ | **6** | = | **2.21** |
| *m³/h* | | *m³/day* | | *h/day* | | *m³/h* |
| **Storage** | = | **13.3** | × | **3** | = | **39.9** |
| *m³* | | *m³/day* | | *day* | | *m³* |

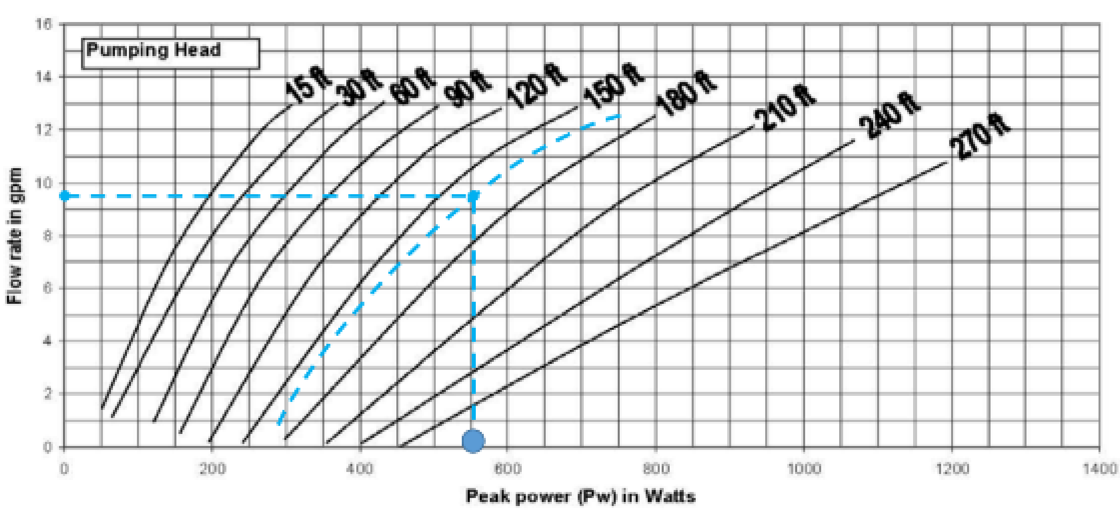



*Figure 21 Pump sizing for example 2*

Using the second method for pump power calculation, with a THD of 50 meters (164 ft) and a flow of 2.21 $m^3/h$ (9.73 gpm), and using the pump sizing chart for positive displacement pumps, the water pump and its relative power can be identified.

| PV Power | = | 560 | ÷ | 80% | × | 100% | = | 700 |
|---|---|---|---|---|---|---|---|---|
| *Wp* | | *W* | | - | | - | | **W** |

The pump operating voltage and technical specification are determined from the datasheets. Assuming that the minimum operating voltage of the pump is 60V.

In order to supply the power of 700 W, six panels will be used each with a power rating of 117 W at 35.5 V and 3.3 A. The panels will be connected in series and parallels (2 groups of three panels each) to reach the 60V voltage requirement of the pump.

The final designed system now utilizes 702 Watt solar panels at 106.5 V and 6.6A.

## *Cost Estimation*

*Table 16: Cost estimation for example 1*

| Component | Unit | Qty | Unit Price | Total Price |
|---|---|---|---|---|
| **Solar Modules** | Watt | 702 | $1.50 | $1,053 |
| **Mounting Track** | Watt | 702 | $0.20 | $140 |
| **Water Pump** | hp | 0.9 | $1,200 | $1,080 |
| **Controller** | Watt | 702 | $0.43 | $302 |
| **Floating Switch** | Pc | 1 | $50 | $50 |
| **Inverter** | Watt | - | - | |
| **Other material** | Watt | 702 | $0.09 | $63 |
| **Installation** | Watt | 702 | $0.30 | $211 |
| **Total Price** | | | | $2,899 |

## *Performance*

| Water Volume | = | 702 | × | 38% | × | PSH | ÷ | 50 | × | 2.722 |
|---|---|---|---|---|---|---|---|---|---|---|
| *$m^3$/day* | | *Wp* | | *-* | | *h/day* | | *m* | | *Kg.h/ $s^2$.$m^2$* |
| | = | 1.96 | × | PSH | | | | | | |
| | | *$m^3$/h* | | *h/day* | | | | | | |

*Table 17: Estimated water pumping by month for example 1*

| Month | PSH *hrs* | Volume pumped *$m^3$* | Demand *$m^3$* | Balance *$m^3$* |
|---|---|---|---|---|
| **January** | 4,213 | 256.0 | 117.8 | + 138.2 |
| **February** | 5,049 | 277.1 | 106.4 | + 170.7 |
| **March** | 6,017 | 365.6 | 117.8 | + 247.8 |
| **April** | 6,721 | 395.2 | 114.0 | + 281.2 |
| **May** | 7,623 | 463.2 | 117.8 | + 345.4 |
| **June** | 8,173 | 480.6 | 114.0 | + 366.6 |
| **July** | 8,096 | 491.9 | 117.8 | + 374.1 |
| **August** | 7,986 | 485.2 | 117.8 | + 367.4 |
| **September** | 7,645 | 449.5 | 114.0 | + 335.5 |
| **October** | 6,479 | 393.7 | 117.8 | + 275.9 |
| **November** | 5,082 | 298.8 | 114.0 | + 184.8 |
| **December** | 3,982 | 241.9 | 117.8 | + 124.1 |
| **Total Annual** | | 4,786.4 | 4,598.7 | + 1,387.0 |

## Operation and Maintenance Guidelines

Solar PV pumping systems are characterized by their simplicity, unattended operation, and low maintenance requirements as compared to conventional systems. Except for the pump itself, there are no moving parts that would require periodic maintenance and incur additional costs every time maintenance is performed.

In the case of battery usage for energy storage, which is not a very good idea, maintenance and battery replacement would be required every four years on average. There are some modern batteries that can live up to 8 years but are still considered expensive and would require very delicate preventive maintenance that might not be present in typical solar PV pumping applications (mainly in rural and remote regions).

For the other components, the PV modules are considered sturdy and strong enough to withstand harsh environmental conditions coming with a warranty of 10 years, an expected lifetime of more than 25 years, and normally an efficiency maintenance guarantee that ensures efficiency drop doesn't exceed 20% over the period of 25 years.

The pump normally lives for more than 8 years and can reach 14 years if well maintained. Usually it is sold with a 2 year-warranty and spare part availability.

Other than that, only occasional inspection and regular maintenance is required, at no cost, to make sure the system is doing fine and avoid losses due to dust or other residues sticking to the panel. It is essential to properly operate and maintain the pumping system to achieve high efficiency and reliable operations.

### Operation Guidelines

- The pump should be switched off when not in operation
- The pump should never run dry. This is a concern only for surface pumps. It is critical to make sure the suction is primed before turning on the pump
- The pump should be properly mounted and fixed on the base-plate to withstand vibrations and avoid unwanted noise that could also reduce the lifetime of the pump
- The pump should be used daily for at least 15 minutes to avoid problems

- Pump should be covered adequately for weather protection. In a pump pit with adequate air venting system (passive or active)
- The surface pump should be kept away from water at all times
- The pump should not be switched on and off too often. There should be at least 15 seconds between a switch off and a switch on
- The pump should never run dry
- Foot-valve should be of minimum 2” size so as to minimize suction losses
- Sharp bends should be avoided in the pipe lines to avoid unnecessary pressure drops
- Delivery and suction pipe lines should be air-tight
- In case of thunders and strong wind, panels should be kept in the zero-tilt position (applicable only for tracking systems)
- The cover of the main junction box should not be left open
- No loose wire should be un-insulated

## *Regular Maintenance*

### *Monthly*

- *Panel Cleaning:* Clean the panels regularly to avoid particles, feces, leaves, and other residues from blocking the sun. Panels can be cleaned with a plain piece of cloth with the use of some water when available.
- *Panel Inspection:* Inspect the PV panels to make sure there are no cracks or damages

### *Biannual*

- *Shadow Prevention:* Check the panels for any shadow and perform necessary trimming of trees if necessary.
- *Wiring inspection:* Check wires regularly for fraying, splitting, or damage

***Annual***

- *Valves Inspection:* Check and clean the foot-valve.
- *Electrical Components Check:* Check switches, fuse, wiring, junction box and connections.

***Biennial***

- *Pump Inspection:* For surface pumps, carbon brushes need to be checked and replaced every two years.

## THE MARKET IN LEBANON

To date, Lebanon is not an oil-producing country, remaining with high dependence on foreign resources of fuel for electricity production. This gives renewable energy and especially solar an added value and presents it as a reliable solution contributing to increasing energy security in the country and reducing energy demand.

The largest renewable energy market in Lebanon is the solar water heaters market. A market that has been developing tremendously since the beginning of this century to be ranked among the most developed markets in the world by the International Energy Agency. The solar PV market is not as developed; it only started during the past couple of years after the Ministry of Energy and Water through the LCEC launched a green loan financing mechanism with the Central Bank of Lebanon. This financing option, called NEEREA, offers individuals or institutions interested in implementing a green initiative to benefit from long term loans with very low interest rates.

As NEEREA developed, the market started growing with several companies adding solar PV solutions to their scope of work and many others being established to offer this service. Yet, there is not much done in the solar pumping sector, and most installations performed are either in the residential or institutional fields being offered as an alternative power supply source to back-up generators.

There is a handful of solar pumping projects that we are aware of to be in operation in Lebanon, but there is a significant potential for the development of this sector, especially with the frequent fluctuation of fossil fuel price and the growth of water demand in rural regions where various agricultural activities are abundant.

Table 18 presents the major socioeconomic factors that play a major role in identifying the potential for solar pumping in Lebanon.

*Table 18: Socioeconomic factors and current status in Lebanon*

| Factor | Situation |
|---|---|
| **Availability of solar radiation** | Lebanon has a total of at least 3,000 sun hours per year, with an annual average solar insolation of more than 2,200 kWh/m$^2$, and a daily global sunny period of more than 4.8 kWh/m$^2$. |
| **Suitability with agricultural needs** | Water for agricultural use is needed most during the summer season. This is the period where the solar insolation peaks making solar pumping a very practical solution |

Having a wider look at the market, there are several barriers that are hindering the development of solar pumping in Lebanon that need to be resolved. This includes market-related, technology-related, and regulatory barriers.

*Table 19: Major barriers and potential solutons for solar pumping in Lebanon*

| | Barrier | Solution |
|---|---|---|
| **Market** | High Capex | Governmental subsidies |
| | Low awareness among consumers | Awareness campaigns |
| | Insufficient technical support | Capacity building |
| | Lack of market information | Provision of adequate market data |
| | Danger of theft | Community owned security |
| **Regulatory** | Restricted financial engineering | Innovative policies and financial engineering |
| | Lack of market-oriented policies | Support policies at the government level |
| **Technology** | No standardization & quality control | Enforce standards and follow up on quality |
| | Lack of local manufacturers | Support of local content |

# CASE STUDIES

## *150hp Irrigation Solar Pumping in Dair Al Ahmar*

| | |
|---|---|
| **Application** | Irrigation (50 ha potato) |
| **Location** | Deir Al Ahmar – Bekaa |
| **PV Power** | 146 kWp |
| **Number of Modules** | 576 |
| **Type of Modules** | Polycrystalline 250W |
| **Collection Area** | 990 $m^2$ |
| **Type of Pump** | Submersible |
| **Water Depth** | 250 m |
| **Pump Size** | 150 hp |
| **Flow** | 100 $m^3/h$ |
| **Water Demand** | 4,800 $m^3$ |
| **Storage Volume** | No Storage |
| **Daily Water Supply** | 1000 $m^3$ |
| **Approximate Budget** | $330,000 |
| **Financing** | NEEREA |
| **Date of commissioning** | November 2014 |
| **Contractor** | GREENESSENCE LEBANON |

## *70hp Village Supply Solar Pumping System in Keb Elias*

| | |
|---|---|
| **Application** | Water supply |
| **Location** | Keb Elias – Bekaa |
| **PV Power** | 81 kWp |
| **Number of Modules** | 324 |
| **Type of Modules** | Polycrystalline 250W |
| **Collection Area** | 534 $m^2$ |
| **Type of Pump** | Submersible |
| **Water Depth** | 180 m |
| **Pump Size** | 70 hp |
| **Flow** | 110 $m^3/h$ |
| **Water Demand** | 800 $m^3$ |
| **Storage Volume** | 1,500 $m^3$ |
| **Daily Water Supply** | 800 $m^3$ |
| **Approximate Budget** | $133,000 (including pump) |
| **Financing** | OTI Lebanon / USAID |
| **Date of commissioning** | September 2014 |
| **Contractor** | acemco; SOLSTICE SOLAR POWER GENERATOR |

## *30hp Irrigation Solar Pumping in Younin*

| | |
|---|---|
| **Application** | Drip Irrigation (17 ha fruit trees) |
| **Location** | Younin – Bekaa |
| **PV Power** | 30 kWp |
| **Number of Modules** | 120 |
| **Type of Modules** | 250W Mono |
| **Collection Area** | 200 $m^2$ |
| **Type of Pump** | Submersible AC (existing) |
| **Water Depth** | 100 m |
| **Pump Size** | 30 hp |
| **Flow** | 46 $m^3$/h |
| **Water Demand** | 370 $m^3$ /day |
| **Storage Volume** | No storage |
| **Daily Water Supply** | 345 $m^3$ /day during summer |
| **Approximate Budget** | $64,000 |
| **Financing** | NEEREA |
| **Date of commissioning** | October 2013 |
| **Contractor** | Elements |

## *10hp Village Supply Solar Pumping System in Terbol*

| | |
|---|---|
| **Application** | Water supply |
| **Location** | Terbol – Bekaa |
| **PV Power** | 10 kWp |
| **Number of Modules** | 40 |
| **Type of Modules** | Polycrystalline 250W |
| **Collection Area** | 66 $m^2$ |
| **Type of Pump** | Submersible AC (Existing) |
| **Water Depth** | 180 m |
| **Pump Size** | 10 hp |
| **Flow** | 3.8 $m^3$/h |
| **Water Demand** | 13 $m^3$/day |
| **Storage Volume** | 130 $m^3$ |
| **Daily Water Supply** | 13 $m^3$/day |
| **Approximate Budget** | $18,000 |
| **Financing** | UNDP Lebanon |
| **Date of commissioning** | November 2014 |
| **Contractor** | Elements |

# APPENDIX I: TECHNOLOGY PROVIDERS IN LEBANON

| Company Name | Service provided* | | | | Website |
|---|---|---|---|---|---|
| | D | S | I | M | |
| **Acemco** | ✓ | ✓ | ✓ | ✓ | www.acemco.com.lb |
| **Albina** | ✓ | ✓ | ✓ | ✓ | www.albinagroup.com |
| **ASACO** | ✓ | ✓ | ✓ | ✓ | www.asacogtc.com |
| **Dawtec** | ✓ | ✓ | ✓ | ✓ | www.dawtec.com |
| **Earth Technologies** | ✓ | ✓ | ✓ | ✓ | www.earthtechnologies.com.lb |
| **Ecosys - Midware** | ✓ | ✓ | ✓ | ✓ | www.itgholding.com |
| **EEG** | ✓ | ✓ | ✓ | ✓ | www.eegroup.info |
| **Elements Sun & Wind** | ✓ | ✓ | ✓ | ✓ | www.elementssw.com |
| **Green Arms** | ✓ | ✓ | ✓ | ✓ | www.greenarms.co.uk |
| **Green Essence** | ✓ | ✓ | ✓ | ✓ | www.greenessencelebanon.com |
| **Panoramic Solar** | ✓ | ✓ | ✓ | ✓ | www.panoramic.ws |
| **SIG** | ✓ | ✓ | ✓ | ✓ | www.saleminternationalgroup.com |
| **Solar Wind ME** | ✓ | ✓ | ✓ | ✓ | www.solarwindme.com |
| **Solar World** | ✓ | ✓ | ✓ | ✓ | www.solarworld.com.lb |
| **Solarnet** | ✓ | ✓ | ✓ | ✓ | www.solarnet-online.com |
| **Yelloblue** | ✓ | ✓ | ✓ | ✓ | www.yelloblue.com |

* D: Design S: Supply I: Installation M: Maintenance

## REFERENCES


[1] ScoutHub, LLC. (2014). Pump Applications. Retrieved December 17, 2014, from http://www.pumpscout.com/all-pump-applications/

[2] Bhavnagri, K. (2010, January 21). Solar Trackers. Retrieved January 3, 2015, from http://www.solarchoice.net.au/blog/solar-trackers/

[3] Solar-Powered Water Pumping Systems for Livestock Watering. Agriculture and Agri-Food Canada.

[4] Gleick, P. (1996). Basic Water Requirements for Human Activities: Meeting Basic Needs. *Water International, 21*, 83-92.

[5] Moore, A. System Information and Sizing Guide. Retrieved from http://www.solarwater.com/well-pump-sizing-guide.htm

[6] Jenkins, T. (December 2014). Designing Solar Water Pumping Systems for Livestock. *Cooperative Extension Service - Engineering New Mexico Resource Network*.

[7] Morales, T., & Busch, J. (2010). *Design of Small Photovoltaic (PV) Solar-Powered Water Pump Systems* (Technical Note No. 28). Portland, Oregon: Natural Resources Conservation Service.

[8] Lebanon Solar Data (Solar Med Atlas). http://www.solar-med-atlas.org/

[9] Institute of Energy and Transport. (Photovoltaic Geographical Information System (PVGIS)). http://re.jrc.ec.europa.eu/pvgis/

[10] Vallvé, X. (2013). *Photovoltaic Plants in Lebanon*. Beirut: CEDRO - UNDP.

[11] Photovoltaic (PV) Pumping. (2014, October 6). Retrieved January 8, 2015, from https://energypedia.info/wiki/Photovoltaic_(PV)_Pumping

[12] Emcon. (2006). *Feasibility Assessment for the Replacement of Diesel Water Pumps with Solar Water Pumps*. Windhoek, Namibia: UNDP.