TOOLBOX ON SOLAR POWERED IRRIGATION SYSTEMS (SPIS)

POWERING AGRICULTURE:
AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

Module 1: Get Informed

Food and Agriculture Organization of the United Nations
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ABBREVIATIONS

Ah	Ampere hour
CWR	Crop Water Requirement
DC/AC	Direct Current / Alternating Current
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
Gd	Daily Global Irradiation
GIZ	Gesellschaft für Internationale Zusammenarbeit
GIWR	Gross Irrigation Water Requirement
GPFI	Global Partnership for Financial Inclusion
HERA	GIZ Program Poverty-oriented Basic Energy Services
H_T	Total Head
IEC	International Electrotechnical Commission
IFC	International Finance Corporation
IRR	Internal Rate of Return
IWR	Irrigation Water Requirement
MPPT	Maximum Power Point Tracking
NGO	Non-Governmental Organization
NIWR	Net Irrigation Water Requirement
NPV	Net Present Value
m^2	square meter
PV	photovoltaic
PVP	Photovoltaic Pump
SAT	Side Acceptance Test
SPIS	Solar Powered Irrigation System
STC	Standard Test Conditions
TC	Temperature Coefficient
UV	Ultraviolet
Vd	Daily crop water requirement
W	Watt
Wp	Watt peak

GET INFORMED

1. An overview to solar and irrigation
2. Solar generator
3. Mounting structure
4. Controller and inverter
5. Water pump
6. Monitoring system
7. Reservoir
8. Irrigation head
9. Fertigation system
10. Irrigation system

MODULE AIM & ORIENTATION

Due to significant advances in technology and drops in prices for solar panels, solar pumps have become an economical, technically and environmentally viable alternative to conventional pumping systems.

Nevertheless, few people are aware of the potential and risks associated with solar pumping for irrigation. Often the solar pump is not optimally integrated into the irrigation system, which results in inefficiencies. Consequently demand amongst producers is low and the reluctance of financial institutions to finance them is high.

The **GET INFORMED** module provides essential information for agricultural advisors and financial service providers to understand the operating principle of SPIS and to differentiate between the individual system components. Moreover, it starts to describe how the different configurations of the components can influence the performance of the entire system. The **GET INFORMED** module will allow agricultural and financial service providers to support potential users of SPIS with up-to-date information on the pros and cons of the technology and its individual components.

BRIEF DESCRIPTION OF THE MODULE

Compared to conventional energy systems, the use of solar energy has some specific characteristics, which must be considered when planning a Solar Powered Irrigation System (see **DESIGN** module).

The following steps describe in detail the available configurations and individual system components of an SPIS operating under constantly varying conditions due to daily and seasonal fluctuations.

The description of the individual components of an SPIS and the relations between them are preceded by information on the basics of solar energy and irrigation. When solar energy and irrigation are combined in one production system we call this a Solar Powered Irrigation System. Typical configurations of SPIS are presented in this module and in the **DESIGN** module.

1. AN OVERVIEW TO SOLAR AND IRRIGATION

THE SOLAR ALTERNATIVE

If traditional pumping technologies, such as manual or animal-powered pumps, reach their technical limits, the customary means of pumping irrigation water are diesel-, gas- or petrol-driven pumps. Such conventional pumps, however, have the double drawback of requiring a lot of maintenance as well as a regular supply of fuel and physical attendance for operation. Particularly in remote areas of developing countries, access to spare parts, maintenance structures or fuel can be limited, leading to frequent outages of several days or longer.

The resulting lack of water can result in yield reduction or failure, and thus poses a great risk for the agricultural enterprise.

In non-electrified parts of the world, solar energy could help to provide access to an environmentally sound and reliable energy supply. Especially in developing countries, the perspective of grid extension and the establishment of a reliable, uninterrupted electricity supply into rural areas is still a remote prospect. Rural electrification in economically weak rural areas of Africa, Asia and Latin America will be largely based on investments into local off-grid solutions for basic consumptive household electrification, with little consideration for productive uses of energy.

Access to electricity wherever the sun shines

(Source: Lennart Woltering)

With the right knowledge on proper operation and maintenance of solar photovoltaic pumps, failures are much less likely than with conventional pumping systems.

Solar pumps for irrigation have been gaining importance since 2010. India, for example, has a large SPIS technology market. There are more than 12 million electric and 9 million diesel irrigation pump sets in operation to provide water for about 39 million hectares of irrigated land. If only 50% of these diesel pumps were replaced with solar PV pump sets, diesel consumption could be reduced in this area to about 225 billion liters per year.

But there are more advantages to the environment. A solar system that replaces a typical diesel generator unit will save about 1 kg of CO_2 per kilowatt hour of output. This already takes emissions during the lifecycle of the PV system into account. Moreover, PV-powered water pumping also helps to avoid the danger of soil and ground water contamination with fuels and lubricants. A diesel engine produces about 300 kg of waste oil over its lifetime. An environmentally sound disposal of this waste is not guaranteed everywhere. On the other hand, due to the unlimited supply of sun for pumping, there is a risk of over-pumping surface and groundwater resources if systems are not adequately sized and planned (see SAFEGUARD WATER module).

Old diesel pump

(Source: Andreas Hahn, 2015)

PV-experienced farm worker

(Source: Andreas Hahn, 2015)

SPECIFICS OF SOLAR ENERGY

Solar radiation

Solar energy has some specific characteristics that must be considered when planning a Solar Powered Irrigation System. Solar radiation captured by a solar panel is never constant due to daily and seasonal variations of solar radiation. The intensity of solar radiation on a surface is called irradiance (S). The irradiance is measured in watts per square meter [W/m^2].

Solar irradiance varies over the course of the day, with maximum values of about 1,000 W/m^2 on a horizontal surface at sea level around noon on a clear day. The energy carried by radiation on a surface over a certain period of time is called global solar radiation (G). The global solar radiation is location-specific as it is influenced by cloud, air humidity, climate, elevation and latitude, etc. The global solar radiation on a horizontal surface is measured by a network of meteorological stations all over the world and is expressed in kilowatt hours per square meter [kWh/m^2].

Tilt angle

Most solar panels are installed with a fixed tilt angle "α" to increase the energy yield. Tilt angle is site-specific and has to be calculated. This can easily be done with the help of software tools such as the meteorological data base METEONORM, which provides climate data for almost every location in the world. A quick estimate of the right tilt angle α can be established when looking at the latitude in which the pumping system is installed.

Typical values for the tilt angle can be estimated to:

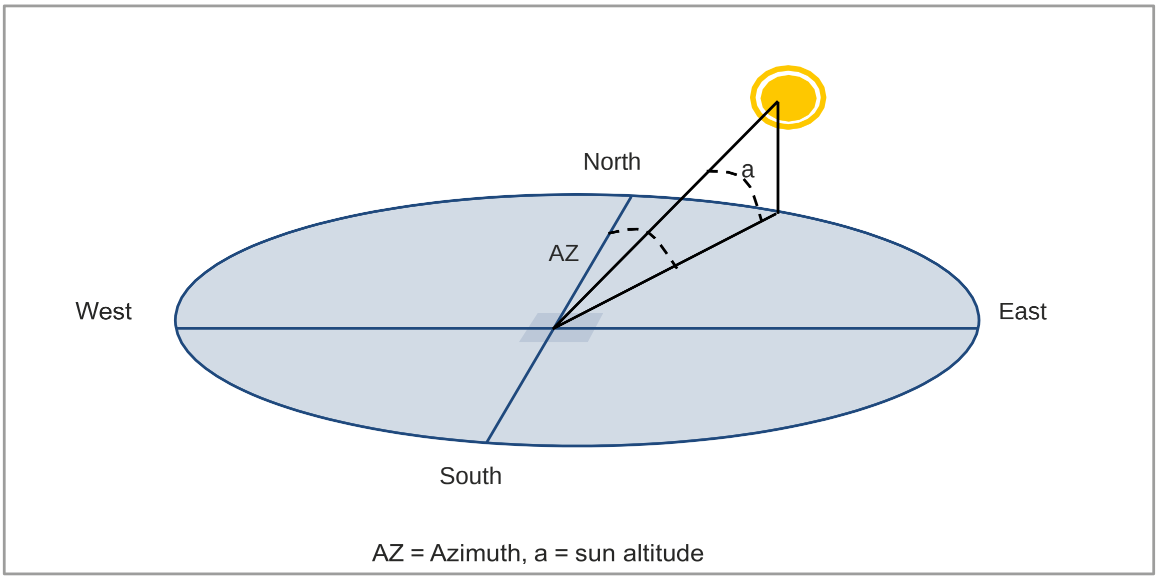
α = absolute value of geographic latitude + / - 10º

To allow rain water and accumulated dust to run off the panel surface, the tilt angle should be at least 15°, even if the system is installed close to the equator. To focus the applications in winter months, the tilt angle might be increased up to +10º, for summer months, the tilt angle might be reduced up to -10º.

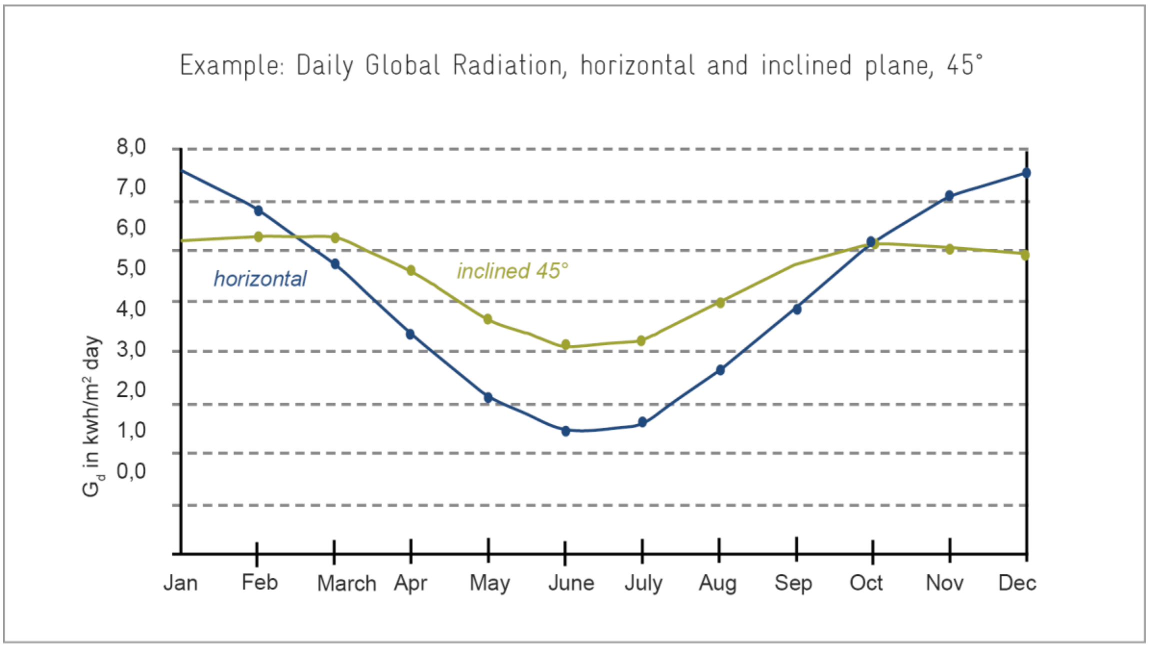
Orientation of the solar generator

In the northern hemisphere, the panels should be facing south to maximize the energy yield, whereas in the southern hemisphere, panels should be facing north. Deviations from true north/south are possible but will result in a reduced overall energy yield.

Another method to further increase the energy yield of a solar generator is solar tracking (see Chapter 2).



Daily movement of the sun in southern hemisphere
(Source: Reinhold Schmidt 2012)



Change of global radiation over the course of the year on a horizontal and tilted surface

(Source: Reinhold Schmidt, Aplicaciones de Energía Solar Fotovoltaica; Diseño, Implementación, Experiencias, June 2012)

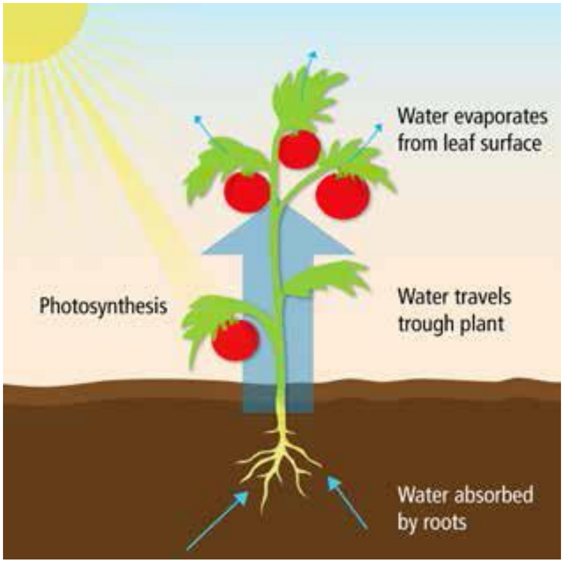
IRRIGATION PRINCIPLES

Irrigation is the controlled application of water to respond to crop needs. Water used for irrigation may be taken from nearby lakes, reservoirs, rivers or wells (groundwater), but also from non-conventional sources such as treated wastewater, desalinated or drainage water. Irrigation water is brought to cultivated land by pipes, hoses or ditches.

Producers who irrigate are less dependent on irregular rainfall for their production. Producers can supplement rainfall with irrigation to respond to the amount of water the crop needs. Moreover, control over water improves the efficiency of other yield-improving inputs such as fertilizers and plant protection products. Consequently, the producer's ability to control the yields is enhanced. This is important for stable productivity and integration into markets.

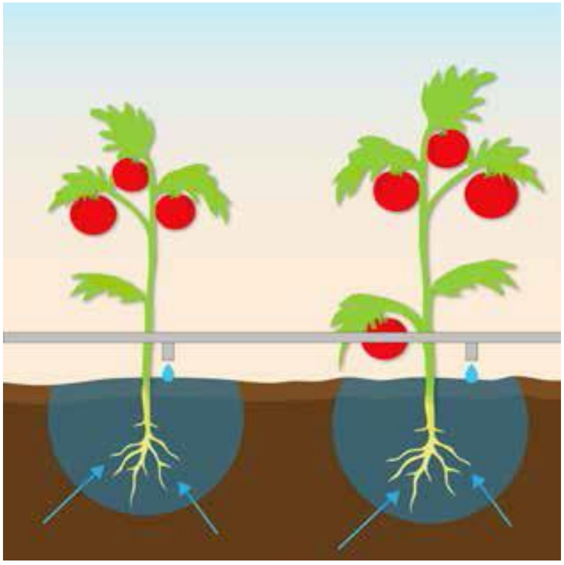
By irrigating, the soil water storage in the plant root zone is replenished. Instigated by the sun and photosynthesis, plants abstract soil moisture with their roots. This triggers a nutrient flow through the stem to the leaves, from where the water is **transpired** back to the atmosphere. Thus, only the water that is taken up through the root system contributes to plant and fruit growth.

Important: Most of the water that is brought to the field via irrigation should concentrate around the root zone of the plant and the volume of water irrigated should not exceed the plants' ability to absorb it.



Photosynthesis turns the energy of sunlight into chemical energy that triggers a nutrient flow in the plant.

(Source: GFA)



In a drip irrigation system, water is delivered directly to where it is needed, the root zone.

(Source: GFA)

WATER REQUIREMENTS

The amount of water needed by a plant is expressed as Crop Water Requirement (CWR). It depends on the climate, the crop as well as management and environmental conditions. In sunny, hot, dry and windy places the CWR is highest. The crop species, variety and growing phase determine how much water the roots need to take up to enable the plant to grow optimally. Producers can reduce the crop water requirement e.g. through mulching, changing the plant density and applying different irrigation technologies.

The CWR of a particular crop is thus very site-specific and varies day by day. It requires on-site, regional data collection e.g. with support from local extension services, to calculate the CWR (see **DESIGN** module). CWR is most often expressed in millimeters (mm), or cubic meters per hectare (m^3/ha). Normally crops require about 2 to 10 m^3 per hectare daily. Details of this assessment are described in the **DESIGN** module.

It is important to note that water is a priced commodity (water fees, pumping costs) and a scarce resource as other users compete for it (industry, energy, domestic consumption, etc.). This should be considered in financial and ecological feasibility assessments.

IRRIGATION EFFICIENCY

When irrigating, it is important to apply the right amount of water at the right time. Too little water will lead to wilting and yield reduction. Too much water can lead to water waste, runoff and erosion as well as leaching of nutrients in the soil and salinization, ultimately leading to yield reductions. A 100% efficient irrigation system would provide an equal amount of water to all plants in the field. However, e.g. plants close to the water source tend to get more water than plants at the far end of the field. As a result, yields of the farm are compromised because some plants get too much water and some get too little water. On big farms, this can have serious consequences on operating expenses and management of water resources. The uniformity of distribution of water over the field is determined by the choice of irrigation technology. The three commonly used irrigation methods are:

- surface irrigation;
- sprinkler irrigation;
- drip irrigation.

Surface irrigation methods such as basin, furrow and border irrigation do not achieve more than 60% field application efficiency as only a limited amount of water actually reaches the root zone.

Sprinkler and drip irrigation systems rely on a network of pipes to distribute the water to the field, thereby reducing conveyance losses common for surface irrigation methods. Sprinkler systems achieve an average field application efficiency of 75%, while drip irrigation systems can go up to 95% uniformity. Drip irrigation allows a slow release of water at the plant’s root zone. As a result, soil moisture conditions are good, and no water is “lost” between plants, or on the plants. Crop yields can be doubled, and significant savings can be made in water, energy and labor.

SOLAR POWERED IRRIGATION SYSTEMS

Using solar energy for irrigation makes a lot of sense. First, irrigation is often implemented in rural areas with poor access to reliable electricity or fossil fuel supplies. Second, solar radiation is an abundant resource in many developing countries where irrigation is essential to food security and international trade. Finally, Solar Powered Irrigation Systems (SPIS) passively self-regulate because the volume of water pumped increases on clear hot days when plants need more water, and vice versa. It is important to note that a SPIS is more than just a solar pump used for irrigation. Panels, pumps and irrigation systems are designed on the basis of water availability and local crop water requirements. SPIS is a system where the different components, from pump to plant, are integrated and harmonized.

Operating Principle

The operating principle of an SPIS is simple. A solar generator provides electricity for an electric motor pump, which delivers water either directly into an irrigation system or to an elevated reservoir. Fundamental design criteria for SPIS include minimum maintenance, maximum reliability as well as resource efficiency. A specific characteristic of SPIS is the fact that generally a battery back-up is not required. This is an advantage since batteries are maintenance-intensive, costly and require regular replacement.

SPIS components

The individual components of a SPIS are introduced in the following sections. The table below shows that, depending on site-specific conditions and capacities of the farmer, different technology options are available. The components and alternative technologies can be combined with each other in a wide range of ways, but some configurations are better depending on the situation in the field.

Major alternative technologies for the most important components of an SPIS

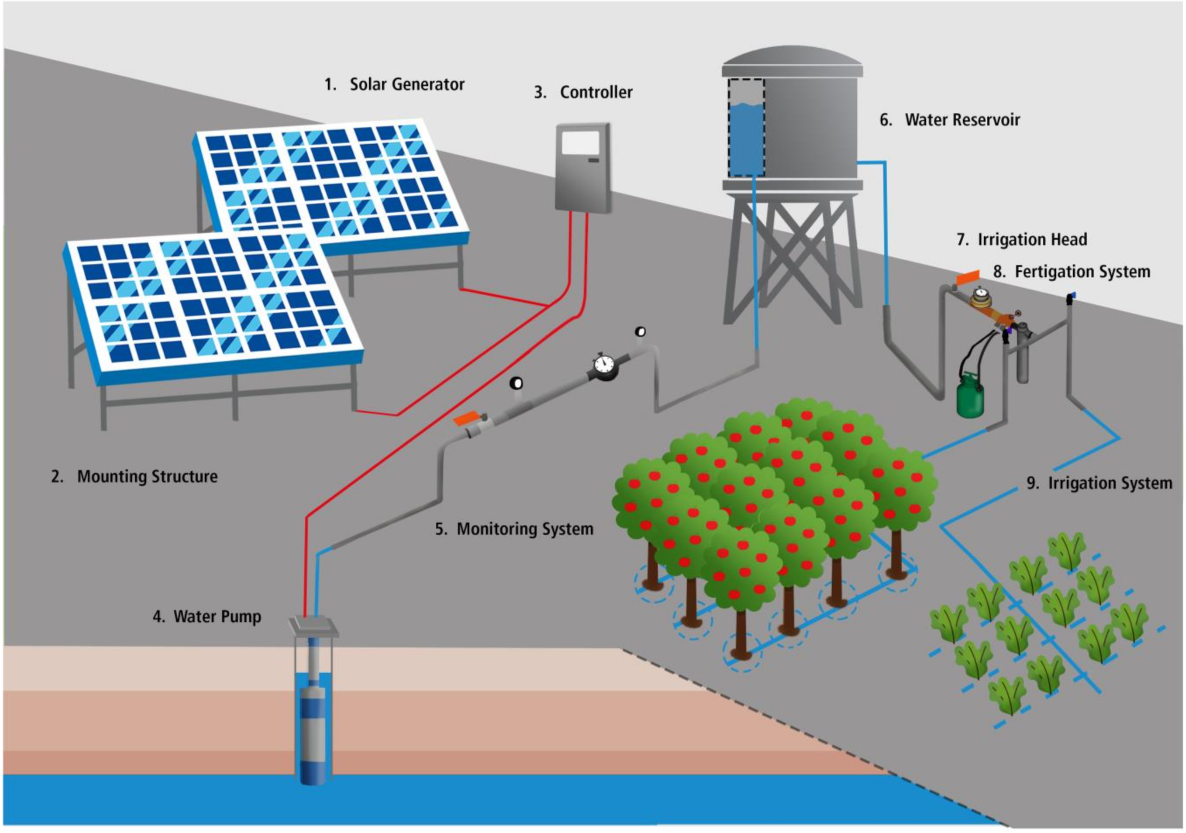
Component	Alternative technologies		Dependent on:
Solar system	fixed	tracking	costs and maintenance intensity
Pump	surface	submersible	costs and (geo-)hydrology
Reservoir	reservoir	no reservoir	costs and irrigation system
Irrigation system	surface	drip or sprinkler	costs and pumping system

SPIS configurations

The most common SPIS configuration is when a solar generator on a fixed mounting structure provides electricity for a submersible pump installed in a borehole. The water is then pumped to a reservoir elevated a few meters above the field. The water is stored at a constant pressure and released to a low pressure drip irrigation system where the water is filtered and mixed with fertilizer before it is slowly released to the plants. This configuration is shown in the figure below.

However, the installation of the water filter on the exit/output side of the tank can be critical/problematic, as the pressure losses in the filter can easily reach/be several meters, and then, at low tank heights, there is no water flowing any longer. Therefore it is recommendable to install the filter on the inpute side, to keep the water clean in the tank.

This configuration would also be possible with a tracking system, but would require higher investment and more maintenance than a fixed mounting of the solar panels. The reservoir provides stable pressure and water supplies to the drip irrigation system in order to make water distribution as uniform as possible. The performance of drip irrigation decreases when the drippers get clogged by small particles in the water. Filters prevent this, but only when properly designed for the particular water quality and irrigation system, and only when regularly cleaned. Therefore, it is strongly recommended to use drip irrigation only in combination with groundwater as groundwater is generally cleaner than water from rivers or reservoirs. Furthermore, it is recommended to have a monitoring system installed between the pump and the reservoir to measure the water flow and pressure.

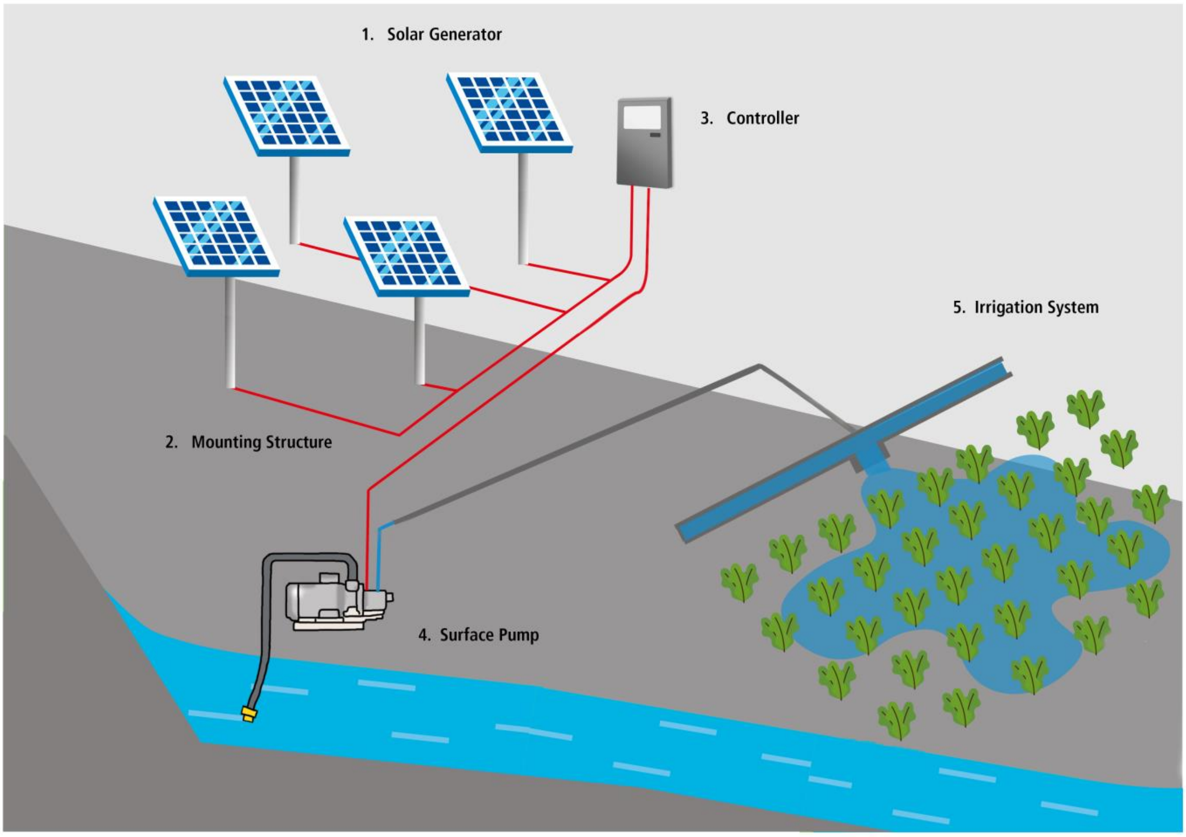


Best-practice configuration of the different components of an SPIS

(Source: GFA)

The simplest SPIS configuration is when a solar generator on a fixed mounting structure provides electricity for a surface pump installed at a reservoir or river. The water is then pumped directly to a surface irrigation system, e.g. through a network of open canals. In this configuration the pumped water does not pass through an elevated reservoir. The pressure and pump flow to the irrigation system corresponds to the actual solar irradiance, which varies over the course of the day, especially with a fixed mounted solar generator. The main advantage of this configuration is the simple installation and relatively low costs. However, the disadvantage is that the producer has little control on the distribution of water in the field over the day as there is no reservoir that regulates flow and pressure. The producer will have to use volumetric valves (see IRRIGATION HEAD) or divide his field into manageable sub-sections to control the watering of the crops as best as possible.

Another configuration to be found in the field is a **hybrid** solution, where a solar-powered pump and a diesel pump are both used for irrigation.



Simple configuration – with a tracking system – of the different components of an SPIS (Source: GFA)

2. SOLAR GENERATOR

The solar generator provides the energy needed to operate the motor pump unit. It is made up of a set of solar panels that consist of individual solar cells. The individual solar cells make use of what is known as the photovoltaic effect, which converts light directly into electricity. Solar cells are made of specially prepared semiconductor materials such as crystalline silicon. When light falls onto the surface of the semiconductor, an electric field develops. This works best with the sun shining directly on the cells, but it also works with indirect solar radiation. On a cloudy day, solar panels can typically produce 10–25% of their rated capacity. By connecting a wire to the back of the solar cell, the voltage of the electric field causes an electric current to flow.

The solar cell

To protect the cells against mechanical stress and humidity, the cell strings are embedded in a transparent bonding material (e.g. EVA), which also insulates the cells electrically. For structural stabilization and electrical insulation, they are usually placed between a plastic cover on the rear side and a glass cover on the front side. The laminate is then protected by an aluminum frame, which allows the panels to be mounted on a mounting structure.

Solar panels are usually certified by the International Electronical Commission[1] and this approval certificate has become generally accepted worldwide as one of the quality marks for solar panels. IEC standard testing, however, does not assess the durability of solar modules over a 25 year period. Standard panels typically come with a 10 year product guarantee and a linear 25 year performance warranty that guarantees at least 80% power output by the end of the 25th year.

Note: Solar panels are rated in peak watts (Wp) according to their output under internationally defined Standard Test Conditions (STC):

(Irradiance = 1,000 W/m², cell temperature = 25°C, air mass (AM) = 1.5)

The panels' electrical power mainly depends on the solar irradiance captured by the panel and the solar cell temperature. Solar cell temperatures increase significantly under normal operation and may easily reach 40 to 65 ºC, depending on the site-specific conditions. This leads to a lower electrical power output as compared to STC. The temperature coefficient (TC) describes the power reduction for each ºC increase in temperature, and for crystalline silicone cells it is approximately -0.5% per ºC.

A set of solar panels are connected to each other in series, parallel or a combination thereof, depending on the required electrical output (voltage, current and power). Combining solar panels in series means connecting the positive terminal of one panel to the negative terminal of the next panel. It allows you to build up the voltage to the level you need (as opposed to parallel wiring, which allows you to increase current/amperage).

[1] IEC – International Standards and Conformity Assessment for all electrical, electronic and related technologies.

3. MOUNTING STRUCTURE

In addition to the irradiance and cell temperature, the output of a solar panel is also dependent on the orientation and tilt angle of the panel surface. To maximize the output, a site-specific optimal orientation has to be found.

Mounting options:

There are basically two alternatives to mount solar panels on a metal structure:

- installation with a fixed tilt angle;
- installation on a solar tracker with varying orientation.

The fixed installation of solar panels on a rigid structure is the cheapest, most reliable and most common method. Metal supports that are pile-driven into the ground are generally recommended for larger systems. They make the utilization of concrete foundations redundant and save labor and material cost. However, in developing countries, simple concrete foundations are often used for smaller installations and represent an appropriate solution, provided that static requirements are met. The installation is typically oriented north or south to have a relatively good distribution of the output over the course of the day.

When the orientation of the mounting structure is variable over one or two axes, this is referred to as a **solar tracker** (see figure on the next page).

Solar tracking has two advantages:

- gain in additional solar radiation – the amount of solar radiation received by the solar panels increases between 25–35% (annual mean value), depending on solar tracker type and installation site.
- even distribution of solar irradiance throughout the day – the generated electricity and thus the pump's water flow is almost constant over the day. This is important in an SPIS configuration where the water is pumped directly to the field without passing through a reservoir.

Disadvantages of solar tracking:

- solar tracking is costly and substantially increases the overall system cost;
- the mechanical parts and the electrical motor of the tracking system require regular maintenance and spare parts.

This has to be kept in mind in particular for installations that are planned for remote areas or areas with limited technical services.

An interesting alternative to solar tracking can be **installations oriented in east and west directions,** which are relatively new. However, it requires more panels to get a stable output over the day. But with falling panel prices, this might be an interesting alternative for remote areas and smaller systems, as they are cheaper and require much less maintenance (as solar tracking solutions).

For both mounting options it is important to avoid galvanic corrosion when connecting metal structures. This can be done by selecting materials with similar corrosion potentials or by breaking the electrical connection by insulating the two metals from each other.

Mounting structure and theft

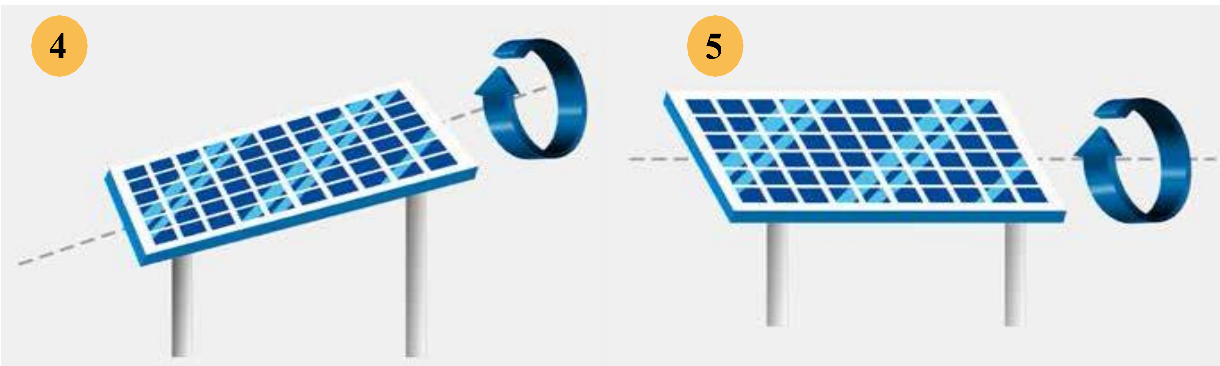
The type and the quality of the mounting structure are also a determining factor with regard to the risk of theft of the PV panels. With the increased application of photovoltaic installations for electricity generation the risk of theft is increasing. Common theft-prevention measures include:

- use of lock tie nuts;

- spraying the owner's ID with non-removable spray paint onto the back of the panels;
- integrating the solar panels into the mounting structure (non-detachable);
- placing the mounting structure out of easy reach by using elevated structures, fences or floating PV systems.

Solar systems (Source: Reinhold Schmidt, 2015):

1. fixed installation
2. one axis tracker, azimuth
3. two axis tracker azimuth and inclination
4. one axis tracker, south + north axis incline
5. horizontal one axis tracker, south/north axis.



4. CONTROLLER AND INVERTER

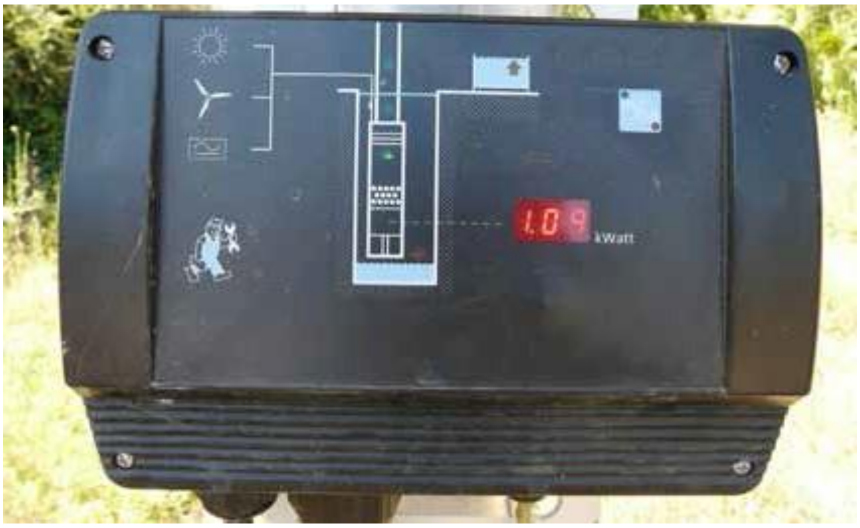
Controller

The controller is the link between the solar generator and the motor pump and is essential for system reliability. It adjusts the fluctuation in the output frequency of the solar generator resulting from varying irradiation levels. Modern controllers incorporate highly efficient power electronics and utilize Maximum Power Point Tracking (MPPT) technology to maximize power use from the solar generator. The controller regulates the number of revolutions of the motor and protects the pump against over and under voltage, reverse polarity, overload and over-temperature.

Inverter

Solar generators always provide DC current. Most electric motors of solar water pumps are powered by direct current (DC). Since DC motors usually have a higher efficiency than AC motors of a similar size, they tend to be preferred by solar pump manufacturers. Water-filled brushless DC motors in particular are gaining importance because they are maintenance-free and are not affected by frequent starts/stops that are typical of solar-powered systems.

Some solar pumps are still equipped with comparably cheap brushed DC motors. The main disadvantage of brushed motors is that brushes are subject to wear and tear and need to be replaced at regular intervals (approximately every two years). DC motors are mainly used for small to medium-sized irrigation schemes, while AC motors are gaining importance in applications where higher output/head combinations are required. The controller has to have an inverter if the pump is AC. Innovations in DC/AC inverter technology have led to the development of specially designed pump inverters that can drive conventional AC motors. Non-compatible inverter/motor combinations may reduce the expected lifetime of the conventional AC motor. Therefore, well matched and tested controller/motor combinations are recommended to increase system reliability.



Controller with display and LED fault indicator

(Source: Andreas Hahn, 2015)

5. WATER PUMP

Depending on the water source, there are two different possibilities for pump installation – submersible or surface. Surface pumps are often installed next to the water source and suck water up on one side before "pushing" it away on the other side of the pump. Surface pumps can pump water up from a maximum depth of six meters. Submersible pumps are installed under water in wells and boreholes and "push up" the water.

Submersible pumps are installed at depths ranging from 10 to 120 meters. Using control switches (such as float switches in water tanks and wells), submersible pumps can be operated in automatic mode. In contrast, surface mounted pumps usually require the attendance of an operator who regularly checks the surface pump's priming behavior. Use of primary chambers and non-return valves can prevent loss of prime.

Surface pumps have several advantages if compared to submersible ones: they are cheaper, can be easier installed and accessed for maintenance and can be used for an easy/simple fertigation at the suction/intake side.

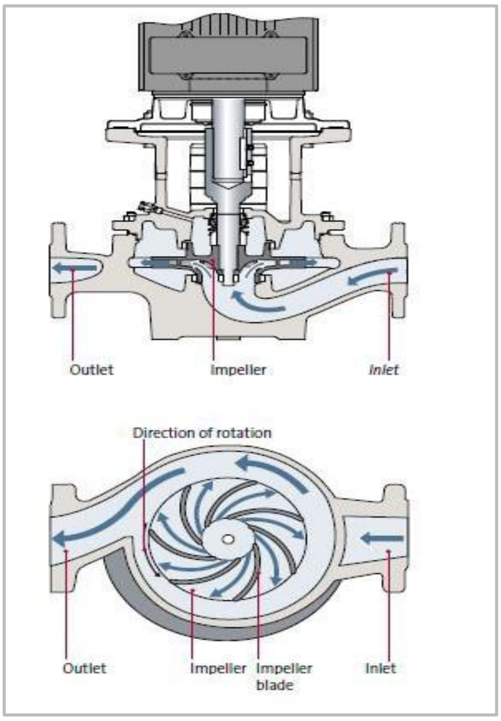
Solar water pumps are generally constructed from non-corrosive stainless steel and are designed to pump clean water without any solids and fibers. The lifetime of a submersible motor pump strongly depends on the water and installation quality. If the pump is installed in a drilled well with a proper well casing (and thus reduced sediment intrusion), submersible pumps may reach lifetimes between 7–10 years. In very poorly constructed wells and boreholes with high sediment content, the hydraulic part of the water pump may have to be replaced after 2–3 years. In order to secure a safe system operation, two safety means are necessary:

- water level sensor installed in the storage tank that switches off the pump in order to avoid overflow;
- second water level sensor installed towards the base of the well to avoid dry running of the pump.

There are two types of pumps to be typically found in today's solar pumping systems: centrifugal and helical rotor pumps.

Centrifugal pump

A centrifugal pump creates an increase in pressure by transferring mechanical energy from the motor to the fluid through the rotating impeller. The fluid flows through the inlet to the impeller center and out along its blades. The centrifugal force increases the fluid velocity and consequently the kinetic energy is transformed to pressure. The pressure can be increased by simply adding several stages in series. Centrifugal pumps are generally utilized where pumping heads are low and water demand is high. For this reason centrifugal pumps are the preferred option for use in irrigation systems.



Centrifugal pump

(Source: Grundfos).

Helical rotor pump

A helical rotor pump is a type of progressive cavity pump that works by the rotation of a helical rotor when sealed against a helix wall, pushing discrete sections of material through the device.

This corkscrew-like action provides a pulse-free flow, and valves are not required as the helical rotor seals the discrete sections of material. The flow rate is determined by the rotor speed and is independent of outlet pressure. Helical rotor pumps are typically found in applications with high pumping heads and low water flow rates, such as for drinking water supply.

Surface pump on a mobile structure
(Source: Lennart Woltering)

6. MONITORING SYSTEM

Operated by the producer on-site or on-line, the monitoring system allows readings of pressure, water flow and water level and helps to assess the performance of the system.

It is used

- to observe and track the system's operation and performance;
- to control pumping quantities to the irrigation system;
- to provide system data for the acceptance test after installation
- to avoid negative environmental impacts (e.g. ground water depletion).

Ultimately, monitoring is important to ensure that the system operates within sustainable limits for long-term productivity of the farm.

Some solar pump manufacturers have included monitoring systems in their product portfolios. Each SPIS should have a basic monitoring system comprising pressure gauges, a flow meter and a water level dipper. The water level dipper is a simple tool to check the water level in a well. Once the metal electrode reaches the water table, a light will flash and the exact value can be read from the dipper tape. Checking the water level several times over the course of the day gives an indication on the dynamic behavior of the well. The dynamic water level is an important parameter to determine the total pumping head (refer to **DESIGN** module).

Especially in cases where the water is pumped directly to the irrigation system without passing through an elevated reservoir, it is important to monitor water flow and pressure in the irrigation system as the amount of water delivered to plants may vary widely across the field. The picture below displays a monitoring system, which is composed of a water flow meter and pressure gauges on each side of the filter, which allow the monitoring of the pressure loss through the filter.

A more sophisticated monitoring system would include sensors to measure

- solar irradiance (e.g. on horizontal and inclined surface);
- rainfall, relative humidity and wind speed;
- the total pumping head.

Monitoring system

(Source: Reinhold Schmidt, 2015)

In addition, the monitoring system can be expanded with sensors in the reservoir and in the irrigation system itself.

More sophisticated (and expensive) monitoring devices may include automatic data logging. The data logger continuously records and stores all system parameters over a longer period of time. Special evaluation software allows for quick data analysis on site. In remote areas not connected to the public grid, data loggers are usually solar-powered and may even include modern communication devices (GSM) with the option of checking system performance via smart phones (also refer to the **MAINTAIN** module).

7. RESERVOIR

A reservoir can have several functions for an irrigation system: it can accumulate and store water pumped in over the day, it can provide pressure for the irrigation system to distribute the water to all corners of the field and, in small drip irrigation systems, it can be used to mix in soluble fertilizers. Since the output of solar pumps varies over the day as a result of irregular solar radiation, a reservoir can be useful to buffer the water amount available for irrigation.

Elevated tank

(Source: Andreas Hahn)

There are numerous ways to store water, ranging from simple open dug reservoirs, concrete and plastic tanks to expensive elevated metal tanks.

Open reservoirs are inexpensive and relatively easy to construct, but the big disadvantages are the high evaporation losses of water and easy accumulation of debris and sediments as well as algae growth. These effects can be significantly reduced by covering the tank, e.g. with a plastic foil. Evaporation and algae growth can be reduced when the solar panels are installed on floating mounting structures.

Elevated water tanks: This is the classic configuration of a Solar Powered Irrigation System. The pumped water is stored in an elevated water tank and irrigation functions by gravity. The elevated tank serves as a battery where energy is stored in the form of water. The irrigation system pressure depends on the height of the water level in the storage tank. It also allows for pre-sunrise irrigation. Ready-to-use plastic tanks are available in different sizes, easy to install and do not corrode as metal or cements reservoirs do.

In order to secure a safe system operation, a water level sensor should be installed in the water tank that switches off the pump to avoid overflow. If a submersible pump is installed in a well, a second water level sensor is required to protect the pump from dry running. Such sensors are often integrated into the motor pump by default. As water tanks usually store huge amounts of water, it is important that the foundation and support structure of the water tank meets the static requirements.

Open plastic foil-lined reservoir

(Source: Jan Sass, 2014)

8. IRRIGATION HEAD

The irrigation head is the part of the irrigation system where the water quantity, quality and pressure are managed. It is indispensable in irrigation systems that operate under pressure such as sprinkler and drip irrigation.

The irrigation head typically contains:

- **valves** to control the quantity of water flowing to the different sections of an irrigation system;
- **filters** to remove particles that could block drip emitters or sprinkler nozzles;
- **a fertigation system** to mix soluble fertilizer in the irrigation water;
- **pressure regulators**.

In surface irrigation systems, the irrigation head may contain valves only. The irrigation head of drip and sprinkler systems contains at least a valve and a filter.

Valves

The irrigation system is usually divided into several sections to improve the control of the quantity and pressure of water in the field. The water flowing in each section is controlled by manual or automatic valves. Automatic valves can be volume- or time-controlled. The producer determines the required irrigation volume per section, and the automatic valve closes as soon as the target value is reached. It is recommended to use volumetric valves especially in cases where water is directly pumped to the irrigation system without passing through a reservoir. The disadvantages of automatic valves include high costs and regular replacement, and it requires electricity to operate the device.

Irrigation head with a disc filter and multiple valves that guide the water to different sections of the irrigation system (Source: Lennart Woltering).

Filter

A filter is essential in any sprinkler or drip irrigation system as it reduces the occurrence of clogging of nozzles and emitters. Clogging is caused by inorganic material such as sand and clay, as well as organic material such as algae and bacteria, that accumulate and block the emitter. Depending on the quality of irrigation water (i.e. sediment, dissolved salts, etc.) filters must be cleaned multiple times per day.

Initially, a water analysis can provide information on the size and amount of particles, and from this you can identify the correct filter technology required. However, this may not be a feasible solution for all farm sites as some may not have access to test kits or laboratories. Surface water from a reservoir or river needs to be filtered much more frequently than water from a well or borehole, where the water is filtered naturally in the ground.

When choosing a filter for an SPIS it is important to realize that:

- filters must be adapted to the flow rate of the pump;
- the pressure loss through the filter should be minimized and monitored;
- maintenance should be easy and the lifetime should be long.

There are three major filter systems:

1. screen filter: a filter using a stainless steel (mesh), polypropylene, nylon or polyester screen to separate particles from the water. The pressure loss in screen filters tends to be quite high; therefore they are not recommended for use in SPIS.
2. disc filter: a disc filter element contains a stack of compressed discs with an overlapping series of grooves. Unfiltered water passes through the stack of tightly compressed discs and the water is forced to flow through the interlocking grooves of the disc rings where debris is trapped. Dirt particles are caught on a very large surface, which is the reason for the comparatively low pressure loss. For manual cleaning, the filter rings have to be taken out of the enclosure and rinsed with clean water. When using disc filters for SPIS, it is advisable to install the next larger model to reduce the characteristic pressure drop, which is proportional to the flow rate, or to install two filters working in parallel. The maintenance intervals should be short so as to significantly reduce the accumulated pressure loss. Automatic backflush systems work with considerably higher pressure and therefore do not suit the pressure minimizing concept of SPIS.
3. Granulate/sand filter: these filters have a large capacity to remove particulates from water. Water is routed through a sand-filled metal tank where the sand traps large and small particles. Eventually the dirt accumulates in the space between the sand particles, requiring a backflushing with clean water. The sand filter requires high pressures for operating and backflushing, which makes it less suitable for SPIS.

9. FERTIGATION SYSTEM

Fertigation is the injection of **fertilizers** into an irrigation system. It is a combination of the words “fertilizer” and “irrigation”. The fertigation system is connected to the irrigation head.

Fertigation is practiced extensively in commercial agriculture and horticulture and is mainly used to spoon-feed additional nutrients. It is usually practiced on high-value crops such as vegetables and fruit trees. Drip irrigation systems in particular are well suited to fertigation because of their operation frequency and since water application can be easily controlled by the producer. Liquid fertilizers often play hazard to clogging attributable to the frequent occurrence of a chemical reaction between the organic and inorganic matter in the irrigation water. To reduce this clogging effect, it is advisable to flush the system with pure water after using liquid fertilizer. Fertilizers delivered as a solution can be injected directly into the irrigation system, while those in a dry granular (e.g. urea) or crystalline form need to be mixed with water to form a solution. Considering the relatively low operating pressure (0.2–0.5 bar) of SPIS, the following fertigation options can be considered:

1. differential pressure tanks;
2. Venturi nozzles;
3. electric metering pumps;
4. water-powered dosing pumps.

1. **Differential pressure tanks**, often referred to as “batch tanks”, are simple injection devices where the amount of fertilizer injected slowly decreases over time, as if a bucket empties. If the chemical concentration needs to be kept relatively constant during injection, batch tanks are not appropriate.
2. **The Venturi nozzle** makes use of the “Venturi hydraulic effect”. Because of the high pressure loss of Venturi nozzles and the fact that the pressure provided by a photovoltaic water pump is not constant (this would cause a strong fluctuation in the fertilizer concentration), the Venturi nozzle is not recommended for SPIS.
3. **Electric metering/dosing pumps** are the most expensive injection devices but they provide a constant and precise injection concentration and are robust systems.
4. For off-grid applications, **water-driven dosing pumps** installed directly in the water supply line are suitable for use in SPIS. They work at comparably low system pressures and the dose will be directly proportional to the volume of water entering the dosing pump, regardless of variations in flow and pressure that may occur in the main line.

In addition, the simplest form of fertigation is to mix soluble fertilizer (e.g. urea) into the elevated reservoir of a low pressure drip irrigation system.
The challenge with fertigation is to control the concentration over time. Overdosing will harm the environment and the production cost budget.
If surface pumps are used for fertigation, it is recommended to inject the fertilizer on the intake/suction side, as it is a cheap, easy and reliable way to fertigate.
Chemigation is used as an overall term for the injection of **fertilizers**, soil amendments, and other water-soluble products into an irrigation system. In a drip irrigation system, chemigation can be used to inject chemicals to dilute debris and other materials that tend to clog the outlets or narrow bends. After a certain period of time, the treated water including the dissolved material is flushed out of each drip line. The assistance of qualified water engineers is required to develop a chemigation plan that suits the producer needs and matches the water quality situation at the farm.

10. IRRIGATION SYSTEM

Water is the most important input required for plant growth in agriculture production. Irrigation is the controlled application of water through man-made systems to supply water requirements of plants not satisfied by rainfall alone. Various methods can be used for irrigation (starting from simply watering plants with a pot or a bucket). The choice of a particular irrigation system mainly depends on the crops to be irrigated, the underlying water availability, irrigation water requirements and energy supply as well as the financial capacity of the farm household. Solar pumps pump up water to the farm, from where it can be collected for further distribution by hand. Alternatively, it can be pumped directly to the field through a system of canals (surface irrigation) or pipes (sprinkler and drip irrigation). In principle, solar pumps can be used for supplying water to any kind of irrigation system. The size (and cost) of the PV generator is mainly determined by the water and pressure requirements of the irrigation scheme. However, it is important to consider that SPIS are relatively expensive, requiring producers to grow high-value crops to guarantee its financial viability. In addition, water savings will have a positive influence on the investment costs of the solar pumping system and the environment.

Surface irrigation systems are not always suitable for high-value crop production and they are far from being water-efficient. However, SPIS with surface irrigation systems are widely used as they do not require the producer to adopt a new irrigation method. SPIS are seldom combined with sprinkler irrigation because sprinkler irrigation requires relatively high water pressures to operate, which demands expensive PV generators.

Water-saving irrigation technologies working at comparably low operating pressures are the preferred option in connection with PV pumping systems.

External drip emitter

(Source: Andreas Hahn, 2015)

Drip irrigation systems normally operate at high pressures of 1–10 bar. Fortunately, the technology has been adapted to cater for low pressures and a more simplified operation. These low-pressure drip irrigation systems can give 80% uniform water application even from a few meters pressure. The performance is very much dependent of the pressure, the size and shape of the field being irrigated. Solar-powered drip irrigation is the "marriage" of two systems that go very well together. Drip irrigation is ideal for high-value crop production such as vegetables and fruits, and due to its high efficiency the solar pump can be quite conservatively sized.

Suitability of irrigation methods to PV pumping

Distribution method	Typical water application efficiency	Typical head	Suitability for use with PV pumps
Flood irrigation	40–50%	0.5 m	barely cost-efficient
Open canals	50–60%	0.5–1 m	depends on local conditions
Sprinkler	70–80%	10–20 m	No
Low pressure drip irrigation	80%	1–10 m	Yes
High pressure drip irrigation	85–95 %	10–100m	No

FURTHER READING, LINKS AND TOOLS

Further reading

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NASA (2016): Surface meteorology and Solar Energy. With the collaboration of Atmospheric Science Data Centre. Retrieved on http://eosweb.larc.nasa.gov/sse.

Some mounting / tracking system manufacturers provide product-specific design tools, which can usually be found on the relevant manufacturer’s website.

SPIS tools

No tools for this module.

TECHNICAL GLOSSARY

Aquifer	Underground geological formation(s), containing usable amounts of groundwater that can supply wells or springs for domestic, industrial, and irrigation uses.
Chemigation	The process of applying chemicals (fertilizers, insecticides, herbicides, etc...) to crops or soil through an irrigation system with the water.
Conveyance loss	Loss of water from a channel or pipe during transport, including losses due to seepage, leakage, evaporation, and other losses.
Crop coefficient	Ratio of the actual crop evapotranspiration to its potential (or reference) evapotranspiration. It is different for each crop and changes over time with the crop's growth stage.
Crop Water Requirement (CWR)	The amount of water needed by a plant. It depends on the climate, the crop as well as management and environmental conditions. It is the same as crop evapotranspiration.
Current (I)	Current is the electrical flow when voltage is present across a conductor, or the rate at which charge is flowing, expressed in amperes [A].
Deep percolation	Movement of water downward through the soil profile below the root zone. This water is lost to the plants and eventually ends up in the groundwater. [mm]
Drawdown	Lowering of level of water in a well due to pumping.
Drip irrigation	Water is applied to the soil surface at very low flow rates (drops or small streams) through emitters. Also known as trickle or micro-irrigation.
Emitter	Small micro-irrigation dispensing device designed to dissipate pressure and discharge a small uniform flow or trickle of water at a constant discharge which does not vary significantly because of minor differences in pressure head. Also called a "dripper" or "trickler".
Evaporation	Loss of water as vapor from the surface of the soil or wet leaves. [mm]
Evapotranspiration (ET)	Combined water lost from evaporation and transpiration. The crop ET (ETc) can be estimated by calculating the reference ET for a particular reference crop (ETo for clipped grass) from weather data and multiplying this by a crop coefficient. The ETc, or water lost, equals the CWR, or water needed by plant. [mm]
GIWR	The Gross Irrigation Water Requirement (GIWR) is used to express the quantity of water that is required in the irrigation system. [mm]
Fertigation	Application of fertilizers through the irrigation system. A form of chemigation.

Financial viability	The ability to generate sufficient income to meet operating expenditure, financing needs and, ideally, to allow profit generation. It is usually assessed using the Net Present Value (NPV) and Internal Rate of Return (IRR) approaches together with estimating the sensitivity of the cost and revenue elements (See Module **INVEST**).
Friction loss	The loss of pressure due to flow of water in pipe. It depends on the pipe size (inside diameter), flow rate, and length of pipe. It is determined by consulting a friction loss chart available in an engineering reference book or from a pipe supplier. [m]
Global solar radiation (G)	The energy carried by radiation on a surface over a certain period of time. The global solar radiation is locations specific as it is influenced by clouds, air humidity, climate, elevation and latitude, etc. The global solar radiation on a horizontal surface is measured by a network of meteorological stations all over the world and is expressed in kilowatt hours per square meter [kWh/m^2].
Gravity flow	The use of gravity to produce pressure and water flow, for example when a storage tank is elevated above the point of use, so that water will flow with no further pumping required.
Head	Value of atmospheric pressure at a specific location and condition. [m]: Head, total (dynamic) Sum of static, pressure, friction and velocity head that a pump works against while pumping at a specific flow rate. [m]; Head loss Energy loss in fluid flow. [m]
Infiltration	The act of water entering the soil profile.
Insolation	The rate at which solar energy reaches a unit area at the earth measures in Watts per square meter [W/m^2]. Also called solar irradiance.
Irradiation	The integration or summation of insolation (equals solar irradiance) over a time period expressed in Joules per square meter (J/m2) or watt-hours per square meter [Wh/m^2].
Irrigation	Irrigation is the controlled application of water to respond to crop needs.
Irrigation efficiency	Proportion of the irrigation water that is beneficially used to the irrigation water that is applied. [%]
Irrigation head	Control unit to regulate water quantity, quality and pressure in an irrigation system using different types of valves, pressure regulators, filters and possibly a chemigation system.
Lateral	Pipe(s) that go from the control valves to the sprinklers or drip emitter tubes.
Latitude	Latitude specifies the north–south position of a point on the Earth's surface. It is an angle which ranges from 0° at the Equator to 90° (North or South) at the poles. Lines of constant latitude, or parallels, run east–west as circles parallel to the

	equator. Latitude is used together with longitude to specify the precise location of features on the surface of the Earth.
Leaching	Moving soluble materials down through the soil profile with the water.
Maximum Power Point Tracking (MPPT)	An important feature in many control boxes to draw the right amount of current in order to maintain a high voltage and achieve maximum system efficiency.
Net Irrigation Water Requirements (NIWR)	The sum of the individual crop water requirements (CWR) for each plant for a given period of time. The NIWR determines how much water should reach the crop to satisfy its demand for water in the soil. [mm]
Power (P)	Power is the rate at which energy is transferred by an electrical circuit expressed in watts. Power depends on the amount of current and voltage in the system. Power equals current multiplied by voltage (P=I x V). [W]
Photosynthesis	Photosynthesis is a process used by plants and other organisms to convert light energy into chemical energy that can later be released to fuel the organisms' activities (energy transformation).
Pressure	The measurement of force within a system. This is the force that moves water through pipes, sprinklers and emitters. Static pressure is measured when no water is flowing and dynamic pressure is measured when water is flowing. Pressure and flow are affected by each other. [bars, psi, kPa]
Priming	The process of hand-filling the suction pipe and intake of a surface pump. Priming is generally necessary when a pump must be located above the water source.
Pump	Converts mechanical energy into hydraulic energy (pressure and/or flow). Submersible pump: a motor/pump combination designed to be placed entirely below the water surface. Surface pump: pump that is not submersible and placed not higher than about 7 meters above the surface of the water.
Root Zone	The depth or volume of soil from which plants effectively extract water from. [m]
Salinity (Saline)	Salinity refers to the amount of salts dissolved in soil water.
Solar panel efficiency	Solar panel efficiency is the ratio of light shining on the panel, versus the amount of electricity produced. It is expressed as a percentage. Most systems are around 16% efficient, meaning 16% of the light energy is converted into electricity.
Suction lift	Vertical distance from the surface of the water to the pump. This distance is limited by physics to around 7 meters and should be minimized for best results. This applies only to surface pumps.

Surface irrigation	Irrigation method where the soil surface is used to transport the water via gravity flow from the source to the plants. Common surface irrigation methods are: Furrow irrigation – water is applied to row crops in small ditches or channels between the rows made by tillage implements; Basin irrigation – water is applied to a completely level area surrounded by dikes, and Flood irrigation – water is applied to the soil surface without flow controls, such as furrows or borders.
Transpiration	Water taken up by the plant's roots and transpired out of the leaves. [mm]
Voltage (U or V)	Voltage is the electric potential between two points, or the difference in charge between two points, expressed in Volts [V].

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TOOLBOX ON SOLAR POWERED IRRIGATION SYSTEMS (SPIS)

POWERING AGRICULTURE:
AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

Module 2:
Promote and Initiate

Food and Agriculture Organization of the United Nations | USAID FROM THE AMERICAN PEOPLE | SWEDEN | german cooperation DEUTSCHE ZUSAMMENARBEIT | DUKE ENERGY | OPIC

The Toolbox on Solar Powered Irrigation Systems is made possible through the global initiative Powering Agriculture: An Energy Grand Challenge for Development (PAEGC). In 2012, the United States Agency for International Development (USAID), the Swedish International Development Cooperation Agency (Sida), the German Federal Ministry for Economic Cooperation and Development (BMZ), Duke Energy, and the Overseas Private Investment Cooperation (OPIC) combined resources to create the PAEGC initiative. The objective of PAEGC is to support new and sustainable approaches to accelerate the development and deployment of clean energy solutions for increasing agriculture productivity and/or value for farmers and agribusinesses in developing countries and emerging regions that lack access to reliable, affordable clean energy.

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Powering Agriculture: An Energy Grand Challenge for Development: https://poweringag.org

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ABBREVIATIONS

Ah	Ampere hour
CWR	Crop Water Requirement
DC/AC	Direct Current / Alternating Current
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
Gd	Daily Global Irradiation
GIZ	Gesellschaft für Internationale Zusammenarbeit
GIWR	Gross Irrigation Water Requirement
GPFI	Global Partnership for Financial Inclusion
HERA	GIZ Program Poverty-oriented Basic Energy Services
H_T	Total Head
IEC	International Electrotechnical Commission
IFC	International Finance Corporation
IRR	Internal Rate of Return
IWR	Irrigation Water Requirement
MPPT	Maximum Power Point Tracking
NGO	Non-Governmental Organization
NIWR	Net Irrigation Water Requirement
NPV	Net Present Value
m^2	square meter
PV	photovoltaic
PVP	Photovoltaic Pump
SAT	Side Acceptance Test
SPIS	Solar Powered Irrigation System
STC	Standard Test Conditions
TC	Temperature Coefficient
UV	Ultraviolet
Vd	Daily crop water requirement
W	Watt
Wp	Watt peak

PROMOTE AND INITIATE

1. Analyze opportunities and risks
2. Analyze access to finance
3. Define target group and stakeholders
4. Define a promotion strategy
5. Plan and implement promotion activities
6. Secure follow-up

MODULE AIM & ORIENTATION

The promotion of modern and efficient Solar Powered Irrigation Systems (SPIS) requires a proactive promotion effort by development practitioners, solar irrigation suppliers and agricultural extension service providers due to insufficient awareness among the target group. This module guides through the most important process steps that have to be considered when disseminating or scaling-up Solar Powered Irrigation Systems.

Promotion activities are the most visible part of any promotion campaign. No such campaign can be conceived, however, without a thorough preceding analysis of objectives, target group and stakeholders and the related potentials and opportunities, risks and restrictions. In addition, no campaign can be approached without considering a systematic follow-up from the beginning onwards.

PROCESS STEPS

The module starts with an insight into three important processes that need to be carried out for the promotion of any technology. To begin, it is important to understand the pros and cons of SPIS in the target area. It does not pre-empt the detailed analysis of the viability of the technology in a given specific farm context, which is the aim of the following modules of the toolbox.

Once objectives and the target group of promotion interventions have been clearly outlined, promotion material has to be produced. The implementation of the promotion activities then have to be planned.

The initiation of actual projects or investments that have been motivated by the promotion campaign is again a process that requires pro-activity of the development practitioner and the agricultural advisor. In the last process steps of the **PROMOTE & INITIATE** module, information is provided on how to pursue this task.

1. ANALYZE OPPORTUNITIES AND RISKS

Promotion efforts provide specific information to targeted producers. This enables decision-making in view of securing and/or increasing the agricultural production potential by modernizing and improving irrigation capacities. It is therefore important to carry out a preliminary reflection of the possible benefits of a particular technology option, the prospect of its application in the specific rural context and the chances resulting there from.

The **GET INFORMED** module familiarizes the agricultural advisor or the development practitioner (the promoter) with the main aspects of the technology. Next, the promoter should obtain information on particular products and system solutions offered on the local market.

The tool **PROMOTE and INITIATE – SPIS Rapid Assessment** helps to understand the market for SPIS in a country and/or project region. The tool provides a report template guiding the author through the relevant aspects of SPIS that need to be assessed. This includes:

- a country/project specific assessment of irrigated agriculture, solar energy and agricultural finance;
- existing technologies, financing and promotion mechanisms; and
- a Strength Weakness Opportunity and Threat (SWOT) analysis.

Important: Not all technology solutions and the related services are available everywhere, local markets may be limited in the range of technology options offered.

Even within the same country, substantial regional differences may be found!

With a good information basis on the availability and specifics of technology options, the promoter can analyze the potentials of different solutions or approaches and reflect on opportunities resulting therefrom. This process step provides guidance on WHAT to ask WHOM.

It is essential to collect information on the following aspects:

- **Availability**:
  - Which technology options and support services are available / accessible in the specific promotion area?
- **Suitability**:
  - Is the environment supportive of large scale promotion of SPIS?
  - Does the catchment area provide enough surface and groundwater for short- and long-term irrigation development (see **SAFEGUARD WATER**)?
  - Other important preconditions are suitable soil and climate (e.g. solar irradiance) conditions, access to input / output markets, and infrastructure security.
- **Acceptability**:
  - What is the level of acceptance of different stakeholders for SPIS technology?
  - Is the cost benefit of SPIS in an area better than for alternative technologies?
  - What are acceptable ways to disseminate and promote information on SPIS in the target area?
- **Supportability**:
  - Are there existing or planned support programs in the target area for SPIS or its components, and are they accessible to producers? An

important aspect is the availability of subsidies for particular irrigation purposes. Subsidies may exist for PV-based modernization options, but also for diesel or grid-based electricity, which may have a significant impact on the financial viability.
   - What service providers are accessible to producers?

However, it is also very important to provide unbiased information about possible restrictions and risks of SPIS.

- **Restrictions** are determined by technical (availability of technical solutions and services), environmental (availability of water, solar resource, suitability for specific crops) and economic (access to finances, positive return on investment and market prices, diesel prices, subsidies) factors. Any irrigation system should be designed taking these restrictions into account in order to ensure that an optimum range of operation is achieved.

- **Risks** mainly arise due to a deviation from the designed operational range and from operation principles. This may result in negative impacts on the environment (excessive water abstraction, over-irrigation) and on the cost-benefit ratio of the production (lack of water causes yield decreases, etc.).

Important: Not every irrigation technology is suitable for all crops and production approaches. Besides technical and agronomic restrictions, the cost-benefit ratio is a vital aspect to consider! In addition, it is important to note that changing an agricultural practice is more than merely an agronomic issue, but has social, gender, economic and environmental repercussions that must be assessed locally.

The analysis of restrictions and risks includes technical, environmental and economic aspects associated with the application of the technology options:

- environmental risks originate from the possibility of over-exploitation of water resources (see **SAFEGUARD WATER**),
- technical risks originating from operating the system outside the design range may cause increased maintenance, repair and replacement costs,
- risk of theft and vandalism of the installation in a particular area, and
- financial risks related to poor water management (not enough water, or over-irrigation), equipment failures, etc.

The tool **PROMOTE and INITIATE – Impact Assessment Tool** allows the promoter to identify positive or negative impacts. The promoter should triangulate and compare information from different relevant sources:

- Manufacturers and technology service providers advertise and market their products intensively and outline their advantages and potentials – this information can be easily obtained from suppliers and system integrators, and via the websites of the manufacturers.
- Producer organizations may already have compiled or evaluated experiences of their members with a specific irrigation and pumping systems. They can also link up the promoter with other producers experienced with advanced technologies.
- International and national development stakeholders (including NGOs) may already have implemented and evaluated pilot projects based on the technology – this information should be available in sector working groups etc.

Recommendation: When approaching technology providers, producer organizations and development stakeholders for information, always ask for reference projects. A visit to these projects / installations and an information exchange with the operating producer is a worthwhile exercise.

Based on this information, the promoter will be able to establish a profile of the different technologies to be included in the promotion campaign. This profile will have to be specific with regard to:

- possibilities of employing the technology for a specific purpose;
- main benefits for the producer (impacts on irrigation operation, farm labor, crop production, market access, farm budget);
- main requirements and preconditions (water availability in the short and long run, land resources, works, adaptation of crop production and marketing, adaptation of irrigation operation, training needs);
- support mechanisms and offers (private sector service provision, extension and advisory services, promotion and subsidization schemes);
- potential negative impacts on the water table, environment, and socio-economic aspects.

PEOPLE STAKEHOLDERS

- Agricultural advisor / development practitioner;
- producer (organizations);
- wholesalers (purchasing agricultural products);
- Water Resource Management Authorities (management of water rights / licenses);
- organizations experienced with irrigation and solar pumping;
- technology provider.

OUTCOME / PRODUCT

- Analysis of availability, suitability, acceptability and supportability of technology options;
- profile of potentials and opportunities of each technology option;
- overview of framework conditions (i.e. water rights, subsidies, etc.);
- use the tool **PROMOTE – SPIS Rapid Assessment** for structured analysis.
- Use the tool **PROMOTE and INITIATE – Impact Assessment** for socio-economic and environmental impact assessments

DATA REQUIREMENTS

- Triangulation of different information sources with regard to technical, economic and environmental information.

IMPORTANT ISSUES

- The availability of a specific technology option may be limited (there may also be sub-regional differences).
- Triangulation (using different information sources) is required to obtain a realistic overview of potentials and opportunities.
- Assess the pros and cons of SPIS in the country, and/or project region, to have a strong knowledge base for the promotion of SPIS.

Innovative cultivation practices in irrigated farming
(Source: Andreas Hahn)

2. ANALYZE ACCESS TO FINANCE

In general, the introduction of modern irrigation technology requires comparatively high investments, which often go beyond the financial capacity of a farm household. This also applies to SPIS. This means that a promotion approach for irrigation technology must consider access to the required capital.

In order to finance investments in irrigation, the following sources, or a combination therefore exist:

- equity of the farm household;
- commercial loans and leasing (market conditions);
- subsidized (soft) loans to end borrower;
- group saving schemes and lending;
- subsidies and development grants;
- sponsoring.

Lack of external finance is often a limiting factor for medium sized farm households due to limited equity and limited credit rating with commercial financing institutions. Financing institutions are usually also very hesitant to open their loan portfolio to new technologies in the agricultural sector as the repayment duration for loans is usually long and risks exist with regard to crop failure. In addition, the lack of conventional loan collateral signifies an obstacle for banks. This is elaborated further in the INVEST module that provides information and tools for financial service providers already financing or planning to finance SPIS

Knowledge about and connections to financial support for SPIS will be essential for promoters because potential SPIS users will be very much interested in this. The aspect of access to finance has to be a mandatory part of the initial analysis and information compilation of the promoter. At local level, producers often do not have access to information on alternative financing options for innovations.

Government has an important role to play in improving the framework conditions, such as minimizing market distortions, promoting private sector involvement, and supporting public goods and financial and physical infrastructures. One important tool for governments is **subsidies** to make modern irrigation technology available to medium-sized farm households. Subsidies usually exist for individual components of an irrigation system such as the pumping system (subsidies for PV pumping), water storage (subsidies for water tanks and farm ponds) and the irrigation system (subsidies for sprinkler and micro irrigation systems). They are mostly conditional (water and energy saving, cropping intensification) and time-bound, with a decreasing subsidy percentage over time.

The promoter needs to provide such information as part of his promotion material and subsequently as a basis for initiating projects. An important aspect is to not only provide information on the existence of financing sources, but to also provide information on how to access these.

With regard to potential follow-up activities related to the development of the financial sector response to modern irrigation financing the following guidelines are recommended by GPFI / IFC:

- Effective government support should be developed.
- Financial infrastructure should be strengthened (credit bureaus, improved collateral registries, alternative forms of collateral).
- Consistent and reliable data sources should be developed for end borrowers and financial operators (financing options and conditions, agricultural production,

supply chains, and market pricing information).

- Producers and financial service providers should be supported to increase knowledge and capacities with regard to financing modern irrigation solutions, so that they can come up with innovative solutions. These may include partial guarantee schemes and risk sharing facilities as an effective mechanism to foster lending for irrigation modernization purposes.

OUTCOME / PRODUCT

- Financing options information sheet (including conditions, institutions, contact details);
- recommendations for financing, options for a range of target groups.

DATA REQUIREMENTS

- Typical investment costs of technology options;
- information on financing options in the region;
- information on subsidy schemes in the region; information on donor and grant schemes.

PEOPLE / STAKEHOLDERS

- Agricultural advisor / development practitioner;
- financing institutions;
- governmental services;
- donors and donor-supported development projects.

IMPORTANT ISSUES

- Modern irrigation technology requires (partial) external financing.
- Subsidy schemes are often available to support the introduction of modern irrigation technology.
- ICT technology and / or regular information dissemination could be used to increase access to finance.

3. DEFINE TARGET GROUP AND STAKEHOLDERS

The analysis carried out in the preceding steps outline a profile of potential, opportunities, restrictions and risks with regard to the promotion of SPIS. The promoter should also have a good insight into the different forms of financial support for financing SPIS. While some farm household may have access to commercial financing services, others may require a 100% subsidy or a grant to introduce the technology to their farm.

Based on the analysis, the promoter will have to define a specific target group for the technology options promoted. Targeting a specific market does not mean that you are excluding people who do not fit your criteria. Rather, target marketing allows you to focus your marketing dollars and brand message on a specific market that is more likely to buy from you than other markets. This is a much more affordable, efficient, and effective way to reach potential clients and generate business. No one can afford to target everyone.

In case of the SPIS technology this concerns usually medium-sized farm households with good market access and a potential to adapt and intensify their production. Large farm enterprises usually obtain the required information directly through private sector service providers and take investment decisions based on their own business planning (and own equity financing).

Small-scale farmers with poor access to markets and subsistence farm households often cannot cope with the operational requirements and related costs that come with high investments such as induced by SPIS options, even though they may benefit from subsidies or grants. Group schemes with shared pumping installations are an alternative to individual systems in case of smallholders or subsistence producers. This option can also cater for the need to promote disadvantaged and impoverished farming communities that may only have access to communal land. In many cases this women and youth a chance to have land rights, which is often a pre-condition for them to access credit and equity financing.

The preceding analysis also reveals the identification of important stakeholders for the promotion:

- technology supplier and service providers - to provide proof of well functioning SPIS configurations;
- financing institutions - to give access to funds to finance SPIS;
- agricultural extension services and service providers - to promote the technology and to optimize the productivity and profitability;
- government institutions managing subsidy schemes - to create awareness on support options and improve access to subsidies and other support;
- producer organizations and groups - to create economies of scale for purchasing, selling and accessing information and services;
- donors and NGOs - to support accessing services, improve organizational capacity, and to pilot and demonstrate SPIS configurations.

The identified stakeholders and their role (actual and potential) should be listed as part of the information compilation. Some of these stakeholders may also assume the role as a multiplier of information in the promotion campaign.

OUTCOME / PRODUCT

- Defined range (size) of target farm households and additional criteria (market access, intensification potential);

- list of stakeholders with roles and responsibilities.

DATA REQUIREMENTS

- Farm household / enterprise profiles in the promotion area;
- functions and functioning of stakeholders.

PEOPLE / STAKEHOLDERS

- Agricultural advisor / development practitioner.

IMPORTANT ISSUES

- Not every farm enterprise can absorb an investment in modern irrigation technologies due to limited market access and potential to adapt and intensify production.
- Group schemes with shared pumping facilities can be a feasible approach for subsistence producers, disadvantaged communities and for women and young people with access to resources.

Farmer group meeting

(Source: Lennart Woltering)

4. DEFINE A PROMOTION STRATEGY

Deciding on a promotion strategy is one of the primary roles of the promoter and this process involves some key decisions about who the customers are, how to contact them, and what the message should be. From the previous steps the target group and its priorities and needs became clear. Now it is important to decide if you want to use the press, advertising (or other media) or personal contact to reach them. Then you need to be clear what your (unique) selling points are in order to create a demand for the promoter services.

In almost any country around the world experience exists with regard to promotion and awareness raising campaigns in the agricultural sector. Successful approaches may be proposed by the extension services and development partners such as donors and NGOs. Appropriate approaches are always target group focused and culturally sensitive. Particular attention has to be given to information access for disadvantaged communities and in particular women and young people. Dissemination meetings and seminars etc. are traditionally dominated by male household heads and lead producers.

Promotion activities should include communicative and interactive instruments as the simple dissemination of information sheets and brochures is often not sufficient to reach all target households.

Possible activities are for example:

- producer field days and producer technology fairs (this can also be organized in cooperation with technology service providers);
- “village road shows” with technology presentations on village level;
- extension seminars with lead producers as multipliers.

Recommendation: Wherever possible, technology suppliers and NGOs should be incorporated into the promotion concept as they can provide valuable information. An agreement needs to be reached as to the impartiality of information provision. It is also advisable to invite representatives of local banks / financing institutions to promotion events in order to contribute to their awareness for the new technologies.

Furthermore, a number of passive dissemination means exist, which also require a very thorough preparation of materials:

- rural radio bulletins;
- short bulletins on the local TV;
- preparation of posters;
- internet videos (posting via YouTube etc.).

Depending on the promotion approach and instruments chosen, the compilation of promotion material can be a significant task. It should include a target group-specific design and layout of documents etc. Sufficient budgetary resources must be available in order to produce good quality promotion material. In addition, the promoter should be well aware of the proper capacity (human resources and financial) to set up and implement a good promotion campaign.

Important: When approaching the promotion of irrigation technology, the prime objective of the promotion effort must always provide the producer with information that enables him to take a decision in view of securing and / or increasing his production potential. Promotion from a development perspective is not marketing of a specific product!

OUTCOME / PRODUCT

- Determination of promotion approach and instruments;
- agreement with relevant stakeholders on cooperation activities;
- design and layout of promotion material.

DATA REQUIREMENTS

- Experiences with different promotion approaches and instruments (agricultural sector);
- own human resources and financial capacity to undertake a promotion campaign.

PEOPLE / STAKEHOLDERS

- Agricultural advisor / development practitioner;
- technology provider;
- producer organizations;
- donors and NGOs;
- financial service providers.

IMPORTANT ISSUES

- Promotion activities should include communicative and interactive instruments.
- Information access to disadvantaged communities, women and young people has to be considered.
- Technology suppliers and NGOs should be incorporated into the promotion concept as they can provide valuable information.

5. PLAN AND IMPLEMENT PROMOTION ACTIVITIES

The implementation of promotion activities should only be started once the required promotion material is developed and available. Ideally, an interactive focus is the foundation of the promotion campaign, which means that planning for the implementation of activities must be done well in advance and in a joint effort with the cooperating partners. At many times of the year, most producers have very limited time to attend seminars and meetings. The planning should therefore be oriented on the agricultural calendar and the regional work peaks. This way good participation can be achieved. Particular attention should be paid to the limited time resources of women and youth.

Planning should also include the identification of suitable presenters or trainers, who have experience with the particular target group. A recommended approach is the inclusion of lead producers as multiplier and co-presenters for dissemination meetings. In order to access women and young people, a balance of gender and seniority must be introduced to the promotion team. The incorporation of staff from local NGOs, for example, may be conducive to the success of the activities. Promoter and presenters should not only be familiar with the promotion material and the objectives and key messages of the campaign, but should also be trained in carrying out extension meetings etc. Local events should be announced in advance to encourage greater participation.

Announcements may be disseminated through:

- black board announcement at the agricultural extension bureau;
- distribution of flyers;
- technology provider shops;
- local newspaper;
- rural radio services;
- SMS-services.

The implementation of the promotion events should always position the producer into the centre of the extension concept. The objective of each event is not only to provide information based on an anticipation of producers' needs, but to allow for practical demonstration, questions, discussions and a capture of the producers' expectations and needs.

Feedback from the participants of the promotion and extension events should be obtained in a systematic way to further develop the didactics. A good documentation of feedbacks and interests / needs for further information will enable an efficient and targeted follow-up at a later stage.

OUTCOME / PRODUCT

- Schedule / plan for local promotion and extension events based on agricultural calendar;
- announcements via flyer / posters local media;
- captured feedback and further information and follow-up requests from the producers.

DATA REQUIREMENTS

- Information on local work peaks in agriculture;
- information on suitable venues / areas for promotion events;
- information on other extension events;
- contact information of important local stakeholders such as banks / financing institutions, producer organizations, NGOs, private sector associations etc. (to be invited).

PEOPLE / STAKEHOLDERS

- Agricultural advisor / development practitioner;
- producer;
- technology provider;
- producer organizations;
- financial service provider;
- donors and NGOs.

IMPORTANT ISSUES

- Producers should be encouraged to interact with the promoters / presenters to ask questions, provide feedback and to articulate further needs / information requirements.
- Producer feedback and further information requirement should be documented.

Field visit to a SPIS site in India

(Source: Lennart Woltering)

6. SECURE FOLLOW-UP

Promotion activities may result in further information requirements and first expressions of interest for the new technology. In many areas the service structure of technology suppliers and their associated installation service providers is not very well developed. Very often, the supplier maintains only a few (if not only one) branches in the country. For many producers interested in modern technology options such as SPIS it is not feasible to travel to the capital to obtain further information. It is therefore required to properly document contract requests and information needs during the promotion and extension events and to provide the producers with contact details for further consultation.

The promoter should process the documented producer's requests in a systematic way and follow-up action should take place without delay after the first contact during the promotion event. With the follow-up after the promotion activity the initiation of a possible future project starts. Now the promoter has to choose how to pursue the follow-up. Possible scenarios are:

- initiation of direct information and contact between the producer and a technology provider / project developer;
- recommendation of follow-up activities to locally operating development partners (NGOs, donors).

The next steps in this initiation process will be a first assessment of the suitability of different technology options in the specific farm context. This requires a physical site visit and a deeper joint reflection process together with the producer. The following modules of this toolbox, in particular the **DESIGN**, **SET UP** and **MAINTAIN** processes, assist the advisor and development practitioner to carry out this preliminary assessment.

OUTCOME / PRODUCT

- Contact between producer and service provider / development partner for follow-up activities;
- initiation of project development activities.

DATA REQUIREMENTS

- Contact details of producer and service provider / development partner for project development.

PEOPLE / STAKEHOLDERS

- Agricultural advisor / development practitioner;
- producer;
- technology provider;
- donors and NGOs.

IMPORTANT ISSUES

- Technology suppliers often do not maintain an extensive network of branch offices, requiring proactive contact management.
- Follow-up activities should be carried out timely after the request for further information to maintain the confidence of the producer.

FURTHER READING, LINKS AND TOOLS

Further reading

Hahn, A., Sass, J. & Fröhlich, C. (2015): Manual and tools for promoting SPIS. Multicountry - Stocktaking and Analysis Report. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Retrieved on https://energypedia.info/wiki/Solar_Powered_Irrigation_Systems_-_Technology,_Economy,_Impacts

International Finance Corporation (2011): Scaling Up Access to Finance for Agricultural SMEs Policy Review and Recommendations. Retrieved on https://www.gpfi.org/sites/default/files/documents/G20_Agrifinance_Report%20(FINAL%20ONLINE).pdf

SPIS tools

PROMOTE and INITIATE – SPIS Rapid Assessment

PROMOTE and INITIATE – Impact Assessment Tool

TECHNICAL GLOSSARY

Aquifer	Underground geological formation(s), containing usable amounts of groundwater that can supply wells or springs for domestic, industrial, and irrigation uses.
Chemigation	The process of applying chemicals (fertilizers, insecticides, herbicides, etc...) to crops or soil through an irrigation system with the water.
Conveyance loss	Loss of water from a channel or pipe during transport, including losses due to seepage, leakage, evaporation, and other losses.
Crop coefficient	Ratio of the actual crop evapotranspiration to its potential (or reference) evapotranspiration. It is different for each crop and changes over time with the crop's growth stage.
Crop Water Requirement (CWR)	The amount of water needed by a plant. It depends on the climate, the crop as well as management and environmental conditions. It is the same as crop evapotranspiration.
Current (I)	Current is the electrical flow when voltage is present across a conductor, or the rate at which charge is flowing, expressed in amperes [A].
Deep percolation	Movement of water downward through the soil profile below the root zone. This water is lost to the plants and eventually ends up in the groundwater. [mm]
Drawdown	Lowering of level of water in a well due to pumping.
Drip irrigation	Water is applied to the soil surface at very low flow rates (drops or small streams) through emitters. Also known as trickle or micro-irrigation.
Emitter	Small micro-irrigation dispensing device designed to dissipate pressure and discharge a small uniform flow or trickle of water at a constant discharge which does not vary significantly because of minor differences in pressure head. Also called a "dripper" or "trickler".
Evaporation	Loss of water as vapor from the surface of the soil or wet leaves. [mm]
Evapotranspiration (ET)	Combined water lost from evaporation and transpiration. The crop ET (ETc) can be estimated by calculating the reference ET for a particular reference crop (ETo for clipped grass) from weather data and multiplying this by a crop coefficient. The ETc, or water lost, equals the CWR, or water needed by plant. [mm]
GIWR	The Gross Irrigation Water Requirement (GIWR) is used to express the quantity of water that is required in the irrigation system. [mm]
Fertigation	Application of fertilizers through the irrigation system. A form of chemigation.

Financial viability	The ability to generate sufficient income to meet operating expenditure, financing needs and, ideally, to allow profit generation. It is usually assessed using the Net Present Value (NPV) and Internal Rate of Return (IRR) approaches together with estimating the sensitivity of the cost and revenue elements (See Module **INVEST**).
Friction loss	The loss of pressure due to flow of water in pipe. It depends on the pipe size (inside diameter), flow rate, and length of pipe. It is determined by consulting a friction loss chart available in an engineering reference book or from a pipe supplier. [m]
Global solar radiation (G)	The energy carried by radiation on a surface over a certain period of time. The global solar radiation is locations specific as it is influenced by clouds, air humidity, climate, elevation and latitude, etc. The global solar radiation on a horizontal surface is measured by a network of meteorological stations all over the world and is expressed in kilowatt hours per square meter [kWh/m^2].
Gravity flow	The use of gravity to produce pressure and water flow, for example when a storage tank is elevated above the point of use, so that water will flow with no further pumping required.
Head	Value of atmospheric pressure at a specific location and condition. [m]: Head, total (dynamic) Sum of static, pressure, friction and velocity head that a pump works against while pumping at a specific flow rate. [m]; Head loss Energy loss in fluid flow. [m]
Infiltration	The act of water entering the soil profile.
Insolation	The rate at which solar energy reaches a unit area at the earth measures in Watts per square meter [W/m^2]. Also called solar irradiance.
Irradiation	The integration or summation of insolation (equals solar irradiance) over a time period expressed in Joules per square meter (J/m2) or watt-hours per square meter [Wh/m^2].
Irrigation	Irrigation is the controlled application of water to respond to crop needs.
Irrigation efficiency	Proportion of the irrigation water that is beneficially used to the irrigation water that is applied. [%]
Irrigation head	Control unit to regulate water quantity, quality and pressure in an irrigation system using different types of valves, pressure regulators, filters and possibly a chemigation system.
Lateral	Pipe(s) that go from the control valves to the sprinklers or drip emitter tubes.
Latitude	Latitude specifies the north–south position of a point on the Earth's surface. It is an angle which ranges from 0° at the Equator to 90° (North or South) at the poles. Lines of constant latitude, or parallels, run east–west as circles parallel to the

	equator. Latitude is used together with longitude to specify the precise location of features on the surface of the Earth.
Leaching	Moving soluble materials down through the soil profile with the water.
Maximum Power Point Tracking (MPPT)	An important feature in many control boxes to draw the right amount of current in order to maintain a high voltage and achieve maximum system efficiency.
Net Irrigation Water Requirements (NIWR)	The sum of the individual crop water requirements (CWR) for each plant for a given period of time. The NIWR determines how much water should reach the crop to satisfy its demand for water in the soil. [mm]
Power (P)	Power is the rate at which energy is transferred by an electrical circuit expressed in watts. Power depends on the amount of current and voltage in the system. Power equals current multiplied by voltage (P=I x V). [W]
Photosynthesis	Photosynthesis is a process used by plants and other organisms to convert light energy into chemical energy that can later be released to fuel the organisms' activities (energy transformation).
Pressure	The measurement of force within a system. This is the force that moves water through pipes, sprinklers and emitters. Static pressure is measured when no water is flowing and dynamic pressure is measured when water is flowing. Pressure and flow are affected by each other. [bars, psi, kPa]
Priming	The process of hand-filling the suction pipe and intake of a surface pump. Priming is generally necessary when a pump must be located above the water source.
Pump	Converts mechanical energy into hydraulic energy (pressure and/or flow). Submersible pump: a motor/pump combination designed to be placed entirely below the water surface. Surface pump: pump that is not submersible and placed not higher than about 7 meters above the surface of the water.
Root Zone	The depth or volume of soil from which plants effectively extract water from. [m]
Salinity (Saline)	Salinity refers to the amount of salts dissolved in soil water.
Solar panel efficiency	Solar panel efficiency is the ratio of light shining on the panel, versus the amount of electricity produced. It is expressed as a percentage. Most systems are around 16% efficient, meaning 16% of the light energy is converted into electricity.
Suction lift	Vertical distance from the surface of the water to the pump. This distance is limited by physics to around 7 meters and should be minimized for best results. This applies only to surface pumps.

Surface irrigation	Irrigation method where the soil surface is used to transport the water via gravity flow from the source to the plants. Common surface irrigation methods are: Furrow irrigation – water is applied to row crops in small ditches or channels between the rows made by tillage implements; Basin irrigation – water is applied to a completely level area surrounded by dikes, and Flood irrigation – water is applied to the soil surface without flow controls, such as furrows or borders.
Transpiration	Water taken up by the plant's roots and transpired out of the leaves. [mm]
Voltage (U or V)	Voltage is the electric potential between two points, or the difference in charge between two points, expressed in Volts [V].

TOOLBOX ON SOLAR POWERED IRRIGATION SYSTEMS (SPIS)

POWERING AGRICULTURE:
AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

Module 3: Safeguard Water

Food and Agriculture Organization of the United Nations · USAID FROM THE AMERICAN PEOPLE · SWEDEN · german cooperation DEUTSCHE ZUSAMMENARBEIT · DUKE ENERGY · OPIC · BGR

The Toolbox on Solar Powered Irrigation Systems is made possible through the global initiative Powering Agriculture: An Energy Grand Challenge for Development (PAEGC). In 2012, the United States Agency for International Development (USAID), the Swedish International Development Cooperation Agency (Sida), the German Federal Ministry for Economic Cooperation and Development (BMZ), Duke Energy, and the Overseas Private Investment Cooperation (OPIC) combined resources to create the PAEGC initiative. The objective of PAEGC is to support new and sustainable approaches to accelerate the development and deployment of clean energy solutions for increasing agriculture productivity and/or value for farmers and agribusinesses in developing countries and emerging regions that lack access to reliable, affordable clean energy.

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Download
https://energypedia.info/wiki/Toolbox_on_SPIS

About
Powering Agriculture: An Energy Grand Challenge for Development: https://poweringag.org

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ABBREVIATIONS

Ah	Ampere hour
CWR	Crop Water Requirement
DC/AC	Direct Current / Alternating Current
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
Gd	Daily Global Irradiation
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)
GIWR	Gross Irrigation Water Requirement
GPFI	Global Partnership for Financial Inclusion
HERA	GIZ Program Poverty-oriented Basic Energy Services
H_T	Total Head
IEC	International Electrotechnical Commission
IFC	International Finance Corporation
IRR	Internal Rate of Return
IWR	Irrigation Water Requirement
MPPT	Maximum Power Point Tracking
NGO	Non-Governmental Organization
NIWR	Net Irrigation Water Requirement
NPV	Net Present Value
m^2	Square meter
PV	Photovoltaic
PVP	Photovoltaic Pump
SAT	Side Acceptance Test
SPIS	Solar Powered Irrigation System
STC	Standard Test Conditions
TC	Temperature Coefficient
UV	Ultraviolet
Vd	Daily crop water requirement
W	Watt
Wp	Watt peak

SAFEGUARD WATER

1. Understanding groundwater
2. Analyze water management and regulation
3. Analyze water extraction
4. Explore cooperative water governance
5. Review potential risks and impacts
6. Adjust planning and operation

MODULE AIM & ORIENTATION

The **SAFEGUARD WATER** module aims to give an introduction to groundwater management and the principles of sustainable water management. It furthermore reviews the risks and impacts related to an overdraft of groundwater resources. This should sensitize the planner and the future user of a SPIS for a responsible and sustainable utilization of water sources in most cases to be shared with neighboring farmers or other users. Finally, this module provides a practical guideline for the integration of water management into the planning and operation of SPIS.

Population growth and higher living standards, the expansion of agricultural production into dry lands or marginal lands, and the impacts of climate change increase additional need for food, energy and water. The sound financial viability of Solar Powered Irrigation Systems (SPIS) may substitute conventional water extraction and pumping options to save energy and increase agricultural production. Governments and international development agencies support the implementation of SPIS because of several advantages:

- The use of renewable green energy is CO2-neutral and does not contribute to the emission of greenhouse gases and hence climate change;
- CO2-Certificates can be sold to fossil energy users;
- Decentral solar powered energy does not rely on energy networks infrastructure and regular fuel supplies which is interesting especially in less developed rural areas;
- Solar powered irrigation can enable agriculture in areas regarded not suitable or profitable and thus increase food production and food security.

However the previous significant financial hurdle for solar irrigated agriculture from low energy costs for diesel or electricity is diminishing. SPIS saves variable costs for energy production and therefore the incentive for water-efficient technologies and crop patterns is undermined. SPIS technology is on the rise while the abstraction of surface and groundwater for agricultural use around the globe increases and often exceeds the availability of renewable groundwater resources. In India, for example, about 30 per cent of aquifers are considered at critical status[1]. Globally, nonrenewable groundwater abstraction contributes nearly 20% to gross irrigation water demand[2]. In some cases, irrigated agriculture is even practiced through exploitation of fossil groundwater that is not renewable at all.

Hence, SPIS might cause or aggravate over-extraction of limited water resources with several side-effects for the environment, economy and society, such as:

- Unsecure water availability through drying wells and springs increase the risk of crop failure;

[1] Source: Central Ground Water Board of India 2014. Dynamic ground water resources of India as of 2011. Faridabad.

[2] Values for 2000, according to Wada et al. 2012. Nonsustainable groundwater sustaining irrigation: A global assessment. In: Water Resources Research 48, W00L06.

- Aquifer salinization and seawater intrusion with long-term implications for agricultural productivity;
- Increased risk of conflicts between different users (e.g. farmers, domestic water supplier, industrial users);
- Environmental impacts on groundwater-dependent ecosystems, such as drying up of wetlands and river base flows.

Irrigation requires the integration of principles of sustainable water management. Especially if groundwater regulation and protection in target countries is weak or even absent. Therefore, this module aims to sensitize SPIS developers about fundamental processes of groundwater use and regulation. Practicing sustainable groundwater use is in the self-interest of farmers and stakeholders of the solar powered agricultural development. That includes strict compliance to the mechanisms of water regulation and monitoring, as further detailed in the following chapters.

Water is one of the most vital natural resources for agriculture. Conservation, protection and sustainable use and management of water represents a global challenge of the 21st century.

Clean water is a vital resource

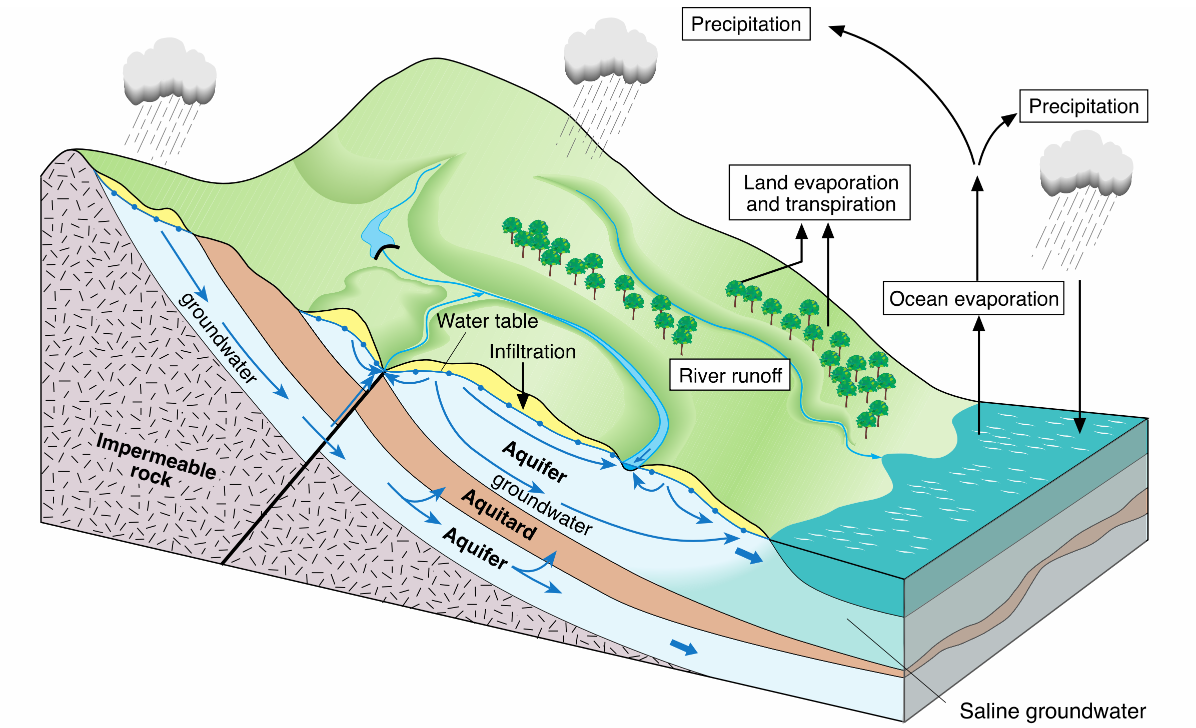
(Source: Federal Institute for Geosciences and Natural Resources (BGR))

1. UNDERSTANDING GROUNDWATER

Groundwater within the hydrogeological cycle

SPIS is based on the abstraction of groundwater from open wells or tube wells. Therefore, it is necessary to understand groundwater systems to manage groundwater in a sustainable manner. Groundwater is the water found underground in the cracks and pores in soil, sand and rock, called aquifer. Aquifers store high amounts of groundwater and are therefore an important reservoir and buffer within the hydrologic cycle (see figure below).

Groundwater is naturally recharged by precipitation or by infiltration from rivers and lakes. The underground water movement from areas of recharge to areas of aquifer discharge through springs and seepage to rivers, lakes, wetlands and coastal zones is called groundwater flow. The natural flow of groundwater occurs, generally at low velocities, through pore spaces and fractures in rock materials. Depending on the aquifer geological composition, water flow velocity varies from 1 meter per day to 1 meter per year or per decade. In contrast, velocities of river flow are much faster and expressed in meter per second. Groundwater levels may vary seasonally and annually. They are then high after the wet season and low at the end of the dry season.



The Hydrologic Cycle

(Source: BGR)

Groundwater balance

Under natural conditions, groundwater storage within the aquifer is in balance. It recharges in wet seasons and provides water for the base flow of rivers, lakes and wetland throughout the year. This balance can be disturbed by human interventions that may affect both the amounts of recharge and discharge.

Important agricultural activities with effects on the groundwater balance

Recharge		
Agricultural activity	**Process**	**Examples for regulative measures**
Land use	Soil sealing accelerates surface runoff on the cost of infiltration of rain- and surface water, whereas increased vegetation cover retards runoff and favors infiltration	Land use planning that procures local rainwater infiltration
Crop choice	As crops have different effects on soil moisture and surface runoff, crop choice influences the amount of rainwater infiltration and thereby the recharge, especially of shallow groundwater	Prescribed cropping arrangements and planting patterns
Soil compaction	Due to natural conditions of drying and wetting, heavy machineries and inappropriate tillage top- and subsoil is compacted and groundwater recharge decreases	Regulations for tillage practices and machinery use
Excess irrigation	Irrigation itself can be an important factor, as surplus irrigation water may infiltrate and recharge groundwater.	Sound irrigation scheduling and appropriate techniques
Discharge		
Groundwater abstraction	Groundwater pumping from wells lowers the water table	Groundwater abstraction quotas, licensing of drilled wells

In order to maintain balanced and plannable groundwater conditions, sustainable groundwater management should be based on the basin's recharge capacity. This capacity is called sustainable yield (or safe yield) of a groundwater system and means the amount that can be extracted without harming ecosystems and communities that depend on it. To determine the sustainable yield it is important to quantify the groundwater recharge.

As recharge processes are complex and dependent of numerous hydrogeological processes, the responsible water authorities and managers need to have as-accurate-as-possible data on the following aspects:

- Total extraction of groundwater by human activities (groundwater pumping) and natural springs
- Whenever possible, the estimation of discharge should rely on metered pumping records and measured spring discharge
- To estimate the recharge, high-resolution data on precipitation, evapotranspiration and runoff are needed. In addition, hydrogeological data on the groundwater flow and underground storage characteristics (e.g. derived from pumping tests) have to be taken into account.
- Land-use and vegetation/crop mapping of the groundwater basin helps to quantify more exactly the evapotranspiration and runoff variables.
- Depending on the available data and resources, the recharge can be estimated via standard formulas and expert knowledge, but also by more sophisticated hydrological (computer) models

In some instances, groundwater may also be subject to artificial recharge, which means the planned technical infiltration of water to groundwater bodies. Some progressive communities are presently practicing the artificial recharge of their aquifers in order to conserve the groundwater resource. For example, in the Terai region of North Bengal (India), gully plugs and bunds have been constructed by local farmer committees to retain rainwater and increase groundwater recharge. This stabilized the water tables and reduced the impact of drought periods on rain-fed paddy cultivation. As a result, the cropping intensity could be doubled and yields as well as farmers' income improved[3].

Groundwater overexploitation

If the extraction of groundwater is higher than the long-term recharge, groundwater decline regionally. This process is called groundwater over-exploitation. In practice however, over-exploitation is invariably much more concerned with the consequences of intensive groundwater abstraction than about its absolute level. Thus the most appropriate definition for over-exploitation is probably that it is reached when the overall costs of the negative impacts of groundwater exploitation exceed the net benefits of groundwater use, although these impacts are not always easy to predict and/or to quantify in monetary terms. It is also important to stress that some of these negative impacts can arise well before the groundwater abstraction rate exceeds long-term average recharge.

Important: Excessive pumping can lead to groundwater depletion. This means that groundwater is extracted at a rate faster than it can be replenished. Aquifer depletion can lead to loss of ecosystems and wetlands, increased greenhouse gas emissions, land subsidence and social conflicts with other water users.

[3] Tuinhof et al. 2012.Profit from storage. The cost and benefits of water buffering. Wageningen: 3R Water Secretariat.

Pumping groundwater causes a drop of the water table. The water table is the surface of the area saturated with groundwater. When groundwater is pumped, the water table drops in the surroundings of the well developing. Cones of depression appear in *unconfined aquifers* as a lowering of water levels (see figure below). In *confined aquifers*, that means that aquifers overlain by a geological layer of low permeability (aquitard or aquiclude), the pressure in the surroundings of the pumped well reduces when water is abstracted.

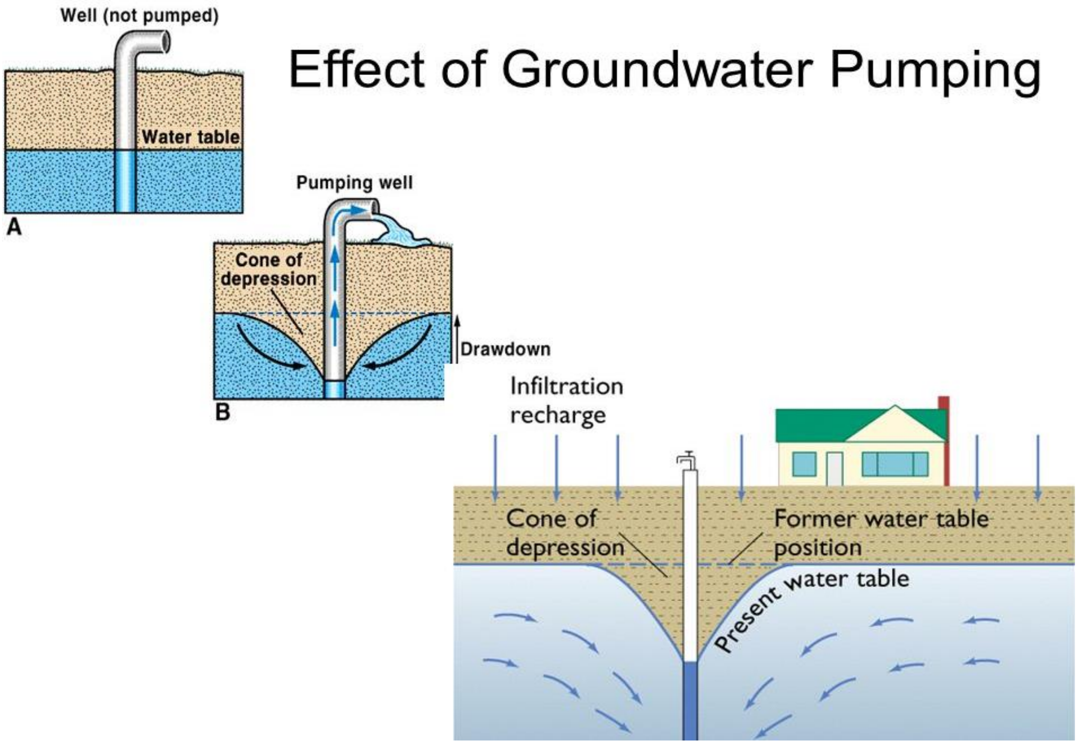


Figure: Effect of Groundwater Pumping

(Source: Thomas V. Cech)

Well interference

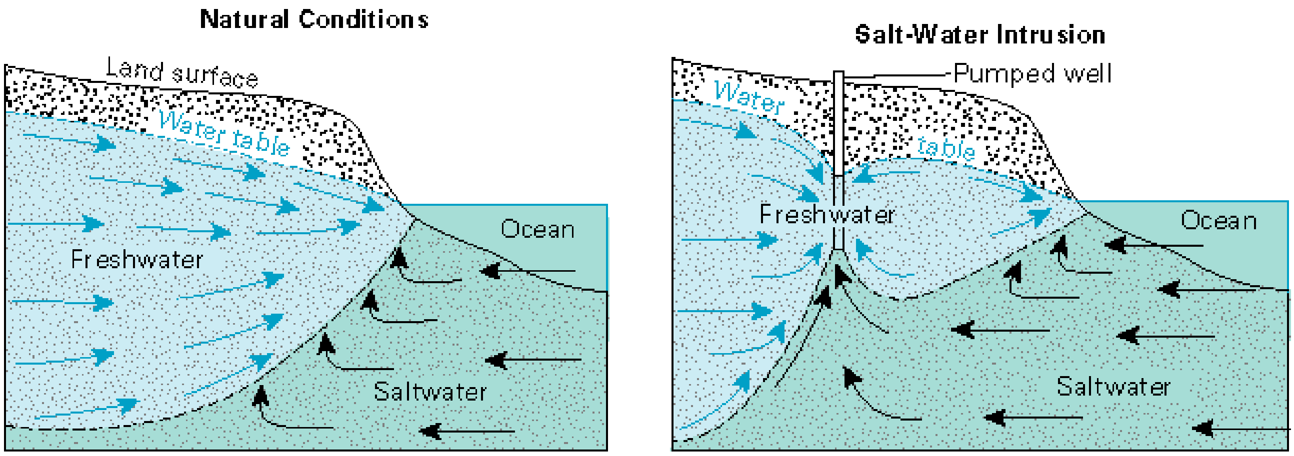
If two cones of depression overlap, there is interference between the wells and the flow of water available to each well reduces. Well interference can be a problem when wells are too close to each other and compete for water from the same aquifer, particularly if they are at the same depth.

Disconnecting groundwater from surface water flow

Ground- and surface water systems often interact closely. Groundwater provides river base flow even in dry periods and supplies freshwater ecosystems. When groundwater is pumped excessively, discharges as springs, base flows and seepages tend to dry out, sometimes permanently. Also groundwater dependent ecosystems are damaged and groundwater availability to user communities is reduced.

Groundwater salinization

A serious thread accompanied with excessive pumping is groundwater salinization. This occurs by up-coning of saline water and mixing with fresh water, giving rise to an irreversible aquifer salinization. Saline water may be mobilized of paleo-saline or connate waters at depth. Special attention has to be paid in coastal areas, as saline seawater may intrude into the freshwater zones of aquifers. The figure below shows a simplified view of the process of seawater intrusion, which can impede groundwater use for agriculture for decades.



Groundwater salinization

(Source: USGS – https://pubs.usgs.gov/gip/gw/images/Intrusion.gif)

Relevance of sustainable management

Despite the risks mentioned, sustainably managed groundwater is *the* crucial resource for agriculture, food security and rural livelihoods. In many regions, it is relatively easy to access and extract, even more if decentralized solar power supply is available. Groundwater has the potential to buffer droughts and increase agricultural production in water-scarce regions, as it is less sensitive to climate variability and change than surface water.

However, groundwater users - and hence the farmer operating a SPIS – share the responsibility for a sustainable management of the resources. Beyond that, in order to take long-term advantage from groundwater, it is rather *self-interest* of the SPIS farmer to avoid aquifer overexploitation and consequent socio-economic and legal conflicts. For the farmer this entails some crucial responsibilities and duties:

- Compliance to the legal and regulatory framework in obtaining user rights and permits and the conditions and quantities they define;
- If no water regulation is in place, farmers should lobby for setting up a regulatory framework in order to get planning and production security (see step 4);
- Monitoring and documentation of water use water based on rights and permits.

Important: Any SPIS development must therefore be integrated into the prevailing legal and regulatory frameworks and into the local water/groundwater management planning and monitoring.

2. ANALYZE WATER MANAGEMENT AND REGULATION

Sustainable groundwater management and governance is based on the concept of an integrated water resources management (IWRM). The three key pillars of IWRM and sustainability in general are:

- **Environmental sustainability** – negative impacts such as water deterioration of aquifers and on groundwater dependent ecosystems have to be avoided;
- **Economic efficiency** - water is an essential good that is required for human consumption and for agricultural and industrial production;
- **Social equity** – access to safe water resources is essential to all human beings and a human right. Transparent and equal water right systems allow for equal access.

A sustainable long-term usage of water resources is in the interest of all users, also with regard to the availability of the resources for long lasting investments in the agricultural sector. Hence, all users should have an interest to set up a functioning institutional environment that safeguards water resources and guarantees water security for agricultural irrigation purpose. Essential parts of public administration of water resources are water management planning and water regulation.

Water management planning is generally undertaken at a basin level by water ministries or basin organizations. At best, a water management plan integrates the needs from all relevant sectors (drinking water, sanitation, irrigated agriculture, industry, environment), matching the available resources with actual and future demands. Apart from water planning, agricultural authorities (e.g. ministries) may also formulate irrigation development plans that may define priority areas and goals for irrigation development.

Water resource management is the activity of planning, developing, distributing and managing the use of water resources. Sustainable water resource management has regard to all the competing demands for water and seeks to allocate water on an equitable basis to satisfy all uses and demands. Observing the principal of a sustainable yield of aquifers is the foundation for the long-term sustainability of water resources development and use.

Water resource regulation is generally based on national law and a set of sound rules and institutions that govern the monitoring of its quantitative and qualitative state, use of the resource, preventing overuse and pollution of the resource as well as guaranteeing its fair distribution among different users and interests. In many places, public water authorities on different governmental levels are in charge of the supervision of water resources. Based on water and environmental laws, these authorities regulate water use, e.g. issuing water rights and licenses for wells and water infrastructure. In many countries, also non-state institutions (self-)regulate water use, such as water user associations. These may be based on local customs and traditions about the use and distribution between the owner of the source and its users.

The information compiled in this process step will be the basis for the technical and agronomic design and planning in following modules. If correctly applied, this process step will also reveal opportunities and limits for the envisaged irrigation development at the earliest point in the SPIS development stage.

The process step “Analyze Water Management and Regulation” is interlinked with the following process steps “Analyze Water Extraction” and “Explore Cooperative Water Governance” - all three process steps define the framework in which the SPIS can be developed from the point of view of a sustainable water resource management.

“Analyze Water Management and Regulation” is based on the collection of information, data and salient features of the source, the water tenure and the legal situation with regard to water permits and licenses. The objective of this exercise is to obtain a clear and legally secure picture with regards to which water source could be exploited, to water tenure rights to be obtained, and to the limits with regard to water abstraction.

The **SAFEGUARD WATER – Water Resource Management Checklist** of this toolbox provides for an orientation for the information and data to be collected and reviewed in section 1. This section of the tool requires compilation of information from public authorities, water management bodies and user groups.

To define the scale of SPIS-infrastructure the farmer or advisor has to consider several **limits and restrictions:**

- **Type of the water source**: the type of source (open or tube well, pond/reservoir, lake or river) and its dimensions (size, depth, water level below surface) are determinants for the technical requirements for an eventual water abstractions – this information is also taken into account in the DESIGN module;
- **Water management and irrigation planning:** the respective plans should guide the decision of the water regulators on water permits and rights. Therefore, it is important for the farmer/advisor to align the envisaged project to these plans;
- **Water rights and obligations**: the ownership of the water source (private, public or common, ownership use-based or property-based) is a determinant for the access of the farmer to a water source;
- **Water permit details and licensing aspects**: the right to withdraw water from the specific source must be based on a legally recognized water permit or water license. The existence of such a legal provision for water withdrawal is the principal determinant for any irrigation development. It also determines quantities (annual quantities, or monthly quotas), conditions and restrictions issued by the water authorities.

The information can be obtained within the authorities/organizations that are managing water licenses and permits.

Important: The information and data required for this process step should be obtained from legally recognized and verified sources. Do not base decision-making on information obtained from secondary sources without proof.

Also informal agreements should incorporate all important information as prescribed by the public authorities, most importantly access rights, abstraction quotas and restrictions/conditions.

A water withdrawal license is mandatory! No SPIS design and planning must take place before a withdrawal license has been obtained! Any SPIS design and planning must be based on the quantities allowed and conditions prescribed by a legally recognized water withdrawal license!

OUTCOME / PRODUCT

- Compilation of data and information on water source, water tenure and water withdrawal license;
- Assessment of principal possibility to develop SPIS based on a specific water source.

DATA REQUIREMENTS

- Information on water source salient features;
- Information on water entitlements and type of water rights;
- Information on type and details of water withdrawal license.

IMPORTANT ISSUES

- Irrigation system development can only be based on a legally recognized water withdrawal license;

- Abstraction quantities/quotas and restrictions as prescribed by the withdrawal license are binding;
- Informal agreements should be legally registered and recognized.

PEOPLE / STAKEHOLDER

- Farmer and Agricultural Advisor
- Water Resource Management and Licensing Authorities
- Farmer Organization / Water User Group

Groundwater pumping and short-term storage

(Source: BGR)

3. ANALYZE WATER EXTRACTION

Water extraction must be based on a corresponding water withdrawal license that also provides for information on the allowed annual or monthly quantities/quotas and on specific conditions or restrictions such as seasonal limits. This step deals with the collection of information on the existing or planned water extraction approach (gravity, manual-lifting or motor-pump) and the water pump. Furthermore, the actual water availability must be evaluated. Both aspects are essential in determining whether an existing or planned irrigation system can be operated in a sustainable way.

The **SAFEGUARD WATER – Water Resource Management Checklist** of this toolbox provides for an orientation for the information and data to be collected and reviewed in Section 2. The analysis of water extraction potential from a well requires technical information that generally is provided by technical service providers (drilling contractor, pump manufacturers, irrigation system contractors and pump installers).

The main aspect in this process is to evaluate the water availability in the selected water source. For surface water sources (pond/reservoir, lake and perennial river) a general assessment is undertaken as to whether the required water quantities can be provided in each month of the year. For wells and boreholes exploiting groundwater resources a test to estimate the hydraulic properties of the aquifer system is required in order to arrive at a sustainable abstraction rate. This is done by means of a pumping test (also called: aquifer test), which should be carried out after the installation of a pump. A pumping test is a field experiment in which a well is pumped at a controlled rate and water-level response (drawdown) is measured in one or more surrounding observation wells and optionally in the pumped well (control well) itself; response data from pumping tests are used to estimate the hydraulic properties of aquifers, evaluate well performance and identify aquifer boundaries. Typically, aquifer properties are estimated from a constant-rate pumping test by fitting mathematical models (type curves) to drawdown data through a procedure known as curve matching and taking into consideration the geological set-up of the aquifer.

Based on the data obtained, key values related to the water abstraction (indicated as flow rates in m^3/hour or m^3/day) can be compared:

- **Water withdrawal capacity**: The quantities of water that can technically be abstracted from a water source with the installed abstraction/pumping device;
- **Water withdrawal license**: Maximum quantity of water a permit holder is legally entitled to in a given period of time (per year, month or day);
- **Expected water withdrawal**: The quantity of water expected to be needed according to the pre-planning of the irrigation system.

The objective of this exercise is to make sure that the pumping capacity:

- does not exceed capacity indicated in the water permit/license;
- meets the crop water demand plus technical storage requirements.

Recommendation: Require your well contractor and pump installer to perform the analysis and provide the corresponding data before any further planning for the SPIS is undertaken.

Important: If one or more of the above principles with regard to the different flow rates are not applicable in the data comparison, the system cannot be operated on a sustainable basis and its operation may result in severe negative ecological (dried out well, negative water balance in the aquifer, dropping water table) and financial impacts (over-dimensioning of system, insufficient water availability for agricultural production). A need to introduce adaptations to the system design or even abandon the project is thus apparent.

OUTCOME / PRODUCT

- Compilation of data and information on flow rates for water source, pump and system;
- Comparison of flow rates for safe yield of water source, water withdrawal license, pump and irrigation system.

DATA REQUIREMENTS

- Water source flow rate;
- Water license quota;
- Water pump flow rate curve;
- Expected water demand of the irrigation system.

IMPORTANT ISSUES

- Safe yield (sustainable withdrawal) of the water source is the determining factor for a sustainable operation;
- Pumping or aquifer test must be performed and requires special expertise;
- Information on existing water sources and pumping installation is available with technical service providers.

PEOPLE / STAKEHOLDER

- Farmer and Agricultural Advisor;
- Water Resource Management
- and Licensing Authorities;
- Farmer Organization / Water User Group;
- Technical Service Providers.

4. EXPLORE COOPERATIVE WATER GOVERNANCE

Every irrigation system exists in a hydrological, socio-economic and cultural environment. Developing solar powered irrigation may affect the interest of other water users. However, good relations to neighboring water users of a common water resource will not only prevent conflicts and competition but also bring opportunities for cooperation and mutual benefits. Regardless of the institutional setting in charge of regulating the access to water, a sustainable operation of irrigation systems requires a high degree of responsibility and compliance with rules and regulations by the farmer. In this context, self-monitoring and self-regulation on the farm and between the water users of a shared water resource may help to effectively implement resource use regulations of the responsible public authorities. Therefore, collective action of water users should be considered in the system design to enable a sustainable operation. The farmer's knowledge and awareness of the local governance system and the limits and restrictions it sets to his irrigation project is key for its sustainability.

The process step "Explore cooperative water governance" suggests the consideration of three levels of irrigation water governance relevant for project planning:

- **Individual farm level**: Water abstraction from water sources and its utilization needs to be based on the framework given by the water withdrawal license and the safe yield principles (see above). This requires thorough water metering at pump outlet and at system intake and a self-monitoring discipline.
- **Neighborhood level**: As groundwater pumping creates a cone of depression in the local water table (see above), users in the "**area of influence**" of a well may be affected by the water abstraction for the envisaged irrigation system. Likewise, the water abstraction of these users influences the water availability for the envisaged project. In order to maintain a sustainable water withdrawal from the specific water source a user agreement and a self-monitoring of the water abstraction must be in place.

Water metering of source water with a low-cost proportional water meter

(Source: M. Eichholz/ BGR)

- **Water user or farm organization level**: Irrigation water users are often organized in user groups or organizations that are responsible to establish and maintain the rules and regulations for water abstraction and the operation of collective irrigation infrastructure. This organization brings obligations and monitoring requirements to be followed, but also opportunities of sharing risks in case of water scarcity.
- The user that may be affected by (or affect) the projected groundwater abstraction can be derived from the analysis of the pumping test undertaken in the preceding step.
- Based on this spatial delineation an assessment of the following aspects should be undertaken:

1. Are there coordination mechanisms or further institutionalized agreements between users?
2. Does the agreement reflect basic principles of sustainable water resource management? May these principles be included?
3. Do all neighboring farms/users practice self-monitoring and metering of their water abstraction and utilization? Do groundwater users in the radius of influence dispose of technical means for that? Are monitoring data handled in a transparent way, through which way? (e. g. the association or authority or to the general public)
4. Do user agreements incorporate a uniform and transparent adaptation of water abstraction in periods of constraint water availability or other situations (e.g. restrictions due to pollution accidents, establishment of additional points of extraction, etc.) or could this be agreed upon? Are there mechanisms of cooperation in case of droughts?

Recommendation: Collective action between water users is a very successful approach to help farmers/producers of a shared resource reach a joint protection of the water source and the adherence to the principles of a sustainable water resource management. Agreements and actions could incorporate important aspects such as water withdrawal quotas for each farmer, the list of seasonal crops, the utilization of water saving irrigation technologies, the approach and routine for water abstraction and utilization monitoring and the joint information in case of crisis/emergencies.

Important: Solar powered irrigation may only contribute to good water governance if the irrigation system is sustainably designed and prudently operated. This includes: system design and outlay based on the water quantities allowed and integration of water metering along the production process. Furthermore, collective user action should be informed by scientific advisory that sensitizes the users for aspects of a sustainable water resource management and provides them with information on water saving crops, irrigation technologies and cultivation methods.

OUTCOME / PRODUCT

- Assessment of additional farmers/users in the area of influence;
- Assessment of groundwater related rules and institutions in place, such as user agreements and self-monitoring systems;
- Assessment of mechanisms of coordination and cooperation between neighboring groundwater users;
- Sensitized farmers/users.

DATA REQUIREMENTS

- Radius of influence (refer to “Analyze Water Extraction”);
- Details of user agreements.

IMPORTANT ISSUES

- Technical provisions for monitoring of water abstraction and utilization need to be incorporated into system design;
- User agreements should be proactively advertised for by advisory services.

PEOPLE / STAKEHOLDER

- Farmer and Agricultural Advisor;
- Water Resource Management and Licensing Authorities;
- Farmer Organization/Water User Group.

5. REVIEW POTENTIAL RISKS AND IMPACTS

Through a thorough review of the risks and impacts related to the abstraction of water from available water sources, the agricultural advisor or development practitioner (the **promoter**) will be able to identify the limits and restrictions of the irrigation development that is envisaged.

The preceding steps aim to gather information on the available water quantities and usage rights. In many countries, information is held by different authorities and often fragmented or incomplete. Thus, it is important that the promoter triangulates information from different relevant sources. This may be public authorities, water user associations, water professionals as well as scientific institutions dealing with local water management.

- Especially when it comes to hydrological data and estimates of available quantities, it is important to note that stable conditions within the water cycle are rarely found. Climate variability and change as well as upstream water developments may change the predicted water quantities used in the design of an irrigation system. This may relate as to the overall quantities as to seasonal fluctuations.
- Changes in water availability may pose a risk to the farm productivity and thereby to the financial viability of a project.
- Water rights and abstraction permit are mandatory for the setup of an irrigation project. Non-compliance with the water regulations may result in penalties, legal prosecution and lead to the suspension of the project.
- It is important to check, if and how water withdrawal is regulated in detail within these permits. Furthermore, farmer organizations or water user groups can provide information on available water quantities and perhaps schedules and utilization restrictions.
- Subsidizing or financing bodies may have particular obligations/restrictions with regard to the irrigation development if financial support is provided – this may relate to the type of irrigation, the system size, the productive use and also to the adherence of sustainability principles in water abstraction and use.

Recommendation: The review of potential risks and impacts of an irrigation development should rest upon official and reliable information gathered in the preceding steps. The process of planning and designing an irrigation system should only be continued with a valid licenses or permits to abstract water.

Summing up the water-related issues raised in this module, it is crucial that - apart from public regulation - also each irrigation farmer is aware about their role and risks with regard to the shared water resources. During the planning of solar powered irrigation, these **critical issues** concerning potential risks and their impact on the project should be addressed:

Key Question Area	Critical issues	Possible Consequence
Water availability and licensing	No availability of license/permit	No basis for system development Need to identify alternative site
	Insufficient water availability in quantity or quality	Need to adapt system size and design Seasonal operation limitations **Risk of overutilization of water sources, leading to negative environmental and economic impacts**
	Restrictions/limitations on use	Need to adapt production Potential danger of lacking financial viability
	High costs of water (subscription and quantity-based consumption)	Need to adapt production Potential danger of lacking financial viability
Water management and governance	Other users affected by water abstraction	Adaptation of water abstraction to harmonized schedule Need to adapt operation and production
	Restrictions/limitations prescribed by legislation/by-laws	Adaptation of water abstraction to harmonized schedule Need to adapt operation and production
	Prescription of operation principles and technical design specifications	Need to adapt system design Need to adapt operation and production Potential danger of lacking financial viability
	Need to invest into supplementary monitoring and into joint installations	Need to adapt system design Potential danger of lacking financial viability
Water source planning	Limited sustainable yield of water source	Need to rehabilitate/expand source installation Need to adapt system design Seasonal operation limitations **Risk of overutilization of water sources, leading to negative environmental and economic impacts**
	Need to share with other users	Need to rehabilitate/expand source installation Need for agreements and co-management Seasonal operation limitations **Risk of overutilization of water sources, leading to negative environmental and economic impacts**
	Water source planning independently from irrigation system design/planning	Potential danger of over- or under-dimensioning of source installation **Risk of overutilization of water sources, leading to negative environmental and economic impacts** Potential danger of lacking financial viability

Key Question Area	Critical issues	Possible Consequence
	Water source planning without hydrological investigation	Potential danger of over- or under-dimensioning of source installation **Risk of overutilization of water sources, leading to negative environmental and economic impacts** Potential danger of lacking financial viability
Technical design and planning	Irrigation system design and planning independently from water source planning	Insufficient adaption of system design to water availability Potential danger of over- or under-dimensioning of irrigation system **Risk of overutilization of water sources, leading to negative environmental and economic impacts** Need to adapt production Potential danger of lacking financial viability
	Irrigation system design and planning without agronomic planning	Potential danger of over- or under-dimensioning of irrigation system Need to adapt production Potential danger of lacking financial viability
	Irrigation system design and planning based on blue print model	Insufficient adaption of system design to water availability Potential danger of over- or under-dimensioning of irrigation system **Risk of overutilization of water sources, leading to negative environmental and economic impacts** Need to adapt production Potential danger of lacking financial viability
	Irrigation system design and planning limited due to prescriptions from subsidizing/financing authority	Insufficient adaption of system design to water availability Potential danger of over- or under-dimensioning of source installation **Risk of overutilization of water sources, leading to negative environmental and economic impacts** Need to adapt production Potential danger of lacking financial viability

A key aspect in the assessment is that none of the question areas can be reviewed independently, because they are strongly interlinked.

At various points, the assessment may identify **risks of overutilization of water sources, leading to negative environmental and economic impacts.** As outlined in the preceding process steps this risk relates to a wide range of negative impacts:

Ecological impacts of over-exploitation of water resources

- Dewatering/drying of biotopes and dying of vegetation;
- Soil degradation;

- Reduction of water levels/flow in surface waters;
- Pollution and salinization of water resources.

Economic impacts of overutilization of water resources

- Increased cost of pumping due to deeper exploitation (higher energy input, larger pumps);
- Increased cost due to treatment requirement of polluted/saline water;
- Limitations in irrigation due to periodic drying/flow reduction of water sources;

Social impacts of overutilization of water resources

- User conflicts due to decreased availability of water;
- Discrimination/marginalization of users with limited financial resources due to drying of open/shallow wells (and inability to invest in even more exploitation);
- Endangered drinking water supply due to competition between irrigation and human water supply.

OUTCOME / PRODUCT

- General analysis of risks and impacts of SPIS project;
- Identification of potential risks endangering viability of SPIS project;
- Check if interdependent factors have been considered.

DATA REQUIREMENTS

- Information on water availability and abstraction regulations and legislation;
- Information on water management and governance framework/organizations;
- Information of system design prescriptions/obligations from subsidizing / financing bodies;
- Data on water source features and capacities;
- Data on water requirements of irrigation system components.

IMPORTANT ISSUES

- No irrigation system development can take place without a legal water abstraction license / water rights;
- Water abstraction quotas are binding and constitute the maximum water availability for peak demand;
- Coordination between stakeholder of the design and planning is not a given, but has to be promoted actively;
- Triangulation (using different information sources) is required to obtain a realistic and comprehensive overview;
- Irrigation systems must be embedded in the hydrological, social and economic context of the region. Blue print systems should be avoided.

PEOPLE / STAKEHOLDER

- Farmer and Agricultural Advisor;
- Water Resource Management and Licensing Authorities;
- Hydrological Services;
- Farmer Organization / Water User Group;
- Well Contractor;
- Manufacturer and Technology Provider;

- Subsidizing/Financing Body.

6. ADJUST PLANNING AND OPERATION

The final process step of this module is based on the results of the preceding steps 2 – 5 in which important factors related to a sustainable utilization of the water resources designated for the irrigation system have been evaluated. None of these process steps should be skipped and it is very important that the underlying analysis along the logic of these process steps is carried out before the envisaged SPIS is finally designed and planned.

The results of the process steps 2 – 5 almost certainly result in limitations and restrictions with regard to the design and outlay of all system components and also the options for the agricultural production. As water resources are limited and increasingly constrained, sustainability criteria with regard to the exploitation of water resources must always prevail. The determining factor for the irrigation system development is therefore the sustainable water availability – **system and production are designed and planned according to the safe yield of the targeted water source**!

Substantial need for adaptation and adjustment in predesigned or blue print model systems based on the above principle may arise from the following:

- **No or insufficient water withdrawal license**: In the worst case, an irrigation development would not be possible due to the non-availability of water abstraction rights or abstraction quotas that are too small to allow for a feasible production. Very often, limits and conditions laid out in withdrawal licenses require a down-sizing of a system design (due to limited water availability) and/or the adaption of crop rotation (due to limited water availability, restriction of crops that can be cultivated seasonally, restriction of use of agricultural inputs due to soil and water protection). This may also impact the management and operation of the system.
- **Low water availability and seasonal variations**: The evaluation of the safe yield of a water source may further limit the options for irrigation and production – often, there are seasonal restrictions (e.g. during dry seasons). It is important to keep in mind that the safe (sustainable) yield of a water sources may be inferior to the quota indicated in a withdrawal license.
- **Overlapping demands on a shared water resource**: Further limitations and thus the need for adaptations/adjustments to system design/outlay, production and operation may result from an analysis of neighborhood effects in the area of influence of the irrigation project. The interest and rights of all affected farmers/users need to be taken into account and need to be harmonized. This can be done by bilateral user agreements between neighboring farmers or under the umbrella of water user associations and result in restrictions of seasonal cultivable crops, rotating water distribution, reduced flow rates).
- **Design requirements from a financing entity:** A particular issue are conditions and restrictions of financing/subsidizing organizations. These conditionalities are often linked to the utilization of a particular technology (e.g. water saving micro irrigation) or the cultivation of particular crops (e.g. x % of crop rotation must be oilseeds or other crops) and may also limit the options for system design and a viable production.

Recommendation: Any irrigation system should be designed and laid out based on a thorough planning from the scratch based on a careful analysis of the framework conditions and the design parameters as further explained in the **DESIGN** module.

Changes in water availability may also occur when the irrigation has been installed according to the given licenses. Given the global increase in climate variability, it is recommended to design a flexible irrigation system that is resilient towards water scarcity. Steps towards drought resilient irrigation may include e.g. selection of crops with low water demand, high water use efficiency and coping mechanisms such as water buffering or insurances. In this context, the role of collective action and risk sharing among water user should be taken into account.

Important: Ignoring the various limiting framework conditions and restrictions may lead to an over- or under-dimensioned system capacity and an unsustainable operation. As far as an over-dimensioned system is concerned, water abstraction above the safe yield will negatively impact the environment and may result in a violation of the allotted water license/permit. A too small water abstraction may result in a low system utilization rate, or under-irrigation, thus having an impact on financial viability. Sustainability in environmental and financial terms can only be achieved if water availability, system design/outlay, crop production and irrigation management and operation are harmonized from the design stage.

In the sense of an adaptive management, it is important to reevaluate the framework conditions in regular intervals as some factors can change, such as the seasonal restriction of particular (water intensive) crops or changed water allocation patterns/quantities. These changes may require adjustments in system operation and production planning after the irrigation system has been constructed.

OUTCOME / PRODUCT

- Adjusted/adapted system design/outlay oriented in adaptive management;
- Adjusted/adapted system operation with focus on efficiency;
- Adjusted/adapted production.

DATA REQUIREMENTS

- Results of process steps 2 – 5.

IMPORTANT ISSUES

- Lack of adjustment/adaptation of system design, operation or production results in adverse ecological and financial impacts;
- Adjustment/adaptation does not stop after the construction of the SPIS but is an iterative process.

PEOPLE / STAKEHOLDER

- Farmer and Agricultural Advisor;
- Water Resource Management and Licensing Authorities;
- Farmer Organization/Water User Group;
- Technology and Service Providers.

FURTHER READING, LINKS AND TOOLS

Further Reading

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SPIS Tools

- **SAFEGUARD WATER – Water Requirement Tool**: calculator to determine monthly water of different crops and livestock
- **SAFEGUARD WATER – SPIS Water Resource Management Checklist**: includes guidelines for regular inspection for the sustainable and legitimate abstraction of water
- **IRRIGATE – Soil Tool**: calculator to determine irrigation interval according to geographic location, precipitation, crop type and soil type

Technical glossary

Aquifer	Underground geological formation(s), containing usable amounts of groundwater that can supply wells or springs for domestic, industrial, and irrigation uses.
Chemigation	The process of applying chemicals (fertilizers, insecticides, herbicides, etc...) to crops or soil through an irrigation system with the water.
Conveyance loss	Loss of water from a channel or pipe during transport, including losses due to seepage, leakage, evaporation, and other losses.
Crop coefficient	Ratio of the actual crop evapotranspiration to its potential (or reference) evapotranspiration. It is different for each crop and changes over time with the crop's growth stage.
Crop Water Requirement (CWR)	The amount of water needed by a plant. It depends on the climate, the crop as well as management and environmental conditions. It is the same as crop evapotranspiration.
Current (I)	Current is the electrical flow when voltage is present across a conductor, or the rate at which charge is flowing, expressed in amperes [A].
Deep percolation	Movement of water downward through the soil profile below the root zone. This water is lost to the plants and eventually ends up in the groundwater. [mm]
Drawdown	Lowering of level of water in a well due to pumping.
Drip irrigation	Water is applied to the soil surface at very low flow rates (drops or small streams) through emitters. Also known as trickle or micro-irrigation.
Emitter	Small micro-irrigation dispensing device designed to dissipate pressure and discharge a small uniform flow or trickle of water at a constant discharge which does not vary significantly because of minor differences in pressure head. Also called a "dripper" or "trickler".
Evaporation	Loss of water as vapor from the surface of the soil or wet leaves. [mm]
Evapotranspiration (ET)	Combined water lost from evaporation and transpiration. The crop ET (ETc) can be estimated by calculating the reference ET for a particular reference crop (ETo for clipped grass) from weather data and multiplying this by a crop coefficient. The ETc, or water lost, equals the CWR, or water needed by plant. [mm]
GIWR	The Gross Irrigation Water Requirement (GIWR) is used to express the quantity of water that is required in the irrigation system. [mm]
Fertigation	Application of fertilizers through the irrigation system. A form of chemigation.
Financial viability	The ability to generate sufficient income to meet operating expenditure, financing needs and, ideally, to allow profit generation. It is usually assessed using the Net Present Value (NPV) and Internal Rate of Return (IRR) approaches together with estimating

	the sensitivity of the cost and revenue elements (See Module **INVEST**).
Friction loss	The loss of pressure due to flow of water in pipe. It depends on the pipe size (inside diameter), flow rate, and length of pipe. It is determined by consulting a friction loss chart available in an engineering reference book or from a pipe supplier. [m]
Global solar radiation (G)	The energy carried by radiation on a surface over a certain period of time. The global solar radiation is locations specific as it is influenced by clouds, air humidity, climate, elevation and latitude, etc. The global solar radiation on a horizontal surface is measured by a network of meteorological stations all over the world and is expressed in kilowatt hours per square meter [kWh/m²].
Gravity flow	The use of gravity to produce pressure and water flow, for example when a storage tank is elevated above the point of use, so that water will flow with no further pumping required.
Head	Value of atmospheric pressure at a specific location and condition. [m]: Head, total (dynamic) Sum of static, pressure, friction and velocity head that a pump works against while pumping at a specific flow rate. [m]; Head loss Energy loss in fluid flow. [m]
Infiltration	The act of water entering the soil profile.
Insolation	The rate at which solar energy reaches a unit area at the earth measures in Watts per square meter [W/m²]. Also called solar irradiance.
Irradiation	The integration or summation of insolation (equals solar irradiance) over a time period expressed in Joules per square meter (J/m2) or watt-hours per square meter [Wh/m²].
Irrigation	Irrigation is the controlled application of water to respond to crop needs.
Irrigation efficiency	Proportion of the irrigation water that is beneficially used to the irrigation water that is applied. [%]
Irrigation head	Control unit to regulate water quantity, quality and pressure in an irrigation system using different types of valves, pressure regulators, filters and possibly a chemigation system.
Lateral	Pipe(s) that go from the control valves to the sprinklers or drip emitter tubes.
Latitude	Latitude specifies the north–south position of a point on the Earth's surface. It is an angle which ranges from 0° at the Equator to 90° (North or South) at the poles. Lines of constant latitude, or parallels, run east–west as circles parallel to the equator. Latitude is used together with longitude to specify the precise location of features on the surface of the Earth.
Leaching	Moving soluble materials down through the soil profile with the water.

Maximum Power Point Tracking (MPPT)	An important feature in many control boxes to draw the right amount of current in order to maintain a high voltage and achieve maximum system efficiency.
Net Irrigation Water Requirements (NIWR)	The sum of the individual crop water requirements (CWR) for each plant for a given period of time. The NIWR determines how much water should reach the crop to satisfy its demand for water in the soil. [mm]
Power (P)	Power is the rate at which energy is transferred by an electrical circuit expressed in watts. Power depends on the amount of current and voltage in the system. Power equals current multiplied by voltage (P=I x V). [W]
Photosynthesis	Photosynthesis is a process used by plants and other organisms to convert light energy into chemical energy that can later be released to fuel the organisms' activities (energy transformation).
Pressure	The measurement of force within a system. This is the force that moves water through pipes, sprinklers and emitters. Static pressure is measured when no water is flowing and dynamic pressure is measured when water is flowing. Pressure and flow are affected by each other. [bars, psi, kPa]
Priming	The process of hand-filling the suction pipe and intake of a surface pump. Priming is generally necessary when a pump must be located above the water source.
Pump	Converts mechanical energy into hydraulic energy (pressure and/or flow). Submersible pump: a motor/pump combination designed to be placed entirely below the water surface. Surface pump: pump that is not submersible and placed not higher than about 7 meters above the surface of the water.
Root Zone	The depth or volume of soil from which plants effectively extract water from. [m]
Salinity (Saline)	Salinity refers to the amount of salts dissolved in soil water.
Solar panel efficiency	Solar panel efficiency is the ratio of light shining on the panel, versus the amount of electricity produced. It is expressed as a percentage. Most systems are around 16% efficient, meaning 16% of the light energy is converted into electricity.
Suction lift	Vertical distance from the surface of the water to the pump. This distance is limited by physics to around 7 meters and should be minimized for best results. This applies only to surface pumps.
Surface irrigation	Irrigation method where the soil surface is used to transport the water via gravity flow from the source to the plants. Common surface irrigation methods are: Furrow irrigation – water is applied to row crops in small ditches or channels between the rows made by tillage implements; Basin irrigation – water is applied to a completely level area surrounded by dikes, and

	Flood irrigation – water is applied to the soil surface without flow controls, such as furrows or borders.
Transpiration	Water taken up by the plant's roots and transpired out of the leaves. [mm]
Voltage (U or V)	Voltage is the electric potential between two points, or the difference in charge between two points, expressed in Volts [V].

POWERING AGRICULTURE:

AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

Module 8: Market

Food and Agriculture Organization of the United Nations
USAID FROM THE AMERICAN PEOPLE
SWEDEN
german cooperation DEUTSCHE ZUSAMMENARBEIT
DUKE ENERGY
OPIC

The Toolbox for SPIS Advisors is made possible through the global initiative Powering Agriculture: An Energy Grand Challenge for Development (PAEGC). In 2012, the United States Agency for International Development (USAID), the Swedish International Development Cooperation Agency (Sida), the German Federal Ministry for Economic Cooperation and Development (BMZ), Duke Energy, and the Overseas Private Investment Cooperation (OPIC) combined resources to create the PAEGC initiative. The objective of PAEGC is to support new and sustainable approaches to accelerate the development and deployment of clean energy solutions for increasing agriculture productivity and/or value for farmers and agribusinesses in developing countries and emerging regions that lack access to reliable, affordable clean energy.

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Download
https://energypedia.info/wiki/Toolbox_on_SPIS

About
Powering Agriculture: An Energy Grand Challenge for Development: https://poweringag.org

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ABBREVIATIONS

USAID	United States Agency for International Development
PAEGC	Powering Agriculture: An Energy Grand Challenge for Development
Sida	Swedish International Development Cooperation Agency
BMZ	German Federal Ministry for Economic Cooperation and Development
OPIC	Overseas Private Investment Cooperation
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
FAO	Food and Agriculture Organization of the United Nations
RISE	Regulatory Indicators for Sustainable Energy
SPIS	Solar Powered Irrigation Systems
SDGs	Sustainable Development Goals
DEMs	Digital Elevation Models
GIS	Geographical Information System
AEZs	Agro-ecological zones
GAEZ	Global Agro-ecological Zones
IIASA	International Institute for Applied Systems Analysis

MARKET

1. Identify a potential market

↓

2. Evaluate geophysical parameters

↓

3. Evaluate the business environment

↓

4. Decide on market potential

1. MODULE AIM & ORIENTATION

The MARKET Module aims to provide high level theory on how to conduct market potential assessments for solar powered irrigation systems within a country or region. It provides parameters for consideration that may be applied by varying stakeholders (including private SPIS companies, policy-makers, financial institutions and development practitioners) in assessing the market potential of SPIS.

The Module recognizes that, in order to carry out the market potential assessment, the user must have identified a target area for evaluation. **Chapter 1: Identifying a potential market** provides factors for consideration in identifying the market and provides tools that can be used.

Additionally, the Module identifies two over-arching categories of parameters that are key to conducting a high-level assessment of the market potential for SPIS in a target country or region: 1) geophysical attributes and 2) business environment. **Chapters 2 – evaluate geophysical parameters** and **Chapter 3 – evaluate the business environment** expound on the specific parameters under each category. These chapters provide the definitions of the parameters and highlight why these parameters are considered key to the market assessment.

The parameters identified under geophysical attributes include: land cover land use, solar radiation, water availability, topography, crop and livestock and ambient temperature.

Parameters affecting the business environment include: government and non-governmental interventions, financing, cost and availability of alternative sources of power, level of SPIS related technical capacity, awareness levels of solar PV and irrigation technologies, significance of agriculture to the economy, land use rights and tenure and transport and communication infrastructure.

The Module is also supplemented by the **MARKET - Market Assessment Tool**, which considers basic geophysical parameters, and provides guidelines and weights to evaluate parameters that inform an enabling business environment for SPIS.

2. IDENTIFYING TARGET MARKETS

Identifying a market of interest is a pre-cursor to assessing the market's potential for SPIS. Key to the identification process, and which affects the evaluation of the market, is **WHO** is interested in the promotion and adoption of SPIS, and **WHY** they are interested. For instance, a private SPIS company may be looking to break into new markets, developing agencies may want to advance sustainable development goals (SDGs) within a region, and policy makers and government agencies may be interested in growing or diversifying their country's economy. The parameters presented in this module and their associated weights, may therefore be seen as parameters for both market assessment and gap analysis.

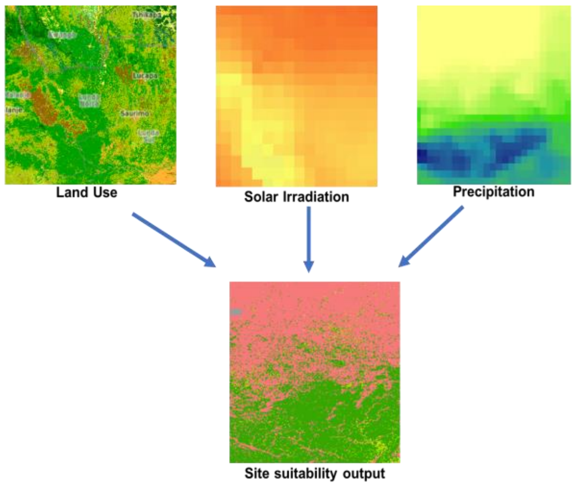
Identification of target markets for SPIS involves the evaluation of numerous parameters. These may include various geo-physical and business environment parameters. For stakeholders who do not have a set target market in mind or who merely want a high-level overview of potential areas where systems could be set up or utilized, this could prove to be a daunting and time-consuming task.

As the guidelines provided in Chapters 2 and 3 help to determine whether a pre-identified location has potential for SPIS rather than identify a target market, this chapter aims to ease the identification process by providing some key considerations in market identification.

Three geophysical parameters are considered core to the viability of SPIS within an area: solar irradiation, precipitation and land cover/land use. These parameters are highlighted below and elaborated on in the geophysical parameter section of the module.

- **Solar irradiation** refers to the energy incident per unit area on the earth's surface measured in Kilowatt hour per square meter (kWh/m^2). While advancements in solar PV technologies have enabled tapping into low levels of irradiation, it is generally concluded that the lower the irradiation levels, the less the economic viability of SPIS due to prohibitive capital costs.
- **Precipitation** is considered a core factor based on the premise that areas receiving rainfall above a certain rain threshold do not require irrigation. For instance, sugarcane is seen to have the highest seasonal water requirement of 1500-2500mm translating to an estimated average water requirement of 200mm per month according to the FAO. It may therefore be said that, areas receiving higher rainfall volumes than 200mm per month have limited application viability for SPIS.
- **Land cover/land use** allows for the elimination of unsuitable areas including but not limited to forests, urban settlements and snow-covered areas.

Suitability maps provide a high-level overview of countries or regions that have large land areas that are suitable for solar powered irrigation. This can act as a guide for stakeholders to conduct further evaluation on geophysical parameters and business parameters within the identified countries.



Core geophysical parameters for suitability mapping

(Source: EED Advisory, Kenia, 2018)

OUTCOME / PRODUCT

- Target market for SPIS

DATA REQUIREMENTS

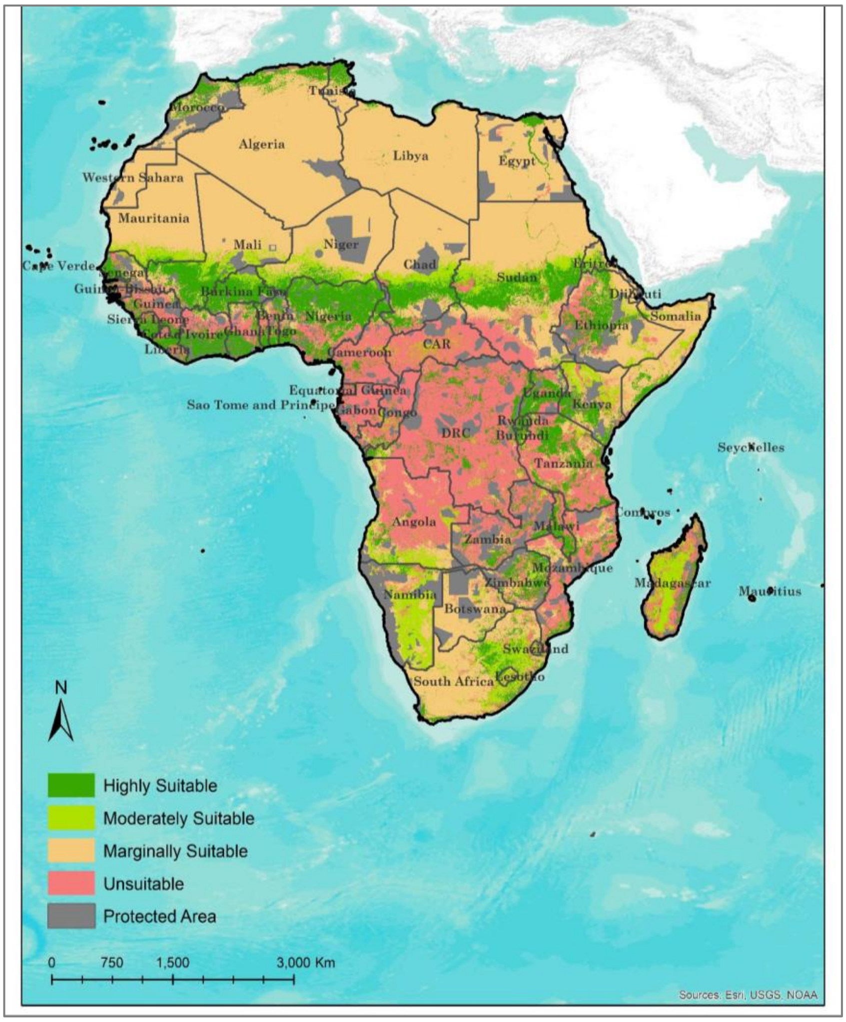
- Precipitation data
- Land cover land use data
- Solar irradiation data

PEOPLE / STAKEHOLDER

- Private SPIS companies
- Policy-makers
- Financial institutions
- Development practitioners
- National and local governments

IMPORTANT ISSUES

- The guidelines provided in the follow up chapters help to determine whether a pre-identified location has potential for SPIS, rather than identify a target market.
- The Suitability Maps tool provides high levels analysis by layering solar irradiation data, precipitation and land cover-land use.



Sample suitability map for SPIS (Esri, USGS, NOAA data)

(Source: EED Advisory, Kenia, 2018)

3. EVALUATION OF GEOPHYSICAL PARAMETERS

Several geophysical parameters can be used to assess SPIS markets. This module highlights 3 that are crucial to the viability of SPIS applications as discussed in Chapter 1: Land cover-land use, solar irradiation and precipitation (under water availability). If the state of these three parameters is unfavourable in the area under assessment, SPIS is unlikely to be practical. An additional 4 parameters that are key to the market assessment for SPIS are also identified – these do not affect the viability of SPIS; they affect the success of SPIS adoption on a case by case basis. The 7 parameters are expounded on below.

LAND COVER/ LAND USE

Land Cover refers to the physical and biological cover over the surface of the earth including water, bare surfaces, forests, and artificial structures among others. Land use on the other hand refers to how people utilize the land whether for recreation, agriculture or wildlife habitats among others.

Land cover/land use is one of the fundamental parameters to be considered during the identification of potential markets for SPIS as it helps determine feasible locations for agriculture from which other parameters may be considered. Land cover is measured either through direct field observations or through remote sensing techniques involving the analysis of satellite and aerial imagery. Based on the land cover analysis, land use data can be inferred through ancillary data. The data assists decision makers and stakeholders in cross-cutting sectors to understand the dynamics of a changing environment and ensure sustainable development.

Land cover data typically consists of eight classes including wetlands, water bodies, urban, shrubs, grassland, forests, bare land and agricultural land. These may, however, be classified into varying classes depending on the source of data. The FAO framework for land suitability for instance, divides land into four classes ranging from highly suitable land for agriculture (S1) to currently not suitable land (S4). For the 8 classes listed above, 'agricultural land' can be classified as highly suitable (S1) and 'grassland', which requires land clearing and levelling, as moderately suitable (S2). 'Shrub land' and 'bare land', which require higher initial investment for land preparation can be classified as marginally suitable (S3) while 'forest', 'water', 'urban', and 'wetlands' can be categorized as not suitable (S4).

In assessing market potential for SPIS for a given country or region, stakeholders need to assess the irrigation viability of their target location from a land cover-land use perspective. For example, areas that are mostly classified as S1 land would have higher potential for SPIS compared to those that are highly urbanized or classified as wetlands.

It should be noted that desktop analysis of land cover/land use data through application of remote sensing techniques should be followed by ground truthing to ascertain the land cover/land use in the selected regions prior to investment.

OUTCOME/PRODUCT

- Classification of land based on agricultural suitability
- Selection of optimal sites to promote solar powered irrigation

DATA/REQUIREMENTS

- Land use - land cover data
- Land suitability classification frameworks (e.g. FAO)

PEOPLE/STAKEHOLDERS

- Land Surveyors
- Remote sensing analysts

- Government land ministries

IMPORTANT ISSUES

It is always important to follow up desktop analysis of landcover with actual on-ground visits to the selected areas. Satellite and aerial images are typically very accurate however if one is not using up to date datasets it becomes important to verify the selection.

SOLAR IRRADIATION

Solar irradiation is a key factor in gauging the market potential of SPIS within a region. It refers to the amount of energy incident per unit area on the earth's surface in units of watts hours per square meter. PV systems use Global Horizontal Irradiation (GHI) which is the total amount of radiation received from above by a horizontal surface. GHI consists of both Direct Normal Irradiation (DNI) – the amount of solar radiation received per unit area by a surface that is always held perpendicular to the incoming rays and; Diffuse Horizontal Irradiation (DHI) – the amount of radiation received per unit area by a surface that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere.

Solar radiation can be categorized into four classes: levels less than 2.6kWh/m^2 are classified as low solar radiation while solar irradiance between 2.6-3kWh/m^2 is moderate solar radiation; irradiance of between 3-4kWh/m^2 is high solar radiation and irradiance higher than 4kWh/m^2 is very high radiation. It is important to note that the classification is used for purposes of distinguishing the efficiency of systems as advances in solar technologies have allowed for the set-up of systems in almost all areas that receive radiation. In areas of low radiation, system efficiency will be compromised due to lower panel output. Additionally, set up of solar panels in regions of low solar radiation could lead to high set up costs resulting from the use of a greater number of panels to generate the same output as regions with higher insolation. It is therefore noted that, because of technological advances, solar irradiation is more of an economic consideration than a question of technical feasibility.

OUTCOME / PRODUCT

- Classification of regions based on GHI or PV system output
- Identification of optimal sites for SPIS

DATA REQUIREMENTS

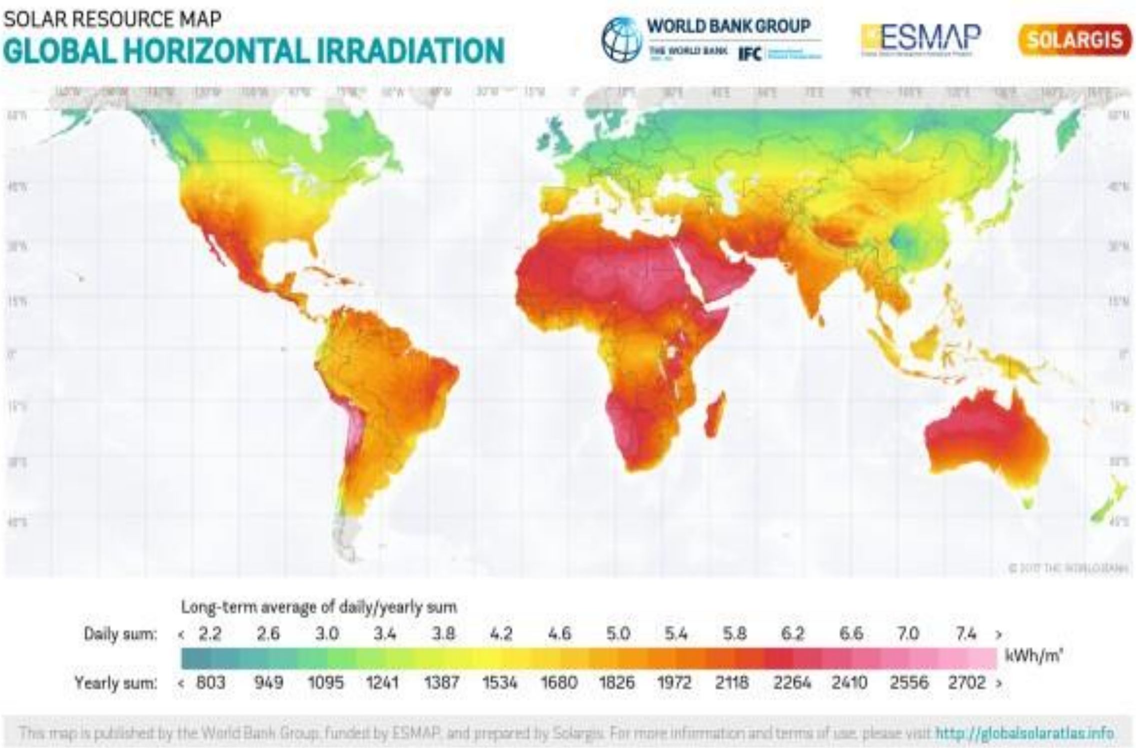
- Global horizontal irradiation data

PEOPLE / STAKEHOLDERS

- Solar PV system installers
- Meteorological service providers
- Solar equipment suppliers

IMPORTANT ISSUES

- There are various other factors that affect the functionality of a PV system in addition to solar irradiance. Two of the most important include temperature and aspect which are further expounded on in the ambient temperature and topography sections of the module.



Global Horizontal Solar Irradiation

(Source: World Bank Group, 2018)

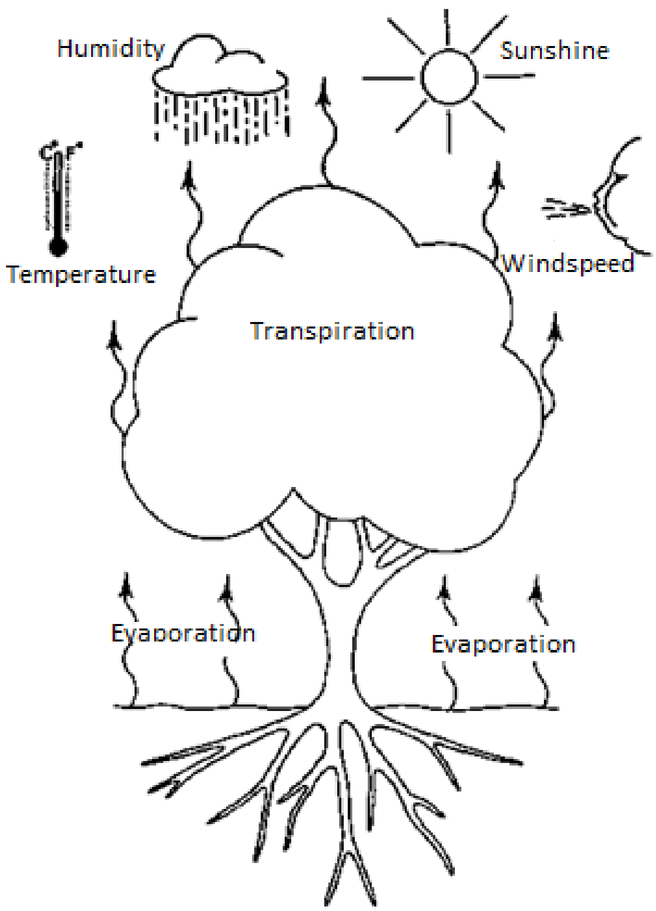
WATER AVAILABILITY

This parameter investigates the amount and quality of water available for irrigation at a potential SPIS area. Irrigation water requirements depend on the balance of the crop water demand against the water availability.

Crop water demand may generally be defined as the amount of water needed for a plant to live and grow and is measured in milimeters per day, month or season. It is affected by various factors including:

1. ***Climatic conditions*** including temperature, humidity and windspeeds. Consequently, water needs for one crop will vary with varying climatic conditions, with the highest demand seen in areas that are hot, dry, windy and sunny;
2. ***The type of crop*** affects its water demand, both in the short term (daily water demand) and the longer term (seasonal water demand);
3. ***The stage of growth*** for a particular crop also affects its water demand. For instance, a mature maize plant may demand more water than one at the shooting stage. Local data on crop water needs is often available with agricultural extension offices. The Water requirement tool under the **SAFEGUARD WATER Module** as well as resources provided by the FAO may also be used in estimating water demand.

Water availability for crop growth is dependent on three main sources: precipitation, ground water and surface water resources.



Major climatic factors affecting crop water demand

(Source: Food and Agriculture Organization of the United Nations)

Precipitation, the amount of rainfall received in an area, has a direct influence on the need for irrigation within an area. If the amount of precipitation received within a region is enough to meet the water demands of the crops grown, irrigation is not necessary; when precipitation volumes are not adequate, water supply through irrigation from ground or surface water resources becomes critical for crop growth. The adequacy of precipitation may be evaluated by comparing the effective rainfall against the crop water demand using the **SAFEGUARD WATER – Water Requirement Tool**.

Effective rainfall – this looks at the amount of water from rainfall received within an area that is available for utilization by crops. This volume is affected by various factors including soil texture and structure, climate, topography and the depth of crops' root zone[1] among others. These factors consequently affect the rate of surface run-off and water percolation / infiltration beyond the root zone. The amount of rainwater retained in the root zone of plants that can be used by plants is referred to as effective rainfall. Most countries have developed tools to determine effective precipitation. However, in the absence of data (e.g. lack of prevailing soil type, rainfall reliability and topography data), the FAO provides rough estimates for effective rainfall per rainfall received.

Ground and surface water sources – the need to tap into these resources to meet the water deficit from rainfall introduces the market potential for SPIS. However, it is important to note that factors such as water source proximity and yield, aquifer recharge rates, water quality, water permits or rights required for abstraction among others must be taken into consideration when identifying and designing SPIS for specific areas. Water source yield, for example, has a direct influence on the type of irrigation method selected. In situations of inadequate water supply, sensitive soils or poor quality water (sedimentation, salinity and water hardness) appropriate methods like drip and sprinkler irrigation are preferred. Surface irrigation is preferred if the irrigation water contains large amounts of sediment which may clog the drip or sprinkler irrigation systems. This is expounded on in the **DESIGN module**.

OUTCOME / PRODUCT

- Classification of regions based on crop water demand vs effective rainfall.
- Identification of ground and surface water sources.

DATA REQUIREMENTS

- Monthly Precipitation data
- Data on surface water bodies and ground water aquifer systems
- Water licensing and abstraction rights
- Water source flow rates
- Crop water demand

PEOPLE / STAKEHOLDERS

- Meteorological Service Providers
- Water resource management authorities and abstraction licensing authorities
- Agricultural advisors and extension officers
- Irrigation boards and organisations

IMPORTANT ISSUES

- Desktop analysis of precipitation and ground and surface water sources should be followed by verification of data from the relevant government bodies (e.g. national meteorological centres and water resources management authorities) prior to investment.
- Determination of crop water requirements can be done using the

[1] Rootzone may be defined as the region within which a plant's roots extend within the soil, and from which it can absorb water.

WATER REQUIREMENT TOOL in the Safeguard water module.

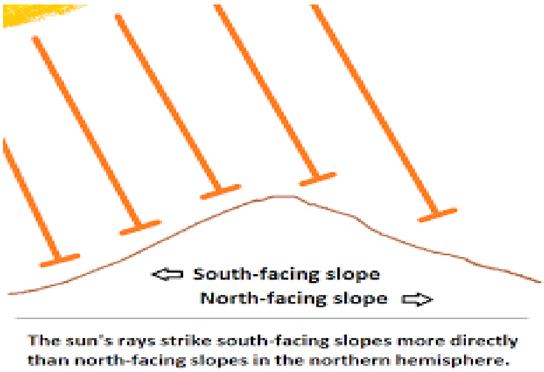
- Adoption of SPIS should ensure sustainable abstraction of water from identified water sources. The SAFEGUARD WATER module provides information on water resource management and sustainable water abstraction and provides a water resource management checklist.

TOPOGRAPHY

Topography describes the elevation and the relief features on the earth's surface. Relief features include both natural and man-made landforms such as roads, hills, valleys, railways among others. Key topographical features in evaluating market potential for SPIS are slope and aspect.

Slope is a measure of the change of elevation over a certain distance. It answers the question of how steep an area is and is a determining factor for the type of irrigation system to promote. This in turn determines the cost and labour requirement (e.g. erosion control practice and water conveyance channels). For instance, surface irrigation is more suitable in undulating areas and is cheaper compared to sprinkler and drip irrigation which are more suited on steeper or unevenly sloping land. Therefore, coupling steep lands with a factor like low access to finance (discussed in Chapter 3) would lead to weak market potential for SPIS.

Aspect describes the direction which a slope faces. It is especially relevant for systems located in higher latitudes and rarely affects systems close to or along the equator. Aspect influences the amount of solar radiation that the slope receives as well as the daily range of temperature and the relative humidity on the slope.



The effect of aspect

(Source: http://www.explorenaturalcommunities.org)

Generally, more direct sunlight tends to fall on the south and southwest slopes while North aspects of slopes are more shaded in the northern hemisphere. The converse is true in the southern hemisphere where more direct sunlight tends to fall on the north and northwest slopes

Topographic analysis for potential SPIS sites can be determined through use of topographic maps that depict the physical configuration of the earth's surface using contour lines as wells as symbols for man-made and natural features. Users can also use Digital Elevation Models (DEMs) that are specialized databases that represent the relief of a surface between points of known elevation. DEMs can be used on Geographical Information System (GIS) platforms. This should be followed by a ground-truthing exercise to determine the exact slope and aspect of the area of interest.

OUTCOME/PRODUCT

- Determination of slope and aspect of potential SPIS markets
- Selection of suitable irrigation systems based on the topography of the potential SPIS market

DATA REQUIREMENT

- Topographic Maps
- Digital Elevation Models(DEMs)

PEOPLE/STAKEHOLDER

- Lands and Survey Authorities

IMPORTANT ISSUES

- Care must be taken when designing irrigation systems on steep slopes as such areas are prone to erosion and runoff.

CROPS AND LIVESTOCK

An overview of the prevailing types of crops and/or livestock in the country or region of interest serves to understand which SPIS are most suitable and is also indicative of the market potential for SPIS technology. This is particularly relevant for SPIS system suppliers and entities seeking to promote adoption of SPIS by farmers. This information can be sourced from government ministries in charge of agriculture, global research studies on cultivated areas, FAO databases on crop cultivation among others.

Additionally, stakeholders interested in promoting or setting up SPIS schemes can use agro-ecological zones (AEZs) to determine the most suitable crops to be cultivated and animals to be reared in an area. AEZs define areas based on combinations of soil, landform and climatic characteristics and match suitable crops and animals to regions. The zones can also be used to determine the potential yields of the main crops grown within the zone thus helping with income projections of the target market. As discussed under Finance in Chapter 3, access to finance is a key parameter in evaluating a market's potential for SPIS.

The Global Agro-ecological Zones (GAEZ) portal by FAO and the International Institute for Applied Systems Analysis (IIASA) provide a comprehensive online portal with details on land resources, agro-climatic resources, suitability and potential yield, actual yield and production and yield and production gaps. Stakeholders interested in SPIS can refer to this or similar tools to determine important characteristics that influence the type of crops or livestock in an area.

OUTCOME/PRODUCT

- List of crops grown and animals reared in selected countries or regions
- AEZ classification for selected areas
- Potential crop/livestock yield within the area of interest

DATA REQUIREMENT

- Global AEZ by FAO and the International Institute for Applied Systems Analysis

PEOPLE/STAKEHOLDERS

- Ministry of Agriculture

AMBIENT TEMPERATURE

As the name suggests, this parameter looks at the temperature of the areas surroundings. This has two main effects on SPIS potential: **1) affects the efficiency of SPIS and 2) affects the crops and livestock found in an area**.

On **efficiency of SPIS**, temperature is a key factor in the design of pumping systems as it affects the functionality and life span of solar PV equipment. The flow of electricity and the voltage output of solar panels depend linearly on the operating temperature of the panels. Lower temperatures produce reduced resistance to electricity flow resulting in higher voltage outputs; higher temperatures increase resistance and subsequently lead to lower voltage outputs. High ambient temperatures also affect the performance of the system's inverter by reducing its frequency which in turn reduces its efficiency and the flow rate of the pump.

Due to the variability of climate in different regions, most panels do not operate under ideal temperature conditions. To correct this, panels in hotter regions of the world are often designed with cooling systems to keep the panels within certain temperatures. Additionally, PV systems in different temperature environments must be sized to ensure that the output voltage is not too high, which could damage the equipment.

The range of crops and livestock that are suitable in an area is often affected by ambient air temperature. Analysis of thermal regimes using agro-ecological zoning discussed in the previous section can reveal crops and livestock suited to a region based on its temperature. This may then inform the need for SPIS for the said region.

OUTCOME/PRODUCT

- Determination of ambient temperatures in potential SPIS markets
- Selection of suitable solar technology based on temperature regimes
- Determination of suitable crops and livestock based on temperatures

DATA REQUIREMENT

- Global AEZ by FAO and the International Institute for Applied Systems Analysis

PEOPLE/STAKEHOLDERS

- Meteorological service providers

IMPORTANT ISSUES

- Panel selection should be done with ambient air temperature in mind to maximize efficiency of the system and to ensure adequate voltage output.

DEMOGRAPHICS

An understanding of demographic characteristics including population density, age, migration levels and patterns and household income provide additional information when making decisions on potential SPIS markets. These characteristics can be used as proxy indicators of poverty levels, labour availability, prevailing agricultural practices, urban settlements among others.

This parameter cannot be used standalone, but in combination with other parameters can assist in a deeper understanding of social dynamics and cultural conditions for a target region. For example, as earlier mentioned, coupling topography with poverty levels could help infer market potential. Also, analysis of population density and land cover-land use data could highlight densely populated areas or urban settlements which could be a factor in determining the viability of a potential SPIS market. SPIS sites cannot be in densely populated urban settlements however they could be located close to such areas as they provide market for produce.

Evaluating demographic characteristics such as household income alongside business parameters such as financing and incidences of poverty can serve to highlight the capability of households to take up SPIS systems.

OUTCOME/INCOME

- Correlation of demographic characteristics with SPIS geophysical and business parameters to identify relevant issues in determining potential SPIS markets

DATA REQUIREMENTS

- Census Reports
- Satellite imagery on global population

PEOPLE/STAKEHOLDERS

- Government Ministries including Ministries of labour and migration
- Statisticians

4. EVALUATION OF THE BUSINESS ENVIRONMENT

While adoption of SPIS within a region may be feasible from a geophysical perspective, the operative business environment plays a key role in the actual uptake of the technology. There are various factors that contribute to an enabling environment for the adoption of SPIS, and whose significance varies with the entity promoting SPIS adoption. The 9 parameters presented in this chapter are seen to play the most significant role.

GOVERNMENT INTERVENTIONS

Government interventions as a business environment parameter for SPIS looks at policies, rules and regulations that govern the irrigation and solar sectors in a country.

Together they provide a complete picture of the strength and breadth of government support and the actions taken to turn that support into reality. Typically, government policies and regulations vary from country to country, but can be assessed in terms of:

1. ***promotion of renewable energy systems*** specifically solar,
2. ***programs promoting irrigation devices*** and in particular SPIS and
3. ***presence of relevant government bodies*** that are providing support to the sector.

An important indicator for an effective policy and regulatory environment for SPIS is the existence of programs to implement and support the frameworks in place. For instance, if the programs have an indicative or projected budget and target, it signals the government's commitment to implementing the policies. Additionally, presence of government bodies to keep track of the progress in implementation and adherence to standards are good indications of implementation of policies and regulations.

By way of example, contrast country X that has a clause in their Energy Act on the country adopting renewable sources of energy including solar to country Y that has the same clause but has also developed Solar PV regulations, has set standards for equipment and has designed a subsidy program to promote adoption of SPIS among small scale farmers. Country Y is seen to have a better environment for promotion and adoption of SPIS.

OUTCOME/PRODUCT

- Determine the regulatory landscape of a region and its appetite to SPIS

DATA/REQUIREMENTS

- Data on government regulations and policies in solar and irrigation equipment
- List of government programs that promote SPIS
- List of government bodies involved in solar and/or irrigation
- World Bank's Regulatory indicators for sustainable energy (RISE) help in comparing national policy and regulatory frameworks for sustainable energy

PEOPLE/STAKEHOLDERS

- National and local governments
- Energy and irrigation ministries

IMPORTANT ISSUES

Some of the policies may cut across different government ministries. For example, a policy on trade may remove custom duty on solar. This would still be a government intervention but focused on finance. This is covered in the financing parameter of the business environment module.

DEVELOPMENT ORGANIZATIONS INTERVENTIONS

Development organizations may introduce an agenda or programs that present a significant influence on the adoption of SPIS within a country or region. Most of these organizations build their agendas around the Sustainable Development Goals (SDGs) necessitating an understanding of SPIS within the SDGs. SPIS falls in an interesting cross-section of several SDGs including:

- ***SDG #2*** which is aimed at ending hunger, achieving food security and improved nutrition and promoting sustainable agriculture;
- ***SDG #7*** on ensuring access to affordable, reliable, sustainable and modern energy for all and;
- ***SDG #13*** on taking urgent action to combat climate change and its actions.

It is therefore important to understand the target areas of action for development organizations working in a country or region to identify opportunities for SPIS.

Development organizations may vary as civil society organizations, research institutions, and bilateral and multilateral development organizations. It is observed that involvement of these organizations in SPIS at a localized level is often well positioned to bring the various elements needed to promote SPIS uptake together in a systematic, integrated way to empower individual actors and create market momentum.

Ordinarily, development organizations vary from country to country, but they can be assessed in terms of:

i) organizations that have national programs that promote adoption of irrigation systems

ii) development agencies that have national programs that specifically promote adoption of SPIS.

Development organizations differ in knowledge, experience, needs and capacity. They each assess the market situation differently, and their specific areas of expertise can address different market development hurdles. Taken together, a comprehensive picture of the market potential for SPIS emerges, including the barriers that currently impede its adoption and the incentives needed to move forward.

Countries or regions with national interventions on irrigation and/or SPIS are more likely to create a positive atmosphere which is more likey to work in to the advantage of SPIS uptake.

OUTCOME / PRODUCT

- Assessment of national development agencies interventions in irrigation and SPIS within a country or region.

DATA REQUIREMENTS

- List of possible development agencies in irrigation and/solar system

PEOPLE / STAKEHOLDERS

- Civil society organizations
- Research institutions
- Bilateral organizations
- Multilateral organizations

IMPORTANT ISSUES

- For an agenda or program to be a significant parameter in influencing the SPIS market potential, it needs to be of a size significant enough to shift market dynamics. For instance, a program implemented at a national scale is likely to have a more significant impact on SPIS operations than one implemented at a very localized level.

FINANCING

Uptake of SPIS is associated with substantial upfront costs which often limits their adoption, especially among low income farmers. For some, farming is the only source of livelihood and investing in SPIS equipment would take away finances from other household needs. The ability to meet the high capital cost of SPIS is therefore seen as a significant barrier to SPIS even though its lifecycle costs are lower than alternative solutions. Facilitating adoption of these systems would therefore require support in terms of financing.

Some governments, development agencies and the private sector have developed various mechanisms in different regions to offer this support. Financing for SPIS can be looked at from two perspectives:

a) End-users financial ability

b) Availability of financial institutional support

End-users financial ability

This parameter assesses the purchasing capacity of the end-users as a key indicator of the market potential of SPIS within a region. It helps determine the amount of capital available and/or accessible to an end-user, including options for external market based financing. This informs their financial empowerment and consequently, ability to purchase SPIS.

A population's general financial ability and access to financial services may be inferred from factors such as incidence of poverty, income and employment indices and the prevalence of financial institutions within an area. Other factors could include number of individual accounts in financial institutions, value of customer savings and borrowing rates at financial institutions, and ease of access to loans. The Gross National Income (GNI) may also be used.

Availability of institutional support

Institutional support can either be from government, development agencies, or private sector. These influence the rate at which an end-user can raise external finance. Government financial support may be in terms of subsidies, tax incentives, rebates, customs and duty incentives. Typically, government support is most effective at the early stages of market development and is phased out as markets mature. Development agencies may also offer subsidies, result based financing (RBF), grants and soft loans. The more the mechanisms available in a country or region the better for the market potential.

It is also critical to evaluate financing mechanisms towards competing sources of power for irrigation. For instance, government support may, directly or indirectly, promote the use of competing sources of fuel such as diesel or electricity. For instance, a rural electrification subsidy or subsidizing of butane gas for cooking may negate adoption of SPIS in a country or region if the recurrent costs of energy are insignificant compared to the upfront cost of SPIS.

OUTCOME / PRODUCT

- Assessment of the financial landscape of the region

DATA REQUIREMENTS

- Incidence of poverty among the rural population
- Ratio of formal bank accounts to population in rural areas
- Value of savings and access to loans among the rural population
- GNI per capita
- Employment figures
- Government fiscal policy on solar and irrigation
- Development agency that finance irrigation and SPIS

PEOPLE / STAKEHOLDERS

- Government
- Civil society organizations
- Research institutions
- Bilateral organizations
- Multilateral organizations
- Financial institutions

IMPORTANT ISSUES

- Evaluation of the financial landscape should go beyond the financial empowerment levels of end users (individual financial ability and available institutional support) to include financing options for competing sources of power for irrigation.

AVAILABILITY AND COST OF ALTERNATIVE FUELS

The economic viability of SPIS within a region may be affected by the availability and cost of alternative fuels. In most cases for the same size of pump, SPIS normally require higher initial capital investment as compared to either diesel or grid-electricity powered pumps. However, the latter two have life-cycle fuel costs while SPIS does not hence the need to evaluate the life-cycle fuel savings and payback periods of SPIS within the target market.

An availability assessment should determine the quantity and quality of alternative fuels for water pumping. For instance, if a country or region is exploiting fossil fuels, it is likely that fossil fuel based power will compete favourably against solar. For electricity, the rural electrification rate can help to determine the availability of electricity for pumping. Holding other factors constant, the more electrified a rural area is (where most farming is carried out), the higher the likelihood that a notable proportion of the population will use electricity for pumping. The cost and quality of the electricity, however, are among the factors that affect actual use of electricity for irrigation. For instance, there might be high penetration rates but frequent outages, that make electricity unreliable,present an opportunity for SPIS.

In some regions, wind can also be seen as a competing resource for irrigation pumping. Some studies have shown that wind applicability and economic viablility of wind competes with solar power at speeds greater than 8 m/s.

In addition to the financing considerations presented in the previous section, cost of alternative fuels may have a significant effect on the potential of SPIS within a market. One way to conduct a **cost assessment** of available fuels is to standardize the unit of measure– determine the per unit market prices (cost / kwh) of the competing fuels in the market. This allows estimation of the amount of fuel needed for a specific pump size, and consequently the cost to power the pump. It is often observed that the lower the costs of alternative fuel compared to the capital investment of acquiring SPIS, the less the market potential of SPIS.

OUTCOME / PRODUCT

- Availability of alternative fuels in the region or country
- Cost analysis per unit of the alternatives

DATA REQUIREMENTS

- Data on energy resources in the country
- Per unit market prices of diesel, petrol
- Market prices of electricity per kwh
- Electrification rate in rural areas
- Quality of electricity in the rural areas

PEOPLE / STAKEHOLDERS

- Government agencies in energy

IMPORTANT ISSUES

- It is important to determine if there are any government subsidies offered to the alternative fuels presented. These may be a deterrent to uptake SPIS in the country or region.

TECHNICAL CAPACITY

A successful intervention to promote and upscale adoption of SPIS would require technical capacity for solar solution providers to design, implement and maintain the systems. Lack of such capacity makes it difficult to sustain the SPIS market in the country or region. The availability of this capacity is especially crucial at the infancy stages of a market – this is the time when end users are introduced to the technology and when first impressions are critical to long-term adoption. As an example, poor installations leading to frequent SPIS breakdowns and lack of timely repairs on SPIS may result in a negative attitude towards SPIS by end users, limiting the market potential for SPIS.

Technical capacity evaluates the availability of skilled personnel for installation and maintenance of SPIS. It may be inferred from:

i) availability of training courses on solar systems;
ii) number of accredited institutions offering solar courses and;
iii) licensing of solar technicians.

In addition to the presence of skilled technicians, presence of a licensing and regulating body for SPIS practitioners is key. Licensing indicates the existence of standards of professionalism and a regulator for the market. For instance the energy regulator in Kenya – Energy Regulatory Commission (ERC) – registers all solar practitioners who have to adhere to a certain code of conduct and standards. It also maintains a members database that acts as a pool for obtaining qualified technicians for installation and maintenance of solar PV systems.

OUTCOME/PRODUCT

- Assessment of level of skilled capacity in the country/region

DATA REQUIREMENT

- List of solar training institutes and courses
- List of licensed technicians

PEOPLE/STAKEHOLDER

- Energy agencies

AWARENESS OF SOLAR PV TECHNOLOGY

General awareness of solar technologies (solar lighting and solar water heating) and irrigation systems, mainly pumps, may be indicative of a population's willingness to adopt similar technologies. The converse is also likely - lack of knowledge and information about solar technologies can pose a barrier to public discussion and decision making on use of solar as an alternative energy solution. By way of example, high levels of awareness among end-users about the benefits, long-term costs and payback periods, and performance of solar lighting compared to use of alternative fuels for lighting (e.g. kerosene) can act as an enabler in the adoption of SPIS. Lack of exposure to real-life solar PV installations, on the other hand, is likely to lead to low confidence in new solar technologies.

Awareness of solar PV technologies may also affect the public's access to market based financing. For instance, financial service providers who are not well-versed with SPIS and its related benefits may be hesitant in disbursing loans for their acquisition, and where loans are available, they may be under limiting conditions (e.g. high interest rates). This hinders the technology adoption due to lack of financing for the high capital costs associated with SPIS.

The level of awareness of SPIS in a region or country can be deduced from various factors including:

1. **Trends in adoption of irrigation pumps**.
   a. Presence of suppliers and distributors of global brands of irrigation pumps and their associated spare parts may be considered a key indicator of market potential. This is especially relevant for SPIS suppliers where presence and growth rate of competitors may be indicative of the markets appetite for SPIS.
2. **The percentage of solar energy in a country's energy mix**
   a. A significant proportion of solar power may be indicating of an enabling environment for adoption of solar PV technologies.
3. **Solar PV adoption trends** over a period of time, say 5 years can be assessed to determine uptake of the technology in the country/region.

OUTCOME/PRODUCT

- Assessment of awareness level of the country/region

DATA REQUIREMENT

- Trends in solar technology adoption
- Number of distributors and suppliers of global brands of irrigation pumps
- Number and distributors of global brands of solar equipment
- Solar energy proportion to the country's energy mix

PEOPLE/STAKEHOLDERS

- Government bodies in energy and trade
- Research institutions

SIGNIFICANCE OF AGRICULTURE IN THE LOCAL ECONOMY

This parameter examines the contribution of agriculture to a target area's economy. Relevant indicators would include:

1. ***Proportion of population engaged in agriculture*** – the higher the proportion of the population practicing agriculture, the higher the probability of good market potential for SPIS. This is because there is a higher population that may be seeking to ensure their water security for farming. Also, there is a higher probability of favorable government and non-governmental interventions to ensure employment opportunities within the sector.
2. ***Existing irrigation culture*** – practice of irrigation farming that is mostly powered through fossil fuels and electricity presents a ready market to shift to solar energy.
3. ***Proportion of the GDP attributed to agriculture*** – regions with a significant proportion of GDP attributed to agriculture are likely to offer an attractive market for SPIS as agriculture would be an established economic driver. It is, however, important to take note of the main crops or livestock contributing to the GDP. For example, coffee and tea could be significant contributors but these do not present obvious avenues for SPIS uptake. This could be contrasted to export of horticultural products (e.g. flowers and vegetables) which are water intensive and therefore ready markets for SPIS.

OUTCOME/PRODUCT

- Contribution of agriculture to the GDP

DATA REQUIREMENT

- GDP figures
- Agricultural output numbers
- FAOstats

PEOPLE/STAKEHOLDERS

- Government ministries in agriculture

IMPORTANT ISSUES

- Although the economic contribution of agriculture to a country's GDP may be steadily declining it may be in sight of the country's broad-based economic growth and agriculture may still be the broadest economic sector in terms of demographics, and plays a significant role in the nation's overall socio-economic fabric.
- In addition to agriculture's contribution to the GDP, the type and method of agricultural practice should be assessed. Areas that practice irrigated farming would be more ideal markets for SPIS.

LAND ACCESS AND TENURE

As SPIS is an agribusiness, land is at its foundation and it is therefore important to determine land rights, land access and land tenure terms in an area under assessment. Therefore, it is key for an area to have a pragmatic land policy environment. A desirable land policy is one that has emphasis on land access and development, secure property rights, is backed by reliable information and has clear permitting processes. A proper land policy has the land administration services including surveys and mapping, land use planning, rural and urban development, housing and market information service providers well established. Paucity of information about the laws, procedures and/or information required to safely and legally complete land and real estate transactions creates uncertainty and discourages investments.

Land access is defined by the availability of land with the required security of ownership, desirable physical and economic attributes and level of transparency and fairness in transactions.

Land tenure is the institutional structure that determines the political, economic and social framework by which individuals and groups secure access to land and associated resources. The absence of reliable information to guide rapidly expanding land market is, by far, the most persistent bottleneck undermining long-term development in most countries.

Clear tenure rights are an important consideration when investing into SPIS. Not only do they provide investment security, but may also serve as collateral when applying for loans. For some countries there are clear demarcations between commercial land (with fixed title deeds) and communal lands (with only informal land use rights and agricultural practices limited to subsistence farming).

OUTCOME/INCOME

- Country land ownership patterns and statistics

DATA REQUIREMENTS

- Land access and tenure rights in the country

PEOPLE/STAKEHOLDERS

- Government Ministries especially that of land

TRANSPORT AND COMMUNICATION INFRASTRUCTURE

Infrastructure is an organizational system of resources that is needed for a society or business to run. Transportation infrastructure such as roads, harbours, airports and rail, and telecommunication infrastructure are physical systems that are needed for efficient operations within a country or region.

Transport infrastructure determines the ease of movement of goods and people.

Lack of transportation infrastructure (e.g in deep rural areas and islands) can have significant cost impacts - inefficient transport systems make it difficult to obtain inputs and to deliver products to customers affecting scalability and quality of services. For SPIS market potential, good transport infrastructure would mean reduced costs of system installation as well as easier access to skilled labour for installation and maintenance. Additionally, lower transportation costs could lead to better allocation of funds in running businesses and ease of access to new markets. Good physical connectivity in the urban and rural areas is therefore essential for SPIS users.

Communication infrastructure (especially mobile phone connectivity) would be relevant to SPIS as indicative of access to mobile banking in rural areas and implementing monitoring devices in SPIS. Mobile phone use can also be used as a proxy indicator for income levels. Mobile phone usage in rural areas also shows the users can access services such as agricultural information and financial services such as mobile remittances and loans.

OUTCOME/PRODUCT

- Assessment of transport and communication infrastructure

DATA REQUIREMENT

- Data on transport network especially roads in rural areas
- Data on mobile penetration particularly in rural areas

PEOPLE/StAKEHOLDERS

- Government ministry of transport and communication
- World bank ease of doing business report

5. DECISION ON MARKET POTENTIAL OF SPIS

This module presents parameters that are key to assessing the market potential of SPIS for any target area. The evaluation of these parameters should be done in consideration of **WHO** is evaluating the market and **WHY** they are evaluating the market.

The evaluation of the parameters presented in this module should be in a sequential order.

EVALUATION OF WEIGHTED GEOPHYSICAL ATTRIBUTES

While several geophysical parameters are identified to guide the assessment of SPIS markets, 3 are considered crucial to the viability of SPIS applications as highlighted in chapter 1. If their state is unfavourable in the area of interest, SPIS is unlikely to be practical. These parameters should therefore be weighted on a binary scale of 1 if conditions are favourable and 0 if unfavourable. Where any of the parameters is scored at a 0, it is then concluded that the target area is not feasible for SPIS.

#	Parameter	Weight
1	Land cover – land use	0 or 1
2	Solar irradiation	0 or 1
3	Water availability (Precipitation)	0 or 1

1. Evaluation of additional geophysical parameters

These are geophysical parameters that are key to market assessment for SPIS but unlike the parameters in Table 1, they do not critically affect the viability of SPIS; they affect the success of SPIS adoption on a case by case basis. The significance of their impact of the SPIS market is dependent on the needs of the user. The parameters are expounded on in chapter 2 and listed below.

#	Parameter
1	Water table
2	Topography
3	Ambient temperature
4	Crops and livestock

2. Evaluation of the business environment

The first and second steps of the evaluation look at the practicality of implementing SPIS within a target country or region. Parameters on the business environment seek to establish the economic and operational feasibility of SPIS within the said market.

The table below highlights the Modules proposed weighting criteria. However, evaluation of these parameters can be weighted based on the user's areas of interest and consideration of most critical factors.

#	Parameter	Weight
1	Government interventions	15%
2	Development Organizations Interventions	10%
3	Financing	15%
4	Availability and cost of alternatives	10%
5	Technical capacity	10%
6	Awareness of solar PV and irrigation technologies	10%
7	Significance of agriculture to the local economy	10%
8	Land Tenure	10%
9	Transport and communications infrastructure	10%
	TOTAL	**100%**

OUTCOME / PRODUCT

- Decision on the SPIS uptake potential for a target market.

DATA REQUIREMENTS

- N/A

PEOPLE / STAKEHOLDER

- Private SPIS companies
- Policy-makers
- Financial institutions
- Development practitioners
- National and local governments

IMPORTANT ISSUES

- The parameters presented in this module present key issues of consideration in conducting a high-level assessment of the SPIS uptake potential for a target market. A detailed market assessment is, however, needed before investment.

FURTHER READINGS, LINKS AND TOOLS

Links

1. Photovoltaic Efficiency: The Temperature Effect- https://www.teachengineering.org/content/cub_/lessons/cub_pveff/Attachments/cub_pveff_lesson02_fundamentalsarticle_v6_tedl_dwc.pdf

2. A.W Worqlul, J. Jeong, Y. Dile, J. Osorio Assessing potential land suitable for surface irrigation using groundwater in Ethiopia, Applied Geography 85 (2017) 1-13

3. N.G. Dastane, FAO Irrigation and Drainage Paper No 25-Effective Rainfall -FAO,1978

4. M. Masri, R. Badishah, Solar Radiation Potential as Energy Source of Photovoltaic Powered Uninterrupted Power Supply in Perlis, Northern Malaysia- IOSR-JEEE PP 31-36, 2014

5. European Wind Energy Association, 2009, The Economics of Wind Energy, http://www.ewea.org/fileadmin/files/library/publications/reports/Economics_of_Wind_Energy.pdf

6. SNV, 2014, Renewable Energy for small holder irrigation, https://www.practica.org/wp-content/uploads/2014/10/Renewable_Energy_for_Smallholder_Irrigation.pdf

SPIS tools

MARKET – Market Assessment Tool

Other relevant tools:

- **PROMOTE and INITIATE – SPIS Rapid Assessment**: includes a (financial) market analysis for financing of SPIS components
- **INVEST – Payback Tool**: to calculate the financial viability of a SPIS and compare that to other alternative pumping systems (diesel and grid power)
- **SAFEGUARD WATER – Water Requirement Tool**: calculator to determine monthly water of different crops and livestock
- **IRRIGATE – Impact Assessment Tool**: to determine the social and environmental impacts of a SPIS project

TECHNICAL GLOSSARY

Aquifer	Underground geological formation(s), containing usable amounts of groundwater that can supply wells or springs for domestic, industrial, and irrigation uses.
Chemigation	The process of applying chemicals (fertilizers, insecticides, herbicides, etc...) to crops or soil through an irrigation system with the water.
Conveyance loss	Loss of water from a channel or pipe during transport, including losses due to seepage, leakage, evaporation, and other losses.
Crop coefficient	Ratio of the actual crop evapotranspiration to its potential (or reference) evapotranspiration. It is different for each crop and changes over time with the crop's growth stage.
Crop Water Requirement (CWR)	The amount of water needed by a plant. It depends on the climate, the crop as well as management and environmental conditions. It is the same as crop evapotranspiration.
Current (I)	Current is the electrical flow when voltage is present across a conductor, or the rate at which charge is flowing, expressed in amperes [A].
Deep percolation	Movement of water downward through the soil profile below the root zone. This water is lost to the plants and eventually ends up in the groundwater. [mm]
Drawdown	Lowering of level of water in a well due to pumping.
Drip irrigation	Water is applied to the soil surface at very low flow rates (drops or small streams) through emitters. Also known as trickle or micro-irrigation.
Emitter	Small micro-irrigation dispensing device designed to dissipate pressure and discharge a small uniform flow or trickle of water at a constant discharge which does not vary significantly because of minor differences in pressure head. Also called a "dripper" or "trickler".
Evaporation	Loss of water as vapor from the surface of the soil or wet leaves. [mm]
Evapotranspiration (ET)	Combined water lost from evaporation and transpiration. The crop ET (ETc) can be estimated by calculating the reference ET for a particular reference crop (ETo for clipped grass) from weather data and multiplying this by a crop coefficient. The ETc, or water lost, equals the CWR, or water needed by plant. [mm]
GIWR	The Gross Irrigation Water Requirement (GIWR) is used to express the quantity of water that is required in the irrigation system. [mm]
Fertigation	Application of fertilizers through the irrigation system. A form of chemigation.
Financial viability	The ability to generate sufficient income to meet operating expenditure, financing needs and, ideally, to allow profit

	generation. It is usually assessed using the Net Present Value (NPV) and Internal Rate of Return (IRR) approaches together with estimating the sensitivity of the cost and revenue elements (See Module **INVEST**).
Friction loss	The loss of pressure due to flow of water in pipe. It depends on the pipe size (inside diameter), flow rate, and length of pipe. It is determined by consulting a friction loss chart available in an engineering reference book or from a pipe supplier. [m]
Global solar radiation (G)	The energy carried by radiation on a surface over a certain period of time. The global solar radiation is locations specific as it is influenced by clouds, air humidity, climate, elevation and latitude, etc. The global solar radiation on a horizontal surface is measured by a network of meteorological stations all over the world and is expressed in kilowatt hours per square meter [kWh/m^2].
Gravity flow	The use of gravity to produce pressure and water flow, for example when a storage tank is elevated above the point of use, so that water will flow with no further pumping required.
Head	Value of atmospheric pressure at a specific location and condition. [m]: Head, total (dynamic) Sum of static, pressure, friction and velocity head that a pump works against while pumping at a specific flow rate. [m]; Head loss Energy loss in fluid flow. [m]
Infiltration	The act of water entering the soil profile.
Insolation	The rate at which solar energy reaches a unit area at the earth measures in Watts per square meter [W/m^2]. Also called solar irradiance.
Irradiation	The integration or summation of insolation (equals solar irradiance) over a time period expressed in Joules per square meter (J/m2) or watt-hours per square meter [Wh/m^2].
Irrigation	Irrigation is the controlled application of water to respond to crop needs.
Irrigation efficiency	Proportion of the irrigation water that is beneficially used to the irrigation water that is applied. [%]
Irrigation head	Control unit to regulate water quantity, quality and pressure in an irrigation system using different types of valves, pressure regulators, filters and possibly a chemigation system.
Lateral	Pipe(s) that go from the control valves to the sprinklers or drip emitter tubes.
Latitude	Latitude specifies the north–south position of a point on the Earth's surface. It is an angle which ranges from 0° at the Equator to 90° (North or South) at the poles. Lines of constant latitude, or parallels, run east–west as circles parallel to the

	equator. Latitude is used together with longitude to specify the precise location of features on the surface of the Earth.
Leaching	Moving soluble materials down through the soil profile with the water.
Maximum Power Point Tracking (MPPT)	An important feature in many control boxes to draw the right amount of current in order to maintain a high voltage and achieve maximum system efficiency.
Net Irrigation Water Requirements (NIWR)	The sum of the individual crop water requirements (CWR) for each plant for a given period of time. The NIWR determines how much water should reach the crop to satisfy its demand for water in the soil. [mm]
Power (P)	Power is the rate at which energy is transferred by an electrical circuit expressed in watts. Power depends on the amount of current and voltage in the system. Power equals current multiplied by voltage (P=I x V). [W]
Photosynthesis	Photosynthesis is a process used by plants and other organisms to convert light energy into chemical energy that can later be released to fuel the organisms' activities (energy transformation).
Pressure	The measurement of force within a system. This is the force that moves water through pipes, sprinklers and emitters. Static pressure is measured when no water is flowing and dynamic pressure is measured when water is flowing. Pressure and flow are affected by each other. [bars, psi, kPa]
Priming	The process of hand-filling the suction pipe and intake of a surface pump. Priming is generally necessary when a pump must be located above the water source.
Pump	Converts mechanical energy into hydraulic energy (pressure and/or flow). Submersible pump: a motor/pump combination designed to be placed entirely below the water surface. Surface pump: pump that is not submersible and placed not higher than about 7 meters above the surface of the water.
Root Zone	The depth or volume of soil from which plants effectively extract water from. [m]
Salinity (Saline)	Salinity refers to the amount of salts dissolved in soil water.
Solar panel efficiency	Solar panel efficiency is the ratio of light shining on the panel, versus the amount of electricity produced. It is expressed as a percentage. Most systems are around 16% efficient, meaning 16% of the light energy is converted into electricity.
Suction lift	Vertical distance from the surface of the water to the pump. This distance is limited by physics to around 7 meters and should be minimized for best results. This applies only to surface pumps.

Surface irrigation	Irrigation method where the soil surface is used to transport the water via gravity flow from the source to the plants. Common surface irrigation methods are: Furrow irrigation – water is applied to row crops in small ditches or channels between the rows made by tillage implements; Basin irrigation – water is applied to a completely level area surrounded by dikes, and Flood irrigation – water is applied to the soil surface without flow controls, such as furrows or borders.
Transpiration	Water taken up by the plant's roots and transpired out of the leaves. [mm]
Voltage (U or V)	Voltage is the electric potential between two points, or the difference in charge between two points, expressed in Volts [V].

POWERING AGRICULTURE:

AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

Module 4: Invest

The Toolbox on Solar Powered Irrigation Systems is made possible through the global initiative Powering Agriculture: An Energy Grand Challenge for Development (PAEGC). In 2012, the United States Agency for International Development (USAID), the Swedish International Development Cooperation Agency (Sida), the German Federal Ministry for Economic Cooperation and Development (BMZ), Duke Energy, and the Overseas Private Investment Cooperation (OPIC) combined resources to create the PAEGC initiative. The objective of PAEGC is to support new and sustainable approaches to accelerate the development and deployment of clean energy solutions for increasing agriculture productivity and/or value for farmers and agribusinesses in developing countries and emerging regions that lack access to reliable, affordable clean energy.

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Download
https://energypedia.info/wiki/Toolbox_on_SPIS

About
Powering Agriculture: An Energy Grand Challenge for Development: https://poweringag.org

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ABBREVIATIONS

Ah	Ampere hour
CWR	Crop Water Requirement
DC/AC	Direct Current / Alternating Current
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
Gd	Daily Global Irradiation
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GIWR	Gross Irrigation Water Requirement
GPFI	Global Partnership for Financial Inclusion
HERA	GIZ Program Poverty-Oriented Basic Energy Services
H_T	Total Head
IEC	International Electrotechnical Commission
IFC	International Finance Corporation
IRR	Internal Rate of Return
IWR	Irrigation Water Requirement
MPPT	Maximum Power Point Tracking
NGO	Non-Governmental Organization
NIWR	Net Irrigation Water Requirement
NPV	Net Present Value
m^2	square meter
PV	Photovoltaic
PVP	Photovoltaic Pump
SAT	Side Acceptance Test
SPIS	Solar Powered Irrigation System
STC	Standard Test Conditions
TC	Temperature Coefficient
UV	Ultraviolet
Vd	Daily crop water requirement
W	Watt
Wp	Watt peak

INVEST

1. Basic decision-making tools
2. Credit policy: Analyze potential
3. Credit policy: Risk analysis
4. Credit policy: Select / Develop suitable financial instruments
5. Loan assessment: Determine financing volume and profitability
6. Loan assessment: Assess credit risk and collateral
7. Loan assessment: Adjust repayment plan to cash flow

MODULE AIM & ORIENTATION

Financing solar-powered irrigation can be an opportunity for financial institutions seeking to diversify their loan portfolio and expanding their range of financial products. The INVEST module focuses on the product features for SPIS loans, considering direct financing by financial institution to a small and medium-scale agricultural end borrower. The module also brings out the difference of financing solar powered irrigation systems as compared to conventional irrigation systems. It provides guidance to financial service providers who are already financing or planning to finance SPIS. It thus addresses two groups:

1. **Stakeholders at management level** who decide upon credit policies of a financial service provider.
2. **Loan officers** who assess single loan applications for financing SPIS.

PROCESS STEPS

Three steps have been elaborated in the INVEST module to support the process of defining the financial service provider's credit policy at the **management level**: Firstly, the analysis of the potential of the SPIS market segment; secondly, the determination of general credit risks involved; and thirdly, the design and test of the suitable financial instruments.

For the specific individual loan assessment process on **loan operations level**, three main steps have been elaborated: Firstly, the determination of the financing volume and calculation of the profitability of the investment; secondly, the assessment of credit risk and collateral of the potential borrower; and finally, determination of the cash flow and the repayment plan for the single potential borrower, along with loan conditions.

1. BASIC DECISION-MAKING TOOLS

An investment decision usually requires an assessment of whether the investment is feasible. This due diligence process will minimize the risk of losing any funds committed to the investment. In essence, this means: if I invest my capital, will I increase my capital, or at the very least avoid losing my capital?

A solar powered irrigation system (SPIS) is generally a long-term investment choice to reduce farm operating expenses or increase agricultural productivity or both. This requires an understanding of the farm enterprise, as a business, in terms of all costs and incomes. The **INVEST – Farm Analysis Tool**, contained in this Toolbox on SPIS, allows for conducting an assessment on farm profitability. It provides entry sheets for adding various farm expenses and incomes and automatically calculates the farm profit margin. It also highlights which fixed and variable costs are most prominent and where savings could have a significant impact. The tool generates a Farm Income Statement, which can be presented to a lending institution.

The tool is useful for:

- Determining the current level of profitability (pre-investment base line)
- Determining the anticipated profitability of the investment (post-investment projection)

Even when the profitability of the farming enterprise is confirmed, this does not automatically imply that an investment into an SPIS is the most sensible choice. This is especially true if other pumping technologies are readily available on the market. A Diesel or Grid-connected electric pump might be more feasible where water pumping is only required for a limited time per year. The **INVEST – Payback Tool** considers and compares solar powered irrigation system (SPIS) with other pumping technologies. Basic data is collected from technology suppliers and the payback period against the farm profit and the different technologies is automatically calculated.

OUTCOME / PRODUCT

- Assessing pre-investment and post-investment profitability;
- Determining most financially viable pumping technology option.

DATA REQUIREMENTS

- Current farm expenditure and income;
- Projected farm income and expenditure;
- Capital costs (capex) for different pumping technologies;
- Operating expenses (opex) for different pumping technologies
- Interest rates from lending institutions
- Inflation and fuel increase rates

PEOPLE / STAKEHOLDERS

- Financial service providers;
- Associations of producers / potential borrowers;
- Technology providers.

IMPORTANT ISSUES

- An annual re-evaluation of farm profitability allows for monitoring improvements, recognizing risks timely and identifying future investment opportunities.

2. CREDIT POLICY: ANALYZE POTENTIAL

Today, solar-powered irrigation is a technically mature and reliable option and an alternative to conventional irrigation approaches. When analyzing options for the development of credit policies for SPIS, the following aspects should be considered:

SPIS is likely to be a feasible option in a region if:

- energy provision for farming is a constraint (availability or cost of fuel, reliability of grid connection);
- an intensification of agricultural production is envisaged;
- producers are market-oriented and not working on subsistence level;
- producers are at least medium sized or organized in small holder groups;
- subsidized refinancing options for financial operators are available;
- grant schemes or subsidies are available to borrowers (producer);
- producers aim at specialized markets using environmental friendly technology (focusing on ecological production, which could give scope for premium pricing);
- technology distributors and system integrators are available in the region;
- water is available and managed adequately so as to prevent ground water depletion in the long run

However, compared to conventional pumping and irrigation methods, PV-based pumping solutions have:

- a comparatively high initial capital investment requirement;
- longer repayment periods or/and significantly higher repayment rates in case of single user; for a community based model, the payback period is reduced
- higher credit risk.

OUTCOME / PRODUCT

- Study on potential of financing SPIS and recommendations for financial service provider.

DATA REQUIREMENTS

- Profile of end customers (cropping patterns, irrigation techniques, pumping systems, other available pumping alternatives, market);
- Current loan products available for potential SPIS customer;
- Water and energy provision regime in region;
- Support/advice structures and subsidy schemes (refinancing) available for the region;
- Environmental impact assessment (long term perspective).

PEOPLE / STAKEHOLDERS

- Management of financial service providers;
- Market analysts/consultants;
- Research and training institutions;
- Public entities promoting and/or subsidizing SPIS initiatives;
- Donors refinancing solar-powered initiatives;
- Associations of producers / potential borrowers;
- Technology and service providers

IMPORTANT ISSUES

- Solar-powered irrigation technology is mature, reliable and systems costs have decreased.

- SPIS generally require higher investment than other irrigation systems, but operational costs are lower.

3. CREDIT POLICY: RISK ANALYSIS

Every SPIS demands a specific solution with changing cropping pattern and the use of a comparatively newer technology like solar.

Therefore, there are no standard "off the shelf" solutions, and hence a thorough loan analysis is an important step, especially when starting with this loan type.

Typical **financial advantages** when changing to solar powered irrigation could be:

- Higher profitability when introducing high value crops;
- Lower and more stable energy costs due to change in energy source (no transport costs or fuel/lubricant supply risks);
- Environment friendly technology (avoid water losses, use of water saving technology, prevent diesel pollution, etc.) can give access to subsidized funds or grants.

SPIS, being based on agricultural activities, follow specific liquidity patterns, such as:

- Irregularity, seasonality;
- Farming-household mix;
- Several cash generating activities;
- System risks (climate, weather, pest, disease, prices).

This requires specific agri-lending tools. Thereby the following risks should be considered:

Financial Risks

- High initial capital investment leads to longer repayment periods and higher interest rates for potential borrowers and thus higher credit risks compared to alternative sources. Other specific risks associated with agriculture.

Technology Risks (see the following modules **DESIGN**, **SET-UP**, **MAINTAIN** for further details).

- High value cropping and water saving irrigation technology is needed;
- Pumps have to be "oversized" in order to meet peak water demands;
- Management capacities to handle the technology should be available;
- Daily operating hours are limited leading to low asset utilization if not operated properly;
- Suitability of location for SPIS;
- Construction risk;
- Overuse of water threatens long term cultivation as well as the environment.

Framework Risks

- Since water is available at very low cost, long term availability of water and good groundwater management is indispensable; (see **SAFEGUARD WATER** module)
- People issues leading to delay in disbursal of subsidy, reluctance to lend or adopt solar pump technology etc.
- Theft or misuse.

OUTCOME / PRODUCT

- Credit risk policy considering the profile of the potential borrowers and adequate portfolio management.

DATA REQUIREMENTS

- Specifics to agri-lending liquidity patterns of borrowers;

- Asset structure of borrowers (potential for collateral), especially land;
- Cropping patterns and profitability of crop types (alternative markets and water availability);
- Organization & management reliability (see **MAINTAIN** module);
- Technology risks (see **DESIGN** module);
- Refinancing options for the region

PEOPLE / STAKEHOLDERS

- Management of financial service providers;
- Public entities promoting or/and subsidizing SPIS initiatives;
- Associations of producers / potential borrowers;
- Market analysts/consultants;
- Technology providers;
- Service providers;
- Research and training institutions (e.g. environmental agency).

IMPORTANT ISSUES

- Consider SPIS specific risks with respect to their long term financing requirements, technological implications (cf. **DESIGN** module), environmental impact (cf. **SAFEGUARD WATER** module) and framework conditions.
- Assume manifold SPIS settings - there is no “off the shelf” loan analysis.
- Generally, minimizing risks can often lead to high(er) transaction costs (except in a community based system) for all parties involved, compared to conventional pumping systems.

SPIS in India

(Source: Lennart Woltering)

4. CREDIT POLICY: SELECT/DEVELOP SUITABLE FINANCIAL INSTRUMENTS

When selecting or developing a loan product for SPIS it is important to ask the following questions:

- **Who?** Market oriented producers, no subsistence production, producer groups possible;
- **What?** Finance for energy source and pumping system used for irrigation; energy and/or water saving technology;
- **How much?** Establish range of loan sum; % own-contribution of producer; % subsidy;
- **When?** Range of loan period (years); repayment frequency (months); disbursement in tranches;
- **Interest rate?** From ..x..% p.a. to ..x..% p.a. (range);
- **Collateral?** Equipment (Solar Pumpset), mortgages, additional collateral (guarantee scheme), non-traditional collateral (future harvest, warehouse), leasing scheme with equipment providers.

Loan products for financing SPIS usually:

- have higher initial investment sums with consequently longer repayment periods and/or high installment rates;
- need alternative guarantee schemes / unconventional collateral;
- have higher interest rate payments due to higher credit risk and long investment period;
- focus on innovative and progressive borrowers, investing in high(er) value crops;
- should be strictly oriented towards water capacity available and the farm's specific requirements;
- use no blueprint; every farm / enterprise is unique

In order to **prevent prohibitive loan transaction costs**, consider:

- guarantee funds with public support or insurance;
- leasing schemes with pumping system providers and others;
- group financing approaches for producer groups;
- public subsidies and sponsoring;
- favorable refinancing options for the financial institutions (e.g. subsidized interest rates offered by donors/public entities).

In order to **overcome the information gap** in respect of the new technology, introduce additional activities such as:

- Encouraging (potential) clients to get informed and consult technical advice through site visits and case studies of existing installations
- Training and sensitization of loan staff on basics about the technology;
- Monitoring loan performance closely;
- Continuous dialogue with solar pump suppliers

Note: SPIS clients could become future clients for other financial products (cross selling).

Automated irrigation system in Morocco – largely subsidized by the state

(Source: Lennart Woltering)

OUTCOME / PRODUCT

- **Guidelines and Procedures** including assessment and decision guidelines, target key performance indicators (KPIs).

DATA REQUIREMENTS

- Comparable clients liquidity pattern in current agricultural portfolio.

Compute, prepare

- repayment plan (with varying interest rates, repayment periods and repayment frequencies);
- profitability margins by crops and farm sizes;
- tables for evaluating types of collateral;
- list of eligible crops;
- list of eligible irrigation systems and average investment cost per component;
- list of eligible SPIS configurations and average investment cost per component (see **DESIGN** and **GET INFORMED**;
- list of eligible types of collateral

PEOPLE / STAKEHOLDERS

- Management of financial service providers;
- Experienced credit staff (senior, agri-finance);
- Associations of producers / potential borrowers;
- Agricultural extension services;
- Research and training institutes (e.g. environmental agencies);
- Providers of service, technology and inputs

IMPORTANT ISSUES

- Prevent prohibitive transaction costs for borrowers;
- Overcome information gap of financial operators;
- Note that standardization potential is limited
- Select capable loan staff for this segment with corresponding background and experience (provide training if required)

5. LOAN ASSESSMENT: DETERMINE FINANCING VOLUME AND PROFITABILITY

While the previous process steps focused on the policy makers, the next steps focus on the loan officers who assess single loan applications for financing SPIS.

Loan officers generally prefer to use the tools provided by their institution, but it is useful to use the tools **INVEST – Farm Analysis Tool** and **INVEST – Payback Tool** as they are specifically designed for SPIS and can provide an first estimation of viability. In fact these tools can be provided to borrowers/loan applicants to verify their own assumptions.

Note: Transaction costs for loan review can be high, especially if the technology has limited scope for standardization. Using specific tools, and encouraging loan applicants to use the same, can minimize unnecessary effort.

OUTCOME / PRODUCT

- Profitability analysis of investment (and alternatives);
- Cash flow analysis;
- Financial projections on investment costs (CAPEX) (and alternatives)

PEOPLE / STAKEHOLDER

- Loan officers financing or planning to finance SPIS;
- Producer(s) / potential borrower(s);
- Management of financial service providers (operational level);
- Agricultural extension services and promotion agencies (e.g. for subsidies);
- Providers of service, technology and inputs;
- Research and training institutes

DATA REQUIREMENTS

Research, collect, analyze, cross-check

- prices for components to be financed;
- cropping pattern and crop prices (fluctuation, trends etc.);
- prices for O&M costs and inputs (including other options);
- sales revenues
- purpose and sums provided as subsidies and/or through sponsors;
- macro-economic variables (inflation, interest rates, etc.);
- tax policies (corporate income tax, GST/VAT dynamics, etc.)

Compute, prepare

- water unit cost;
- annual revenue and operating expenses (OPEX) --> Annual gross margin of production (current and future);
- CAPEX (capital expenditure); i.e. total/annual sum for financing investment in SPIS (and alternative system);
- cash flow projections (current, future, alternative energy source);
- life cycle cost of SPIS investment;
- Payback Period (PP), Net Present Value (NPV) and Internal Rate of Return (IRR) of SPIS investment.

IMPORTANT ISSUES

- Compare PV with alternative pumping solutions with the same scenarios and consider varying profitability of different SPIS systems (crops, size).
- Loan should be assessed by informed, trained and capable loan staff

6. LOAN ASSESSMENT: ASSESS CREDIT RISK AND COLLATERAL

Apart from "normal" credit risks applying to agricultural loans, such as variations related to external shocks and an irregular cash flow based on seasonality, financing SPIS brings additional challenges. These are mainly related to technological risks or risks in respect to operation and maintenance. Also, high initial investment costs increase the overall financial risk. Finally oversizing of the pumping system can be an issue.

When **valuing assets for collateral**, the view should be broadened by considering the whole farm as well as the overall family situation, and not only specifically the planned investment. The borrower should be encouraged to contribute with own capital and alternative collateral should be accepted by the financial operator. Panels of the solar powered irrigation systems can be used as collateral, if there is a market for second hand panels.

Since solar power is considered an **environmental friendly technology, given that water is used adequately** (**SAFEGUARD WATER** module), there is a scope for external public or donor funded guarantee schemes and subsidies from where producers can get access to finance. These opportunities should be actively explored and assessed.

OUTCOME / PRODUCT

- Family/farm balance sheet;
- Total value of collateral and/or types of guarantees;
- General risk analysis;

DATA REQUIREMENTS

Research, collect, analyze

- market for respective crops, inputs, etc.;
- availability of risk guarantee options / opportunities or insurance.

Compute, prepare

- valuation of farm (and family) assets and liabilities;
- revenue earned through agriculture production and other additional income generating activities, if any
- borrower's own (capital) contribution;
- revenue of collateral and/or guarantee schemes;
- assessment of technology and O&M risk (**DESIGN**, **SET UP**, **MAINTAIN**).

PEOPLE / STAKEHOLDERS

- Loan officers financing or planning to finance SPIS;
- Producer(s) / potential borrower(s);
- Management of Financial Service Providers (operational level);
- Public entities promoting and/or subsidizing SPIS initiatives;
- Sponsors.

IMPORTANT ISSUES

- Look for alternative types of collateral (e.g. guarantee schemes) and assess if PV panels could be a guarantee
- Minimize risk of theft or damage of the collateral (e.g. fencing of panels, guards, insurance)
- Minimize associated costs

7. LOAN ASSESSMENT: ADJUST REPAYMENT PLAN TO CASH FLOW

SPIS, being based on agricultural activities, follows **specific liquidity patterns**, such as:

- irregularity, seasonality;
- farming-household mix;
- several cash generating activities (agricultural, non-agricultural);
- external shocks (climate, weather, pest, disease, prices).

Determining specific loan features (disbursement pattern, repayment rate, collateral, repayment frequency) should be based on cash flow projections of a particular case.

This requires:

- in depth understanding of the farm and family economics;
- strong interaction with the potential borrower;
- networking with other sources of information in the sector and region;
- thorough understanding of the market and market trends;
- trained staff with innovative attitudes.

SPIS requires **high initial investment**. These may result in:

- long repayment periods (5-10 years);
- a need for high profitability of the SPIS;
- a need for a grace period at the beginning of the repayment plan.

Note: High installments resulting from very short loan repayment periods can create a threatening liquidity shortage – especially in the first year.

OUTCOME / PRODUCT

- Cash flow statement (current, projected);
- Tailor-made disbursement and repayment plan;
- Financial risk analysis/adjustment;
- Summarized risk analysis;
- Tailor-made loan details for decision

DATA REQUIREMENTS

Collect, compute, prepare:

- total farm liquidity analysis (both current and that projected with SPIS);
- borrower's own capital contribution;
- repayment potential;
- repayment plan;
- loan details
- subsidy/ re-finance details

PEOPLE / STAKEHOLDERS

- Loan officers financing or planning to finance SPIS;
- Producer(s) / potential borrower;
- Management of financial service providers (operational level);
- Public entities promoting and/or subsidizing SPIS;
- Sponsors

IMPORTANT ISSUES

- Specific liquidity patterns need to be identified for every single case
- Data collection process is challenging due to intermingled family-farm economy
- High initial investment should ideally not lead to prohibitive transaction costs (consider bank loans or external subsidies);

- High initial investment should ideally not lead to liquidity shortage for the borrower (be flexible when defining installment plans)

0.5 ha solar powered drip irrigation system used by a woman's group in rural Northern Benin for production of lettuce and other vegetables.

(Source: Lennart Woltering)

FURTHER READING, LINKS AND TOOLS

Links

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Tools

- **INVEST – Farm Analysis Tool**: to calculate the overall profitability of the farm enterprise and to determine the extent of variable and fixed costs.
- **INVEST – Payback Tool**: to calculate the financial viability of SPIS and to compare that to other alternative pumping systems (diesel and grid connected systems)

Other relevant tools:

- **PROMOTE – SPIS Rapid Assessment**: includes a (financial) market analysis for financing of SPIS components

FINANCIAL GLOSSARY

Assets	Position in balance sheet which represents what a company owns.
Capital expenditures (CAPEX)	Are one-time expenses. Normally they are long-term investments in non-consumable parts of the business, for example money that is spent on pump, panels, machines, etc.
Cash Inflows	All cash receipts realized within a given period (e.g. from sales).
Cash Flow	Is the incoming and outgoing cash of a business. Cash outflows are considered as negative cash flows and cash inflows as positive ones.
Cash Outflow	Outgoing cash, all cash payments realized during a given period (e.g. for buying production inputs, loan installments, buying equipment).
Creditors	Payable occurring from past credit (money owed to suppliers for expenses).
Collateral	Property or other assets that a borrower offers a lender to secure a loan.
Credit Sales	Sales made without receiving cash.
Current Assets	Cash and other assets which are expected to be converted into cash or consumed during the normal operating cycle of a business.
Debtors	Receivables occurring from past credit sales.
Depreciation	A cost charged against fixed assets for their replacement. Note: “depreciation” is one of the few expenses for which there is no associated outgoing cash flow
Expenses / expenditure	Payment of cash or cash equivalent for good or services received. Cost of resources used up or consumed by the activities of the business.
Finished Good Stock	An inventory of final products ready for sale.
Financial Viability	Ability to generate sufficient income to meet operating expenditure, financing needs and, ideally, to allow profit generation. Financial viability is usually assessed using Net Present Value (NPV) and Internal Rate of Return (IRR) approaches together with estimating the sensitivity of the cost and revenue elements. Both NPV and IRR are the most commonly used decision criteria of a cost-benefit analysis.
Fixed Assets	Assets required for long-term use and for physical use in the business (machinery, buildings, office equipment, cars, etc.).
Fixed Cost	Costs that do not vary with the level of production.
Fixed Investment	Investment made in fixed assets (e.g. machinery).
Gross Margin	Gross income minus gross expenses.

Income	Income is money generated from the activities of the business.
Inflation	The rate at which the general level of prices for goods and services is rising and, consequently, the purchasing power of currency is falling.
Internal Rate of Return	Gives the discount rate over the life-span of a capital investment; i.e. the profit rate generated by a certain investment (amount) over its life-span. By calculating IRR of a project you can answer the question whether the money is well spent or if less risky investment alternatives might be more profitable in the long run, e.g. putting the money on a bank account to get interest on it.
Liabilities	Claims by creditors against the assets of a business.
Life Cycle Costing	Is a technique for evaluating total cost of ownership to compare different alternatives.
Material Stocks	An inventory of all raw materials not yet used in production.
Net Present Value	Determines the present worth of an investment by discounting the cash inflows and cash outflows generated by this investment over its life span. For the determination of the NPV you need to define the expected life span of the investment as well as a discount factor, which might be near to the interest rate on deposits. You could also use the NPV for comparison of alternative investment options.
Net Working Capital	Current Assets minus Current Liabilities.
Operating expenses (OPEX)	Are the ongoing costs for running a business that are related with the operation and maintenance. They are the expenses related to the production activity of the business and they are divided into fixed and variable costs.
Payback Period (PP)	Is the length of time required to recover the cost of an investment.
Profitability	Income minus expenses. It is stated in the income statement (or Profit and Loss Statement), which reports a company's revenue, expenses, and net income over a period of time.
Raw Material Purchases	Cost incurred on purchase of raw material.
Revenue	Is the income earned by a business typically through selling goods/products or services.
Variable Cost	Cost that varies directly with the level of production delivered.

ANNEX – COLLECTION OF FORMULAE (FINANCES)

AVERAGE CASH FLOW*

**Definition: The "cash flow" is the incoming and outgoing cash of a business. Expenses (costs) are considered as negative cash flows and revenues as positive ones.*

Formula: *(Revenue-R –Operating Expenses-C) = Cf. = Cash flow*

PAYBACK PERIOD* (PP)

**Definition: The payback period is the length of time required to recover the cost of an investment.*

Formula: I/(R-C) = PP = Payback Period

I=Initial investment (CAPEX)

C=Average annual operating expenses (OPEX), excluding depreciation

R=Average annual revenue

(R-C) = Cf. = Cash flow

NET PRESENT VALUE* (NPV)

**Definition: The "Net Present Value" or NPV determines the present worth of an investment by discounting the cash inflows and cash outflows generated by this investment over its life span. For the determination of the NPV you need to define the expected life span of the investment as well as a discount factor, which might be near to the interest rate on deposits. You could also use the NPV for comparison of alternative investment options.*

Formula:

$$NPV = \sum_{t=1}^{n} \frac{Cf_t}{(1+r)^t} - I_0 + S$$

r= Discount factor

S= Salvage Value

I= Initial investment cost

t= years counting from base year

n= lifetime of project (panels)

INTERNAL RATE OF RETURN* (IRR)

**Definition: The "Internal Rate of Return" or IRR gives the discount rate over the life-span of a capital investment; i.e. the profit rate generated by a certain investment (amount) over its life-span. By calculating IRR of a project you can answer the question whether the money is well spent or if less risky investment alternatives might be more profitable in the long run, e.g. putting the money on a bank account to get interest on it.*

Formula:

$$NPV = 0, \text{ or}$$

$$\sum_{t=1}^{n} \frac{Cf_t}{(1+IRR)^t} - I_0 + S = 0$$

C_f = Net Cash Inflow

I_0 = Initial Capital Investment

t = time period in years

TOOLBOX ON SOLAR POWERED IRRIGATION SYSTEMS (SPIS)

POWERING AGRICULTURE:
AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

Module 10: Finance

The Toolbox on Solar Powered Irrigation Systems is made possible through the global initiative Powering Agriculture: An Energy Grand Challenge for Development (PAEGC). In 2012, the United States Agency for International Development (USAID), the Swedish International Development Cooperation Agency (Sida), the German Federal Ministry for Economic Cooperation and Development (BMZ), Duke Energy, and the Overseas Private Investment Cooperation (OPIC) combined resources to create the PAEGC initiative. The objective of PAEGC is to support new and sustainable approaches to accelerate the development and deployment of clean energy solutions for increasing agriculture productivity and/or value for farmers and agribusinesses in developing countries and emerging regions that lack access to reliable, affordable clean energy.

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Download
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About
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ABBREVIATIONS

EUR	Euro
FI(s)	Financial Institution(s)
JOYWO	Joyful Women Organization
KSh	Kenyan Shilling
MFI(s)	Micro Financial Institution(s)
MNRE	Ministry of New and Renewable Energy
NABARD	National Bank for Agriculture and Rural Development
PAYGO	Pay-as-you-go
SACCOs	Savings and Credit Cooperative Organization
SMEs	Small and medium-sized enterprises
SPIS(s)	Solar Powered Irrigation System(s)
USD	US Dollar

FINANCE

1. Bank Loan
2. Rural Bank / Development Bank Loan
3. Loan from Micro Financial Institutions (MFIs)
4. Value Chain Loan
5. Leasing / Repurchase Agreement
6. Cooperatives
7. Informal Saving Groups
8. Pay-Per-Use Business Model

MODULE AIM & ORIENTATION

The **FINANCE** module describes general financial services possibly available to farmers who want to adopt a Solar Powered Irrigation System (SPIS). The goal of the module is to inform decision-making agencies (governments, financial institutions, technology providers, development practitioners, etc.) about the financial option more suitable for farmer needs considering their specific characteristics. As a result, more farmers will have access to finance for procuring Solar Powered Irrigation Systems (SPISs), increasing the efficiency and sustainability of the agriculture sector.

If farmers possess enough money to purchase a SPIS without the need of a loan, they should consider the **INVEST** module.

Agricultural productivity and profitability are highly correlated with the state of development of financial sector in a country. Therefore, agricultural financing is an important driver for growth. Unfortunately, limited access to adequate financing is a common problem among farmers, especially in developing countries. This shortage of agricultural funds derives mostly from the unwillingness of financial institutions (FIs) especially banks to finance new technologies in the agriculture sector. The main reason for this is the perceived risk of non-repayment due to the uncertainty of the sector w.r.t. price, production, highly unpredictable markets and risks associated with a new technology. Furthermore, the remote location of some farms, the shortage of knowledge about the agricultural sector and inadequate policies like strict collateral requirements constrain the access to agricultural financing.

These difficulties could be overcome with innovative finance products, the adoption of adequate insurance, increasing awareness about agricultural specific risks and the expansion of agriculture financial service providers. As a result, the financing of Solar Powered Irrigation Systems could be seen as an opportunity for financing institutions, technology providers and governments to diversify their loan portfolio, expand their range of financial products, and enhance the economic development of a country.

This module differentiates between two main financing model categories: development models and business models. Development models are mostly used by governments, NGOs and non-profit institutions that aim to enhance the livelihood and overall development for farmers. Development models would typically include grants, subsidies and infrastructure programmes. Business models on the other side are adopted by banks and financial institutions, which, besides enhancing the economic growth of a country, aim to obtain profits from the provided credit. Business models are suitable for more mature markets, where appropriate credit mechanisms are readily available.

Even if, in rural areas, the loans from family members, neighbors and friends are widespread, they are not going to be described in this module, since they do not add overall value to the market.

In this module eight financing models are described and subcategorized between development and business financial models.

1 BANK LOAN

OUTCOME / PRODUCT

A commercial bank is defined as a financial institution whose main occupation consists of giving loans and taking deposits. A commercial bank earns its income through the interest resulting from the loans provided. Therefore, a commercial bank uses a **business financial model**.

Depending on the size, the length and the purpose of the credit, banks offer different types of agricultural loans. Unfortunately, the majority of commercial banks have not developed a financial product specific for the purchase of Solar Powered Irrigation Systems yet. Consequently, a standard agricultural loan needs to be requested.

In order to secure a loan from a commercial bank, several documents are required to be signed by both parties. A **note** in which the borrower agrees to pay the loan back at the decided interested rate, a **loan agreement** which contains the terms and conditions of the loan, a **security agreement** which explains what will happen with the collateral in case the borrower fails to pay back the loan and finally a **financial statement.**

Depending on their term, loans can be subdivided into three categories: short, intermediate and long term loans. Normally for the purchase of a farm equipment an intermediate term loan, which has a life span between 1 to 5 years, is used. Since the usual payback time for a SPIS stretches between 2 to 5 years, depending upon the farm income and other associated economics, an intermediate loan, is the best solution.

Once the loan is availed, interest needs to be paid. It can be fixed, adjustable or variable. Fixed interest remains constant during the entire loan period, adjustable interest is allowed to change but only in determinate intervals of time while variable interest changes as per the market conditions.

Bank loans can be paid through fixed constant payments or fixed principal payments**.** In the first case, interest and the principal are equally divided among the length of the loan. In the second case the principal is equally divided and interest is calculated each time based on the amount of the loan remaining to be repaid. In case of fixed principal payments, the initial payments are the highest.

Due to the high risk of the agricultural sector, interest on agrarian loans are typically high.

One example: in Kenya, which is the East African country with the highest financial inclusion, interest rates range between 20 and 30% (as at 2017). The Equity Bank of Kenya requires 18% of interest plus an additional 3% for the application fee. The KCB Bank, partly owned by the Kenyan government, charges 22% interest and an additional 2.5% for the application fee. In addition, two compulsory insurances are required: a credit insurance with a 2.5% interest rate and a crop insurance with a 7% interest rate. Overall, the interest reaches about 30%.

DATA REQUIREMENTS

The data required in order to finalize a credit are the following for most commercial banks:

Farmer personal data:

- Sex: According to studies women are more likely to pay back debts than men.
- Age: Some banks offer credit only to specific age groups: i.e. between 25 and 55 years old. In addition, in many countries, interest rate subventions are provided to senior citizens.
- Marital status: Married people with kids are more likely to pay back debts.
- Documents of identification.

Farm information:

- Property certification: If the land is leased, the chance to obtain credits is much lower.
- Credit history: Did the farmer pay back all his past loans? Is the farmer creditworthy?
- Insurance of the loan (if applicable)
- Bank account statement: In order to check the farmer's cash flow and transactions.
- Income from agriculture
- Income from other activities besides farming
- Collaterals: Banks need a security in case the farmer is not be able to pay back his debt.

PEOPLE / STAKEHOLDER

- Commercial Bank
- Financial experts / Risk analysts
- Farmer

IMPORTANT ISSUES

Generally, big farmers are more likely to obtain credits from big banks; conversely, small farmers will be better off dealing with smaller financial institutions. Small farmers with narrow financial means and limited access to the market and customers, are challenged to obtain credits from a commercial bank. Collaterals, alternative sources of income and a bank account represent the main barriers for credit eligibility. Collaterals and alternative source of income act as an insurance for the bank, safeguarding them in case the agricultural activity is not profitable.

Unfortunately, the solar pump itself is not considered as collateral, since banks lack information about this product. Therefore, financial institutions which mostly rely on internal data, do not have experts that can assess the risk of the loan. In order to use a solar pump as collateral, a financial analyst is required to know the initial price, the lifespan and the depreciation rate of the product in order to be able to trace its value back. Furthermore, it is necessary to know the optimal utilization conditions, presence of a second-hand market and risk of theft. Banks require this kind of information in order to safeguard themselves from inconvenient situations, which will end up in a loss of money. If for example, the system is stolen or the pump is positioned in an area with high salinity and it breaks down, the farmer is not likely to continue to pay the loan back and the bank will end up with unpaid credit and a worthless collateral.

2 RURAL/DEVELOPMENT BANK LOAN

OUTCOME / PRODUCT

Agrarian development banks also referred to as rural development banks, are financial institutions operating at regional level, which provide financial services with comparatively low interest rates, flexible repayment terms, amortized lending and technical and marketing support to actors involved in the food value chain. The main goal of a rural bank is the development of rural areas in terms of standards of living, food security and sustainability of the agrarian production though financial inclusion of SMEs. This implies, that rural banks use financial models which are substantially more focused on **development** than their conventional counterparts.

Rural development banks are able to offer convenient conditions because they collaborate with governments, NGOs and private companies, which support them economically. This strategic cooperation imposes limitations to financing activities since farmers need to meet specific requirements of the donors. For example, just specific food value chains, considered relevant for the development of a country, are subsidized by the government. And private companies finance just farmers, who agree to sign commercial contracts with them.

The main weaknesses of rural banks are a higher operating risk, lower earning capacity and the competitiveness of minor financial institutions as MFIs. Usually, rural banks finance just part of the investment (around 75%), meaning that farmers need to possess seed capital. Interest rates are much lower than the ones charged by commercial banks. For instance, the interest rate charged by the Agricultural Bank of Ghana ranges between 4 and 8.5%.

One example of a governmental program is the subsidy scheme for Solar PV systems launched by the Indian government and supported by the National Bank for Agriculture and Rural Development (NABARD). This sharply reduced the price burden on farmers. Farmers could buy SPIS from manufacturers approved by the Ministry of New and Renewable Energy (MNRE) with a discount of 40%. Out of remaining 60%, 20% is beneficiary contribution and 40% is eligible for a soft loan, which usually could be repaid in 5 years at the bank-specific interest rate.

DATA REQUIREMENTS

The information needed in order to finalize a credit with a rural or a development bank are mostly the same as those requested by commercial banks. In addition, environmental and social considerations also play a role:

- Farmer personal data: as those requested by commercial banks.
- Farm information: as those requested by commercial banks.
- In some cases farmers need to pay a deposit: In order to secure the loan.
- A bank account at the rural bank or at another financial institution is required: In order to check the farmer's cash flow and transactions.
- Collateral or alternative source of income are requested in order to secure the investment: In the framework of some development programs, farmers need to provide soft collateral only, or in some cases the donors provide guarantee for them.
- Proof of identity: Normally just citizens of a specific country, can get access to government subsidies.
- Insurance on the loan: In some development projects, insurance is provided by the donor.
- Submission of business proposal: Banks need to verify if the business plan of the farmer matches the requirements imposed by donors or within the pillars of the subsidy scheme.
- Environmental and social feasibility of the project need to be verified.

PEOPLE / STAKEHOLDER

- Rural/ Development Bank
- Government/NGOs/Private Company
- Farmer

3 LOAN FROM MICRO FINANCIAL INSTITUTION (MFIS)

OUTCOME / PRODUCT

Micro Finance Institutions (MFIs) are organizations which provide financial inclusion to the poor strata of the population (excluding the poorest). There are innumerable typologies of organizations acting as MFIs: commercial and development banks, saving groups, cooperatives and NGOs with non-profit status. These institutions can provide micro loans with favourable conditions to the urban and rural poor. MFIs are considered one of the best ways to decrease poverty and enhance development; therefore they most often adopt a **development financial model**.

Thanks to the spread of internet accessibility and mobile devices amongst the population in developing countries, and due to better access of finance for the poor, micro financing has been booming worldwide.

Due to the variety of profiles of MFIs, it is challenging to define an absolute micro financing model. Usually, non-profit organizations are financed by donors and in order to provide micro credits, they first need to loan money from financial institutions. This double loan system, does not guarantee a constant availability of funds and the interest rate for the final debtor is high. Conversely, classical financial institutions, which decide to enter in the micro financing business, have the advantage to rely on existing infrastructures, the know-how and their own capital. Different than non-profits, which work on local level, formal financial institutions (FIs) lack the physical connectivity to poor people. Therefore, they need to find an alternative way to check the credit worthiness of farmers and to find substitutes for collateral. Furthermore, due to the innumerable transactions and the small amount of money dealt, micro loans barely cover the transaction cost faced by formal FIs.

In general, MFIs offer quick loan disbursement, frequent repayment rates and customized loans, which imply an intensive personal relationship between lender and borrower. Micro financing loans range usually between 4 and 12 months and they need to be repaid either with monthly, weekly or even daily rates. Typical loans from MFIs range between 100 and 300 USD. However, with the entry of for-profit FIs, the loan's range has increased substantially, allowing farmers to purchase capital intensive farming equipment such as SPIS.

MFIs offer loans both to a single famer as well as groups of farmers. Planting Model Group are established specifically for the purchase of SPIS and allow farmers to obtain higher loans. Group members provide a guarantee for each other: if a farmer fails to repay his debt, the other members are responsible to take it over. Just farmers, who trust each other, are willing to form Planting Model Groups. Similarly, in India, Joint Liability Groups consisting of 4-10 members are formed for the purpose of availing bank loan on individual basis through group mechanism against mutual guarantee. Generally, the members engage in a similar type of economic activity and offer joint undertaking to the bank that enables them to avail loans.

DATA REQUIREMENTS

Due to the variety of the institutions involved in the micro financing business, the requirements that farmers need to meet in order to obtain a micro loan vary considerably. It is therefore necessary to check the data requirements requested by the individual FIs in the other chapters of this module.

Nevertheless a list with the most common documents necessary to obtain a loan are as follows:

- Documents of identification.

- Minimum age: 18 years old.
- Experience in the sector: normally 1 year requested.
- A bank account at the MFI or at another financial institution is required: In order to check the farmer's cash flow and transactions.
- Credit history: Did the farmer pay all his past loans? Is the farmer creditworthy?
- Soft collaterals or guarantors.
- Insurance on the loan (if applicable).
- A clear purpose of the loan need to be given to the MFI.
- MFIs' loan are mostly based on human relationship therefore personal interviews need to be conducted.

PEOPLE / STAKEHOLDER

- Micro Finance Institution (MFI)
- Farmer or Group of Farmers

IMPORTANT ISSUES

Micro financing allows social inclusion but does not always alleviates poverty, as expected. In fact high interest rates, which on average are around 37% and can reach 70%, can make poor people even worse off.

As commercial banks are more likely to be financial partners of big farmers, so MFIs have mostly SMEs farmers as customers with limited financial means and no collateral. Similarly, Savings and Credit Cooperative Organizations (SACCOs) are owned, managed and run by its members to provide a source of fair loans and reasonable rates of interest.

Sometimes MFIs and SACCOs are confused between each other. Here same main differences between these two institutions:

- From the loan application at a MFI till the loan disbursement just few days pass. SACCOs require instead up to 6 months to pay the loan out.
- Interest rate of MFIs are much higher than the one for SACCOs' members.
- The repayment time allowed by MFIs is much shorter.
- MFIs are run by paid workers while SACCOs are run by cooperative members.
- In SACCOs, debtors are members which share the ownership of the cooperative, in MFIs debtors are clients.

4 VALUE CHAIN LOAN

OUTCOME / PRODUCT

Value chain finance is a financial method to enable investments and loans within the value chain. This type of loan is a partnership between different actors in the same value chain, who want to increase the productivity and the competitiveness of the value chain itself. Suppliers and traders act as financial providers and enable farmers to access financial products, which they would otherwise not be able to obtain from classic financial institutions. Value chain actors either lend their own capital to farmers, or, if they do not possess the financial means necessary for the loan, they act as financial mediators between farmers and FIs. Actors involved in value chain loans work with a **business financial model**.

This type of financing creates a win-win situation for all parties: farmers obtain a customized loan, which they will need to start to pay months after the disbursement, suppliers and traders guarantee themselves a profit through the interest earned and the improved value chain.

The main advantage of a value chain loan is that it reduces the typical risks of agricultural financing. Suppliers and traders, working at the local level, take care of money transfers, facilitating the transactions. Furthermore, thanks to their personal relationship with farmers, suppliers and traders can guarantee for them. The main disadvantage is the interest rate which can be as high as 30% since banks` interest are summed up with financial mediators' interest.

This financial model can also apply to loans for the purchase of SPISs:

- SPISs' producers supply farmers with the technology, farmers need to pay them just at a later time, normally after the sale of the harvest. Using this type of loan, more farmers will be willing to purchase a SPIS, and suppliers will increase their customer base.
- Food traders instead, pay farmers in advance for the food they will buy at a later point, providing farmers with the cash necessary to purchase a SPIS. Farmers in return, will guarantee traders the delivery of the food after the harvest. Food traders agree to this kind of financial agreement because they have obligations to deliver high quantity of quality food to downstream actors. SPISs increase both these variables. Furthermore, traders use this type of loan to earn the loyalty of farmers, preventing them from selling their harvest to other interested buyers.

Examples of value chain loans both from upstream and downstream actors include:

Hortifruti is a company which provides fruit to wholesale supermarkets in Costa Rica. In the 70s, when Hortifruti started to operate in the sector, the fruit market was fragmented, farmers lacked infrastructures and technologies, making it impossible for retailers to sell good quality fruits on a large scale. Hortifruti therefore decided to support farmers with technical support and financing. Hortifruti developed two types of financial models: a bank financing and a non-bank financing model. The bank financing was supported by the BAC San Jose´- Hortifruti guaranteed to the bank that they will buy fruits from the farmer with the bank financing comprising 60% of the production costs. In this model, no collateral was requested, but an insurance on the yield was required. The farmer, needed to pledge that he will deliver the crops to Hortifruti at a later point. With just a selling contract, the farmer was considered creditworthy at BAC San Jose`. The second type of loan is a non-bank financing model in which Hortifruti paid for 30% of the fruit production costs. No interest was charged. The farmer only needed to sign a contract to deliver the food in the future and in return obtained the required inputs.

An example of an upstream value chain loan is the one offered by the equipment dealer SolarNow in Kenya. SolarNow proposes loans with 6, 12 and 24 months terms. In order to get a 6 months loan, the farmer needs to deposit half of the price of the pump upfront, to secure the loan. Since the total price of the pump is KSh. 68,500, the payment will be of KSh.34, 250. After the first payment, six equal installments of KSh. 6,550 each will need to be paid. At the end of the loan the farmer will have paid KSh. 73,550, which is 7% more expensive than the original price of the pump. For the 12 months loan, the upfront deposit will be of 15%, followed by 12 monthly payments of KSh. 10,275 each. Finally, the 2 year loan requires a 15% deposit also, followed by 24 installments of KSh. 3,850 each.

Futurepump in Kenya provides farmers with the option to purchase a SPIS through loans with major banks. Equity Bank offers loans up to 2 years with an upfront deposit of 30%, a 5% set-up fee and an interest rate of 14%. With KCB, a lower deposit of 10% needs to be given in advance and the interest rate is 14% plus an additional set-up fee.

Finally, SunCulture ran a pilot initiative in 2017 with 150 Rainmakers. Every Rainmaker cost KSh. 50,000. Farmers needed to deposit 20% of the total cost followed by 12 monthly installments of KSh. 4,500 each. Therefore, every farmer invested KSh. 64,000 in the system. This price did not include the delivery, the installation and the training cost. After this pilot project, SunCulture decided to increase the price of the Rainmaker since they decided to improve the product and they realized that higher margins are needed.

DATA REQUIREMENTS

Farmers will obtain a loan under the following conditions:

- Documents of Identification.
- Bank account: In order to check the farmer's cash flow and transactions.
- In some cases farmers need to pay a deposit: In order to secure the loan.
- Show the existence of a market for the food produced.
- Prove one or two successful past harvests: In order to verify the experience on the field.
- This type of loan, implies a closer relationship between farmers and financial providers. The latter need to trust farmers and be convinced in their ability to succeed and repay the loan.
- Sometimes financial institutions ask for quotations from suppliers and traders (similar to a guarantee).
- Purchasing or sales contracts are necessary to finalize the loan: FIs need to be sure that the farmer will earn money.
- Collateral as assets and alternative source of income are normally not required.
- Farmers do not need to be a land owners: land could be rented or leased.
- Size of the farm and type of food cultivated play an important role: Traders have obligations to supply downstream actors with large quantities of a specific product, therefore they will choose among farmers, who meet their expectations.

PEOPLE / STAKEHOLDERS

- Upstream / Downstream Actors (SPIS's manufacturers and suppliers, food processors, food traders)
- Financial institutions
- Farmer

IMPORTANT ISSUES

Value chain loans can reduce farmers` independence. Buying and purchasing contracts are mostly necessary for the loans, binds farmers to specific suppliers and/or distributors. Furthermore, farmers need to meet some requirements in order to be eligible for a loan.

5 LEASING / REPURCHASE AGREEMENT

OUTCOME / PRODUCT

Leasing is a financial instrument which allows the use of an equipment without the need to purchase it. A leasing contract involves a lessor, the owner of the asset, and the lessee, who is the actor with the right to utilize the asset in exchange for a monthly contribution. At the end of the lease agreement the lessee can use the option to buy the equipment. Different kinds of institutions are active in the leasing business as MFIs, banks and equipment producers and dealers. Leasing is a **business financial model**.

In spite of its for-profit scope, leasing acts as an alternative financing method, since it overcomes the development barrier in rural areas. Leasing provides farmers, who normally are excluded from credit, access to innovative agrarian equipment. Farmers with a leasing agreement are therefore able to use a SPIS without ownership on it.

Lease agreements cover just a part of the total value of the equipment, meaning that at the end of the lease, the equipment will still have a residual value. The length of a lease agreement depends on the lifespan of the leased asset itself. Leasing agreements are seen as flexible since the assets can be sold and traded at any time. Equipment more suitable to be leased are assets with innovative technology, that turn obsolete fast, and assets that experience a lot of wear and tear.

From the lessor`s perspective, the main challenge of a leasing contract is the difficulty in monitoring the payments and to verify that the lessee utilizes the asset correctly without damaging it. Therefore, the institutions with the highest success rates are the ones working at local level, reaching farmers who live in remote areas.

There are several typologies of leasing. The two most common are operating and capital leasing. Operating leasing is similar to rent. The lessee pays the lessor a fee for the utilization and another fee for the depreciation of the asset. In turn, the lessor takes care of the maintenance and pays both the insurance and registration fee. In financial leasing (more similar to a loan), the lessee pays part of the total value of the assets plus the agreed interest rate in monthly rates during the entire lease agreement. At the end of the leasing contract, the lessee can buy the asset at a nominal price (residual amount decided upfront). With this contract typology, the lessee is in charge of paying the insurance and maintenance cost. For instance, if a SPIS costs 3,000 USD, during the leasing contract the farmer pays just 60% of its entire value plus an interest rate. At the end of the contract, the SPIS has a residual value of 40% (1,200 USD), that need to be paid in order to purchase the equipment.

The equipment producer and dealer “Kickstart” provides micro-leasing for the purchase of solar pumps where 30% of the payment needs to be made in advance. The residual payment can be made 5 months later, when the farmer would have earned the money from the yield sold.

DATA REQUIREMENTS

The requirements for a lease are much less stricter than the one for a loan. Therefore, small farmers are more likely to obtain a lease than a loan.

The following requirements are necessary to be eligible for an equipment lease:

- Documents of Identification.
- Bank account: In order to check the farmer’s cash flow and transactions.
- Farmer´s credit history: A leasing contract will not be recorded in the credit history of a farmer, but in order to verify his credibility, the past credit history needs to be checked.
- Show the existence of a market for the food produced.
- Prove one or two successful past harvests: In order to verify the experience on the field.

- Insurance on the lease is sometimes required.
- An upfront payment to secure the assets could be requested.
- Collaterals or alternative sources of income are not normally required. A guarantor can be present.

PEOPLE / STAKEHOLDER

- Lessor (Equipment Producer or Dealer / Financial Institution or both)
- Lessee (Farmer)

IMPORTANT ISSUES

The main advantage of a lease is that it is generally cheaper than a loan. Farmers with a leasing agreement need to pay part of the total value of a SPIS plus an interest rate. On the opposite, farmers, who purchase a SPIS must pay the total value of the equipment plus an interest rate. If the farmer decides to purchase the SPIS at the end of the lease agreement, then the lease would be more expensive than a loan.

In some leasing contracts, farmers need to agree upfront with the lessor on how many hours they will utilize the SPIS. The more precise the approximation will be, the more the farmer will gain. In fact, hours not used will not be reimbursed, and extra hours will be heavily penalized.

Most of the leasing contracts are arranged between equipment manufacturers or dealers and farmers. But usually the former, working at local level, acts as an intermediary between farmers and FIs. Manufacturers and dealers in fact do not possess the capital, the knowledge and infrastructure necessary to manage the lease, therefore, they involve a third party in the transaction. Usually, the FI buys the solar pump from the dealer and leases it to the farmer. Normally, the pump is used as collateral, just in few cases instead, the dealer is asked to guarantee for the farmer. The FI can own the equipment until the lease is over. In an event of a non-payment, the FI just claims the asset back, rather than going through bankruptcy procedures and the sale of the equipment. FIs have innumerable advantages acting as lessors: they collect interest and principal payments as in a loan, but since they own the asset, the leasing is less risky than a loan. Furthermore, leasing contracts broaden the customer base, since the credit assessment is focused on the lessee's ability to repay and not on the credit history or the assets base of the farmer. After the equipment is no longer usable, the FI can either sell it to the market or for scrap value. More specifically, SPIS have "buyback provisions" from the solar irrigation equipment provider. That means that in an event of a non-payment or the end of the leasing contract, the equipment dealer agrees to buy back the equipment. For example, a SPIS manufacturer agrees to a 2 year lease, and establishes the resale value of its equipment starting from a default scenario of 3 months. If, for instance, the lessee defaults at 9 months and the residual value at that point is 75%, the SPIS manufacturer will repay the FI the "buyback value", while the FI would retain leasing payments on the initial 25%.

6 COOPERATIVES / JOINT LIABILITIES

OUTCOME / PRODUCT

A cooperative is “an independent association of women and men, united voluntarily to meet their common, social, economic and cultural needs and aspirations through a jointly owned and democratically controlled enterprise” *(ILO, Recommendation 193: Promoting Co-operatives, 2002)*. Cooperatives unify people with a common bond, which could be the same occupation, living location, or religious affiliation. The main goal of Agricultural cooperatives` is to increase agricultural production and the income of its members by bringing food producers together which enables them to obtain economic and financial advantages that individual farmers would not be able to obtain. Cooperatives are non- for- profit organizations, therefore they adopt a **development financial model**.

Financial services are provided from specific branches called Savings and Credit Cooperatives (SACCOs). Every person, sharing the common bond, which characterizes that specific SACCO can become a cooperative member after payment of the registration fee.

Normally, agrarian cooperatives are financed by banks, governmental and international development programs or voluntary deposits from its members. Each member of the SACCO is a partial owner, receives dividends and has the right to vote (with the 1 man - 1 vote principle). The board is formed by unpaid volunteers elected from the cooperative members.

SACCOs, thanks to their non-profit status, are able to offer their members competitive loans with reasonable interest rates. Cooperatives normally obtain a loan from a classical financial institution and then divide it among their members. A loan for the purchase of a SPIS does not normally require collateral. If the farmer fails to repay the loan, the solar pump will be given to another member or the amount of the loan will be deducted from the dividends of the farmer. Group loans are also possible: members co-guarantee for each other- if one of the borrower defaults, the other members are forced to assume the debt obligation.

SACCOs offer innumerable types of loans which most of the time work with multipliers. This means that if a member has contributed 200 EUR to the cooperative fund and the SACCOs uses a multiplier of 2, then he/she can obtain a maximum loan of 400 EUR. The Kenyan Waumini SACCO for example, offers a development loan with a multiplier of 3, an interest rate of 12% and a maximum repayment period of 60 months fully secured. In the same SACCO, it is also possible to get a group super flex loan in which group members co-guarantee for each other. Insurance is required at 1% interest and the loan can stretch between KSh. 10,000 to KSh. 3,000,000. Another SACCO in Kenya called Hazina offers a normal loan with a multiplier of 4, and a maximum loan of KSh. 3,000,000 repayable in 72 months.

DATA REQUIREMENTS

The condition to become a member of a Cooperative are the following:

- Identification documents.
- Common bond with the other cooperative members.
- Photograph taken from the cooperative branch.
- An account opened at that specific SACCO.
- A one-time non-refundable entrance fee (KSh. 500 at Waumini SACCO).
- A one-time minimum deposit contribution (KSh. 300 at Waumini SACCO).

- Share capital that can be paid all together or in different rates (KSh. 15,000 at Waumini SACCO).
- Sometimes a risk insurance is required to be paid monthly (KSh. 50 at Waumini SACCO).

A cooperative's member in order to be eligible for a loan need to:

- Fill an application form.
- Find other members who can guarantee for him, in case it is a group loan.

PEOPLE / STAKEHOLDERS

- Cooperative (SACCO)
- Financial Institutions
- Cooperative members

IMPORTANT ISSUES

The main differences between banks and cooperatives are the following:

- Anyone can join a bank, but only people with specific characteristics are allowed to become a cooperative member and therefore apply for a loan.
- Cooperatives are normally smaller institutions with one or two branches and a limited number of ATMs.
- SACCOs offer the same service as banks do, but the interest rates at SACCOs are lower, the loans are customized, the customer service is better and the system is based on trust rather than collateral.
- Cooperatives are less attractive for big players since they have lower capital incentives.
- Sometime cooperatives have difficulties in getting loans for their members, since they first need to apply for a loan from a larger financial institution.
- In cooperatives the decision-making process is slower and not as effective since every member has the right to vote.

7 INFORMAL SAVING GROUPS

OUTCOME / PRODUCT

Informal saving groups are groups of people who save money in a common fund and borrow directly from their savings. Informal saving groups are based on a predetermined rotation where every member is able to obtain a loan. Among these groups, credit is perceived as a human right, therefore, a **development financial model** is utilized.

Informal saving groups have between 10 and 30 members who meet on a monthly basis. During these meetings, group members are required to deposit their savings. The money collected will then be given to a group member. As soon as the debtor repays his loan, another member obtains his credit. The main benefit of Informal saving groups' is that they discipline people. Owing to the social pressure, members are more likely to meet their monthly saving commitments. The interest rate that members need to pay on their loans are much lower than the ones requested by banks and MFIs. These kinds of organizations are spreading rapidly in rural areas of developing countries.

Every group serves a specific purpose. In Kenya for example, Joyful Women's Organization (JOYWO), a table banking organization, helps rural woman and youths to promote food security. The term "table banking" comes from the method on which money is deposited and exchanged, perhaps on a table. Members of a group share a common bond: for instance in JOYWO, members are women above 18 years old and young men between 18 and 35 year old. Due to the success of the group, more males are willing to join. Therefore, a new rule allows 1/3 of the group members to be male. In JOYWO groups, both short- and long-term loans are possible. People who are members more than 6 months can apply for a long-term loan up to 3 times the amount of their savings with an interest rate of 1% monthly and a payback time between 12 and 24 months. Short term-loan need to be repaid in 1 month with an interest rate of 10%. The loans provided are mostly unsecured, where smaller valued collaterals such as household assets (television or chairs) are required sometimes. Group members guarantee for each other: If a member fails to repay her loan due to a genuine reason, the other members will do a fundraiser and clear her/his debt. In case of financial distress, a member can withdraw all her/his savings, but a penalty may be applied.

DATA REQUIREMENTS

In order to join a saving group, the following requirements need to be met:

- Nationality of a specific country (i.e. people with Kenyan citizenship can only become JOYWO's members).
- Members need to belong to a specific social group and /or share a common bond.
- Group members need to know the new applicant and must accept him/her into the group.
- The new member must commit to take part to the monthly group meetings.
- Monthly donations are required.
- The members need to show commitment to the group and to group activities.

PEOPLE / STAKEHOLDER

- Group of people willing to organize their saving.
- Sometimes informal saving groups are administrated from a central organization, which also helps them

to expand their funds through external donors.

IMPORTANT ISSUES

Even though formal financial institutions offer saving accounts too, poor people need to organize their savings themselves. Their low amount of savings and their frequent transactions do not cover the operating cost that banks charge.

8 PAY-PER-USE BUSINESS MODEL

OUTCOME / PRODUCT

The pay-per-use system is a business model offered by equipment manufacturers and dealers, who want to provide a service rather than sell a product. Manufacturers and dealers transport their equipment from consumer to consumer, perform the service and get paid depending on the time of utilization, or on the output provided. Different from the other chapters of this module, the pay-per-use model is a business model rather than a financial product.

In the SPIS business, the pay-per-use model is growing and it is spreading rapidly among SPIS's manufactures and dealers. Farmers, who want to irrigate their fields with a solar pump, but lack the capital and the knowledge, can rely on experts, who will irrigate their fields on scheduled dates in return of upfront payments. Farmers will therefore not pay for the SPIS, but for the amount of water pumped, making them more conscious about the water used, and limiting wastefulness.

The main advantage for farmers is that they pay for just what they use without any investment or maintenance cost. The pay-per-use system allows farmers, who normally possess irregular cash flow, to pay for high-quality solar products with a small amount of money over time. Manufacturers and dealers, on their side, use this model to enlarge their business and win more clients. The pay-per-use system will significantly change the business model of many companies and will also influence the value chain of innumerable food related products.

This system is more suitable for farmers situated nearby dealers or manufactures, who can be reached fast and on a regular basis. Also farmers, who do not need to irrigate their fields often or can rely on alternative sources of water (i.e. rain), will save money paying for only the service rather than for the entire product.

Examples of companies adopting this model are Claro Energy India and Kickstart International. Claro Energy provides farmers a pay-per-use system with a toll-free line, a pre-paid and scheduled irrigation plan and a remote activation system through credit card which can reach farmers living in the most isolated location. Furthermore, trainings and demonstrations are offered. Kickstart International is also developing with Angaza Design, a pay-as-you-go (PAYGO) technology for solar irrigation called Futurepump. Angaza is a web interface, which helps both manufacturers and distributors to manage pay-per-use operations in the renewable energy sector for off-grid consumers.

DATA REQUIREMENTS

Different from all other financial services, the pay-per-use model does not have a lot of requirements. Farmers only need to:

- own a bank account with a credit card in order to make the upfront payments.
- possess a water license (if applicable): For environmental reasons water cannot always be extracted from the ground.

PEOPLE / STAKEHOLDER

- SPIS's distributors or manufacturers
- Farmer

FURTHER READING, LINKS AND TOOLS

Tools

FINANCE – Finance Deployment Tool

Other relevant tools:

- **PROMOTE – SPIS Rapid Assessment**: includes a (financial) market analysis for financing of SPIS components
- **INVEST – Payback Tool**: calculates the financial viability of a SPIS and compares that to other alternative pumping systems (diesel and grid power)
- **INVEST – Farm Analysis Tool**: reviews the profitability of a farming enterprise and allows for compiling a farm income statement for submission to a lending institution

GLOSSARY

Secured Loan	A loan is considered secured when the debtor pledge a collateral. In case the debtor defaults, the creditor will obtain the possession of the collateral.
Seed Capital	The seed capital is the capital used to start a business activity.
Loan Term	A loan term is the length of time you have a disposal to pay your debt back.
Set up fee	A set-up fee is an initial fee requested by a Financial Institution (FI) in order to setup an account.

TOOLBOX ON SOLAR POWERED IRRIGATION SYSTEMS (SPIS)

POWERING AGRICULTURE:

AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

Module 5: Design

Food and Agriculture Organization of the United Nations

USAID FROM THE AMERICAN PEOPLE

SWEDEN

german cooperation DEUTSCHE ZUSAMMENARBEIT

DUKE ENERGY

OPIC

The Toolbox on Solar Powered Irrigation Systems is made possible through the global initiative Powering Agriculture: An Energy Grand Challenge for Development (PAEGC). In 2012, the United States Agency for International Development (USAID), the Swedish International Development Cooperation Agency (Sida), the German Federal Ministry for Economic Cooperation and Development (BMZ), Duke Energy, and the Overseas Private Investment Cooperation (OPIC) combined resources to create the PAEGC initiative. The objective of PAEGC is to support new and sustainable approaches to accelerate the development and deployment of clean energy solutions for increasing agriculture productivity and/or value for farmers and agribusinesses in developing countries and emerging regions that lack access to reliable, affordable clean energy.

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Download
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About
Powering Agriculture: An Energy Grand Challenge for Development: https://poweringag.org

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ABBREVIATIONS

Ah	Ampere hour
CWR	Crop Water Requirement
DC/AC	Direct Current / Alternating Current
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
Gd	Daily Global Irradiation
GIZ	Gesellschaft für Internationale Zusammenarbeit
GIWR	Gross Irrigation Water Requirement
GPFI	Global Partnership for Financial Inclusion
HERA	GIZ Program Poverty-oriented Basic Energy Services
H_T	Total Head
IEC	International Electrotechnical Commission
IFC	International Finance Corporation
IRR	Internal Rate of Return
IWR	Irrigation Water Requirement
MPPT	Maximum Power Point Tracking
NGO	Non-Governmental Organization
NIWR	Net Irrigation Water Requirement
NPV	Net Present Value
m^2	square meter
PV	photovoltaic
PVP	Photovoltaic Pump
SAT	Side Acceptance Test
SPIS	Solar Powered Irrigation System
STC	Standard Test Conditions
TC	Temperature Coefficient
UV	Ultraviolet
Vd	Daily crop water requirement
W	Watt
Wp	Watt peak

DESIGN

1. Collect data
2. Analyze agricultural production options
3. Determine water requirements and availability
4. Select SPIS configuration
5. Estimate system size and costs
6. Assess financial viability
7. Pre-select potential suppliers
8. Evaluate quotations and assess quality
9. Contract supplier

MODULE AIM & ORIENTATION

This module provides information and tools for agricultural service providers on how to estimate the dimensions, type and financial viability of Solar Powered Irrigation Systems for a specific farming situation. An SPIS consists of multiple components that work under constantly varying daily and seasonal conditions. The design of an SPIS lays the foundation for the system's technical, financial and environmental viability. In particular with regard to financial implications and the risk of unsustainable water abstraction, the decision requires thorough consideration. Therefore, this module is also highly relevant for financial service providers. For more this module should enable the advisor to judge whether the installation of an SPIS would be more suitable and viable than using alternative irrigation systems. The tools are described and referred to in the different process steps of this module. Important design parameters can be estimated with simplified formulas to gain insights into understanding a more detailed design. Given the complex interactions between the different components under different environments, the tools of this module do not replace a detailed technical design created by professionals in solar and irrigation technology.

PROCESS STEPS

Before designing an SPIS, it is important to assess the opportunities and threats of an SPIS in a particular area. The institutional setting and environmental aspects, as described in the **PROMOTE & INITIATE** and the **SAFEGUARD WATER** modules, are important framework conditions. In addition, local, up-to-date information on markets for input and output (crop sales) and other information are key to deciding whether designing an SPIS for a particular location makes sense at all. Once it is confirmed that an SPIS is the preferred option, it is crucial that design adheres to the intended use. Once the crop water requirements, solar radiation and system pressure have been established, the technical design can then be prepared. The technical planner can choose from a number of methods of varying complexity and accuracy to come up with a final design. Before deciding on a particular contract provider, the cost quotation from the system integrator should be thoroughly assessed.

1. COLLECT DATA

For a proper design of an SPIS, a set of data and information is required on the meteorology, soil, crop, water and other site-specific parameters. The data can be obtained from a combination of interviews with the producer, on-site field observation and off-site data (internet, databases, etc.). The producer has to tell the designer what crops are to be grown at what time and how the crops are to be managed. The producer may want to use fertigation for accelerated growth, or the producer may opt for fruit trees instead of annual crops. Based on the location of the farm, a lot of data can be collected off-site, such as meteorological data, topography and perhaps even information on water availability. While an on-site survey of solar radiation and other meteorological data would be a worthwhile exercise, most systems are based on existing data derived from nearby reference locations. Data and information on evapotranspiration and crop water requirements can be obtained from agricultural offices or extension services. Finally, a field visit has to be organized to validate the collected data and to complement it with local information on e.g. soil and water quality, shadowing from trees or hill tops, ease of access to the site, the pumping head and more.

The **DESIGN – Site Data Collection Tool** contains interview guidelines and check-lists to ensure that all required information for creating an SPIS design is available. The **DESIGN – SPIS Suitability Check Tool** is used to make a qualitative check if a site is suitable for an SPIS.

SPIS data collection field in India

(Source: Lennart Woltering)

OUTCOME / PRODUCT

- Detailed description of farm-specific situation, as a basis for the assessment of the suitable configuration and the technical design;
- **DESIGN –Site Data Collection Tool** to collect all the information required to create a design for an SPIS;
- **DESIGN – SPIS Suitability Check Tool** to check a site's suitability for SPIS.

DATA REQUIREMENTS

- **meteorological data:** insolation, temperature, wind speed, humidity, rainfall, evaporation;
- **site data:** longitude, latitude, altitude, water source, pumping head, shadowing, climate, terrain;
- **crop data:** crop type and variety, growing season, crop rotation, crop water requirements, fertilizer, crop protection requirements;
- **soil data:** soil type, salinity, water holding capacity, organic matter content, fertility;
- **water data:** availability, groundwater recharge, water rights, salinity, temperature, algae content, sediment content;
- **market data:** demand situation, selling price, seasonality, market type and distances.

PEOPLE / STAKEHOLDERS

- producers / producer groups;
- agricultural service providers;
- water resources management authorities;
- meteorological service providers;
- system integrators.

IMPORTANT ISSUES

- SPIS requires the producer to cope with varying water flows over the day and over the year.
- Insufficient evaluation of water requirements and availability on-site often lead to under- or oversized PV systems. This frequently occurs in subsidy-driven markets, where the system designs are standardized and the size is not scalable.

2. ANALYZE AGRICULTURAL PRODUCTION OPTIONS

It is important to design an SPIS that is affordable and profitable. Profitability depends on the revenues, or the income earned from selling the crop. The choice of crops to grow is therefore critical:

- Tree crops, such as oranges and mangos, only start generating revenues after 3 to 5 years.
- Vegetables are difficult to grow and transport, but generally bring high revenue.
- Staple crops such as millet, sorghum and maize are often low value and seldom justify the investment in irrigation systems.
- Other crops or crops for processing (biofuel) can bring high revenues, depending on the local market.

Each crop has a different crop budget: costs of production vs. expected revenues. The role of the agricultural extension advisors is to inform producers what (mix of) crops bring the best returns in a particular area. The producer then draws up a crop calendar for the whole year indicating which crop should be grown when and on what area of the field. Since the market for crops is dynamic, it is crucial remain up-to-date on price developments. Prices for vegetables can easily multiply 3 to 4-fold within a season.

Important:

The profitability of an irrigated farm highly depends on the cultivation of the right crop at the right time. Two identical SPIS systems, where one farmer grows maize and the other grows tomatoes, will show very different financial returns.

The definition of a high-value crop depends on the market. In general vegetables and fruits are considered to be high-value crops. Proper production of fruits and vegetables requires skilled labor and a suitable strategy on soil fertility and pest management. Agricultural advisors play an important advisory role in this regard and should be able to give farmers access to capacity building programs.

OUTCOME / PRODUCT

- Overview of crop budgets showing costs of production and expected revenues based on local market information;
- model cropping calendar.

DATA REQUIREMENTS

The data required for analyzing agricultural production is available from the farm's own records and external service providers. It includes:

- a compilation of all crops in the farm's actual cropping pattern;
- yield level and market price for crops;
- production costs (seed, fertilizer, plant protection, traction, transport, labor, services).

PEOPLE / STAKEHOLDERS

- Producers/farm households;
- agricultural extension services;
- technology and service providers.

IMPORTANT ISSUES

- The agricultural extension agent should be able to help producers to develop an annual cropping calendar with the optimum mix of crops.
- Depending on water availability, producers should aim to cultivate year-round to justify the investment in the irrigation infrastructure.
- The capacity of the producer to grow high-value crops is critical.

3. DETERMINE WATER REQUIREMENTS AND AVAILABILITY

Water requirements: The amount of water needed by a plant depends on the climate, the crop as well as management and environmental conditions. It is expressed as Crop Water Requirement (CWR) (see **GET INFORMED** – Irrigation Principles).

Calculating crop water requirements is a complex task but with the help of useful software tools, such as CROPWAT, experienced agricultural extension workers are able to give advice to individual producers. CROPWAT is available with FAO after registration and is free of charge (see link at the end of this module). Agricultural offices and extension services are usually in a position to provide CWR data for the most common crops in an area, based on the prevailing local climate conditions.

The sum of the individual Crop Water Requirements (CWR) for each plant in the field determines the Net Irrigation Water Requirements (NIWR) for a given period of time. The NIWR determines how much water a crop requires to satisfy its demand for water in the soil. However, water is never 100% efficiently applied as there may be leaks or other losses in the system. Efficiency is largely dependent on the irrigation method (e.g. furrow, basin, drip or sprinkler irrigation). The Gross Irrigation Water Requirement (GIWR) is used to express the quantity of water that is required in the irrigation system. It is important to subtract the water that is fed to the root zone of the plants through precipitation. The **DESIGN – System Sizing Tool** helps design the irrigation system so as to ensure that as little pressure as possible is lost in the system. In addition, it serves as a checklist to identify pressure losses, e.g. due to leaks in an existing system.

Water availability: In terms of planning and designing any irrigation system, the initial consideration should always be the requirement and the availability of water (access to water, water rights and concession, well or borehole yield). Subsequently, a system can be designed based on the water availability and the most suitable and possible cropping pattern. Water abstraction and irrigation system components need to be adapted to each other in order to achieve the best result in terms of technical, financial and environmental viability.

Water availability is a crucial design factor for any irrigation system

(Source: Lennart Woltering)

OUTCOME / PRODUCT

- Water availability;
- total irrigation water demand;
- alternative irrigation schedules;
- hydraulic characteristic of irrigation system;
- **DESIGN – System Sizing Tool** to check on pressure losses in the system.

DATA REQUIREMENTS

- Local evapotranspiration (ETo data);
- rainfall, wind and insolation data;
- crop details (e.g. ETc values);
- soil characteristics;
- type of irrigation system and efficiency;
- water license/rights, well and aquifer capacities on site.

PEOPLE / STAKEHOLDERS

- Producers;
- agricultural service providers;
- meteorological service providers;
- water authorities;
- water user associations.

IMPORTANT ISSUES

- CROPWAT includes standard crop and soil data but would require local data input to do accurate prediction at farm level;
- Overexploitation or persistent groundwater depletion may occur if groundwater abstraction continuously exceeds the natural groundwater recharge (severe negative environmental impact), see **SAFEGUARD WATER** module;
- a proper pump design takes the site-specific well capacity into account;
- efficient water abstraction monitoring needs to be planned;
- demand for irrigation water will vary throughout the year, with peak demands often more than twice the average demand.

4. SELECT SPIS CONFIGURATION

A SPIS can be designed in many ways; major variations will lie in the combination of key components:

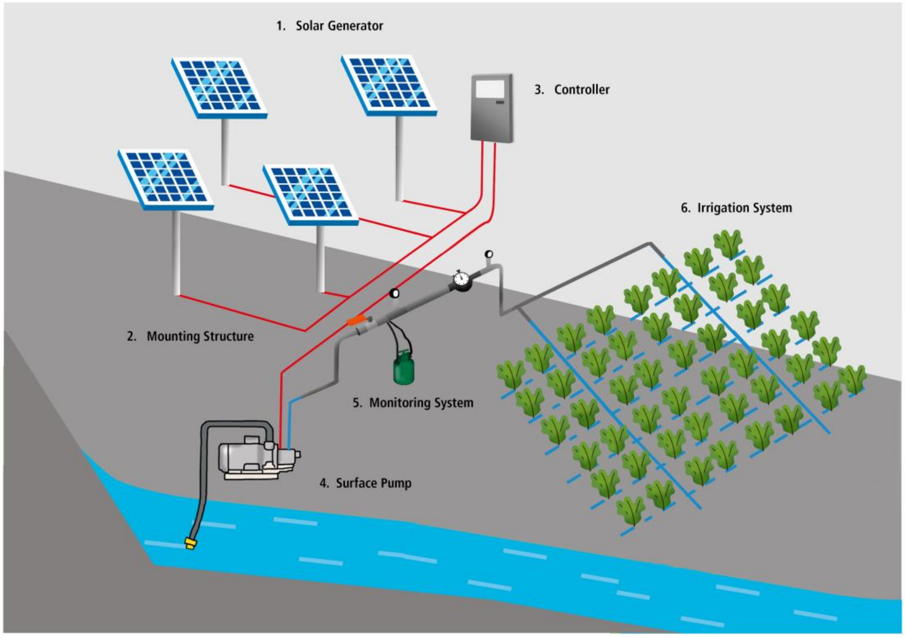
- solar mounting system (fixed or tracking);
- motor pump installation (submersible or surface);
- integration of a reservoir or not;
- irrigation method – mainly drip or surface irrigation.

An overview and description of different configurations of the individual components is provided in the **GET INFORMED** module.

Technically, any irrigation method can be combined with a solar water pump. However, it becomes a matter of cost. Pressure and high discharge require more energy and therefore higher costs. Drip irrigation, working at comparably low operating pressures and water efficient, suits solar pumping systems best. Yet, it requires that the producer learns new irrigation management skills. The suitability of a particular system configuration for a given farm depends on the water availability, the farm's specific water requirements, its agricultural production and the producer's skills and budget.

The human and financial resources required for maintenance should already be considered in the design of the system. As a rule, higher investments in good quality equipment outweigh the time and effort put into maintaining and repairing poor quality equipment.

The figure below shows an SPIS configuration where one saves on the costs for the reservoir but spends on the tracking systems. The tracking system enables a relatively stable pump dis-charge which is important, because there is no reservoir to buffer the amount of water going to the field. The water can further be controlled by the valves and by splitting up of the drip irrigation system in sections.



SPIS configuration with a solar tracking system, surface pump and drip irrigation (Source: GFA)

The next figure shows another, more common, configuration where water is pumped from the ground and stored in an elevated reservoir. The water goes through the irrigation head, which can be equipped with volumetric valves, and/or a fertigation system. Nevertheless the producer is forced to divide the field into small sections to allow a relatively controlled distribution of water across the field. This SPIS configuration requires relatively little maintenance as the panels and the pump are fixed.

DATA REQUIREMENTS

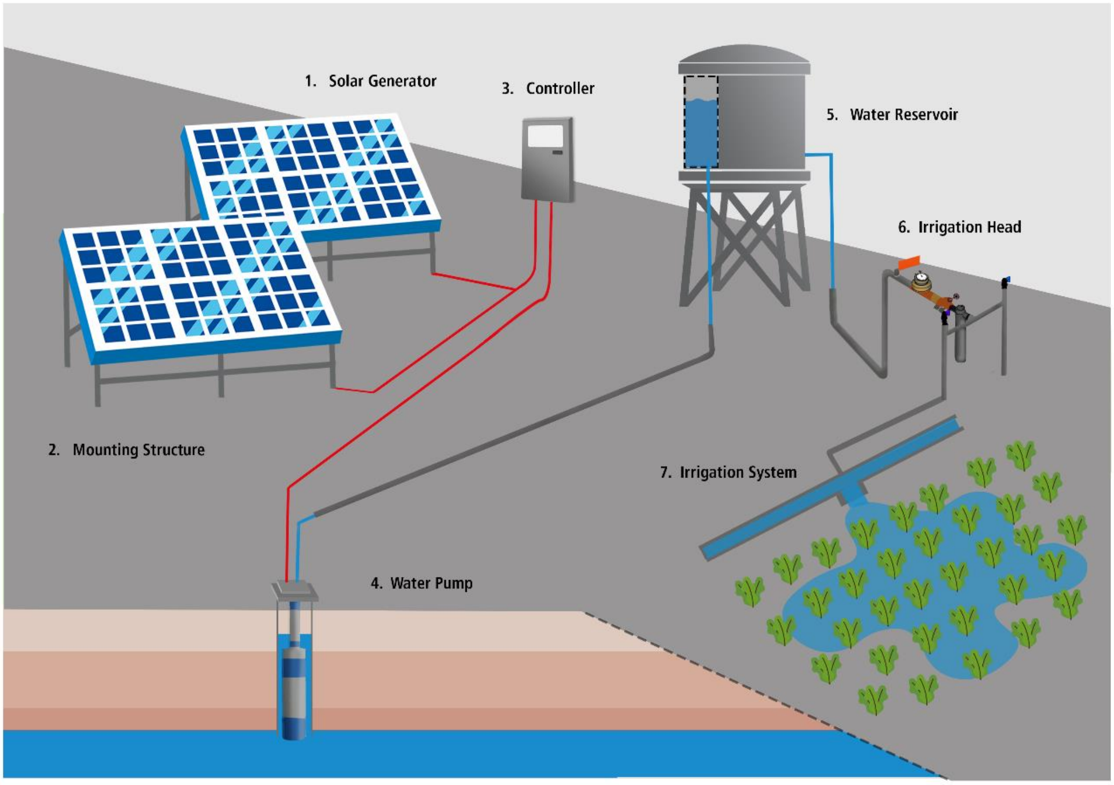
- Results of on-site data collection;
- results of comparative financial analysis.

PEOPLE / STAKEHOLDERS

- Producers;
- agricultural service providers;
- technology providers/system integrators.

IMPORTANT ISSUES

- PV water pumping works best with low pressure drip irrigation systems.
- The direct connection of the solar pump to the irrigation system leads to a dynamic and varying hydraulic load, which makes planning more complex.
- Varying hydraulic loads can be mitigated by (a) using automatic valves, (b) adapting irrigation field size (c) and solar tracking.
- Combining PV-based water pumping with traditional surface irrigation methods tends to be non-viable in financial terms.



SPIS configuration with the solar panels fixed, submersible pump, a reservoir and surface irrigation (Source: GFA)

5. ESTIMATE SYSTEM SIZE AND COSTS

Proper sizing of the components of an SPIS is critical, since an SPIS with insufficient capacity will not satisfy the farmers' needs and an over dimensioned system will induce unnecessary operation and capital costs. Negligence of the sustainable water yield of water sources may result in water shortage and a depletion of water resources, thus having negative impacts on the farm budget and the environment. It is therefore very important to be in close contact with the farmer during the planning phase and to inform him about the advantages and limits of SPIS.

The required size of the PV generator can be estimated using the following parameters:

- daily crop water requirement V_d [m^3/day]
- total pumping head H_T [m]
- mean daily global solar radiation G for the design month [kWh/m^2day].

A simple arithmetic formula that takes the individual system component efficiencies into account can be used to estimate the required solar-generating peak power P_{peak} [Wp]

$$P_{peak} = 8{,}0 \frac{H_T \times V_d}{G_d}$$

Example: It is calculated that crops in an irrigation system require 30 m³/d and field observations confirm that water needs to be pumped up 50 meters from a borehole to a reservoir. From the NASA website it becomes clear that the daily total global irradiation at the location of the farm is 5 kWh/m²day. According to this equation, a 2400 Wp PV generator is required.

The **DESIGN – Pump Sizing Tool** (Excel-based worksheet) can be used to determine the approximate solar generator size, which serves as guideline when engaging with SPIS technology suppliers.

The approximate cost of the planned PV system can be calculated by multiplying the country-specific average system cost [currency/kWp] and the calculated PV generator power (P_{peak}).

The final design of the PV pump and irrigation system should be left to experienced system integrators who use computer-based system sizing and simulation tools such as COMPASS, WinCAPS and PVSYST, HydroCALC, GESTAR (See Further Reading, Links and Tools at the end of the Module).

Following this procedure, the principal analytical steps to support decision-making should be completed. The technical, agronomical and financial aspects of the possible SPIS configuration (and alternatives) should now be available.

OUTCOME / PRODUCT

- Required PV generator size;
- pre-selection of motor/pump unit;
- motor/pump characteristics;
- layout of water distribution system;
- daily course of solar irradiation and water flow;
- system cost estimate;
- system cost parameters;
- suitability check list / evaluation.

DATA REQUIREMENTS

- Daily crop water requirement Vd [m^3/day];
- total pumping head Ht [m];
- mean daily global solar radiation G for the design month [kWh/m^2day];
- country-specific costs of PV pump [Currency/kWp].

PEOPLE / STAKEHOLDERS

- Agricultural service providers;
- experienced system integrators.

IMPORTANT ISSUES

- A commercial software solution that integrates design for the PV pump and the irrigation system is currently not available on the market.
- SPIS usually have to be oversized to meet these peak demands, resulting in a fairly low degree of system utilization.

6. ASSESS FINANCIAL VIABILITY

Solar Powered Irrigation Systems have become a financially viable alternative to electric and diesel water pumps for irrigation of agriculture crops. This is mainly due to the fact that:

- PV module costs have declined in recent years;
- PV systems are more reliable and cost effective;
- PV equipment is more accessible in many parts of the world, including expertise for set up and maintenance.

The tools **INVEST – Farm Analysis Tool** and **INVEST – Payback Tool** (under the **INVEST** Module) are both designed to assist in determining financial viability of the SPIS. While the former allows for assessing the profitability of the farm enterprise, the latter compares that payback potential of different irrigation technologies.

Note: cost estimates needed for these tools should be secured from technology and service suppliers.

The following key indicators and financial statements help to assess the financial viability:

Assessment criteria	Used as it shows:
cf - Cash flow analysis	...if a project generates enough cash in order to stay liquid; i.e. it can pay all cash.
PP - Payback Period	...how long it takes for the cost of an investment to be recovered; very basic calculation.
NPV – Net Present Value	...if a project generates sufficient income (and surplus) to finance the employed capital and interest on that capital.
IRR – Internal Rate of Return	…the estimated profit rate generated by the project / investment over its life-span.
Total life cycle cost	...differences in costs between project alternatives over the entire life cycle of these alternatives.

Assessing the financial viability of a SPIS is a complex procedure, which should be discussed with financial experts. This module only gives an overview of key data required. Note that all calculations:

- need to be based on prices which can be determined but also on estimates and assumptions;
- will have to consider the current situation and future scenarios;
- should compare options for alternative pumping systems (electric, diesel).

The financial analysis builds on three major inputs:

1. the **revenues** from
   a. direct: selling goods/services;
   b. indirect: avoided payments (e.g. consumption of food produced, or energy costs).
2. **Capital expenditure (CAPEX)**: long term, one-time, investments in non-consumable parts of the business, like
   a. costs for solar pumping system, reservoir, irrigation system;

b. (opportunity cost for) labor for construction and set up;

c. equipment for processing, storage;

d. reinvestment costs.

3. **Operating expenses (OPEX)**: ongoing operational and maintenance costs (fixed and variable)

a. seeds, fertilizer, pesticides and other inputs for production;

b. costs for processing such as cleaning, packaging, quality control;

c. maintenance, transport and advertising costs;

d. labor costs, incl. opportunity cost for producers own work;

e. depreciation and maybe credit costs to pay back a loan.

OUTCOME / PRODUCT

- Cash flow projections;
- Payback Period (pp);
- Net Present Value (NPV);
- Internal Rate of Return (IRR);
- total life cycle costs of the SPIS investment.

DATA REQUIREMENTS

Research, collect, analyze, cross-check:

- project/SPIS functional lifetime;
- capital expenditures / initial capital investment (i.e. prices for components to be financed) for solar and alternative options
- sales revenues (market prices);
- operating and maintenance costs;
- macroeconomic variables (inflation, interest rates, etc.);
- tax policies (corporate income taxes, VAT dynamics, etc.);

Compute, prepare:

- water unit cost;
- annual revenue and operating expenses (OPEX) and annual gross margin of production (current and future + other energy options);
- CAPEX (capital expenditure); i.e. total/annual sum for financing investment in SPIS (and alternative system).

PEOPLE / STAKEHOLDERS

- Agricultural service provider;
- financial service providers;
- public entities promoting or/and subsidizing SPIS initiatives;
- farmers, associations of producers / potential lenders;
- market analysts/consultants;

IMPORTANT ISSUES

When comparing PV systems to diesel or electric pumping systems the following statements apply:

- CAPEX: Initial capital costs needed for a Diesel-based system are lower than PV solutions; however replacement costs for Diesel systems occur more frequently.
- OPEX + cash flow:
  - diesel and electric systems have higher regular operating expenses (petrol cost + transport/energy price + grid connection) than PV;
  - maintenance costs for the PV system are low (see MAINTAIN module);
  - due to the high initial investment of PV systems they risk having higher regular financing costs (loan instalments and interest rate payments) when compared to diesel-based systems.

These factors influence the financial viability of the different options; hence, different scenarios should be elaborated before taking a decision.

7. PRE-SELECT POTENTIAL SUPPLIERS

Now that a technical design with costing is available, it is time to compare quotations and select a supplier.

Supplier pre-selection: The market for SPIS is still developing. Therefore the solar pumps are mostly not found in the portfolio of traditional agricultural service providers. Instead, PV pump manufacturers often select specialized PV distributors and system integrators to market their products. Several aspects need to be considered when shortlisting potential suppliers/system integrators:

- look for leading brands in the service provider's portfolio;
- check for long-term experience in the field of solar water pumping;
- check if a regional distribution network and a functioning spare part supply exists;
- check whether after-sale services are provided.

Holistic solutions, which include the photovoltaic pump **and** the water distribution system, can only rarely be found on the market, although it is useful to have integrated system configuration to increase overall system efficiency and reliability of SPIS. Suppliers offering turn-key solutions should be preferred, if they are able to adapt all system components to site conditions and to producer needs.

Quality and safety requirements: A precondition for safe operation and durability of the SPIS is that all system components fulfill minimum quality and safety standards. When requesting quotations and tender bids, it should be clearly stated that only high-quality products, which meet international standards (e.g. IEC, ISO) are to be offered. Certificates have to be provided by the system integrator to confirm system quality. A quotation should also include the service provider's after-sale warranty and service details and costs.

Also assess whether the service provider maintains any local representation in the area of the farm. This enables swift response to maintenance and repair requests, including spare part supply. Long service response times can result in crop damage during system breakdowns.

Design data and timing: A complete set of high-quality design data has to be included when requesting a quotation. The accuracy of the site-specific sizing data (Vd, Ht, G) needs to be assured. A submission deadline for quotations / offers should be set by leaving sufficient preparation time (e.g. 4 weeks).

OUTCOME / PRODUCT

- Request for quotation;
- if a tender process is preferred to a straight-forward dealer / buyer arrangement: set of tender documents, including a comprehensive description of system requirements;
- system cost and after-sale services included in quotations / offers.

DATA REQUIREMENTS

- Results of on-site data collection;
- information on product portfolio;
- experience of potential suppliers / retailers.

IMPORTANT ISSUES

- An integrated SPIS design that includes a pumping and irrigation system is usually not available – system components need to be harmonized to provide the best result.
- Large quality differences exist in all system components available on the market.

8. EVALUATE QUOTATIONS AND ASSESS QUALITY

On the submission date, the quotations / offers by different suppliers are to be opened and need to be evaluated with regard to technical and financial aspects. The following factors should be taken into consideration:

- For the comparison and evaluation of the different quotations / offers, it is advisable to prepare an Excel worksheet in which features and prices of the individual system components and services are entered.
- The definition of evaluation criteria and weighting of technical and financial aspects facilitate the assessment.

The following aspects help to assess the quality of system components offered:

Warranty period

It is important to assess the warranty period, which is often limited to 5 years. Individual system components, such as solar panels, usually come with a 10 year product guarantee and a linear performance warranty which guarantees at least 80% power output by the end of the 25th year.

Solar generator/quality of solar panels

Installed under harsh environmental conditions, solar panels are constantly exposed to high temperatures and UV irradiance, dust, humidity and rain. This puts a lot of stress on embedding materials and electrical connections. Therefore, only high-quality products should be offered that meet the standards of the International Electrotechnical Commission (IEC).

Cabling

For the electrical installation of a photovoltaic system, wiring and cabling should be used that meet the requirements for this application. For DC connections, single-wire cables with double insulation are a practicable and reliable solution. They should be UV and weather resistant and suitable for a wide temperature range.

PV array combiner box

The combiner box should be made to Protection Class II and demonstrate a clear separation of the positive and negative sides within the box. If mounted externally, it should be protected to at least IP54 Ingress Protection rating or higher).

Note: The protection class from EN60529 is indicated by short symbols that consist of the two code letters IP and a code numeral specifying the protection degree. The first digit represents limited protection against dust ingress (no harmful deposits). The second digit represents protection against splash water from any direction.

Mounting structures

In most Solar Powered Irrigation Systems, PV panels are installed in the open field and therefore require a sturdy and weather-resistant mounting structure. Quality mounting systems consist of galvanized steel or aluminum profiles. When mounting PV panels and profiles, specially developed brackets, screws, washers and nuts should be used (this also contributes to reducing the risk of theft, which should be part of the evaluation criteria). To avoid galvanic corrosion, it is important to select materials with similar corrosion potentials or to break the electrical connection by insulating the two metals from each other.

Pump controller / inverter

Modern controllers must incorporate high-efficiency power electronics and utilize Maximum Power Point Tracking (MPPT) technology to maximize power use from the PV generator. Additional features to increase system reliability should include over- and under-voltage protection as well as protection against reverse polarity, overload and over-temperature.

Motor pump

Solar water pumps must be constructed from non-corrosive stainless steel. Since DC motors tend to have higher overall efficiency levels than AC motors of a similar size, they are often the first choice of quality solar pump manufacturers. Some solar pumps are still equipped with comparably cheap brushed DC motors. The main disadvantage of brushed motors is that brushes are subject to wear and tear and need to be replaced at regular intervals (approximately every two years). Therefore, in terms of system reliability, the **use of brushed DC motors is not recommended** as regular maintenance cannot be assured in remote areas of developing countries.

Water distribution system

Water-saving irrigation technologies working at comparably low operating pressures are the preferred option in connection with PV pumps. To assess the suitability of the distribution systems, it is important to know the hydraulic characteristic. Details should be provided by the supplier / system integrator. The performance under low operating pressures (e.g. in the early morning and late evening) and the uniformity of water distribution across the field is of particular interest.

After a first technical evaluation

- Results should be discussed with other technical experts (agricultural advisors, research institutes etc.).
- Quoted prices of suppliers and related services offering similar products need to be compared.
- The providers with the best quotations / offers should be invited for individual presentation and negotiation.

OUTCOME / PRODUCT

- Structured comparison of qualified quotations / offers;
- ranking of quotations / offers;
- invitation of potential suppliers / system integrators for presentation and negotiation.

DATA REQUIREMENTS

- Quotations / offers including technical and financial parts;
- unit price listing;
- quality and safety certificates;
- technical data sheets of system components;
- hydraulic characteristic of irrigation system;
- information on warranty and after-sale services.

PEOPLE / STAKEHOLDERS

- Producers;
- agricultural service providers;
- suppliers / system integrators.

IMPORTANT ISSUES

- High-quality systems that are good value for money should always be given preference.
- Costs should never be reduced by compromising on system quality or by decreasing support services.
- A conclusion of maintenance contracts between the producer and the service provider is recommended but not very common.
- System integration in the form of turn-key solutions is preferable, yet still very hard to find.

9. CONTRACT SUPPLIER

In a final step, the best system provider needs to be selected based on cost-quality considerations. In a meeting of the producer, the agricultural service provider and the shortlisted candidates, the following topics should be addressed:

- detailed presentation of offer and the SPIS experience by provider;
- explanation of design procedure and tools to be used (e.g. computer-based sizing);
- product quality and safety certificates;
- warranty, after-sale services and spare part supply (e.g. maintenance contracts);
- final negotiation on price, if required;
- implementation schedule;
- contract details and payment conditions.

The contract should only be concluded once all open questions have been clarified.

In the **negotiations** with the supplier it is important to:

- define your goals;
- identify negotiation areas;
- look for win-win situations;
- make realistic proposals;
- clear up misunderstandings;
- make a final summary.

OUTCOME / PRODUCT

- Ultimate quality provider with the best cost-quality ratio;
- supply contract, including after-sale services.

DATA REQUIREMENTS

- Technical and financial quotations / offers;
- shortlisted candidates;
- structured comparison of qualified bids;
- clarification of open questions during negotiation.

PEOPLE / STAKEHOLDERS

- Producers;
- agricultural service providers;
- suppliers / system integrators.

IMPORTANT ISSUES

- Quotations / offers often deviate from technical specifications;
- Significant differences exist between bidders in terms of services and warranty.
- Implementation scheduling needs to be firm and agreed upon.

- Negotiate with the supplier.

FURTHER READING, LINKS AND TOOLS

Links

Alfredson, T. & Cungu´, A. (2008): Negotiation Theory and Practice. A Review of the Literature. FAO. Retrieved from http://www.fao.org/docs/up/easypol/550/4-5_negotiation_background_paper_179en.pdf

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GRUNDFOS. Retrieved from http://de.grundfos.com/

The Grundfos sizing software is called WebCAPS and can be found at http://net.grundfos.com/Appl/WebCAPS. It works only for the company's borepump products, the SQF range, although the site gives you the option of selecting surface pumps.

Irrigation Association (2017): Irrigation Glossary. Retrieved from http://www.irrigation.org/IAGlossary

LORENTZ: Submersible Solar Pumps. Retrieved from https://www.lorentz.de/products-and-technology/pump-types/submersible-solar-pumps

NASA (2016): Surface meteorology and Solar Energy. With the cooperation of Atmospheric Science Data Centre. Retrieved from http://eosweb.larc.nasa.gov/sse

SPIS tools

DESIGN – Site Data Collection Tool

DESIGN – Pump Sizing Tool

DESIGN – Pump Suitability Check Selection Tool

The following tools that are assigned to other Modules are also relevant:

SAFEGUARD WATER – Water Requirement Tool

IRRIGATE – Soil Tool

INVEST – Payback Tool

INVEST – Farm Analysis Tool

GLOSSARY

Aquifer	Underground geological formation(s), containing usable amounts of groundwater that can supply wells or springs for domestic, industrial, and irrigation uses.
Chemigation	The process of applying chemicals (fertilizers, insecticides, herbicides, etc...) to crops or soil through an irrigation system with the water.
Conveyance loss	Loss of water from a channel or pipe during transport, including losses due to seepage, leakage, evaporation, and other losses.
Crop coefficient	Ratio of the actual crop evapotranspiration to its potential (or reference) evapotranspiration. It is different for each crop and changes over time with the crop's growth stage.
Crop Water Requirement (CWR)	The amount of water needed by a plant. It depends on the climate, the crop as well as management and environmental conditions. It is the same as crop evapotranspiration.
Current (I)	Current is the electrical flow when voltage is present across a conductor, or the rate at which charge is flowing, expressed in amperes [A].
Deep percolation	Movement of water downward through the soil profile below the root zone. This water is lost to the plants and eventually ends up in the groundwater. [mm]
Drawdown	Lowering of level of water in a well due to pumping.
Drip irrigation	Water is applied to the soil surface at very low flow rates (drops or small streams) through emitters. Also known as trickle or micro-irrigation.
Emitter	Small micro-irrigation dispensing device designed to dissipate pressure and discharge a small uniform flow or trickle of water at a constant discharge which does not vary significantly because of minor differences in pressure head. Also called a "dripper" or "trickler".
Evaporation	Loss of water as vapor from the surface of the soil or wet leaves. [mm]
Evapotranspiration (ET)	Combined water lost from evaporation and transpiration. The crop ET (ETc) can be estimated by calculating the reference ET for a particular reference crop (ETo for clipped grass) from weather data and multiplying this by a crop coefficient. The ETc, or water lost, equals the CWR, or water needed by plant. [mm]
GIWR	The Gross Irrigation Water Requirement (GIWR) is used to express the quantity of water that is required in the irrigation system. [mm]
Fertigation	Application of fertilizers through the irrigation system. A form of chemigation.

Financial viability	The ability to generate sufficient income to meet operating expenditure, financing needs and, ideally, to allow profit generation. It is usually assessed using the Net Present Value (NPV) and Internal Rate of Return (IRR) approaches together with estimating the sensitivity of the cost and revenue elements (See Module **INVEST**).
Friction loss	The loss of pressure due to flow of water in pipe. It depends on the pipe size (inside diameter), flow rate, and length of pipe. It is determined by consulting a friction loss chart available in an engineering reference book or from a pipe supplier. [m]
Global solar radiation (G)	The energy carried by radiation on a surface over a certain period of time. The global solar radiation is locations specific as it is influenced by clouds, air humidity, climate, elevation and latitude, etc. The global solar radiation on a horizontal surface is measured by a network of meteorological stations all over the world and is expressed in kilowatt hours per square meter [kWh/m²].
Gravity flow	The use of gravity to produce pressure and water flow, for example when a storage tank is elevated above the point of use, so that water will flow with no further pumping required.
Head	Value of atmospheric pressure at a specific location and condition. [m]: Head, total (dynamic) Sum of static, pressure, friction and velocity head that a pump works against while pumping at a specific flow rate. [m]; Head loss Energy loss in fluid flow. [m]
Infiltration	The act of water entering the soil profile.
Irradiation	The integration or summation of insolation (equals solar irradiance) over a time period expressed in Joules per square meter (J/m2) or watt-hours per square meter [Wh/m^2].
Irrigation	Irrigation is the controlled application of water to respond to crop needs.
Irrigation efficiency	Proportion of the irrigation water that is beneficially used to the irrigation water that is applied. [%]
Irrigation head	Control unit to regulate water quantity, quality and pressure in an irrigation system using different types of valves, pressure regulators, filters and possibly a chemigation system.
Lateral	Pipe(s) that go from the control valves to the sprinklers or drip emitter tubes.
Latitude	Latitude specifies the north–south position of a point on the Earth's surface. It is an angle which ranges from 0° at the Equator to 90° (North or South) at the poles. Lines of constant latitude, or parallels, run east–west as circles parallel to the equator. Latitude is used together with longitude to specify the precise location of features on the surface of the Earth.

Leaching	Moving soluble materials down through the soil profile with the water.
Maximum Power Point Tracking (MPPT)	An important feature in many control boxes to draw the right amount of current in order to maintain a high voltage and achieve maximum system efficiency.
Net Irrigation Water Requirements (NIWR)	The sum of the individual crop water requirements (CWR) for each plant for a given period of time. The NIWR determines how much water should reach the crop to satisfy its demand for water in the soil. [mm]
Power (P)	Power is the rate at which energy is transferred by an electrical circuit expressed in watts. Power depends on the amount of current and voltage in the system. Power equals current multiplied by voltage (P=I x V). [W]
Photosynthesis	Photosynthesis is a process used by plants and other organisms to convert light energy into chemical energy that can later be released to fuel the organisms' activities (energy transformation).
Pressure	The measurement of force within a system. This is the force that moves water through pipes, sprinklers and emitters. Static pressure is measured when no water is flowing and dynamic pressure is measured when water is flowing. Pressure and flow are affected by each other. [bars, psi, kPa]
Priming	The process of hand-filling the suction pipe and intake of a surface pump. Priming is generally necessary when a pump must be located above the water source.
Pump	Converts mechanical energy into hydraulic energy (pressure and/or flow). Submersible pump: a motor/pump combination designed to be placed entirely below the water surface. Surface pump: pump that is not submersible and placed not higher than about 7 meters above the surface of the water.
Root Zone	The depth or volume of soil from which plants effectively extract water from. [m]
Salinity (Saline)	Salinity refers to the amount of salts dissolved in soil water.
Solar panel efficiency	Solar panel efficiency is the ratio of light shining on the panel, versus the amount of electricity produced. It is expressed as a percentage. Most systems are around 16% efficient, meaning 16% of the light energy is converted into electricity.
Suction lift	Vertical distance from the surface of the water to the pump. This distance is limited by physics to around 7 meters and should be minimized for best results. This applies only to surface pumps.
Surface irrigation	Irrigation method where the soil surface is used to transport the water via gravity flow from the source to the plants. Common surface irrigation methods are:

	Furrow irrigation – water is applied to row crops in small ditches or channels between the rows made by tillage implements; Basin irrigation – water is applied to a completely level area surrounded by dikes, and Flood irrigation – water is applied to the soil surface without flow controls, such as furrows or borders.
Transpiration	Water taken up by the plant's roots and transpired out of the leaves. [mm]
Voltage (U or V)	Voltage is the electric potential between two points, or the difference in charge between two points, expressed in Volts [V].

TOOLBOX ON SOLAR POWERED IRRIGATION SYSTEMS (SPIS)

POWERING AGRICULTURE:

AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

Module 6: Set Up

Food and Agriculture Organization of the United Nations
USAID FROM THE AMERICAN PEOPLE
SWEDEN
german cooperation DEUTSCHE ZUSAMMENARBEIT
DUKE ENERGY.
OPIC

The Toolbox on Solar Powered Irrigation Systems is made possible through the global initiative Powering Agriculture: An Energy Grand Challenge for Development (PAEGC). In 2012, the United States Agency for International Development (USAID), the Swedish International Development Cooperation Agency (Sida), the German Federal Ministry for Economic Cooperation and Development (BMZ), Duke Energy, and the Overseas Private Investment Cooperation (OPIC) combined resources to create the PAEGC initiative. The objective of PAEGC is to support new and sustainable approaches to accelerate the development and deployment of clean energy solutions for increasing agriculture productivity and/or value for farmers and agribusinesses in developing countries and emerging regions that lack access to reliable, affordable clean energy.

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Download
https://energypedia.info/wiki/Toolbox_on_SPIS

About
Powering Agriculture: An Energy Grand Challenge for Development: https://poweringag.org

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ABBREVIATIONS

Ah	Ampere hour
CWR	Crop Water Requirement
DC/AC	Direct Current / Alternating Current
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
Gd	Daily Global Irradiation
GIZ	Gesellschaft für Internationale Zusammenarbeit
GIWR	Gross Irrigation Water Requirement
GPFI	Global Partnership for Financial Inclusion
HERA	GIZ Program Poverty-oriented Basic Energy Services
H_T	Total Head
IEC	International Electrotechnical Commission
IFC	International Finance Corporation
IRR	Internal Rate of Return
IWR	Irrigation Water Requirement
MPPT	Maximum Power Point Tracking
NGO	Non-Governmental Organization
NIWR	Net Irrigation Water Requirement
NPV	Net Present Value
m^2	square meter
PV	photovoltaic
PVP	Photovoltaic Pump
SAT	Side Acceptance Test
SPIS	Solar Powered Irrigation System
STC	Standard Test Conditions
TC	Temperature Coefficient
UV	Ultraviolet
Vd	Daily crop water requirement
W	Watt
Wp	Watt peak

SET UP

1. Select a suitable installer

2. Plan site preparation and installation

3. Install

4. Acceptance test PVP

5. System test

6. Documentation

7. Hand over and user training

MODULE AIM & ORIENTATION

This module summarizes necessary steps for the installation of the Solar Powered Irrigation System. The design of the SPIS and the selection of the technology provider are completed (see **DESIGN** module). The installation of an irrigation system requires planning and decision-making by the producer, as the system should be set up according to set preferences and operation requirements. This module contains the relevant process steps to be taken to finally set up the system. In this module it is assumed that the technology provider is not necessarily the service provider for the installation of the SPIS.

PROCESS STEPS

With the signing of a contract or purchase order with a technology provider all decisions concerning the system components have been made. The quotation or offer from the provider should include a system layout plan in which the specific installation requirements are described. The practical installation is often not done by the producer. Instead, a qualified installer is required to assemble and mount the system components as required. A good quality installation lays the foundation for the reliable operation of the SPIS, taking into consideration the specific site conditions. The installation process will require active decision-making by the future user (i.e. the SPIS client or agricultural producer).

The set up or installation starts with choosing a suitable service provider. Then a detailed planning of the necessary works has to be made. In the installation planning, all requirements of the producer and the installer will be considered. Once the system components are installed, their proper functioning and the systems overall performance have to be tested.

The producer, as the future user of the system, has to follow this process closely to assure that the SPIS is installed according to the agreed planning and also to understand the system's functionality. Upon completion of the installation, the producer should insist on receiving appropriate documentation of the system and a personal introduction to its operation.

1. SELECT SUITABLE INSTALLER

The installation itself should be considered when selecting the technology provider. The quotations submitted by the equipment providers need to specify whether the system installation is included. If the installation services are included in the contract for the system components, the provider would nominate an installer.

When technology providers do not do the installation directly, they should recommend a qualified installer and a separate contract for the installation services has to be concluded. For this, a pre-selection of qualified installers should be established and quotations or offers for the services should be obtained, evaluated and decided upon (see **DESIGN** module).

Installers need to be chosen based on their general qualification and familiarity with the specific products (system components) the producer has opted for. Some technology providers only allow installation by certified installers as part of their warranty conditions and hence, should recommend certified service providers.

In order to make an offer, the installer visits the site and reviews the planned installation together with the producer.

When selecting suitable installers:

- check if the technology provider is able to recommend a qualified installer from his network;
- verify if the installer is certified for the installation of the purchased system components / brands;
- check the experience of the installer with installations in your area (reference list, other producers);
- obtain clarity on the installers' after installation services and whether they are available for maintenance, troubleshooting and repair.

OUTCOME / PRODUCT

- Shortlist of qualified installers;
- quotations / offers for installation services;
- selection of installer based on cost-quality considerations;
- installation services contract.

DATA REQUIREMENTS

- List of qualified and certified installers from technology provider;
- system layout and system component description (provided in contract with technology provider);
- unit price listing (quotation / offer of installer);
- information on post-installation services.

PEOPLE / STAKEHOLDERS

- Producer;
- supplier / system integrator (technology provider);
- installation service provider;
- agricultural service provider.

IMPORTANT ISSUES

- Installation may be included in the purchase contract for the system components, but may also have to be contracted separately.
- It may not be feasible that the same installer is able to install PV generator, pump, storage tank and irrigation system.
- The warranty of the system components depends on the installation by a qualified and certified service provider.
- It is recommended to work with an installer who can also provide maintenance, troubleshooting and repair services.

2. PLAN PREPARATION AND INSTALLATION

The selected installer is required to consider the site-specific conditions in his quotation or offer. In this process step, he should already have taken into account the views of the producer with regard to the location, spacing and protection of the planned system. After conclusion of the installation service contract, a detailed planning of the installation has to take place.

For this, a further site visit and joint review of all relevant aspects may be required in cooperation with the producer.

The aim of this installation planning is to:

- verify site access and material storage conditions;
- determine the exact planned location and the spacing of the system components (PV generator, water pump, control units, water storage tank, water distribution network, irrigation pipes);
- assess the site-specific conditions relevant for the installation (soil / underground conditions, surface profile, water source conditions, security hazards);
- identify preparatory works to be done (de-installation of old installations, well-cleaning / rehabilitation and pumping tests, earth works, site clearing, field preparation);
- plan preparatory works and installation;
- identify health and safety precautions.

A proper pre-installation planning helps avoid delays in the installation process because preparatory works and installation can be timed in succession. The producer may also have some particular additional considerations with regard to location, spacing and protection of the future system, which have to be taken into account by the installer prior to assembling and mounting the components. Specific site conditions, such as exposure to strong winds, flood water, stray animals or risks related to theft or vandalism (see **GET INFORMED**, mounting structure) are factors that influence the installation and the materials to be used (lock tie nuts, spray, seals, etc.).

The installation planning must also be harmonized with the cropping calendar and the agricultural work schedule of the specific farm household (see **DESIGN**, process step 2). Installation works should not disturb the production routine in an unnecessary way.

If more than one installer is required (for example one for the PV pumping system and one for the irrigation system components), the planning needs to take this into account. The work of the different installers must be coordinated.

The required land resources to establish the SPIS are often underestimated. The PV generators and the water storage tank (if part of the system) will occupy land that is otherwise available for cultivation. The system components must be spaced in a way that the solar panels are not shadowed by neighboring components, or that there is enough space to reach specific parts for maintenance, for example.

Note*:* System integrators estimate that about double the area covered by solar panels should be reserved for proper operation and maintenance. This is necessary to allow for space required by fencing, moving around the installation for maintenance, and reduce the impact of shading.

The planning in cooperation with the installer should also result in a clear understanding of both parties on the process of handing over the system and the provision of an orientation training of the user upon handover.

OUTCOME /PRODUCT

- Location of each system component;
- list of preparatory works / requirements;
- schedule for preparatory works and installation;
- schedule for hand over and user training.

DATA REQUIREMENTS

- System layout plan (provided in contract with technology provider);
- data on well / water source conditions;
- data on soil / underground conditions.

PEOPLE / STAKEHOLDERS

- Producer;
- installation service provider;
- agricultural service provider.

IMPORTANT ISSUES

- Implementation planning requires a site visit of the installer and a joint review with the famer.
- Site-specific conditions and hazards need to be considered.
- Land resources are required for the installation.
- Preparatory works requirements have to be identified prior to installation.
- Preparatory works need to be concluded prior to installation.
- Installation planning should include handover and user training timing;
- Multiple installers may need to be coordinated.

Installer visiting an SPIS site in Tamalé, Ghana (Source: Lennart Woltering)

3. INSTALL

The installation of the different components of a Solar Powered Irrigation System will be carried out by a contracted qualified installer. The installer will follow the system layout and the technical specifications provided from the system technology service provider (system integrator, supplier) and the considerations of the producer with regard to location and spacing.

The installer will temporarily require access to the site and a storage and assembly space to unload and assemble the system components. This should be considered by the producer in particular on small holdings where uncultivated areas are in short supply.

The actual time required for the assembly and the mounting and connection of the different components of an SPIS depends on system size and site conditions. The installer may have to carry out the installation process in several steps. A time consuming partial work is the establishment of a proper foundation for the mounting structure of the solar panels and the water storage tank (if part of the system).

These foundations are often established with reinforced concrete foundations that might require prior excavations works and curing time of cement after casting.

It is very important that the producer, and if possible also the agricultural advisor, take time to be present during the set up of the system, so that they:

- are available to provide information and to take decisions;
- can check on the completeness of all components while they are installed;
- obtain an additional understanding of the different system components, their particularities and the location of connections; switches etc. (ask questions!);
- can monitor the adherence of the installation to layout, plan and schedule (component compliance) or take note of any deviations from that due to unforeseen circumstances.

OUTCOME / PRODUCT

- Complete Solar Powered Irrigation System.

DATA REQUIREMENTS

- System layout plan (provided in contract with technology provider);
- list of components and bills of quantity;
- installation planning.

PEOPLE / STAKEHOLDERS

- Producer;
- installation service provider;
- agricultural service provider.

IMPORTANT ISSUES

- Temporary space has to be made available for site access, material storage and assembly.
- Installation may have to be made in separate steps if foundation works etc. have to be done.
- The producer should be present during the installation and accompany and monitor the process.

Installation of a drip irrigation system

(Source: Lennart Woltering)

4. ACCEPTANCE TEST PVP

Upon completion of the installation, the functionality and the performance of the system should be tested in the presence of the future user (producer). The testing includes a number of separate analyses. The first step is the acceptance test for the photovoltaic pumping system (PVP) which includes the PV generator, the mounting and tracking system (if part of the system), the controller and the water pump. These components are the "engine" of the SPIS, their performance is vital for the successful use of the irrigation system.

This acceptance test (also referred to as Site Acceptance Test, SAT) is the second level of material testing in view of quality management. Manufacturers of system components are obliged to run a Factory Acceptance Test (FAT) prior to releasing products to the supplier. Ideally, both levels of testing should be presented when evaluating an SPIS, but are not always readily available.

The acceptance test for the PVP includes the following main steps:

- visual check of all main components and their joints / connections;
- visual check of wiring and insulation;
- mechanical check of mounting and tracking system;
- functional check of PVP operation;
- functional check of the PVP electronic controller
- existence of system documentation (technical data sheets, electrical wiring plan, operational procedures);
- measurement of solar irradiance, electric power, pumping head and water flow so that the difference between calculated flow and actual measured flow can be established.

The measurements are usually carried out in the following sequence:

Measurement of solar irradiance --> Calculation of electrical power output--> Measurement and calculation of total pumping head --> Measurement of actual water flow ---> Comparison of measured and designed water flow

The different measurements should be carried out within a short time interval under clear sky conditions. At least two acceptance test runs are advisable, measuring at high irradiance (800 – 1,000 W/m2) and low irradiance levels (approx. 500 W/m^2). The equipment for the test will be provided by the installer.

Important: Check on the tightness of seals and joints, screws and bolts.

Check for signs of corrosion and cracked concrete foundations.

Check for leaking pipes and fittings.

Record any deficiency and malfunction and discuss their amendment with the installer by the installer!

The results of the acceptance test should be compared with the design performance of the PV pumping system. The **DESIGN – Pump Sizing Tool** could be used to record the most important data and to compare it with the design values. The acceptance test protocol should be signed by the installer and the producer.

The tool **SET UP – PVP Acceptance Test** provides more details on the steps, required equipment and calculations involved in the acceptance test.

OUTCOME / PRODUCT

- Completed acceptance test for the photovoltaic water pumping system;
- comparison of actual performance to design performance;
- acceptance test protocol:

- **SET UP – PVP Acceptance Test**.

DATA REQUIREMENTS

- Measured solar irradiance, total pumping head and water flow;
- calculated electrical power output, design, pumping head and design water flow;
- observations from visual check.

PEOPLE / STAKEHOLDERS

- Producer;
- installation service provider;
- agricultural service provider.

IMPORTANT ISSUES

- The on-site acceptance test is mandatory to verify if the PVP systems achieves design performance.
- Testing should be done by the installer in presence of the producer considering all relevant criteria.
- Testing requires clear sky conditions, a minimum of two measurements need to be done.
- A thorough check on the mechanical parts is recommended.

Measuring the irradiance during the Site Acceptance Test (Source: Reinhold Schmidt)

5. SYSTEM TEST

After the testing of the PV generator, the functionality of the other system components and their joint functionality must be checked and tested. This testing step should follow the same principles as the preceding PVP acceptance test. At least the following should be tested:

- water abstraction and discharge monitoring devices (water meters);
- distribution valves, distribution pipes and connectors;
- reservoir and filters (if part of the system);
- irrigation pipes and watering devices (emitters, mini sprinklers) by doing a Water Application Uniformity test (see Tool **MAINTAIN – Water Application Uniformity Field Guide**).

The system test for the aforementioned components includes:

- Visual checks (bolts and screws, etc.);
- mechanical check of mounting supports for tank and pipelines;
- functional check of water distribution and discharge, storage tank and filter operation;
- functional check of maintenance modus;
- existence of system documentation (technical data sheets, hydraulic plan, operational procedures);
- measurement of water pressure input and pressure distribution in all system sections and water discharge.

Measurements are usually carried out "from head to tail", starting with the release of the water into the supply line (to storage tank or direct injection) and ending with the flushing outlets of the irrigation pipes. Pressure measurements have to be taken at all system joints / distribution knots to assess the hydraulic distribution in all sections. These measurements have to take into account the pressure variation during the day caused by fluctuating irradiance levels. The results need to be documented as a hydraulic profile of the irrigation system.

Calibration: The water discharge to the field needs to be calibrated in order to manage crop water distribution efficiently. Pressure differences may exist between different sections of the irrigation system and the pressure inputs vary in a PV pumping system without elevated storage, causing water discharge from the irrigation devices to differ from section to section and within the course of a day. The water discharge from the irrigation devices has to be measured at different times of the day to calculate the actual water discharge, which can then be managed by varying the irrigation interval per area unit.

Note: This calibration measurement is a time consuming exercise!

Considerable differences between the designed and actual performance can be a sign for a poor design (collected data, poor choice of component, etc.) or poor workmanship. Quality of workmanship has a direct influence on system performance and sustainability, and poor workmanship can compromise even the best system components. The Tool **SET UP – Workmanship Quality Checklist** comprises various workmanship indicators clustered into different categories. The purpose is to assess whether quality of installation adheres to best practices, safety requirements and overall installation sustainability.

OUTCOME / PRODUCT

- Completed system test for the irrigation system;
- comparison of actual performance to design performance;

- system test protocol;
- hydraulic profile of the irrigation system;
- water discharge data for all irrigation sections.

DATA REQUIREMENTS

- Measured pressure and water discharge in all irrigation sections;
- calculated system pressure and water discharge;
- observations from visual check.

PEOPLE / STAKEHOLDERS

- Producer;
- installation service provider;
- agricultural service provider.

IMPORTANT ISSUES

- The on-site system test is mandatory to verify whether the irrigation systems achieve design performance.
- Testing should be done by the installer in presence of the producer.
- Testing must include pressure and water discharge measurements in all irrigation sections.
- Calibration of the irrigation discharge system is important to efficiently manage crop water distribution.

Measuring water flow

(Source: Reinhold Schmidt)

6. DOCUMENTATION

An SPIS comprises multiple components that have particular technical specifications and operation and maintenance requirements. Indeed, some mechanical and electrical technology may be vulnerable to defects if operated wrongly. Careful operation of the system not only prevents system failure and costly repairs, but also assures a longer lifespan. While technical data sheets and installation instructions exist most individual SPIS components, operational manuals covering an entire system are the exception. Since an SPIS is designed for an individual case, the operation and maintenance manuals should be customized.

Comprehensive documentation of the system and its operation and maintenance needs to be provided by the supplier and the installer during the acceptance, system test or final hand-over! This should be agreed on with the technology provider and/or the installer during contract negotiations.

The documentation should cover the following main aspects:

- system layout plan including all components of the water source, pumping system, water storage and irrigation system (and connection and wiring plans);
- technical data sheets for all system components including a recording of serial numbers of modules and other components, for example to claim ownership when submitting an insurance claim;
- operational guidelines for all system components;
- warranty information and maintenance instructions and schedules for all system components;
- security instructions, health risk warnings and emergency procedures;
- contact details of maintenance / repair services, help desks etc.

Ideally, the operational manual also includes information about the negative implication of excessive water abstraction for the environment. A systematically designed irrigation system operates on the principle of a sustainable water abstraction in line with the available water resources and the underlying water rights / permits.

OUTCOME / PRODUCT

- Documentation of all SPIS components including technical specifications, connection/ wiring plans, security instructions, emergency procedures and maintenance information;
- system operation manual;
- emergency contact details / help desk information.

DATA REQUIREMENTS

- Technical specifications of SPIS components.

PEOPLE / STAKEHOLDERS

- Producer;
- installation service provider;
- agricultural service provider.

IMPORTANT ISSUES

- The documentation of all system components must be complete and understandable.
- Security and emergency instructions should be clearly indicated and visibly attached to the respective system component.
- The installer should provide an operational manual with all relevant procedures and information.

7. HAND-OVER AND TRAINING

The final step of the installation process is to formally hand over the SPIS to the user (producer). The handing-over is usually combined with a thorough introduction to all technical aspects of the system and a practical training on its operation as per the designed performance. This step should be thoroughly planned because the user should have sufficient time to go through all system components and operation and maintenance aspects together with the technicians of the installer.

Prior to this step, all other requirements should have been completed, in particular the PVP acceptance and the system tests and the system's documentation. Ideally, the user could accompany and follow the entire installation process including the testing steps. This way they will already have obtained knowledge about their system and will have had the opportunity to be familiarized with the main technical and operational features.

During the testing stages of the installation process, defects or quality problems are identified and recorded and an agreement between the installer and the user is concluded on how and when these defects are corrected. This is laid down in the test protocols. A handing over of the system should not take place before all repairs and amendments are implemented.

The handing-over and the related instruction and training usually take place during a final test run of the system. It should not be done as a theoretical class room exercise. Supporting material for the training should consist of the operational guidelines and the manual that is provided as part of the system's documentation.

Important features of the orientation and training are:

- introduction to the specifics of all system components;
- operation of the system under different conditions, in particular crop water distribution management based on pressure and supply duration management;
- security precautions and protection of system components;
- health and environmental hazards;
- emergency procedures;
- maintenance works and schedules.

The handing over should be concluded by signing a hand over protocol that states the condition of the system and all activities carried out to instruct and train the producer.

OUTCOME / PRODUCT

- Hand-over protocol.

DATA REQUIREMENTS

- PVP acceptance and system test data;
- system documentation and operation manual.

PEOPLE / STAKEHOLDERS

- Producer;
- installation service provider;
- agricultural service provider.

IMPORTANT ISSUES

- Hand over should only take place if the system is perfectly running, with no remaining deficiencies.
- Hand over should be accompanied by a practical introduction and training of the user including information on security precautions, system protection and hazards.
- A hand-over protocol should be prepared and signed

SPIS with an elevated reservoir used for irrigation in- and outside of the greenhouse (Source: Lennart Woltering)

FURTHER READING, LINKS AND TOOLS

Links

Centre for Land and Water: Knowledge Resources for Primary Industry. Retrieved from http://www.claw.net.nz/resources/irrigation/

Hahn, A., Sass, J. & Fröhlich, C. (2015): Manual and tools for promoting SPIS. Multicountry - Stocktaking and Analysis Report. GFA Consulting Group. Retrieved from [currently under revision]

Schultz, R. & Suryani, A. (2015): EnDev2 Indonesia: Inspection Guide for Photovoltaic Village Power (PVVP) Systems. Edited by GIZ. Retrieved from https://energypedia.info/images/3/39/Inspection_Guide_for_PVVP_150524_%28GIZ_2015%29.pdf

SPIS tools

SET UP – PV Acceptance Test: Guideline to compare the installed with the actual capacity of the pump

SET UP – Workmanship Quality Checklist: Checklist for inspecting and verifying the workmanship quality

The following tools that are assigned to other Modules are also relevant:

PROMOTE – SPIS Rapid Assessment: on the analysis of the market for service provision

DESIGN – Pump Sizing Tool: to verify SPIS acceptance testing

MAINTAIN – Water Application Uniformity Guide: that should be implemented directly after setting up the system

TECHNICAL GLOSSARY

Aquifer	Underground geological formation(s), containing usable amounts of groundwater that can supply wells or springs for domestic, industrial, and irrigation uses.
Chemigation	The process of applying chemicals (fertilizers, insecticides, herbicides, etc...) to crops or soil through an irrigation system with the water.
Conveyance loss	Loss of water from a channel or pipe during transport, including losses due to seepage, leakage, evaporation, and other losses.
Crop coefficient	Ratio of the actual crop evapotranspiration to its potential (or reference) evapotranspiration. It is different for each crop and changes over time with the crop's growth stage.
Crop Water Requirement (CWR)	The amount of water needed by a plant. It depends on the climate, the crop as well as management and environmental conditions. It is the same as crop evapotranspiration.
Current (I)	Current is the electrical flow when voltage is present across a conductor, or the rate at which charge is flowing, expressed in amperes [A].
Deep percolation	Movement of water downward through the soil profile below the root zone. This water is lost to the plants and eventually ends up in the groundwater. [mm]
Drawdown	Lowering of level of water in a well due to pumping.
Drip irrigation	Water is applied to the soil surface at very low flow rates (drops or small streams) through emitters. Also known as trickle or micro-irrigation.
Emitter	Small micro-irrigation dispensing device designed to dissipate pressure and discharge a small uniform flow or trickle of water at a constant discharge which does not vary significantly because of minor differences in pressure head. Also called a "dripper" or "trickler".
Evaporation	Loss of water as vapor from the surface of the soil or wet leaves. [mm]
Evapotranspiration (ET)	Combined water lost from evaporation and transpiration. The crop ET (ETc) can be estimated by calculating the reference ET for a particular reference crop (ETo for clipped grass) from weather data and multiplying this by a crop coefficient. The ETc, or water lost, equals the CWR, or water needed by plant. [mm]
GIWR	The Gross Irrigation Water Requirement (GIWR) is used to express the quantity of water that is required in the irrigation system. [mm]
Fertigation	Application of fertilizers through the irrigation system. A form of chemigation.

Financial viability	The ability to generate sufficient income to meet operating expenditure, financing needs and, ideally, to allow profit generation. It is usually assessed using the Net Present Value (NPV) and Internal Rate of Return (IRR) approaches together with estimating the sensitivity of the cost and revenue elements (See Module **INVEST**).
Friction loss	The loss of pressure due to flow of water in pipe. It depends on the pipe size (inside diameter), flow rate, and length of pipe. It is determined by consulting a friction loss chart available in an engineering reference book or from a pipe supplier. [m]
Global solar radiation (G)	The energy carried by radiation on a surface over a certain period of time. The global solar radiation is locations specific as it is influenced by clouds, air humidity, climate, elevation and latitude, etc. The global solar radiation on a horizontal surface is measured by a network of meteorological stations all over the world and is expressed in kilowatt hours per square meter [kWh/m^2].
Gravity flow	The use of gravity to produce pressure and water flow, for example when a storage tank is elevated above the point of use, so that water will flow with no further pumping required.
Head	Value of atmospheric pressure at a specific location and condition. [m]: Head, total (dynamic) Sum of static, pressure, friction and velocity head that a pump works against while pumping at a specific flow rate. [m]; Head loss Energy loss in fluid flow. [m]
Infiltration	The act of water entering the soil profile.
Insolation	The rate at which solar energy reaches a unit area at the earth measures in Watts per square meter [W/m^2]. Also called solar irradiance.
Irradiation	The integration or summation of insolation (equals solar irradiance) over a time period expressed in Joules per square meter (J/m2) or watt-hours per square meter [Wh/m^2].
Irrigation	Irrigation is the controlled application of water to respond to crop needs.
Irrigation efficiency	Proportion of the irrigation water that is beneficially used to the irrigation water that is applied. [%]
Irrigation head	Control unit to regulate water quantity, quality and pressure in an irrigation system using different types of valves, pressure regulators, filters and possibly a chemigation system.
Lateral	Pipe(s) that go from the control valves to the sprinklers or drip emitter tubes.
Latitude	Latitude specifies the north–south position of a point on the Earth's surface. It is an angle which ranges from 0° at the Equator to 90° (North or South) at the poles. Lines of constant lati-

	tude, or parallels, run east–west as circles parallel to the equator. Latitude is used together with longitude to specify the precise location of features on the surface of the Earth.
Leaching	Moving soluble materials down through the soil profile with the water.
Maximum Power Point Tracking (MPPT)	An important feature in many control boxes to draw the right amount of current in order to maintain a high voltage and achieve maximum system efficiency.
Net Irrigation Water Requirements (NIWR)	The sum of the individual crop water requirements (CWR) for each plant for a given period of time. The NIWR determines how much water should reach the crop to satisfy its demand for water in the soil. [mm]
Power (P)	Power is the rate at which energy is transferred by an electrical circuit expressed in watts. Power depends on the amount of current and voltage in the system. Power equals current multiplied by voltage (P=I x V). [W]
Photosynthesis	Photosynthesis is a process used by plants and other organisms to convert light energy into chemical energy that can later be released to fuel the organisms' activities (energy transformation).
Pressure	The measurement of force within a system. This is the force that moves water through pipes, sprinklers and emitters. Static pressure is measured when no water is flowing and dynamic pressure is measured when water is flowing. Pressure and flow are affected by each other. [bars, psi, kPa]
Priming	The process of hand-filling the suction pipe and intake of a surface pump. Priming is generally necessary when a pump must be located above the water source.
Pump	Converts mechanical energy into hydraulic energy (pressure and/or flow). Submersible pump: a motor/pump combination designed to be placed entirely below the water surface. Surface pump: pump that is not submersible and placed not higher than about 7 meters above the surface of the water.
Root Zone	The depth or volume of soil from which plants effectively extract water from. [m]
Salinity (Saline)	Salinity refers to the amount of salts dissolved in soil water.
Solar panel efficiency	Solar panel efficiency is the ratio of light shining on the panel, versus the amount of electricity produced. It is expressed as a percentage. Most systems are around 16% efficient, meaning 16% of the light energy is converted into electricity.
Suction lift	Vertical distance from the surface of the water to the pump. This distance is limited by physics to around 7 meters and should be minimized for best results. This applies only to surface pumps.

Surface irrigation	Irrigation method where the soil surface is used to transport the water via gravity flow from the source to the plants. Common surface irrigation methods are: Furrow irrigation – water is applied to row crops in small ditches or channels between the rows made by tillage implements; Basin irrigation – water is applied to a completely level area surrounded by dikes, and Flood irrigation – water is applied to the soil surface without flow controls, such as furrows or borders.
Transpiration	Water taken up by the plant's roots and transpired out of the leaves. [mm]
Voltage (U or V)	Voltage is the electric potential between two points, or the difference in charge between two points, expressed in Volts [V].

TOOLBOX ON SOLAR POWERED IRRIGATION SYSTEMS (SPIS)

POWERING AGRICULTURE:
AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

Module 8: Irrigate

USAID FROM THE AMERICAN PEOPLE

SWEDEN

german cooperation DEUTSCHE ZUSAMMENARBEIT

DUKE ENERGY

OPIC

The Toolbox on Solar Powered Irrigation Systems is made possible through the global initiative Powering Agriculture: An Energy Grand Challenge for Development (PAEGC). In 2012, the United States Agency for International Development (USAID), the Swedish International Development Cooperation Agency (SIDA), the German Federal Ministry for Economic Cooperation and Development (BMZ), Duke Energy, and the Overseas Private Investment Cooperation (OPIC) combined resources to create the PAEGC initiative. The objective of PAEGC is to support new and sustainable approaches to accelerate the development and deployment of clean energy solutions for increasing agriculture productivity and/or value for farmers and agribusinesses in developing countries and emerging regions that lack access to reliable, affordable and clean energy.

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Responsible
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Download
https://energypedia.info/wiki/Toolbox_on_SPIS

About
Powering Agriculture: An Energy Grand Challenge for Development: https://poweringag.org

Version
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ABBREVIATIONS

Ah	Ampere hour
CWR	Crop Water Requirement
DC/AC	Direct Current / Alternating Current
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
Gd	Daily Global Irradiation
GIZ	Gesellschaft für Internationale Zusammenarbeit
GIWR	Gross Irrigation Water Requirement
GPFI	Global Partnership for Financial Inclusion
HERA	GIZ Program Poverty-oriented Basic Energy Services
H_T	Total Head
IEC	International Electrotechnical Commission
IFC	International Finance Corporation
IRR	Internal Rate of Return
IWR	Irrigation Water Requirement
MPPT	Maximum Power Point Tracking
NGO	Non-Governmental Organization
NIWR	Net Irrigation Water Requirement
NPV	Net Present Value
m^2	square meter
PV	photovoltaic
PVP	Photovoltaic Pump
SAT	Side Acceptance Test
SPIS	Solar Powered Irrigation System
STC	Standard Test Conditions
TC	Temperature Coefficient
UV	Ultraviolet
Vd	Daily crop water requirement
W	Watt
Wp	Watt peak

DEFINITIONS

Aquifer	Underground geological formation(s), containing usable amounts of groundwater that can supply wells or springs for domestic, industrial, and irrigation uses.
Chemigation	The process of applying chemicals (fertilizers, insecticides, herbicides, etc...) to crops or soil through an irrigation system with the water.
Conveyance loss	Loss of water from a channel or pipe during transport, including losses due to seepage, leakage, evaporation, and other losses.
Crop coefficient	Ratio of the actual crop evapotranspiration to its potential (or reference) evapotranspiration. It is different for each crop and changes over time with the crop's growth stage.
Crop Water Requirement (CWR)	The amount of water needed by a plant. It depends on the climate, the crop as well as management and environmental conditions. It is the same as crop evapotranspiration.
Current (I)	Current is the electrical flow when voltage is present across a conductor, or the rate at which charge is flowing, expressed in amperes [A].
Drainage	The natural or artificial removal of surplus ground and surface water and dissolved salt from the land in order to enhance agriculture production. In the case of natural drainage, the excess waters flow from the fields to lakes, swamps, streams and rivers. In an artificial system surplus ground or surface water is removed by means of sub surface or surface conduits.
Deep percolation	Movement of water downward through the soil profile below the root zone. This water is lost to the plants and eventually ends up in the groundwater. [mm, where 1 mm = 10 m3/ha)]
Drawdown	Lowering of level of water in a well due to pumping.
Drip irrigation	Water is applied to the soil surface at very low flow rates (drops or small streams) through emitters. Also known as trickle or micro-irrigation.
Emitter	Small micro-irrigation dispensing device designed to dissipate pressure and discharge a small uniform flow or trickle of water at a constant rate which does not vary significantly because of minor differences in pressure head. Also called a "dripper" or "trickler".
Evaporation (E)	Where liquid water is converted into water vapour and removed from the evaporating surface. This loss of water as vapor occurs from the surface of the soil or wet vegetation, [mm, where 1 mm = 10 m3/ha)]
Evapotranspiration (ET)	Combined water lost from evaporation and transpiration; evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. The crop ET (ETc) can be estimated by calculating the reference ET for a reference crop (ETo for clipped grass) from weather data and multiplying this by a crop coefficient.

	The ETc, or water lost, equals the CWR, or water needed by plant. [mm, where 1 mm = 10 m3/ha)]
GIWR	The Gross Irrigation Water Requirement (GIWR) is used to express the quantity of water that is required in the irrigation system [mm, where 1 mm = 10 m3/ha)].
Infiltration	The act of water entering the soil profile.
Fertigation	Application of fertilizers through the irrigation system. A form of chemigation.
Financial viability	The ability to generate sufficient income to meet operating expenditure, financing needs and, ideally, to allow profit generation. It is usually assessed using the Net Present Value (NPV) and Internal Rate of Return (IRR) approaches together with estimating the sensitivity of the cost and revenue elements (See Module INVEST).
Friction loss	The loss of pressure due to flow of water in a pipe. It depends on the pipe size (inside diameter), pipe roughness, fittings, flow rate, and length of pipe. It is determined by consulting a friction loss chart available in an engineering reference book or from a pipe supplier. [m]
Full Control Irrigation	A term referring to surface irrigation, sprinkler irrigation, and / or localized irrigation
Global solar radiation (G)	The energy carried by radiation on a surface over a certain time period. The global solar radiation is location specific as it is influenced by clouds, air humidity, climate, elevation and latitude, etc. The global solar radiation on a horizontal surface is measured by a network of meteorological stations all over the world and is expressed in kilowatt hours per square meter [kWh/m^2].
Gravity flow	The use of gravity to produce pressure and water flow, for example when a storage tank is elevated above the point of use, so that water will flow with no further pumping required.
Head	Value of atmospheric pressure at a specific location and condition. [m]: Head, total (dynamic) = Sum of static, pressure, friction, and velocity heads that a pump works against while pumping at a specific flow rate. [m]; Head loss = Energy loss in fluid flow. [m]
Insolation	The rate at which solar energy reaches a unit area at the earth measures in Watts per square meter [W/m^2]. Also called solar irradiance.
Irradiation	The integration or summation of insolation (=solar irradiance) over a time period expressed in Joules per square meter (J/m2) or watt-hours per square meter [Wh/m^2].
Irrigation	Irrigation is the controlled application of water to respond to crop needs.

Irrigation efficiency	Proportion of the irrigation water that is beneficially used to the irrigation water that is applied. [%]
Irrigation head	Header tank of water at an elevation above ground level to regulate water quantity, quality and pressure in an irrigation system. Usually accompanied and regulated by different types of valves, pressure regulators, filters and possibly a chemigation system.
Land Tenure	The relationship, whether legally or customarily defined between people, as individuals or groups, with respect to land (VGGT 2012).
Lateral	Pipe(s) that go from the control valves to the sprinklers or drip emitter tubes.
Latitude	Latitude specifies the north–south position of a point on the Earth's surface. It is an angle which ranges from 0° at the Equator to 90° (North or South) at the poles. Lines of constant latitude, or parallels, run east–west as circles parallel to the equator. Latitude is used together with longitude to specify the precise location of features on the surface of the Earth.
Leaching	Moving soluble materials down through the soil profile with the water.
Maximum Power Point Tracking (MPPT)	This allows solar panels to rotate automatically about a pivot to remain at the optimum angle to the solar irradiance. An important feature in many control boxes to draw the right amount of current in order to maintain a high voltage and achieve maximum system efficiency.
Net Irrigation Water Requirements (NIWR)	The sum of the individual crop water requirements (CWR) for each plant for a given period of time. The NIWR determines how much water should reach the crop to satisfy its demand for water in the soil. [mm, where 1 mm = 10 m3/ha)]
Power (P)	Power is the rate at which energy is transferred by an electrical circuit expressed in watts. Power depends on the amount of current and voltage in the system [W]
Photosynthesis	Photosynthesis is a process used by plants and other organisms to convert light energy into chemical energy.
Pressure	The measurement of force within a system. This is the force that moves water through pipes, sprinklers and emitters. Static pressure is measured when no water is flowing and dynamic pressure is measured when water is flowing. Pressure and flow are affected by each other. [bars, psi, kPa]
Priming	The process of hand-filling the suction pipe and intake of a surface pump. Priming is generally necessary when a pump must be located above the water source.
Pump	Converts mechanical energy into hydraulic energy (pressure and/or flow). Submersible Pump - A motor/pump combination designed to be placed entirely below the water surface. Surface Pump - A pump that is not submersible and placed not higher than about 7 meters above the surface of the water.

Root Zone	The depth or volume of soil from which plants effectively extract water from. [m]
Salinity (Saline)	Salinity refers to the amount of salts dissolved in soil water.
Salinization	Occurs when surface water or groundwater containing mineral salts is used for irrigating crops, carrying salts out into the root zone. In the process of evapotranspiration, the salt is left behind in the soil, increasing its salt content.
Solar panel efficiency	Solar panel efficiency is the ratio of light shining on the panel, versus the amount of electricity produced. It is expressed as a percentage. Most systems are around 16% efficient, meaning 16% of the light energy is converted into electricity.
Suction lift	Vertical distance from the surface of the water to the pump. This distance is limited by physics to around 7 meters and should be minimized for best results. This applies only to surface pumps.
Surface irrigation	Irrigation method where the soil surface is used to transport the water via gravity flow from the source to the plants. Common surface irrigation methods are: Furrow irrigation- water is applied to row crops in small ditches or channels between the rows made by tillage implements; Basin irrigation- water is applied to a completely level area surrounded by dikes, and Flood irrigation- water is applied to the soil surface without flow controls, such as furrows or borders.
Transpiration (T)	Liquid water taken up by the plant's roots, contained in plant tissues, and vaporized or transpired into the atmosphere through small openings in the plant leaf, called stomata. [mm, where 1 mm = 10 m3/ha)]]
Voltage (U or V)	Voltage is the electric potential between two points, or the difference in charge between two points, expressed in Volts [V].
Waterlogging	Results primarily from inadequate drainage and over-irrigation and, to a lesser extent, from seepage from canals and ditches. Waterlogging concentrates salts, drawn up from lower in the soil profile, in the plants' rooting zone.
Water Tenure	Refers to the formal and informal arrangements that determine how people, communities and organizations gain access to, and use, water resources (FAO 2016b).

IRRIGATE

1. Introduction

⇩

2. Understand Water Resources

⇩

3. Assess Environmental and Socio-Economic Impacts

⇩

4. Calculate Water Requirements

⇩

5. Select Field Irrigation Method

⇩

6. Plan Intake Structures, Conveyance And Distribution

⇩

7. Irrigation Efficiency Tips

MODULE AIM & ORIENTATION

Irrigation is an important means to improving agricultural productivity, but in many developing countries, the potential for irrigated agriculture has not been realized. While irrigation bears obvious benefits, it is not without substantial impact on the environment (and by extension societies and economies dependent on this environment). Numerous technologies and approaches have therefore been developed to minimize the negative environmental and socio-economic effects.

This **IRRIGATE** Module provides an introduction to the complexities surrounding irrigation. It is part of the Toolbox on Solar Powered Irrigation Systems (SPIS) (GIZ FAO, 2017), which comprises further modules and complimentary tools relevant to informed decision making around SPIS.

Furthermore this module is supplemented by two Excel-based tools:

- **IRRIGATE – Soil Tool** for determining an appropriate irrigation schedule for selected crops and calculate water storage capacities

1 INTRODUCTION

IRRIGATION IS ESSENTIAL FOR FOOD SECURITY AND RURAL DEVELOPMENT

Globally, irrigated agriculture accounts for about 70 percent of water withdrawals, making it the largest water user. Irrigated agriculture provides approximately 40 percent of the world's food, including most of its horticultural output, from an estimated 20 percent of agricultural land, or about 300 million ha worldwide (FAO 2011). Most future growth in crop production in developing countries is likely to come from intensification with irrigation increasingly playing a strategic role (AQUASTAT).

In many countries around the world, irrigation has had direct benefits on productivity and food security, typically producing food at higher cropping intensities and at least twice the yields of nearby rain-fed crops (Faurès et al. 2007). It can reduce dependency on rainfed agriculture in drought-prone areas and increase cropping intensities in humid and tropical zones by 'extending' the wet season and introducing effective means of water control. As such, irrigation is often seen as the engine that drives rural development, producing food, providing job opportunities and generating income.

Nevertheless, irrigation has also been associated with negative environmental impacts, including a reduction in water flows, changes in downstream access to water, increased soil salinity or reduction of wetlands that provide important ecological functions for biodiversity, nutrient retention, and flood control. Related changes in land use and unsustainable resources management can lead to quality deterioration and depletion of water resources and associated ecosystems, upon which livelihoods depend.

Moreover, the water quality used for irrigation influences the yield and quantity of crops as well as soil permeability and productivity, and overall ecosystem health. Despite this, water scarcity and pollution levels are so significant in many parts of the world that millions of farmers are driven to irrigate with marginal quality water, such as urban wastewater or saline agricultural drainage water.

The impacts of climate change are already affecting irrigated agriculture as water demand is increasing, crop productivity is reducing, and water availability is becoming more limited in exactly those parts of the world where irrigation is most needed or has a clear comparative advantage.

WHAT MAKES A GOOD SOLAR-POWERED IRRIGATION SYSTEM?

Solar-powered irrigation is typically introduced as a new system, or when an already existing system is being modernised. In the latter case, solar energy replaces conventional forms of energy with photovoltaics (PV). Pumps powered by solar energy may be used to withdraw surface or groundwater resources.

When designing a Solar-Powered Irrigation System (SPIS), it is crucial that the full cycle of the water supply system is taken into account (Figure 1). This includes the water resources, water intake, conveyance and distribution, field irrigation methods, crop water supply, and drainage. Energy in the water supply system stems from the intake, conveyance, and distribution sections via pumping, lifting, and transporting.

Examining these elements, this module provides guidance on some of the key issues around planning and managing a solar powered irrigation system for agriculture.

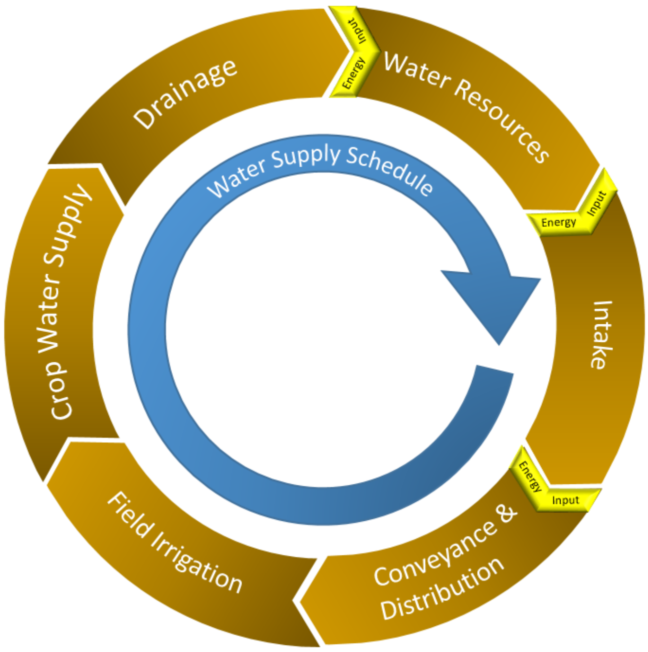


Figure 1: Schematic analysis of agricultural water supply system, adapted from "Irrigation Techniques for Small-scale Farmers" (FAO 2014)

DATA REQUIREMENTS

- Site data, including climate forecasts, farm location, topography, crop rotations desired, area of land to be irrigated, soil type
- Water data, including water quality, quantity, flow, depth and variability
- Information on the design/ layout of the irrigation system

PEOPLE / STAKEHOLDER

- Irrigation system designers & managers, water user groups or farmer organization
- Project managers
- Policy-makers

IMPORTANT ISSUES

- Understand the linkage of the water and energy supply cycle
- Assess climate risks and understand the limitations that exist for the water supply system

OUTCOME / PRODUCT

- General introduction of the role of irrigation in agriculture and potential environmental impacts
- Overview of agricultural water supply system and energy inputs

2 UNDERSTAND WATER RESOURCES

The type of water source, the elevation or depth, the water quantity, resource responsibility, and quality all have a significant influence on establishing boundaries within which crop choices and decisions on the irrigation method can be made. The understanding of these aspects should be a first step in any SPIS planning or implementation project

Sources of water can be surface water, groundwater and non-conventional water. Typically, water for irrigation is extracted from rivers, lakes and aquifers. About 61 percent of the irrigated area worldwide uses surface water, and 38 percent groundwater. In Asia, Northern Africa and the Middle East, groundwater use has grown rapidly in recent years following the introduction of tubewell technology, accompanied by improved energy access and low energy prices (data from 2013, AQUASTAT 2016). Non-conventional sources, such as treated wastewater and desalinated water, provide a minor source of irrigation water globally (about 1 percent). The use of this water for irrigation is focussed in the Mediterranean, Middle East, and Andes regions.

The **elevation** difference between the water source and the field determines whether water can be delivered under pressure. This is particularly relevant for surface water for which it is important to understand whether gravity alone can support pressurised irrigation systems or whether it needs to be supported through pumps. For groundwater, the depth of the water table is decisive for the size of pump and the associated costs. Nowadays, pumps powered by solar energy can lift up water up to 200m (and increasing). However, these pumps are more expensive and less commonly available.

The available discharge from the source (the **quantity of water**) and variability is also important. Understanding what water resources are available, under what conditions, helps in deciding which irrigation method is most appropriate in the given environmental (climate, soils, and landscape) and agricultural context. When and how much does it rain during the year? What are the available surface and groundwater resources? What is the variability of these water resources throughout the year in terms of flow, quantity and quality? How variable is the water availability in the context of climate change? What are the requirements of other users? What are the environmental flow requirements?

The **SAFEGUARD WATER – Water Resource Management Checklist** tool helps to get a rough idea of the availability of water resources. In existing water scarce regions and regions predicted to experience water scarcity over the coming 20 years (See WRI predictions), it is advisable to run a more in-depth water balance analysis and feasibility study with tangible data before installing a SPIS.

A study should be conducted on the aquifer to establish sustainable abstraction rates. The **responsibility** of carrying out this analysis depends on the allocation of resource ownership within the watershed. In most cases it is prudent to establish a basin committee that engages the relevant stakeholders and takes responsibility for the aquifer analysis, as well as permitting, monitoring, and enforcement of abstraction. If resources are managed in a more fractured manner, then the permitting authorities should consider the impacts of their actions on the wider basin, other stakeholders, and the ecosystem. In either arrangement the resilience to future climate scenarios is key to the longevity of agricultural production.

The **quality of water** also needs to be taken into account as it affects the choice of irrigation method and the kinds of crops that can be grown. Both the chemical composition of water and the sediment load can influence this choice. The presence of certain elements, like sodium (Na), chlorine (Cl) and Boron (B), beyond a certain threshold, can cause leaf burn and defoliation under sprinkler irrigation. Similarly, the total concentration of salts in water affects leaching requirements, which makes saline water not very suitable for furrow irrigation. The sediment load of water determines the filtration requirement for drip irrigation and the selection and maintenance program of drippers, hence, its applicability under certain conditions. Similarly, sediments increase the wear of pumps and other components of sprinkler irrigation.

OUTCOME / PRODUCT

- Identification of key factors determining irrigation method
- General overview of how water quantity, quality and variability
- Awareness of environmental hazards that need of specific attention
- Establishment of basin committee or structured means of assessing sustainable abstraction
- Understanding the need for governance of water resources
- Awareness of the risks posed by climate change and the need to be resilient

DATA REQUIREMENTS

- Information on the source of water (surface, groundwater, non-conventional water) and its behaviour (recharge rates, drawdown rates, etc.)
- Information on the elevation between water source and field
- Information on water availability, quality and flows.
- Information on future water availability scenarios
- Information on other user requirements upstream and downstream

PEOPLE / STAKEHOLDER

- Water Resources Management and Licensing Authority
- Hydrological services
- Irrigation managers, water user groups or farmer organization
- Farmers
- Downstream water users
- Environmental protection agencies or similar, environmental NGOs

IMPORTANT ISSUES

- No irrigation development can take place without a legal water abstraction permit or similar.
- Water abstraction quotas are binding and constitute the maximum water availability for peak demand.
- Assess climate risks and understand the limitations that exist for water supply system.
- Regular review of the permits is necessary to ensure resilience and fair allocation of water resources as the climate and water availability change.
- Aquifer and watershed analysis are necessary to understand the hydrological system, foresee impacts of the SPIS, and mitigate negative outcomes.

3 ASSESS ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS

Irrigation and drainage projects invariably result in many far-reaching environmental and socio-economic changes. Some of these benefit human population, while others threaten the long- term productivity of the irrigation and drainage projects themselves as well as the natural resource base. Negative changes are not limited to increasing pollution or loss of habitat for native plants and animals; they cover the entire range of environmental components, such as soil, water, air, energy, and the socio-economic system.

IRRIGATION AND THE ENVIRONMENT

Irrigation makes possible the expansion and intensification of agriculture. Yet, without appropriate management, irrigation development can have significant negative environmental impacts.

At basin level, irrigation schemes can negatively affect the hydrology. Large irrigation projects which store or divert river water have the potential to cause major environmental disturbances, resulting from changes in the hydrology and limnology of river basins. Reducing the river flow changes flood plain land use and ecology and can cause salt water intrusion in the river and into the groundwater of adjacent lands. Diversion of water through irrigation further reduces the water supply for downstream users, including municipalities, industries and agriculture. A reduction in river base flow also decreases the dilution of municipal and industrial wastes added downstream, posing pollution and health hazards.

Groundwater irrigation can increase the risk of over-abstraction, resulting in groundwater depletion, land subsidence, decreased water quality, and saltwater intrusion in coastal areas.

Moreover, it is important to understand how water quality is affected through irrigation development. The quality of water entering the irrigation area is influenced by upstream land uses, particularly when it comes to the sediment content (for example from agriculture-induced erosion) and chemical composition (for example from agricultural and industrial pollutants). The use of river water with a large sediment load may result in canal clogging. Polluted return flows, containing harmful concentrations of salts, organic wastes, agrochemical residues or other substances, lead to the degradation of downstream ecosystems. Increased nutrient levels in the irrigation and drainage water can result in algal blooms, proliferation of aquatic weeds, and eutrophication in irrigation canals and downstream waterways.

At field level, there is a great risk of waterlogging and salinization. Irrigation-induced salinity can arise as a result of the use of saline water, irrigation of saline soils, and rising levels of saline groundwater combined with inadequate leaching. Salinity reduces plant growth and soil productivity. Salt-affected soils are more fragile and prone to erosion. In the case of sodic soils, the loss of organic matter leads to weakened soil structures, increased carbon dioxide emissions, and decreases water infiltration due to surface sealing. This inevitably affects agricultural productivity, yields, and farmers' incomes.

Irrigated lands, especially areas with high water tables, typically require drainage to avoid waterlogging. Because groundwater drainage is a complex and expensive operation (often more expensive than the initial development of irrigation itself), there is a temptation to start new irrigation projects while ignoring the need for drainage or delaying its installation until it is urgently needed. However, by the time the need for drainage becomes inescapable, the cost of implementing it may be prohibitive.

Monitoring water tables by means of observation wells (piezometers) as well as groundwater quality is crucial. This can provide an early warning of the danger of salinization and groundwater depletion.

Table 1 Potential Negative impacts of irrigation schemes

Increased evaporation in the scheme
Degradation of irrigated land
• Salinization
• Alkalisation
• Increased groundwater recharge, waterlogging and drainage problems
• Soil acidification
• Soil compaction
• Soil erosion
Poor water quality
• Reduction in irrigation water quality and leaching
• Water quality problems for downstream users cause by irrigation return flow quality
Groundwater depletion
• Drying up of drinking and irrigation wells
• Saltwater intrusion along coasts
• Reduced base flow
Reduced downstream river discharge
Ecological degradation
• Reduced biodiversity in irrigated and surrounding area
• Damage to downstream ecosystems due to reduced water quantity and quality
Negative impacts on human health
• Increased incidence of water-related diseases

CAN SOLAR-POWERED IRRIGATION HELP IMPROVE WATER USE EFFICIENCY?

The introduction of solar technology can be coupled with more water efficient irrigation methods that can help improve the water application efficiency in the field. Nevertheless, there is a risk that instead of saving water, this may actually lead to increased water consumption in situations where no barrier exists to encourage or incentivize efficient water use. Farmers may (i) apply more water in the field overall (for example, when shifting from deficit to optimal irrigation), (ii) expand the area of land under irrigation, (iii) shift to higher value, but often more water-intensive crops, (iv) sell water to neighbouring farmers and communities. This is particularly an issue in areas where groundwater resources are already overexploited and recharge rates are slow.

It may be important to distinguish between the following concepts:

Water Use Efficiency represents the ratio between effective water use and actual water withdrawal. It characterizes, in a specific process, how effective the use of water is. Efficiency is scale and process dependent.

Irrigation Efficiency: The ratio or percentage of the irrigation water requirements of crops on an irrigated farm, field or project to the water diverted from the source of supply.

Scheme Irrigation Efficiency: The scheme irrigation efficiency (in %) refers to the water pumped or diverted through the scheme inlet, which is effectively consumed by the plants.

The scheme irrigation efficiency can be sub-divided into:

- The **conveyance efficiency**, which represents the efficiency of water transport in canals. It mainly depends on the length of the canals, the soil type or permeability of the canal banks, and the condition of the canals.

- The **field application efficiency,** which represents the efficiency of water application in the field

UNINTENDED CONSEQUENCES OF EFFICIENCY

It is often argued that SPIS in combination with drip irrigation will ensure that water is efficiently used at field level. Drip and sprinkler systems allow farmers to improve the timing and distribution uniformity of irrigation, which can enhance crop yields, such that transpiration per hectare increases. The prospect of higher returns per hectare, however, will encourage some farmers to expand planted area or to switch to higher-value, more water-intensive crops (Berbel and Mateos, 2014). Assuming drip irrigation will automatically lead to water savings at the farm level is a fallacy.

Water efficiency at field or farm level can also have implications at basin level. Water resource systems are highly integrated, and apparent gains (in terms of water use efficiency) in one part of the system can be offset by real losses in other parts of the system. Rainfall, surface water, groundwater, soil moisture and rates, and processes of evaporation from different land uses are all part of the same hydrological cycle and cannot be regarded as separate. Changes in water use in one domain may lead to unintended or undesirable consequences locally or downstream.

SOCIO-ECONOMIC IMPACTS

The main objective of irrigated agriculture is to increase agricultural production and consequently improve the economic and social well-being of the people using it. However, changing land use patterns due to irrigation may have other socio-economic impacts too such as land tenure, water tenure, and changes in labour inputs for construction, operation, and maintenance.

Small plots, communal land use rights, and conflicting traditional and legal land rights all create difficulties when land is converted to irrigate agriculture. Traditional land tenure arrangements are likely to be disrupted by major development and rehabilitation works (e.g. building of dams, reservoirs, and canals). The most significant impact would be the resettlement of people. This can be particularly disruptive to communities and requires sensitive project development and adequate compensation. Land use change such as new irrigation development can also negatively affect those using the land for other purposes as well as the local biodiversity. Other uses of land such as hunting, grazing, collecting fuel wood, charcoal making, or growing vegetables are negatively impacted if the same land is then used for irrigated mono-cropping agriculture. Women, migrant groups and poorer social classes have often lost access to resources and gained increased workloads. Conversely, the increased income and improved nutrition from irrigated agriculture may benefit women and children in particular.

Similar problems can arise as a result of changes to water access and infrastructure. Such developments often increase inequity in opportunity. For example, land owners benefit in a greater proportion than tenants or those with communal rights to land.

These socio-economic impacts need to be assessed and taken into account in the planning processes of irrigation schemes or their modernization. This may be less relevant for individual pumping units or projects using community-led design, planning and management. It should ensure that the needs of local communities and users are met and potential challenges are foreseen with mitigation measures in place should they arise.

POTENTIAL HEALTH IMPACTS OF IRRIGATION

The risks of water-borne or water-related disease increase in areas that lack adequate drainage of canals and soil, have unlined canals and unchecked vegetation growth, or are left with stagnant water (e.g. pits, but also on rice or sugar cane fields). For diseases, such as malaria, bilharzia (schistosomiasis) and river blindness (onchocerciasis), vectors proliferate in the irrigation waters.

Other irrigation-related health risks include those associated with increased use of agrochemicals, deterioration of water quality, and increased population pressure in the area. The reuse of wastewater for irrigation has the potential, depending on the extent of treatment, to transmit communicable diseases. The population groups at risk include agricultural workers, consumers of crops and meat from the wastewater-irrigated fields, and people living nearby.

ENVIRONMENTAL ASSESSMENT TOOLS

Wise management of the environment requires an ability to forecast, monitor, measure and analyse environmental trends and assess the capabilities of land and water at different levels, ranging from a small irrigated plot to a catchment. Adoption of environmental impact assessments (EIAs) will enable countries to plan water and land use in an integrated manner, avoiding irreversible environmental damage.

The **PROMOTE & INITIATE – Impact Assessment Tool**, based on the ICID Environmental Check-List to Identify Environmental Effects of Irrigation, Drainage and Flood Control Projects" (Mock and Bolton, 1993) can serve as a starting point.

WATER ACCOUNTING

It is important to systematically study the current status and trends in water supply, demand, accessibility and use (FAO 2012). This is called water accounting. By evaluating return flows, measuring both basin and field efficiencies, and distinguishing between consumptive and non-consumptive savings, water accounting helps to address questions, such as: What are the underlying causes of imbalances in water supply (quantity and quality) and demand of different water users and uses? Is the current level of consumptive water use sustainable? What opportunities exist for making water use more equitable or sustainable (FAO 2016)? This assessment should be made prior to the SPIS, to establish a baseline, as well as periodically after implementation to measure the changes due to irrigation.

When assessing the impacts of solar-powered irrigation on water use efficiency, it is important to distinguish between these different levels of analysis (field/ farm/ scheme/ basin) and to carry out systematic water accounting to understand what options there are for optimising water use overall.

These efforts need to be complemented by appropriate regulation and policies. Subsidies may follow specific criteria (e.g. only in areas where groundwater is not overexploited) or provide incentives to use water, tenders may set standards (e.g. a groundwater metering system will be integrated in the solar pump), regulation may restrict SPIS use at certain times or places. If all this is considered, SPIS has the potential to fundamentally improve the lives of many people. For more information on this please refer to the 2017 FAO report "*The Benefits and Risks of Solar Powered Irrigation – A Global Overview"*.

ENVIRONMENTAL MANAGEMENT TOOLS

Many of these negative environmental impacts can be addressed through effective planning and implementing of environmental protection and conservation measures.

Not only can negative impacts be reversed, but with an integrated management approach, further benefits can be reaped. Irrigation, for instance, can play a positive role in land use management. By intensifying food and forage production in the most favourable lands, for example, pressure on marginal lands can be reduced, using them for rain-fed agricultural production or grazing. Dams and reservoirs offer ways to mitigate the potential negative impacts of changes to flood flows but require care in planning to not disrupt the flow to downstream users and environments. Planning irrigation systems with designated flood plains and provisions for natural infrastructure, like wetlands, can improve groundwater recharge and attenuate peak discharge flows.

Further information on sustainable land, soil and water management practices can be found here:

http://www.fao.org/land-water/land/sustainable-land-management/slm-practices/en/

SOIL SALINITY ASSESSMENT

Soil Salinity Assessment. FAO Irrigation and Drainage Paper 57. www.fao.org/docrep/019/x2002e/x2002e.pdf

Visual Soil Assessment Field Guides by FAO http://www.fao.org/3/a-i0007e.pdf

LAND DEGRADATION ASSESSMENT

Land Degradation Assessment in Dry Lands by FAO www.fao.org/fileadmin/templates/nr/kagera/Documents/LADA_manuals/MANUAL2_final_draft.pdf

WATER QUALITY

USGS *Water Quality Assessment – Field Methods and Techniques*: https://water.usgs.gov/owq/methods.html

SOCIO ECONOMIC CHECKLIST

PROMOTE & INITIATE – IMPACT ASSESSMENT TOOL

OUTCOME / PRODUCT

- Understanding of the links between irrigation, the environment, and society
- Understanding of the risks SPIS poses to environmental flows and the options for risk mitigation
- Awareness of efficiencies in solar powered irrigation systems
- Awareness of the impacts on and roles of water rights, land rights, and gender equality in the socio-economic ecosystem
- Awareness of health impacts and delayed costs posed by poorly planned irrigation schemes and lack of adequate drainage
- Understanding of water accounting and the potential policies, subsidies, and governance systems that can produce responsible irrigation systems
- Awareness of tools available for environmental management

DATA REQUIREMENTS

- Data necessary for environmental management tools
- Baseline data to monitor the socio-economic and environmental impacts of irrigation (gender data, income data, biodiversity data, employment data, water use, water quality, health data, behavioural data from government interventions, land use change, soil data, etc.)

PEOPLE / STAKEHOLDER

- Irrigation planners/ system managers
- Policy makers
- Water Resources Management and Licensing Authority
- Irrigation managers, water user groups or farmer organization
- Environmental protection agencies or similar, environmental NGOs

IMPORTANT ISSUES

- The far-reaching impacts, both positive and negative, of solar powered irrigation schemes
- The importance of upfront planning for drainage, public health, and inclusive basin wide development
- The need to engage in baseline data collection

- Understand the different efficiencies in SPIS and recognize the potential negative consequences
- Use nature-based solutions as measure to understand the impact of irrigation on land use, biodiversity, and potential climate change mitigation, adaptation, and resilience
- Understand that land rights, water rights, and gender issues interact with land use and agricultural productivity

4 CALCULATE WATER REQUIREMENTS

Understanding when, where, and how much water is needed for agricultural production and other uses is crucial for efficient water management.

CROP WATER REQUIREMENTS

Crop water requirements are defined as the total amount of water needed to meet the water loss through evapotranspiration. In other words, it is the amount of water needed by the various crops to grow optimally.

The crop water requirement always refers to a crop grown under optimal conditions, i.e. a uniform crop, actively growing, completely shading the ground, free of diseases, and favourable soil conditions (including fertility and water). The crop thus reaches its full production potential under the given environment.

The crop water need mainly depends on:

- *Climate*: in a sunny and hot climate crops need more water per day than in a cloudy and cool climate
- *Crop type*: crops like maize or sugarcane need more water than crops like millet or sorghum
- *Growth stage of the crop*: fully grown crops need more water than crops that have just been planted.

Table 2 Impact of climate conditions on crop water needs (Source: FAO 1989)

Climatic Factor	Crop water need	
	High	**Low**
Temperature	hot	cool
Humidity	low (dry)	high (humid)
Windspeed	windy	little wind
Sunshine	sunny (no clouds)	cloudy (no sun)

Nevertheless, real-life conditions are rarely optimal and there are many other factors that also influence evapotranspiration rates. Factors such as soil salinity, poor land fertility, limited use of fertilizers and chemicals, lack of pest and disease control, poor soil management and limited water availability at the root zone may limit crop development and reduce evapotranspiration.

Other factors that affect evapotranspiration are groundcover and plant density. Cultivation practices and the type of irrigation system can alter the microclimate, affect the crop characteristics, and affect the wetting of the soil and crop surface.

IRRIGATION WATER REQUIREMENTS

Irrigation water requirements refer to the water that must be supplied through the irrigation system to ensure that the crop receives its full crop water requirements. If irrigation is the sole source of water supply for the plant, the irrigation requirement will always be greater than the crop water requirement to allow for inefficiencies in the irrigation system. If the crop receives some of its water from other sources (rainfall, water stored in the ground, underground seepage, etc.), then the irrigation requirement can be considerably less than the crop water requirement.

In humid climates, precipitation and soil moisture can be sufficient for to ensure satisfactory growth in rainfed agriculture. In arid climates or during extended dry seasons, however, irrigation is necessary to compensate for the evapotranspiration (crop transpiration and soil evaporation) deficit due to insufficient or erratic precipitation.

In order to understand how much irrigation water is required, an analysis of the water balance is needed. There are three levels to such an analysis.

The first is the balance of agricultural and other demands within a watershed. This helps establish the safe yield of water from various sources and thereby how much irrigation is possible within sustainable margins see module **SAFEGUARD WATER**.

Another water balance perspective is at farm (or command area) level. Fields are often not irrigated individually, but they share the water delivered through a canal or well. They also often share drainage channels. A water balance at the farm looks at the access to water, priority uses, timing and duration of irrigation. This is the basis for efficient design of the system and delivery of services.

A third perspective looks at the water requirements of crops in a field. Providing the crop with irrigation at the appropriate time and in the appropriate quantity requires experience and will depend on climate, rainfall, soil and crops stage, as well as the field irrigation system and irrigation technology used.

Special computerized irrigation programmes, such as the FAO CROPWAT programme, may be used to advise farmers on water supply and irrigation schedules for the given climatic conditions, crop, soil and field irrigation method.

The **SAFEGUARD WATER – Water Requirement Tools** and the **IRRIGATE– Soil Tool** may be useful in roughly assessing the crop water supply needed.

IRRIGATION SCHEDULING

Once the crop water and irrigation requirements have been calculated, the next step is the preparation of field irrigation schedules. Three parameters have to be considered in preparing an irrigation schedule:

- The daily crop water requirements
- The soil, particularly its total available moisture or water-holding capacity
- The effective root zone depth

Plant response to irrigation is influenced by the physical condition, fertility and biological status of the soil. Soil condition, texture, structure, depth, organic matter, bulk density, salinity, sodicity, acidity, drainage, topography, fertility and chemical characteristics all affect the extent to which a plant root system penetrates into and uses available moisture and nutrients in the soil. Many of these factors influence the water movement in the soil, the water-holding capacity of the soil, and the ability of the plants to use the water. The irrigation system used should be able to function under all or most of these conditions.

In the field, the actual value may vary from site to site, season to season and even within the season. Within the season, it varies depending on the type of farm and tillage equipment, number of tillage operations, residue management, type of crop, and water quality.

Soils to be irrigated must also have adequate surface and subsurface drainage, especially in the case of surface irrigation. Internal drainage within the crop root zone can either be natural or from an installed subsurface drainage system.

WHAT CROPS ARE BEST SUITED FOR SOLAR-POWERED IRRIGATION?

There are no crops that are particularly suitable (or unsuitable) for solar-powered irrigation as long as the irrigation method can meet crop water requirements and is compatible with farming practices, climate, water resources, and other agronomic aspects.

The cropping pattern should be such that the selected crop can be successfully grown under the prevailing climate and soil conditions, and the irrigation system should be compatible with crops and agricultural practices. Furthermore, adequate attention should be given to the selection of the crops and cropping calendar. Crops should be marketable at economic prices.

SELECTION OF SUITABLE CROPS FOR IRRIGATION

Specific agronomic aspects to be considered include the following:

- Cropping calendar of present common crops grown in the area during the wet and dry seasons, indication of seasonal hazards (drought, floods, pests and diseases)
- New crops with good potential to be introduced under irrigation
- Crops for self-sufficiency and (household/ national) food security
- Crops destined for the market
- Experience, motivation and priorities given by farmers in selection of the crops.

The use of crops or varieties with greater resilience to dry spells is preferable. This can also help farmers to adapt to changing temperatures and rainfall patterns. Increased agricultural diversification, including better integration of trees, crops, fish and livestock can reduce risk and increase the resilience of farming systems.

Some crops are sensitive to the way water is applied to them. Systems, which wet the whole crop, such as sprinkler irrigation, may have undesirable consequences, such as leaf burn, fruit spotting and deformation, crown rot, and other. These considerations would influence the choice of the irrigation method (Savva and Frenken 2004).

As a rule, most vegetable (and other row) crops have shallow effective root zone depth and respond better to low moisture depletion levels. They are therefore well suited for localized, drip irrigation, which is often linked to PV powered pumps.

It is important to note that plant breeding and biotechnology can help by increasing the harvestable parts of the biomass, reducing biomass losses through increased resistance to pests and diseases, reducing soil evaporation through vigorous early growth for fast ground cover, and reduced susceptibility to drought (FAO 2012).

In selecting suitable crops, farmers need to ensure that they have access to agricultural inputs, such as quality seeds, fertilizers, pesticides and tools, as well as credit to buy the necessary inputs.

SUITABLE AGRICULTURAL PRACTICES AND INPUTS

- Present agricultural practices of common crops grown in terms of inputs, labour and tools;
- New or improved agricultural practices to be introduced for the irrigated crops to ensure optimum production levels
- Assessment of inputs required for optimal production in terms of quality seed, organic and inorganic fertilizers, tools, availability of inputs, and access to credit.

OUTCOME / PRODUCT

- Understanding of what affects crop water requirements
- Recognizing the difference between crop water requirements and irrigation water requirements
- Incorporating the different perspectives of water requirements into the irrigation plan
- Incorporating the necessary parameters in irrigation scheduling and drainage design

DATA REQUIREMENTS

- Crop rotations planned
- Schedule of planting and harvesting
- Consumption requirements of other water users in the basin
- Future climate scenarios for the area

PEOPLE / STAKEHOLDER

- SPIS advisors
- Farmers

- Irrigation managers, water user groups or farmer organization

IMPORTANT ISSUES

- The CWR and IWR need to be resilient to future climate scenarios
- Irrigation schemes require planning at multiple scales, from basin to farm to individual crop
- The soil health and type are key to calculating the water requirements
- Boundaries on seasonal water availability should influence the crop choice balancing CWR, other user requirements, and water availability
- Soil drainage should be an upfront concern and consideration
- Choice of crops should also factor in other availability of other inputs such as labour, fertilizer, tools, herbicides, etc.

5 SELECT FIELD IRRIGATION METHOD

The vast majority of the total global irrigated area is equipped for full control irrigation. Full control irrigation methods differ in the way water is distributed (AQUASTAT)

Once the crop requirements, water resources, and impacts of implementing a SPIS are understood, the appropriate irrigation methods can be selected.

WHAT IRRIGATION METHODS ARE THERE?

Surface irrigation uses gravity to move water over land. This category can be subdivided into small channels (furrows), strips of land (borders) and basin irrigation (including submersion irrigation of rice).

Surface irrigation is widely utilised and therefore a well-known system, which can be operated without any high-tech applications. In general, it is more labour intensive than other irrigation methods. When designing a surface irrigation system, the soil type (texture and infiltration rate), slope and levelness of the field, stream size and length of run should be taken into account. It is generally more difficult to obtain a high uniformity of water distribution in long fields on coarse textured soil (gravels and sand) than on fine textured soils (loams to clay). Levelling the field and building water ditches and reservoirs may be expensive, but once this is done, costs are low and the farmer has greater capacity to respond to changing demand for irrigation.

Sprinkler irrigation consists of a pipe network, through which water moves under pressure before being delivered to the crop via sprinkler nozzles. The system basically simulates rainfall in that water is applied through overhead spraying.

The pump is usually a centrifugal pump, which takes water from the source and provides adequate pressure for delivery in the pipe system. Mainline and sub-mainline pipes deliver water from the pump to lateral pipes. The laterals then deliver water to the sprinklers. They can be permanent, but more often they are portable and made of light material (e.g. aluminium) that is easy to carry.

Rotor-type sprinklers operate by rotating streams of water over an area of land. This includes impact and gear-drive sprinklers, producing streams of water, and spray nozzles that discharge water in patterns.

Due to the high-capital investment costs, the more elaborate systems (e.g. centre pivots, side roll systems etc.) are typically used for high-value crops, such as vegetables. A higher-level of expert knowledge is needed to operate the systems, even though the overall labour requirement is low due to the high level of automation. Motors, pipes and other mechanical components all need to be systematically maintained to avoid damage and high repair or replacement costs.

Sprinkler irrigation is suited for most row, field and tree crops, and water can be sprayed over or under the crop canopy. However, large sprinklers are not recommended for delicate crops, such as lettuce, because the large water drops produced by the sprinkler may damage the crop.

Localized irrigation consists of “water being distributed under low pressure through a piped network, in a pre-determined pattern, and applied as a small discharge to each plant or adjacent to it” (AQUASTAT 2016).

A typical **drip irrigation** system has a pump unit, a control head, mainlines and sub-mainlines, lateral lines and emitters or drippers. It may also feature reservoir tanks, filters and fertigation devices.

With drip irrigation, water is applied more frequently (usually 1-3 times a day) than with other methods, providing a favourable high level of soil moisture. As long as the water application rate is below the soil's infiltration capacity, the soil remains unsaturated and no free water stands or runs over the surface. This way water resources can be used very efficiently and water losses can be reduced to a minimum.

Moreover, fertiliser and nutrients can be used with high efficiency as water is applied locally and leaching is reduced. Weed growth is reduced as water and nutrients are supplied only to the cultivated plant.

Nevertheless, drip irrigation has a high initial investment cost as well as it requires a high-level of technical knowledge and regular investments to replace equipment, which is vulnerable to clogging and dysfunction, especially when water quality is not optimal. There also is a risk of rising soil salinity.

The method is suitable for most soils. On clay soils, water must be applied slowly to avoid surface water ponding and run-off. On sandy soils, higher emitter discharge rates will be needed to ensure adequate lateral wetting of the soil.

Drip irrigation is most suitable for row crops, such as vegetables and fruits, tree and vine crops. Given the high investment, drip irrigation tends to be used for high-value crops.

Other types of irrigation include:

Equipped lowland areas, such as (i) cultivated wetland and inland valley bottoms that have been equipped with water control structures for irrigation and drainage; (ii) areas along rivers where cultivation occurs making use of structures built to retain receding flood water; (iii) developed mangroves and equipped delta areas.

Spate irrigation, using floodwaters of ephemeral streams and channelling it through short steep canals to where cropping takes place. Dams are often built in the streams to be able to store the water whenever it arrives.

WHAT IRRIGATION METHOD IS BEST SUITED FOR SOLAR-POWERED SYSTEMS?

PV water pumping systems have shown significant advancements in the last decade. The limitations in the design of solar pumps from the 1970s – such as terminals that did not readily provide good electrical connection or overheated electronic circuitry - have been overcome, and solar pumps are now much more efficient and reliable.

Nowadays, they can support drip, sprinkler, pivot or flood irrigation technologies. Systems range from sophisticated computer controlled setups with high start-up costs to moderate-cost systems that include bubblers, mini-sprinklers and drip irrigation.

Generally, the size – and cost – of the solar pumping system is determined by the water and pressure requirements of the irrigation system. Methods working at comparably low operating pressures are often the preferred option in combination with PV pumps.

Sprinkler irrigation requires relatively high water pressure to operate, which demands a specific SPIS composed of high capacity solar modules and an integrated energy storage capacity (battery). In contrast, drip irrigation requires low pressure and have the potential to apply water more efficiently.

Drip irrigation – also known as micro-, localised, or trickle irrigation – uses networks of pipes and tubes to apply water directly to the soil surface or root zone of plants. It has the potential to reduce the 'drop per crop' water consumption through minimising non-productive evaporative losses (e.g. Narayanamoorthy, 2004; Rijsberman, 2006). Another advantage is that moderately saline water may be used for irrigation. Marginal plots of land may be used productively as drip irrigation techniques can deliver required water and nutrients directly to the plants.

Drip irrigation is ideal for high-value crop production such as vegetables and fruits, tree and vine crops, and due to its high efficiency, the solar pump can be quite conservatively sized.

Nevertheless, drip irrigation comes at a high initial capital cost and requires sufficiently good quality water (to avoid clogging of the emitters) or a pre-treatment system. Moreover, good irrigation management is needed to operate the system effectively, apply fertigation and maintain equipment.

Table 3 Suitability of irrigation methods for solar pumps, adapted from "Manual and Tools for promoting SPIS – Stocktaking and Analysis Report" (2015).

Irrigation method	Typical application efficiency	Suitability for use with solar pump
Flood	40-50%	Depends on local conditions
Open channels	50-60%	Depends on local conditions
Sprinkler	70-80%	Yes
Drip	85-95%	Yes

Beyond these technical considerations, there are other factors determining the suitability of irrigation methods regardless of the source of energy powering the pumps. These include natural conditions such as:

- *Soil type*, determining water storage capacity and infiltration rate;
- *Slope of land*, influencing water drainage and whether land needs levelling;
- *Climate*, including winds (e.g. that may disturb spray from sprinklers), sun radiation and precipitation patterns, and temperature;
- *Water availability,* see Section 2
- *Water quality,* see Section 2
- *Resilience* requirements, see Section 2

It is also important to consider the type of crop grown both from an economic as well as from an agronomic point of view. Due to the higher capital investment costs per hectare, sprinkler and drip irrigation are commonly used for high-value cash crops, such as vegetables, fruit trees and spices. Drip irrigation is better suited for individual plants, trees or row crops.

There are also other socio-economic aspects to consider when selecting the irrigation method. Labour input is one such factor. The construction, operation and maintenance of surface irrigation often requires higher labour input than sprinkler or drip. Surface irrigation requires accurate land levelling, regular maintenance and a high level of farmers' organisation to operate the system. Another aspect to consider are unexpected complications when introducing new irrigation methods. Getting farmers to change practices and servicing the equipment may be challenging.

When selecting an irrigation method, these aspects needs to be weighted and a cost/benefit analysis of the available options needs to be made. Costs include the capital investment, construction and installation as well as operation and maintenance, including energy. These costs should be compared to the expected benefits, including yields, market prices, avoided operational costs, and labour savings. This cost benefit analysis is explained in further detail in the SPIS Toolbox section on financing.

OUTCOME / PRODUCT

- Understanding the different irrigation methods and their respective advantages / disadvantages
- Ability to incorporate the natural conditions that affect irrigation into the choice of irrigation method
- Appropriate application of the cost benefit analysis
- Understanding the trade-offs involved in different irrigation methods regarding capital and operational costs, water efficiency, and increased agricultural production and income.

DATA REQUIREMENTS

- Water pressure
- Seasonal water availability (sustainable abstraction allowance)
- Water quality
- Soil type
- Slope of land
- Capital, operational, and maintenance costs
- PV efficiency and power available
- Power requirement of different irrigation methods

PEOPLE / STAKEHOLDER

- Policy makers
- Irrigation advisors/ planners
- Irrigation managers, water user groups or farmer organization
- Farmers

IMPORTANT ISSUES

- Different irrigation methods exist that provide different benefits and drawbacks
- The ultimate decision of which irrigation method to use should be a balance of the financial and environmental costs / benefits over the life of the asset

6 PLAN INTAKE STRUCTURES, CONVEYANCE AND DISTRIBUTION

The principal engineering challenge of any irrigation system consists in withdrawing water from a source, delivering it to land in due time and in the required amount, distributing it among individual farms and crop-rotation fields, and providing soil moisture needed for plants on fields. All this requires energy to move water, maintain pressure and ensure quality.

The operation of the system should offer enough flexibility to supply water to the crop in variable amounts and schedules that allow the irrigator some scope to manage soil moisture for maximum yields as well as water, labour and energy conservation.

Water may be supplied on a continuous or a rotational basis in which the flow rate and duration may be relatively fixed. In those cases, the flexibility in scheduling irrigation is limited to what each farmer or group of farmers can mutually agree upon within their command areas. At the preliminary design stage, the limits of the water supply in satisfying an optimal irrigation schedule should be evaluated (see Section 1).

INTAKE STRUCTURE

The *intake structure* is used for water withdrawal from an irrigation source and delivery to an irrigation network. These can be gravity and water-lifting types.

Pumps powered by solar energy can be used both for surface water and groundwater withdrawal. There are two main types of pumps: centrifugal pumps and positive displacement pumps. Both can be used for SPIS.

Solar-powered pumps have to be oversized to meet peak demand, which means they tend to be underutilised during the off-season. To a certain extent, this seasonal variability in water demand can be balanced by adapted crop rotations (including permanent crops) and irrigation management.

The performance of solar-powered pumps depends on the crop water requirements, size of water storage, head (m) by which water has to be lifted, volume of water to be pumped (m^3), PV array virtual energy (kWh), energy at pump (kWh), unused PV energy (kWh), pump efficiency (%), system efficiency (%), and diurnal variation in pump pressure due to change in irradiance and pressure compensation. All this needs to be considered when designing the SPIS and is best done by an expert.

The fluctuations in solar irradiance, the accumulation of dust on PV modules and high air temperatures affect the performance of the PV systems and hence the pump. Spraying clean water on the PV modules results in cleaning the dust as well as cooling of modules improves the module efficiency and hence the water flow rate. Therefore, PV modules should be easily accessible for maintenance purposes.

The **DESIGN – Pump Sizing Tool** can be helpful in ensuring that the pumping system is designed to purpose and to avoid unnecessary pressure loss.

CONVEYANCE AND DISTRIBUTION

Once the water has entered through the intake structure, it needs to be delivered through *conveyance and distribution systems*. Typical conveyance and distribution systems are diversion dams, lined or partially lined canals and ditches, pipelines, hydrants and other means.

A distinction can be made between water provision for lands of a single (on-farm irrigation system) or several (inter-farm irrigation system) farms, associations of farms and agricultural enterprises, and even several administrative centres.

A badly planned conveyance and distribution system can lead to high water losses, poor irrigation efficiency and much smaller areas than planned being irrigated.

Design software is available for irrigation system planning. For example, GESTAR is a software developed by the Faculty of Fluid Mechanics at the University of Zaragoza and can be used to size medium to large-scale irrigation schemes. GESTAR tools and methods are specifically designed for pressurized irrigation (such as sprinkler and drip irrigation). Planning tools specific to an irrigation method also exist.

WHAT ARE THE IMPLICATIONS OF SOLAR-POWERED IRRIGATION FOR ENERGY?

SPIS can provide a reliable and affordable source of energy in rural areas, potentially reducing energy costs for irrigation and reducing greenhouse gas emissions associated with fossil fuel pumping systems.

Irrigation systems use energy to lift water from a well or reservoir, to pressurize water to overcome friction losses in pipes and to distribute water evenly over the soil. Pumps are typically powered by diesel or electrical energy, with the latter supplied from the grid, or by decentralized energy sources.

- **Energy efficiency**: How efficiently irrigation systems use water and energy is determined primarily by the type of system and the way it is operated, maintained, and managed. When specifying pump size and designing water distribution systems, engineers consider the distance the water has to be lifted and transferred, the depth from which water needs to be transported, and the friction caused within pipes and channels as determined by layout, diameter and operating pressures. They should also consider the system resilience to future climate scenarios and changes in groundwater levels that may occur through widespread implementation of SPIS.

  Energy savings can be made through efficient design (e.g. pipe layout), appropriately sized pumps, and optimised equipment (e.g. variable speed drives). A further consideration is the trade-off between water application efficiency and energy efficiency. For instance, forcing water through a drip irrigation network will use more energy than running it through channels and furrows, but this type of system will apply water more efficiently than a more energy-efficient centre pivot irrigation system.

- **Energy costs**: Pressurised systems tend to be more efficient, but have higher energy requirements and thus higher energy costs. These costs depend on the source of energy, energy price per unit as well as other factors, such as the depth of the aquifer from where the water is pumped. As such, the energy costs can potentially undo any cost savings that were anticipated when investing in making irrigation systems more efficient. It leaves scope for interventions at technical and management level to improve both water and energy use efficiency and to reduce operating costs.

  Solar-powered photovoltaic systems can provide an economically viable alternative source of energy without emitting greenhouse gas emissions. They also have the advantage of not depending on the availability and costs of fossil fuels.

  Nevertheless, it requires some prior knowledge of how to set-up and use solar pumps optimally. In contrast to motor-driven pumps, the dimensioning of PV irrigation systems is a critical strategic decision for farmers, given the initially higher investment costs and the complexity in designing, operating and maintaining the system. Usually this is done by technical experts. Training of farmers is necessary to operate the PV system for maximum benefits.

Although costs have decreased significantly in recent years, the economic viability of PV systems varies, especially for small-holder farmers for whom a solar pump represents a substantial investment. Thus, the economic viability of such an investment needs to be assessed to understand whether the introduction of PV pumps is economically viable.

The **INVEST – Payback Tool** can be useful in assessing the costs of solar systems vs. other types of energy systems for irrigation.

OUTCOME / PRODUCT

- Understanding of the different aspects of an irrigation system
- Overview of how to size pumps and other parts of a SPIS
- Recognition of the long-term cost savings from installing a SPIS
- Understanding of the need to design in resilience and adaptability to the system

DATA REQUIREMENTS

- Water volume and pressure required
- Pump size, pump cost, electricity requirements
- PV system size requirement and cost
- Ancillary structures and systems, sizes, and costs

PEOPLE / STAKEHOLDER

- Irrigation system planners
- Irrigation managers, water user groups or farmer organization
- Farmers
- Financers

IMPORTANT ISSUES

- Careful life-cycle cost-benefit analysis should be carried out
- Resilience and adaptability should be built into the system by design
- A poorly designed system can be damaging to the environment and other watershed users
- Technical expertise are required for the sizing, installation, and maintenance of such systems

7 IRRIGATION EFFICIENCY TIPS

Irrigation water is a precious resource. This not only applies directly to agricultural production, but also indirectly to the ecosystem at large. The wise use and conservation of irrigation water is hence essential. A number of best practices and tips can reduce overall water consumption, improve plant growth and lead to higher yields.

MAP IT OUT

Review the layout of the land and map the optimal placement of irrigation piping, with attention to reducing the number of fittings used (prone to leakages). Keep in mind that slopes would cause an uneven distribution of water and could result in run-off. Hence levelling and terracing is advised when using flood or sprinkler irrigation (drip lines should run horizontal to the slope). Sprinkler irrigation disperses water in a circle around the central nozzle. Determine the radius and place sprinklers in such a fashion that overlaps are kept to a minimum, while still ensuring that a maximum area is covered (i.e. few dry areas remain).

PRESERVE TREES

Ideally, large trees should remain in the crop area. Not only do they provide moving shade, but certain species (e.g. acacias) support nitrogen-fixing bacteria which enhance soil fertility.

ACROECOLOGICAL APPROACH

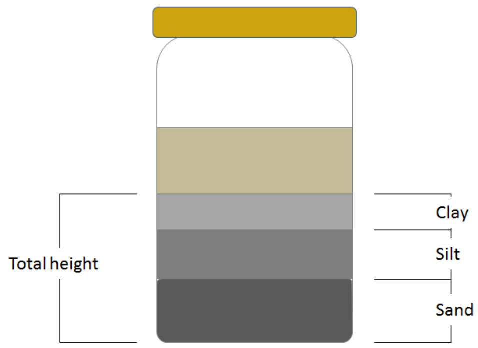
The ten agro-ecological principles outlined by the FAO highlight aspects that relate to water resources, use, reuse, governance, and rights. These principles also provide a means to look beyond the farm level intervention to impacts in the wider community and food system.

The **PROMOTE & INITIATE – Impact Assessment Tool** incorporates, to some extent, these principles.

SOIL TESTING

Soil moisture available to plant roots is depended on soil type. The soil type can be determined in the laboratory using a particle size analysis. Sand, silt and clay have different diameters, by sieving them their distribution delivers information about the soil type. Another way to determine the soil type is the "Jar Test":

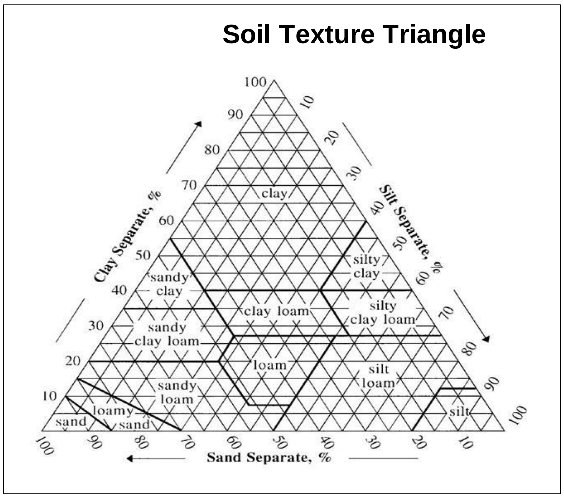
1. Remove soil from the zone to be irrigated
2. Place the soil sample into the jar (halfway) and fill it with water (until two-thirds full)
3. Shake the jar and let it sit for two hours, the particles will settle to the bottom, in their different layers
4. Measure the total height of all layers, then the height of each layer.
5. Divide the height of each layer by the total height which gives you the percentage of clay, silt and sand.



Sedimentation layers in the soil jar test

(Source: K Blumenthal)

Putting in the obtained percentages of clay, silt and sand, a soil texture triangle, as seen in the figure below, shows the type of soil present.



The Soil Texture Triangle

(Source: United States Department of Agriculture)

The **IRRIGATE– Soil Tool** describes the different soil type properties and allows for establishing a soil-based irrigation schedule according to different crops.

IRRIGATION SCHEDULING

Scheduling irrigation based on soil-plant or atmosphere measurements can decrease water use while improving yields. Software programs can collect weather data including local temperature, rainfall, humidity, and crop evapotransporation to provide recommendations for optimal irrigation scheduling (see FAO Irrigation and Drainage Paper 56). The **IRRIGATE– Soil Tool** allows for establishing a soil-based irrigation schedule according to different crops.

MULCH

Mulching is an effective technique to reduce evaporation of soil moisture, insulate against cold weather and gradually enhance the organic composition of soils. It helps to prevent soil compaction, acts as a soil conditioner, and encourages the presence of natural aerators, like earthworms. It adds nutrients by contributing to the availability of potassium and can add nitrogen, phosphorus, and trace elements to the soil. Furthermore it is an ideal way to make use of recycled crop waste.

Mulching comprises the layering of organic (straw, wood bark, leaf litter, maize stalks) or inorganic (PVC sheeting) materials over the crop area, through which the crops can grow. Mulching can also be achieved through intercropping, by for instance planting ground creepers (water melon, pumpkin) between rows of maize. Important considerations regarding mulching include:

- Once you begin mulching stay with it. Removing a layer of mulch will dry out the soil and potentially injure the roots below.
- Mulching against a tree’s trunk can lead to bark rot, disease, and insect problems. Thus leave several centimeters of space between the base of the tree and the mulch layer.
- Avoid over applying mulch. Spreading mulch too thickly can cause roots to grow shallow and make them more susceptible to dying during extended dry periods. As a general rule the mulch layer should not exceed 5 cm.
- Use woody or bark mulches in areas where little digging is required, e.g., around trees and in flower beds. Lighter mulch materials such as straw, which is easily worked into the soil, is better suited for seasonal crops and vegetable gardens where replanting is regular.
- Before applying a new layer of mulch, rake through and mix the older mulch layer. Mulch, especially from woody materials, can compact over time and thus prevent soil aeration and water penetration.

INTERCROPPING

Intercropping is a multiple cropping practice involving growing two or more crops in proximity. The most common goal of intercropping is to produce a greater yield on a given piece of land by making use of resources or ecological processes that would otherwise not be utilized by a single crop (*Ouma, George; Jeruto, P (2010)*). The elements of intercropping (*Wikipedia, "Intercropping", January 2018*) include:

- **Resource partitioning**: Careful planning is required, taking into account the soil, climate, crops, and varieties. It is particularly important not to have crops competing with each other for physical space, nutrients, water, or sunlight. Examples of intercropping strategies are planting a deep-rooted crop with a shallow-rooted crop, or planting a tall crop with a shorter crop that requires partial shade.

- **Mutualism**: Planting two crops in close proximity can especially be beneficial when the two plants interact in a way that increases one or both of the plant's fitness (and therefore yield). For example, plants that are prone to tip over in wind or heavy rain (lodging-prone plants), may be given structural support by their companion crop. Climbing plants can also benefit from structural support. Some plants are used to suppress weeds or provide nutrients. Delicate or light-sensitive plants may be given shade or protection, or otherwise wasted space can be utilized. An example is the tropical multi-tier system where coconut occupies the upper tier, banana the middle tier, and pineapple, ginger, or leguminous fodder, medicinal or aromatic plants occupy the lowest tier. Intercropping of compatible plants can also encourage biodiversity, by providing a habitat for a variety of insects and soil organisms that would not be present in a single-crop environment. These organisms may provide crops valuable nutrients, such as through nitrogen fixation.

- **Pest management**: There are several ways in which increasing crop diversity may help improve pest management. For example, such practices may limit outbreaks of crop pests by increasing predator biodiversity. Additionally, reducing the homogeneity of the crop can potentially increase the barriers against biological dispersal of pest organisms through the crop.
  There are several ways pests can be controlled through intercropping:

  - Trap cropping involves planting a crop nearby that is more attractive for pests compared to the production crop, the pests will target this crop and not the production crop.
  - Repellant intercrops have a repellent effect to certain pests. This system involved the repellant crop masking the smell of the production crop in order to keep pests away from it.
  - Push-pull cropping, this is a mixture of trap cropping and repellant intercropping. An attractant crop attracts the pest and a repellant crop is also used to repel the pest away.

Agricultural extension officers and advisors should be able to give guidance regarding intercropping and companion planting.

RAINWATER CATCHMENT

Ensuring that rainwater does not run-off, but percolates into deeper soil layers avoids top soil erosion and can improve groundwater recharge, while improving soil moisture at depth. Strategically placed furrows can trap rainwater and divert it to crop areas (or the pump well), while roof gutters leading to water storage tanks can build up reserves for the dry season.

MONITORING

Monitoring water consumption and soil moisture levels regularly, ensures a deeper understanding of the water resources necessary for healthy crops. Water flow meters and hand-held soil moisture meters are important devices through which data is collected and recorded for analysis.

IMPROVED FURROWS

Numerous techniques exist to optimize water flow through furrows. These may include covering furrows with plastic PVC sheeting or rock slabs to reduce evaporation, lining or firming main furrows to reduce water infiltration rate at the head end of the field (then additional water is available to advance further down the furrow. The result is faster advance time to the end of the field and improved water distribution) or optimizing slope angles to ensure efficient water flow.

EVAPORATION AVOIDANCE

Evaporation from uncovered water storage and water conveyance systems implies a direct loss of water resources to the atmosphere. This loss has financial implications where costs were incurred to pump the water from a well or procure it from a service provider. Stopping evaporation is a question of restricting the solar energy available to the water (to energise water molecules) and lowering its exposure to dry air. When water evaporates it forms a moist layer of air over the surface, lowering the capacity of the air to accept more water molecules from the liquid. Moving air draws water vapor away from the area over the surface of the water and replaces it with drier air, increasing evaporation. Using sealed tanks or covering open storage tanks and canals is advisable. For larger irrigation reservoirs or dams floating covers can be considered, along with wind breaks (e.g. hedges and trees) around the perimeter. The latter might also contribute towards shading the water surface, thus reducing the kinetic energy available to water molecules.

IRRIGATION TIMING

In principle it is best to irrigate during the morning hours starting just before sunrise. Cooler air and lower wind speeds reduce evaporation losses, while crops are assured an adequate water supply at the root zone in preparation for higher daytime temperatures. Watering in the late afternoons and evenings is not advised, as crops cannot absorb the available water and stagnant water offers a breeding ground for pests and fungi.

OUTCOME / PRODUCT

- Understand some practical approaches towards reducing irrigation water demand

DATA REQUIREMENTS

- Information on intercropping and companion planting
- Soil properties in crop areas

PEOPLE / STAKEHOLDER

- Agricultural extension officers and advisors
- Irrigation planners and service providers
- Horticulture and permaculture specialists

IMPORTANT ISSUES

- Irrigation efficiency can only be ensured through active and regular monitoring. Any improvement measure should be scrutinized carefully before implementation and baseline information captured (e.g. amount of water consumed, amount of fertilizer added). Comparing the baseline information with the new post-measure data, allows to assess the success or failure of the improvement. This deepens understanding.

FURTHER READING, LINKS AND TOOLS

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Water Accounting: http://wateraccounting.org/

WOCAT *Global Database on Sustainable Land Management*: https://qcat.wocat.net/en/wocat/

SPIS tools

PROMOTE & INITIATE – Impact Assessment

IRRIGATE – Soil Tool

DESIGN – Pump Sizing Tool

The following tools that are assigned to other Modules are also relevant:

SAFEGUARD WATER – Water Requirement Tool

INVEST – Payback Tool

INVEST – Farm Analysis Tool

Tool

DESIGN – Site Data Collection Tool

TOOLBOX ON SOLAR POWERED IRRIGATION SYSTEMS (SPIS)

POWERING AGRICULTURE:

AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

Module 7: Maintain

The Toolbox on Solar Powered Irrigation Systems is made possible through the global initiative Powering Agriculture: An Energy Grand Challenge for Development (PAEGC). In 2012, the United States Agency for International Development (USAID), the Swedish International Development Cooperation Agency (Sida), the German Federal Ministry for Economic Cooperation and Development (BMZ), Duke Energy, and the Overseas Private Investment Cooperation (OPIC) combined resources to create the PAEGC initiative. The objective of PAEGC is to support new and sustainable approaches to accelerate the development and deployment of clean energy solutions for increasing agriculture productivity and/or value for farmers and agribusinesses in developing countries and emerging regions that lack access to reliable, affordable clean energy.

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https://energypedia.info/wiki/Toolbox_on_SPIS

About
Powering Agriculture: An Energy Grand Challenge for Development: https://poweringag.org

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ABREVIATIONS

Ah	Ampere hour
CWR	Crop Water Requirement
DC/AC	Direct Current / Alternating Current
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
Gd	Daily Global Irradiation
GIZ	Gesellschaft für Internationale Zusammenarbeit
GIWR	Gross Irrigation Water Requirement
GPFI	Global Partnership for Financial Inclusion
HERA	GIZ Program Poverty-oriented Basic Energy Services
H_T	Total Head
IEC	International Electrotechnical Commission
IFC	International Finance Corporation
IRR	Internal Rate of Return
IWR	Irrigation Water Requirement
MPPT	Maximum Power Point Tracking
NGO	Non-Governmental Organization
NIWR	Net Irrigation Water Requirement
NPV	Net Present Value
m^2	square meter
PV	photovoltaic
PVP	Photovoltaic Pump
SAT	Side Acceptance Test
SPIS	Solar Powered Irrigation System
STC	Standard Test Conditions
TC	Temperature Coefficient
UV	Ultraviolet
Vd	Daily crop water requirement
W	Watt
Wp	Watt peak

MAINTAIN

1. Establish and refine maintenance plan

↓

2. Select suitable service provider

↓

3. Implement maintenance routines

↓

4. Documentation and monitoring

MODULE AIM & ORIENTATION

Maintaining an SPIS does not require advanced technical skills. The overall effort is relatively low when compared to most other technologies. However, it does require good and systematic monitoring to anticipate problems and react timely to service needs. Given the relatively high initial investment in SPIS, it is important to properly maintain each component. In addition, it is important to monitor changes in other factors that affect the performance of the system, such as water availability, soil health, etc.

PROCESS STEPS

The maintenance routines will influence the efficiency of operation as well as the lifetime of the SPIS. The plan can be formulated by the producer with the help of a professional service provider. This module provides examples of maintenance checklists. It is important that the maintenance activities are documented and monitored precisely.

Concrete irrigation canal

(Source: Lennart Woltering)

1. ESTABLISH AND REFINE MAINTENANCE PLAN

After installation of the system an operations manual should be handed over to the producer (see **SET UP** Module) by the technology supplier, or service provider. The operations manual includes instructions for operation, maintenance and troubleshooting, along with the contact details of the service provider. Based on this, the service provider and producer should develop a maintenance plan. The producer and the agricultural advisor should revise the maintenance plan regularly.

Checklists are helpful tools to ensure that maintenance is done regularly and properly. For this SPIS toolbox have been developed with checklists on the proper maintenance of the PV generator and the irrigation system. The following aspects are important for each of the main components of an SPIS:

- **Water source and pump:** Solar pumps generally do not need a lot of maintenance if used in clean water, free of sand, sediments or aquatic plant growth. The water source therefore needs to be kept clean. Under these conditions pumps can last up to 10 years.
- **Solar panels and mounting structure:** Solar panels and their mounting structure generally require very little maintenance since there are no moving parts. Panels need to be kept clean and free of shade however, while the mounting structures should be stable. The PV array should be protected from animals and falling objects. Well cared for solar panels and mounting structures last up to 20 years.
- **Electronics and controls:** As controllers/inverters are sensitive to overheating, they have to be installed in a place where faultless operation is guaranteed. Factors to be considered include the ambient temperature, the heat dissipation capability (ventilation) and the relative humidity. For service and maintenance purposes, the controller should be easily accessible. Furthermore, there has to be a circuit breaker between the PV generator and the controller. Insects and small animals, such as lizards, like to build their nests in junction boxes and may destroy electronic components (e.g. by formic acid). Proper sealing of all openings (e.g. with cable glands) is essential
- **Irrigation System:** If drip irrigation is applied, the water must be filtered because the drip emitters can clog easily. Depending on the sediment load of the water, the filters must be cleaned regularly – this can be up to several times a day. This requires a certain level of technical knowledge and skills. In addition, the drip lines must be flushed regularly and the drip elements must be examined for blockages and replaced if necessary. The SPIS tool **MAINTAIN – Water Application Uniformity Guide** is applied to check the uniformity of water distribution in a drip irrigation system. The test is part of the system acceptance (see module **SET UP**) but is also part of a routine check. It should also be considered that for hard water (irrigation water with high dissolved lime concentrations), scaling up and clogging of pipes will occur if pipes are exposed to heat (direct sunshine).

On the next page an overview of common failures from the field and the associated fixes are given.

EXAMPLES OF COMMON INSTALLATION MISTAKES

Example of a dangerous cable connection

Although the installer already used rubber tape to insulate the wires, the cable connection is exposed on the ground. Electrical safety is questionable, particularly during irrigation or strong rains.

Galvanic corrosion of a manual tracking system

Over time, metal objects are subject to rust and corrosion. Corrosion is normally associated with non-precious metals such as steel, zinc and aluminum. In the presence of air, water or salt, these metals will corrode rapidly and need to be covered with a protective sealant.

Limited heat dissipation capability of corroded controller housing

The metal housing of the pump controller is extensively corroded. Furthermore, the housing has no natural ventilation and after closing its front door, overheating of the controller may happen.

EXAMPLES OF INADEQUATE MAINTENANCE

Accumulated grime at the lower end of a PV panel

Even though only a small part of the panel is covered in grime it has a big negative impact on the efficiency of the panel. It can be easily removed through scrubbing with a cloth covered sponge or soft brush with clean water.

Example of shadowing by not maintained ground vegetation

Solar panels produce less power when they are shaded and should be placed where there is no risk of shadows on them. A shadow falling on a small part of a panel can have a surprisingly large effect on output because the cells within a panel are normally all wired in series, the shaded cells will affect the current flow of the entire panel!

Example of a dangerous cable connection; Galvanic corrosion of a manual tracking system; Limited heat dissipation capability of corroded controller housing; Examples of inadequate maintenance Accumulated grime at the lower end of a PV panel; Example of PV shadowing by not maintained ground vegetation- (Source: Andreas Hahn, 2015)

OUTCOME / PRODUCT

- Maintenance plan;
- **MAINTAIN – Maintenance Checklist**;
- **MAINTAIN – Water Application Uniformity Guide**.

DATA REQUIREMENTS

- Instructions on proper maintenance of each component of the SPIS;
- checklist on water analysis.

PEOPLE / STAKEHOLDER

- Producers / producer groups;
- agricultural advisors;
- technology and service providers (electricians, companies providing PV systems).

IMPORTANT ISSUES

- Regular maintenance is indispensable for efficient and long term operation of any pumping and irrigation system.
- An SPIS is reliable and maintenance costs are low if maintained adequately.
- Maintenance plans should be reviewed regularly together with the technology/service provider and the agricultural advisor.

Cleaning of solar panels in Ghana as a routine maintenance activity

(Source: Lennart Woltering)

2. SELECT SUITABLE SERVICE PROVIDER

Since the SPIS contains multiple components that might not be installed by one provider, it is very likely that several stakeholders are involved in the maintenance of the SPIS.

The following **maintenance services** are relevant:

- training/introduction on operations and use of maintenance tools;
- regular inspection and maintenance visits (especially in first months of operation);
- provision of an operation manual and maintenance tools (hardcopies);
- warranty on components;
- troubleshooting service (online, telephone).

Ideally the contract with the technical provider and / or company responsible for installation should include maintenance services.

In case of system failure, do not forget to check if there is warranty on the components and service. However, do not try to repair the defective component on your own. There is a risk of losing warranty!

In case of the solar panels, warranty means performance guarantee, which usually decreases with the years (e.g. 90% performance after 10 years, 80% performance after 20 years).

It is recommended to select an installer who can also provide maintenance services. If this is not possible, two or three quotations of different service providers should be obtained and compared:

- determine if prices are quoted for same range/ type of service;
- discuss proposals with other technical experts (agricultural advisors, research institutes, etc.);
- discuss proposals with technical providers to understand the details;
- decide and contract the service provider **before the system starts operating**.

OUTCOME / PRODUCT

- Service contract.

DATA REQUIREMENTS

- Quotations from service providers;
- contract details.

PEOPLE / STAKEHOLDER

- Producers / producer groups;
- agricultural advisors;
- technology and service providers (electricians, companies providing solar-powered systems).

IMPORTANT ISSUES

- Ideally, the contract with technical provider and / or the company responsible for installation should include maintenance services.
- Technology and service providers can provide valuable assistance / training, ask for it!

3. IMPLEMENT MAINTENANCE ROUTINES

Once the maintenance plan is in place and the responsible persons identified, the maintenance should become a routine.

Critical regular maintenance activities are:

1. Check daily if the system is working. If the pump is not working:
   a) check the water source and pipes (any dirt, blockage, enough water?);
   b) check the electronics (any burned parts, loose wires, emergency lights?).
2. Inspect the system once a week with respect to:
   a) energy generated by PV system;
   b) pump performance (pumping rate);
   c) condition of water source (purity of water);
   d) condition of controller and electronics (visible signs of malfunctioning);
   e) blockage of drip emitters;
   f) condition of water storage facility and pipes (leaks, water level);
   g) condition of solar panels and their mounting system (stability, cleanness).
3. Clean solar panels every two to four weeks:
   a) clean water and a little scrubbing with a cloth covered sponge or soft brush should remove the most persistent grime;
   b) clean in the early morning or late evening, when panels are cool;
   c) do not step or walk on the panels as they could be damaged.

Note: Hot panels should not be sprayed with cold water – they might crack!

Visual check of the solar panels

(Source: Lennart Woltering)

4. **Throughout the year (every two to three months)** the PV system should be checked thoroughly so that:
   a) no plants grow close to the panel, the mounting structure, water source, controller, junction box, etc.;
   b) there is no shade on the panels (plants, poles, fences etc.), so as to permit maximum radiation;
   c) the fencing of the solar array is not damaged;
   d) the mounting structures are stable.

In addition, the reservoir should be cleaned and the irrigation system should be flushed regularly.

Note: Inspect your system **always after strong winds, hail storms, lightening or earth quakes** have occurred in your region.

After the first experience with a particular maintenance plan, the timing and frequency of maintenance can be adapted to suit the local conditions and capacities of the producer.

Note: Call your technology provider (panels, pumping, and controller) or electrician (electronics) who installed the system for help – this should be part of the service contract.

OUTCOME / PRODUCT

- Maintenance plan;
- maintenance sheets;
- checklist for visits to farm;
- weekly inspection sheet;
- bi-monthly inspection sheet;
- **MAINTAIN – Maintenance Checklist**.

PEOPLE / STAKEHOLDERS

- Producers /producer groups;
- agricultural advisors;
- technology and service providers (electricians, companies providing solar powered systems).

IMPORTANT ISSUES & DECISIONS

- Maintaining an SPIS does not require advanced technical skills and the overall effort is relatively low, when compared to other technologies.
- It is important to establish inspection and maintenance routines and to schedule them as part of the work plan of the farm.

4. DOCUMENTATION AND MONITORING

The monitoring system of a SPIS contains water meters, pressure meters and other gauges. The measurement of water flow, water levels and system pressures are critical for the operation of a SPIS. In addition, the monitoring system is used to:

- provide system data for the acceptance test after installation;
- observe the system's operation and performance at any time;
- control water provision and consumption;
- prevent ground water depletion and connected environmental risks.

Even a simple monitoring system with just a water flow meter and a water level gauge will be useful for improved decision making on SPIS operation.

During daily operation and regular inspections of the SPIS, the producer should collect and register systematically data about the system and its performance. This data is fundamental for the producer and service providers, to do regular analysis of the system performance. Observations, results of performance checks and repairs should be documented systematically. The establishment of a "log book" is strongly recommended

OUTCOME / PRODUCT

- Monitoring data booklet.

DATA REQUIREMENTS

- Costs incurred for replacements and services (bills, dates, brief description of cause);
- findings during maintenance visits by agricultural advisors and/or technology/service providers (maintenance check list);
- system failures (date, description).

PEOPLE / STAKEHOLDERS

- Producers /producer groups;
- agricultural advisors;
- technology and service providers (electricians, companies providing solar powered system).

IMPORTANT ISSUES

- Collecting data should be linked to the maintenance plan;
- data should be compiled regularly;
- producer might need assistance or/and training initially to enable correct data registration and analysis;
- maintenance efforts can be obsolete when groundwater in the region is not managed adequately. Groundwater levels should therefore also be monitored.

FURTHER READING, LINKS AND TOOLS

Links

NETAFIM: Drip Irrigation Maintenance. Retrieved from http://www.netafim.com/

SPIS tools

MAINTAIN – Maintenance Checklist

MAINTAIN – Water Application Uniformity Guide

The following tools that are assigned to other Modules are also relevant:

DESIGN – Site Data Collection Tool: on the human resources available on the farm for operation and maintenance

TECHNICAL GLOSSARY

Aquifer	Underground geological formation(s), containing usable amounts of groundwater that can supply wells or springs for domestic, industrial, and irrigation uses.
Chemigation	The process of applying chemicals (fertilizers, insecticides, herbicides, etc...) to crops or soil through an irrigation system with the water.
Conveyance loss	Loss of water from a channel or pipe during transport, including losses due to seepage, leakage, evaporation, and other losses.
Crop coefficient	Ratio of the actual crop evapotranspiration to its potential (or reference) evapotranspiration. It is different for each crop and changes over time with the crop's growth stage.
Crop Water Requirement (CWR)	The amount of water needed by a plant. It depends on the climate, the crop as well as management and environmental conditions. It is the same as crop evapotranspiration.
Current (I)	Current is the electrical flow when voltage is present across a conductor, or the rate at which charge is flowing, expressed in amperes [A].
Deep percolation	Movement of water downward through the soil profile below the root zone. This water is lost to the plants and eventually ends up in the groundwater. [mm]
Drawdown	Lowering of level of water in a well due to pumping.
Drip irrigation	Water is applied to the soil surface at very low flow rates (drops or small streams) through emitters. Also known as trickle or micro-irrigation.
Emitter	Small micro-irrigation dispensing device designed to dissipate pressure and discharge a small uniform flow or trickle of water at a constant discharge which does not vary significantly because of minor differences in pressure head. Also called a "dripper" or "trickler".
Evaporation	Loss of water as vapor from the surface of the soil or wet leaves. [mm]
Evapotranspiration (ET)	Combined water lost from evaporation and transpiration. The crop ET (ETc) can be estimated by calculating the reference ET for a particular reference crop (ETo for clipped grass) from weather data and multiplying this by a crop coefficient. The ETc, or water lost, equals the CWR, or water needed by plant. [mm]
GIWR	The Gross Irrigation Water Requirement (GIWR) is used to express the quantity of water that is required in the irrigation system. [mm]
Fertigation	Application of fertilizers through the irrigation system. A form of chemigation.

Financial viability	The ability to generate sufficient income to meet operating expenditure, financing needs and, ideally, to allow profit generation. It is usually assessed using the Net Present Value (NPV) and Internal Rate of Return (IRR) approaches together with estimating the sensitivity of the cost and revenue elements (See Module **INVEST**).
Friction loss	The loss of pressure due to flow of water in pipe. It depends on the pipe size (inside diameter), flow rate, and length of pipe. It is determined by consulting a friction loss chart available in an engineering reference book or from a pipe supplier. [m]
Global solar radiation (G)	The energy carried by radiation on a surface over a certain period of time. The global solar radiation is locations specific as it is influenced by clouds, air humidity, climate, elevation and latitude, etc. The global solar radiation on a horizontal surface is measured by a network of meteorological stations all over the world and is expressed in kilowatt hours per square meter [kWh/m^2].
Gravity flow	The use of gravity to produce pressure and water flow, for example when a storage tank is elevated above the point of use, so that water will flow with no further pumping required.
Head	Value of atmospheric pressure at a specific location and condition. [m]: Head, total (dynamic) Sum of static, pressure, friction and velocity head that a pump works against while pumping at a specific flow rate. [m]; Head loss Energy loss in fluid flow. [m]
Infiltration	The act of water entering the soil profile.
Insolation	The rate at which solar energy reaches a unit area at the earth measures in Watts per square meter [W/m^2]. Also called solar irradiance.
Irradiation	The integration or summation of insolation (equals solar irradiance) over a time period expressed in Joules per square meter (J/m2) or watt-hours per square meter [Wh/m^2].
Irrigation	Irrigation is the controlled application of water to respond to crop needs.
Irrigation efficiency	Proportion of the irrigation water that is beneficially used to the irrigation water that is applied. [%]
Irrigation head	Control unit to regulate water quantity, quality and pressure in an irrigation system using different types of valves, pressure regulators, filters and possibly a chemigation system.
Lateral	Pipe(s) that go from the control valves to the sprinklers or drip emitter tubes.
Latitude	Latitude specifies the north–south position of a point on the Earth's surface. It is an angle which ranges from 0° at the Equator to 90° (North or South) at the poles. Lines of constant latitude, or parallels, run east–west as circles parallel to the

	equator. Latitude is used together with longitude to specify the precise location of features on the surface of the Earth.
Leaching	Moving soluble materials down through the soil profile with the water.
Maximum Power Point Tracking (MPPT)	An important feature in many control boxes to draw the right amount of current in order to maintain a high voltage and achieve maximum system efficiency.
Net Irrigation Water Requirements (NIWR)	The sum of the individual crop water requirements (CWR) for each plant for a given period of time. The NIWR determines how much water should reach the crop to satisfy its demand for water in the soil. [mm]
Power (P)	Power is the rate at which energy is transferred by an electrical circuit expressed in watts. Power depends on the amount of current and voltage in the system. Power equals current multiplied by voltage (P=I x V). [W]
Photosynthesis	Photosynthesis is a process used by plants and other organisms to convert light energy into chemical energy that can later be released to fuel the organisms' activities (energy transformation).
Pressure	The measurement of force within a system. This is the force that moves water through pipes, sprinklers and emitters. Static pressure is measured when no water is flowing and dynamic pressure is measured when water is flowing. Pressure and flow are affected by each other. [bars, psi, kPa]
Priming	The process of hand-filling the suction pipe and intake of a surface pump. Priming is generally necessary when a pump must be located above the water source.
Pump	Converts mechanical energy into hydraulic energy (pressure and/or flow). Submersible pump: a motor/pump combination designed to be placed entirely below the water surface. Surface pump: pump that is not submersible and placed not higher than about 7 meters above the surface of the water.
Root Zone	The depth or volume of soil from which plants effectively extract water from. [m]
Salinity (Saline)	Salinity refers to the amount of salts dissolved in soil water.
Solar panel efficiency	Solar panel efficiency is the ratio of light shining on the panel, versus the amount of electricity produced. It is expressed as a percentage. Most systems are around 16% efficient, meaning 16% of the light energy is converted into electricity.
Suction lift	Vertical distance from the surface of the water to the pump. This distance is limited by physics to around 7 meters and should be minimized for best results. This applies only to surface pumps.

Surface irrigation	Irrigation method where the soil surface is used to transport the water via gravity flow from the source to the plants. Common surface irrigation methods are: Furrow irrigation – water is applied to row crops in small ditches or channels between the rows made by tillage implements; Basin irrigation – water is applied to a completely level area surrounded by dikes, and Flood irrigation – water is applied to the soil surface without flow controls, such as furrows or borders.
Transpiration	Water taken up by the plant's roots and transpired out of the leaves. [mm]
Voltage (U or V)	Voltage is the electric potential between two points, or the difference in charge between two points, expressed in Volts [V].