POWERING AGRICULTURE:
AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

TOOLBOX ON SOLAR POWERED IRRIGATION SYSTEMS (SPIS)

Module 5: Design

Food and Agriculture Organization of the United Nations

USAID FROM THE AMERICAN PEOPLE

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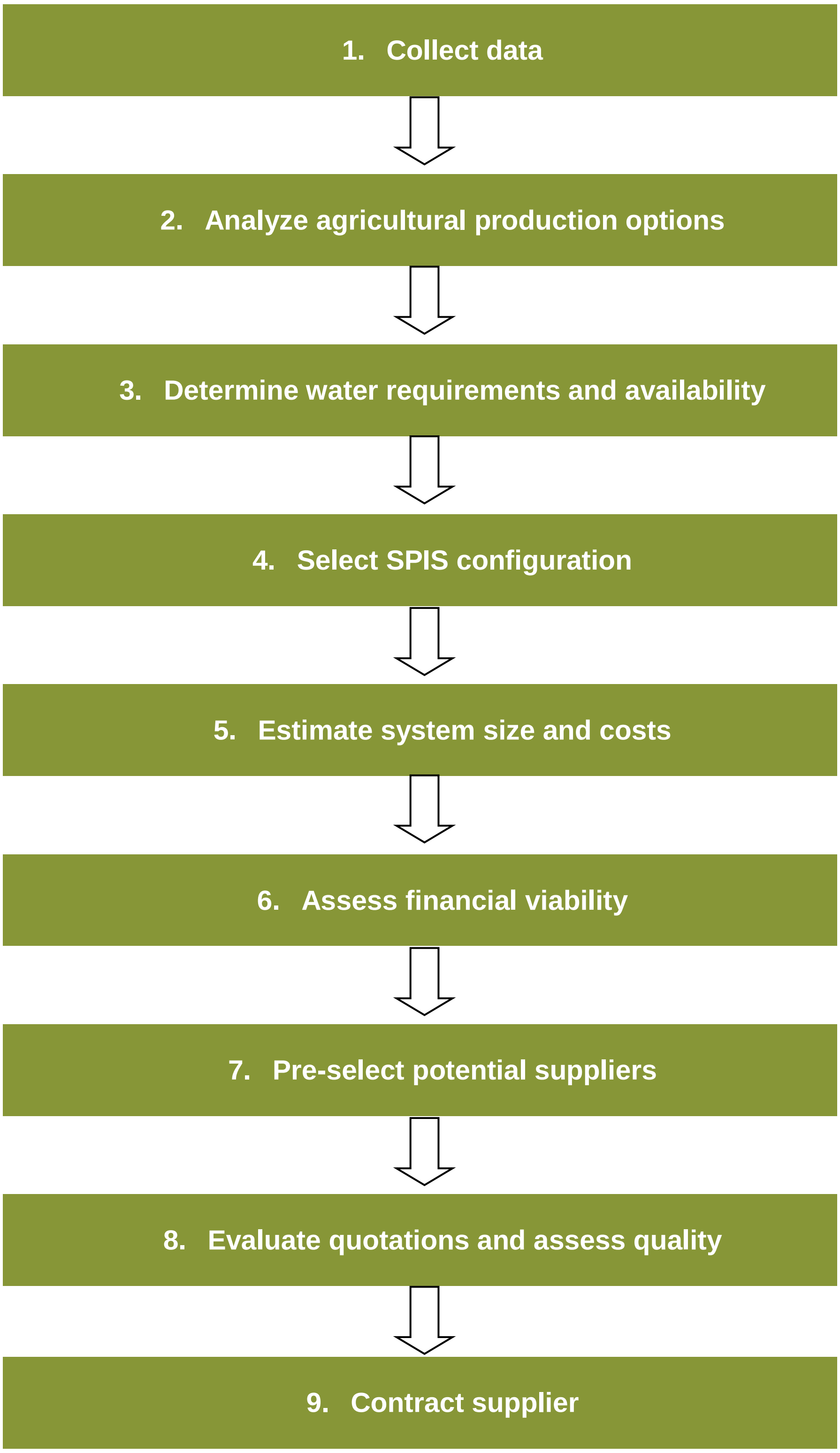
ABBREVIATIONS

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.

Photo: Lennart

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:

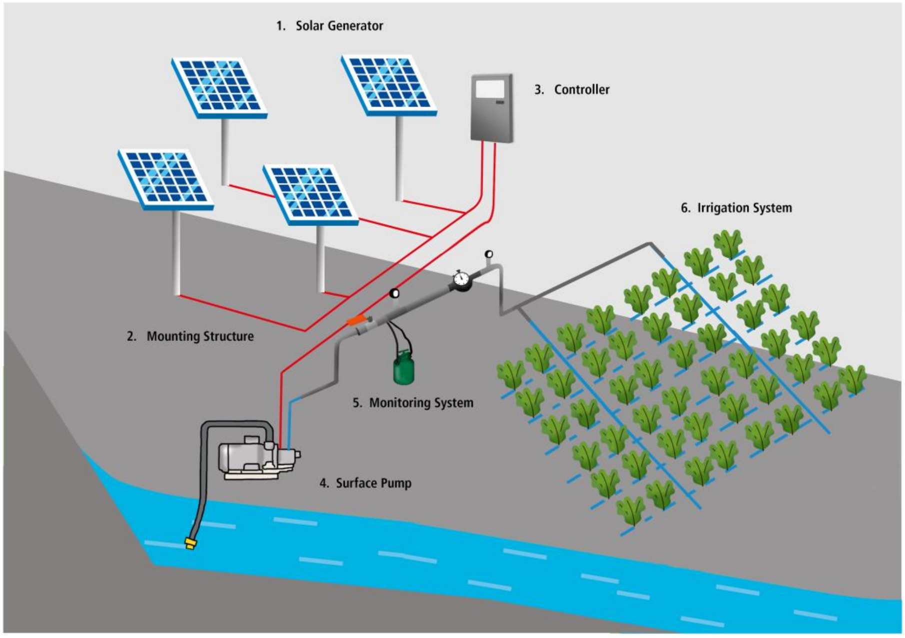
- solar mounting system (fixed or tracking);
- motor pump installation (submersible or surface);
- integration of a reservoir or not;
- irrigation method – mainly drip or surface irrigation.

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

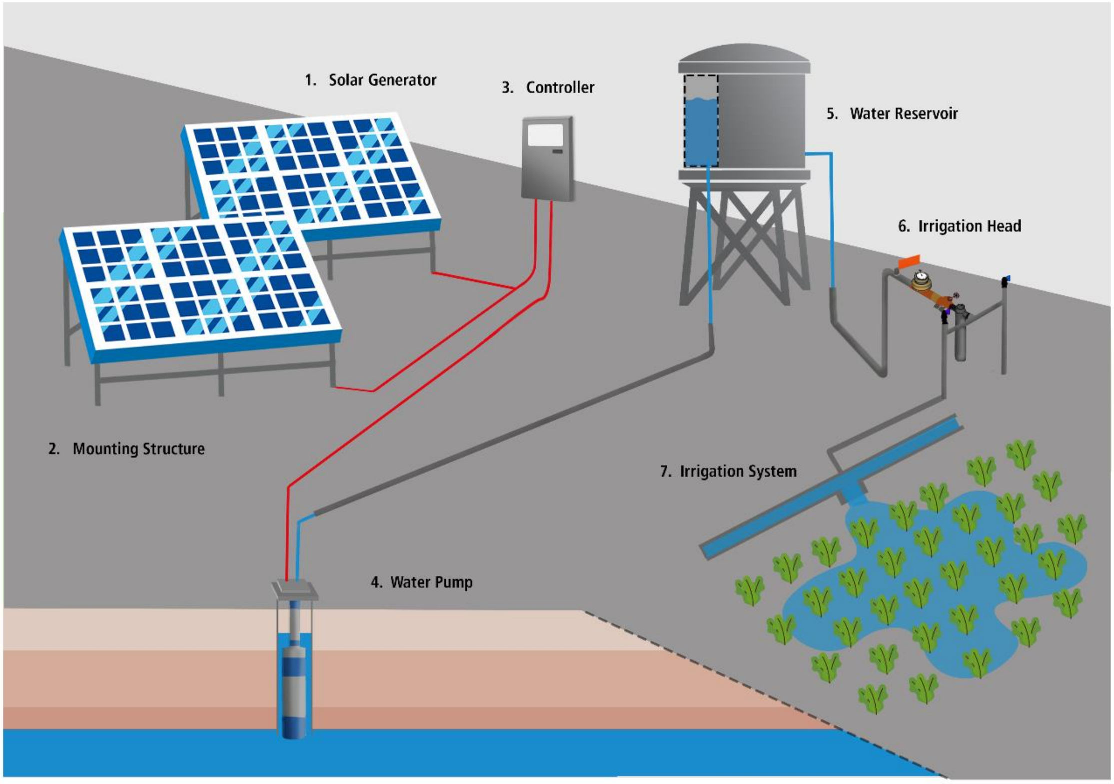
- Results of on-site data collection;
- results of comparative financial analysis.

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

Food and Agriculture Organization: Land & Water. Retrieved from http://www.fao.org/land-water/en/

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].