


TRAINING MANUAL FOR IRRIGATORS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952879

Document information

This manual has been possible thanks to the Project SolaQua (Accessible, reliable, and affordable solar irrigation for Europe and beyond), financed by the European Union's Horizon 2020 research and innovation program under grant agreement no. 952879. The members of the consortium are:

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- EUROMEDITERRANEAN IRRIGATORS COMMUNITY (EIC)
- CONFERENCE DES REGIONS PERIPHERIQUES MARITIMES D EUROPE - ASSOCIATION (CPMR)
- CONSIGLIO DELL'ORDINE NAZIONALE DEIDOTTORI AGRONOMI E FORESTALI (CONAF)
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This manual is the one that has been used in the training workshops for irrigators under SolaQua project. In addition, it is freely available in the webpage of the project and in zenodo platform (in SolaQua community).

For more details, please visit www.sol-aqua.eu

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Table of content

Summary 3
1. Introduction 4
  1.1. SolaQua in a nutshell 4
  1.2. Purpose and scope 5
  1.3. About this document 5
2. PVIS technology 6
  2.1. To be integrated in the pre-existing irrigation system 6
  2.2. To match PV production and irrigation needs 7
  2.3. To be robust against PV power fluctuations due to passing clouds 7
  2.4. To ensure reliability for, at least, 25 years 8
3. Types of PVIS 9
  3.1. Is it possible to sell electricity to the national grid? 10
4. Key Performance Indicators for PVIS 12
  4.1. Passing clouds 12
  4.2. Performance Ratio for photovoltaic irrigation 13
5. Examples of large-power PVIS 16
6. Self-assessment tool 19
  6.1. Inputs 19
  6.2. Outputs 20
7. SISIFO tool 22
8. Business models 24
9. References 26

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Acronyms

EU	European Union
FC	Frequency converter
IP	Irrigation Period
ISINPA	Irrigators, SMEs, Investors and Public Authorities
KEMT	Key Enabling Materials and Tools
MP	Motor-pump
PPA	Power Purchase Agreement
PR	Performance Ratio
PR_{PV}	PR considering only losses strictly associated to the PV system itself
PV	Photovoltaic
PVIS	Photovoltaic Irrigation Systems
RE	Renewable Energy
SI	Solar Irrigation
SME	Small and Medium Enterprise
UR_{EF}	Ratio of the irradiation required to keep P_{AC} stable during the irrigation scheduling to the same irradiation during the IP
UR_{IP}	Ratio of the total irradiation throughout the irrigation period to the total annual irradiation
UR_{PVIS}	Ratio of the irradiation strictly required to keep P_{AC} equal to the stable AC power requirement to the total irradiation throughout the IP
WP	Work Package

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Summary

This document was developed under SolaQua project with the aim of training irrigation associations professionals regarding PVIS technology and business models, and will be used during the training sessions organized by SolaQua project oriented to those professionals.

The document includes information about photovoltaic irrigation systems (PVIS), particularly their main characteristics, ways to evaluate them, and examples of already installed PVIS. It also includes a description of how to use the Self-Assessment Tool to do a preliminary planning of a PVIS, as well as information on how to perform a more detailed simulation of a PVIS using a freely available software called SISIFO. The document ends with a description of the business model proposed in the project.

Along the training sessions and with the support of this training manual, professionals of irrigation associations will be provided with the necessary skills to identify both the suitability of PVIS to their needs, and technical alternatives and providers, as well as to carry out the evaluation of offers and the implementation and management of PVIS.

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1. Introduction

1.1. SolaQua in a nutshell

SolaQua's overall objective is to increase the share of **renewable energy (RE)** consumption in Europe by facilitating the market uptake of **photovoltaic irrigation systems (PVIS)** in the farming sector. A PVIS is based on a combination of **photovoltaic (PV)** technology, hydraulic engineering, and high-efficiency water management techniques to optimize irrigated farming.

The consortium of SolaQua, which represents more than 70% of European irrigators, is aware of the potential of PVIS to decisively improve the sustainability of farming and rural communities in Europe. Nevertheless, to fulfil this potential, it is necessary to overcome the existing barriers to the market uptake of SI. To do this, SolaQua will accelerate the clean energy transition in European agriculture by facilitating the development of a well-functioning market for SI. This will be done by producing and exploiting a set of 7 **Key Enabling Materials and Tools (KEMT)** and by creating awareness, skills, action, engagement, and commitment (ASAEC) opportunities among more than 150,000 farmers, 70 local SMEs, and 40 Public Administrations in Europe and beyond.

The execution of SolaQua will result not only in a reduction of the cost of PVIS for farmers but also in the availability of effective standards for consumers and environmental protection, more efficient policies and supporting schemes, and new business opportunities for SMEs. Furthermore, to exploit the project's results and to trigger the PVIS market, SolaQua will facilitate a joint promotion of more than 100 MW of reliable and affordable PVIS led by the end-users themselves: the farmers.

To achieve the overall objective of increasing the share of RE in the European farming sector by facilitating PVIS market uptake, SolaQua has established the following 5 specific objectives:

1. **Produce and disseminate a set of 7 KEMT**, designed to solve technical, economic, and legal issues which are acting as barriers for the market uptake of SI.
2. **Produce awareness and skills of PVIS among the target groups in six countries** (France, Italy, Spain, Romania, Portugal, and Morocco). At least 150,000 potential end-users will be reached, 70 SMEs will be trained, and 38 Public Authorities will be able to produce more informed policies and supporting schemes.
3. **Trigger the European PVIS market by facilitating a joint promotion of at least 100 MW of PVIS**, exploiting SolaQua's KEMT and led by the target audiences engaged in PVIS because of the project's dissemination and communication actions.
4. **Increase the effectiveness of public supporting schemes for on-farm investments for the promotion of PVIS**: SolaQua will produce a new European Agrarian Fund for Rural Development (EAFDR) financial instrument that will be implemented in 3 European regions and will support more than 40 MW of new PVIS capacity.
5. **Facilitate market uptake of reliable and affordable PVIS in markets outside the EU** that will result not only in increased cooperation but also in business opportunities for European SME´s and investors.

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1.2. Purpose and scope

This document was developed under SolaQua project to be used during the training sessions with irrigation associations.

1.3. About this document

This document contains information to train professionals of irrigation associations regarding PVIS technology and business models.

It is going to be used during the training sessions oriented to such professionals in order to equip them with the necessary skills to identify the suitability of PVIS to their needs, the identification of technical alternatives and providers, the evaluation of offers and the implementation and management of SI.

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2. PVIS technology

Traditionally, photovoltaic pumping systems of small power, typically less than 40 kW, have been called Solar Pumping or Solar Irrigation. This small power was used to supply drinking water and to irrigate small areas, but it did not satisfy the needs of professional irrigators in southern Europe. High-power solutions were only technically feasible if they were hybridized with the grid or if batteries were incorporated, but they were economically unfeasible due to their high price.

The Polytechnic University of Madrid developed solutions that made it possible to extend the power of solar pumping systems to that needed by European irrigators, solving the problems associated to PV power intermittences without the need for batteries and without hybridizing with the grid and saving up to 70% in electricity costs for the farmers. To distinguish it from previous systems, they have been called stand-alone large-power PV irrigation systems, in short PV Irrigation Systems (PVIS). The PVIS were demonstrated on a real scale and in real operating conditions in the European project MASLOWATEN (www.maslowaten.eu).

A PVIS is commonly made up of a PV generator, a frequency converter (FC), a standard centrifugal pump and a water tank and/ or an irrigation network (Figure 1) [1]. These systems do not integrate batteries and a connection to the national grid is not strictly necessary.

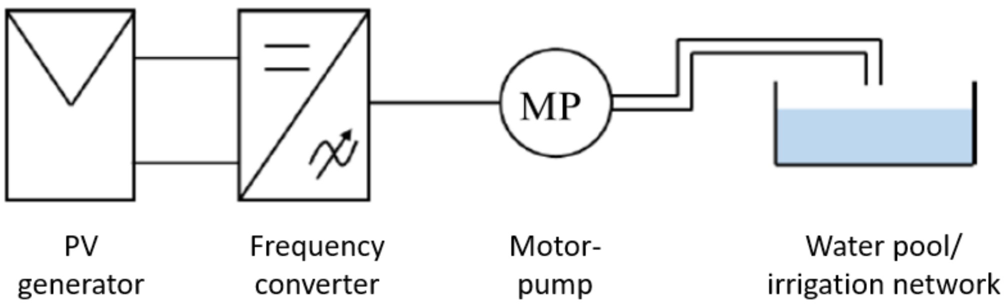

Figure 1 – Components of a PV irrigation system: PV generator, frequency converter, motor-pump and water tank.

It is crucial to keep in mind that a PVIS is based on a combination of PV technology, hydraulic engineering, and high efficiency water management techniques. A PVIS must [2]:

- Be **integrated in the pre-existing irrigation system**.
- **Match PV production and irrigation needs**.
- Be **robust against PV power fluctuations** due to passing clouds.
- **Ensure reliability for**, at least, **25 years** to guarantee the compliment of the business plan.

2.1. To be integrated in the pre-existing irrigation system

A significant part of the potential PV irrigation market will be the retrofitting of already existing irrigation systems fed by the national grid or diesel generators [14]. Accordingly, it makes sense to keep the already existing irrigation structure and to integrate the PV system on it.

In addition to the irrigation system components, it is also very important to know the irrigation scheduling and possible restrictions.

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2.2. To match PV production and irrigation needs

The PV energy, the availability of water in the source and the water needs of each crop change throughout the year [3], [4]. Thus, when designing a PV irrigation system, both solar energy and water resources should be considered [5]. Accordingly, the yearly production of the PV generator should be as similar as possible to the yearly profile of water demand. Since the water pumped should be adapted to the needs of the crop, which is normally high in summer months and null in winter months, it is good news that the water requirement is higher when more solar energy is available [4], [6], [7].

The use of a North-South horizontal axis tracker (1xh) is highly recommended [2], [8] since it presents four main advantages:

1) it maximizes the water pumped during the irrigation period (the match between the yearly profile of irradiance and the yearly water demand of the crops is very good, much better than using the typical static structure facing the Equator [8]);

2) the daily profile of irradiance is almost flat in this type of tracker [8], which also benefits an irrigation system [9];

3) the tracker also allows the extension of the irrigation time per day when compared to the typical static structure oriented to the Equator [2], [8], [10]; and

4) it requires less nominal power to pump the same water volume than PV static structures [2], [8].

2.3. To be robust against PV power fluctuations due to passing clouds

This is another key point to assure the economic feasibility since PVIS are large-power systems and do not integrate batteries.

The frequency converters adjust both the output voltage and the frequency to the PV- power available which, in turn, depends on the in-plane incident irradiance. Two types of PV-power variations affect the system performance: the variation throughout the day that can be calculated mathematically and the variation due to passing clouds that occurs in a random way [2], [11], [12], [13].

This latter variation is essential to the reliability of large-power PVIS [14]. In fact, the quick intermittence of PV power due to the passing of clouds (up to 80% of PV-power variation in one minute [15]) can translate into control instabilities leading to a sudden motor shutdown encompassing water hammer and AC overvoltage that seriously threaten the integrity of both the hydraulic and electric components [2], [16]. Particularly, the deep boreholes and large water flows lead to strong water hammers which can damage or decrease the lifetime of the hydraulic components of the system [2]. On the other hand, the electric components can be damaged due to the overvoltage caused both by the abrupt stop of the FC and the long length of the wires between the FC and the motor-pump.

These instabilities have been solved through the implementation of specific FC tuning control procedures and algorithms. These procedures take advantage of the possibility of power regeneration of the centrifugal pumps and have been patented [8]. This way, instead of a sudden stop of the motor-pump, its frequency is reduced but the motor-pump does not stop.

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An example of the implementation of this control algorithm can be seen in Figure 2. It shows both the motor-pump frequency and the irradiance received by the PV generator between 10:59:31 and 11:02:24 in the 19th of October 2017, in a 360 kWp stand-alone PVIS in Villena (Spain). The irradiance (in orange) fallen sharply due to a cloud (it falls more than 75% in 20 seconds), but the frequency converter does not abruptly stop (its frequency decreases 13% in the same period).

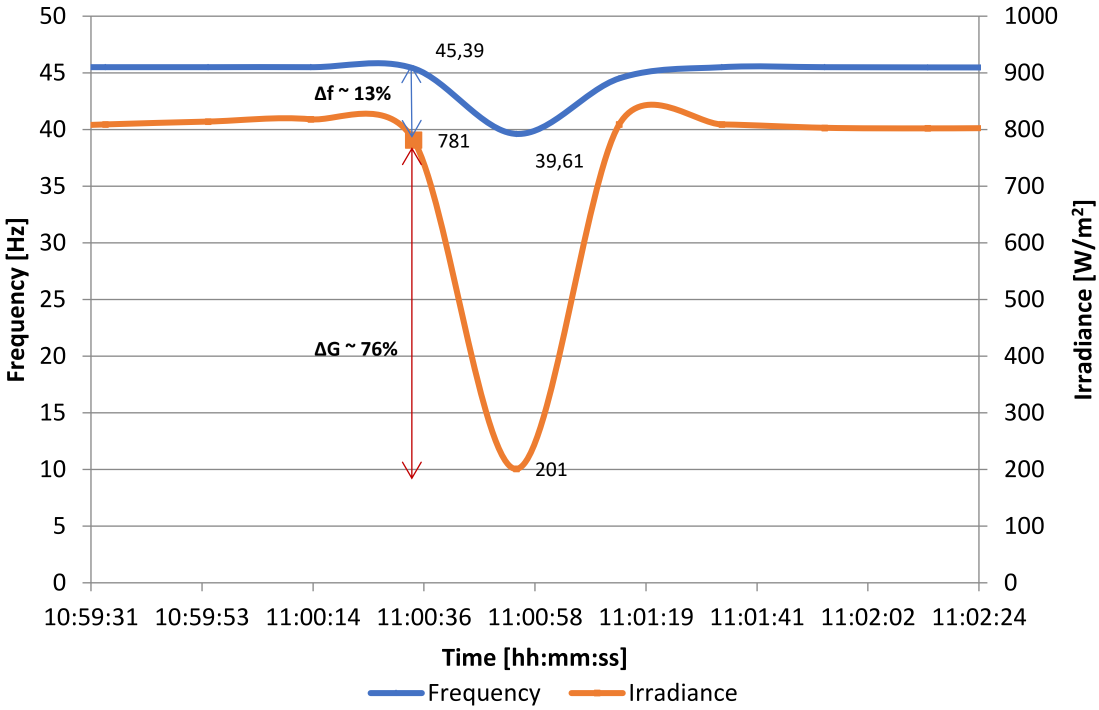

Figure 2 – Motor-pump frequency and irradiance on 19th of October 2017, Villena (Spain).

It should be mentioned that the use of batteries was not considered as an option to solve this problem because their reliability has not been proven yet, as well as due to issues related to its economic feasibility.

2.4. To ensure reliability for, at least, 25 years

Technical specifications which include quality control procedures were developed within MASLOWATEN project, best practices were developed under SolaQua project[1], and SMEs have received training on PVIS. Accordingly, the inclusion of these specifications in the contracts, and the installation, operation and maintenance by these SMEs will not only guarantee long-term reliability but also the optimization of costs and energy efficiencies.

[1] The Best practices guide for planning, installing and operating (which includes quality control procedures) is available at www.sol-aqua.eu.

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3. Types of PVIS

PV irrigation systems can be, according to their energy source, **Stand-alone PVIS** or **Hybrid PVIS**.

In stand-alone PVIS, the irrigation system is only fed by the energy produced by the PV generator using frequency converters (Figure 3).

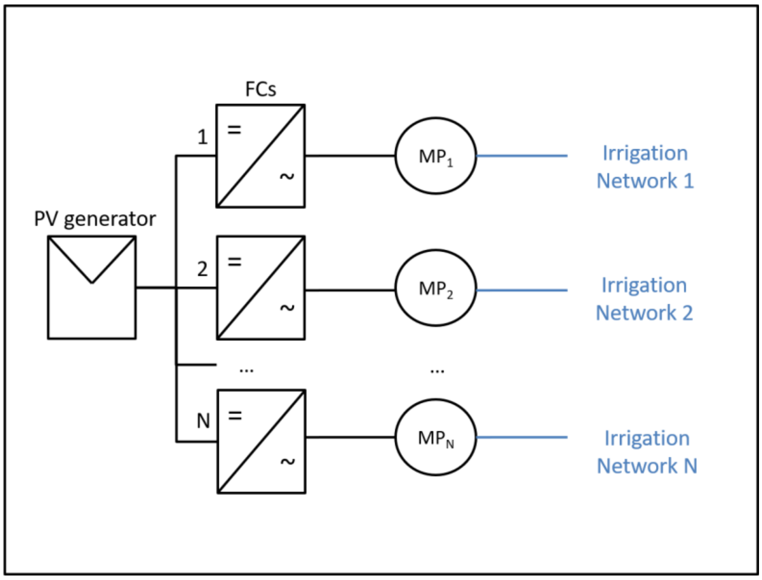

Figure 3 - Stand-alone PVIS: the irrigation system is fed by energy produced by PV generators. Figures depicted in black represent the electrical part, in blue the hydraulic part. FCs stands for frequency converters, while MP is for motor-pump.

In hybrid PVIS, the irrigation system is fed both by the energy produced by the PV generator and by other energy source. The other energy source can be a diesel generator set, a gas generator set or the conventional electricity grid.

Two types of hybridization can be found:

- **Hydraulic hybrid systems** (Figure 4): the hybridization is carried out into the hydraulic circuit – the water outflow pipes are associated in parallel, and the sources of energy are not electrically interconnected. These systems can work isolated from the electrical grid and therefore, may be an interesting solution in locations far from the grid.
- **Electric hybrid systems** (Figure 5): The hybridization among the PV generator and the other source is carried out in the electric part of the system. These systems are considered as self-consumption systems and are subject to applicable regulations.

A hybrid PVIS is needed when the irrigation network requires more irrigation hours than those available with PV (usually due to the diameter of the pre-existing tubes). In addition, hybrid PVIS are an interesting solution if there is a peak of irrigation in some months of the year – for example, instead of oversizing the PV generator, the end-user can rent a diesel generator for some months. A hybrid PVIS can also be considered to get the irrigator operator confidence in the PV system.

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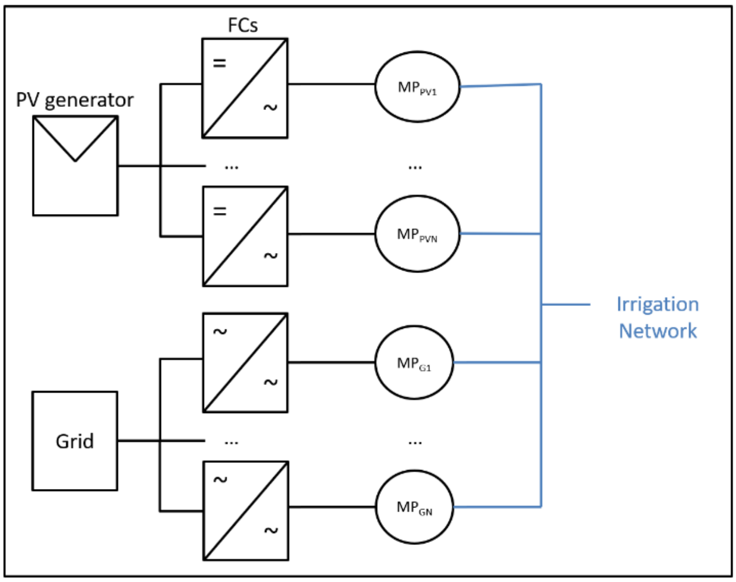

Figure 4 - Hydraulic hybrid systems: the irrigation system is fed by energy produced by PV generators but also from other sources (diesel or gas generator sets and conventional electricity grid), but hybridization is carried out into the hydraulic circuit.

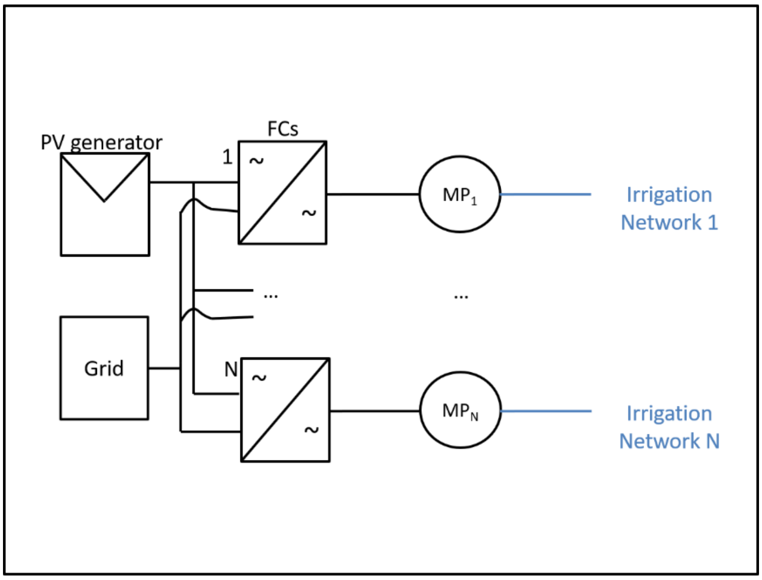

Figure 5 - Electric hybrid systems: hybridization among PV generators and the other sources is carried out in the electric part of the system.

3.1. Is it possible to sell electricity to the national grid?

A PVIS is not a photovoltaic self-consumption system, understood as the traditional PV system connected to the grid through an inverter in which the loads (in this case, the motor pumps) are fed from the low voltage grid where the inverters inject the PV electricity. A PV self-consumption installation does not allow to disconnect from the conventional electricity grid, so the savings are limited by having to contract the power terms of the electricity bill. However, the PVIS can work isolated from the grid, which will allow to obtain greater savings.

Although, if the irrigation period of a specific crop is only in few months of the year, some countries allow the possibility of export the PV electricity to the national grid in the non-irrigation period. To do this, a grid-inverter must be added to the system, as well as a single pole

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double throw switch. This way, the system is a PVIS during the irrigation period (the PV generator is connected to the frequency converters through the switch), while it is a typical grid-connected system outside the irrigation period (the PV generator is connected to the grid-inverter through the switch). This configuration can be seen in the next figure (in which the switch is in the PVIS position).

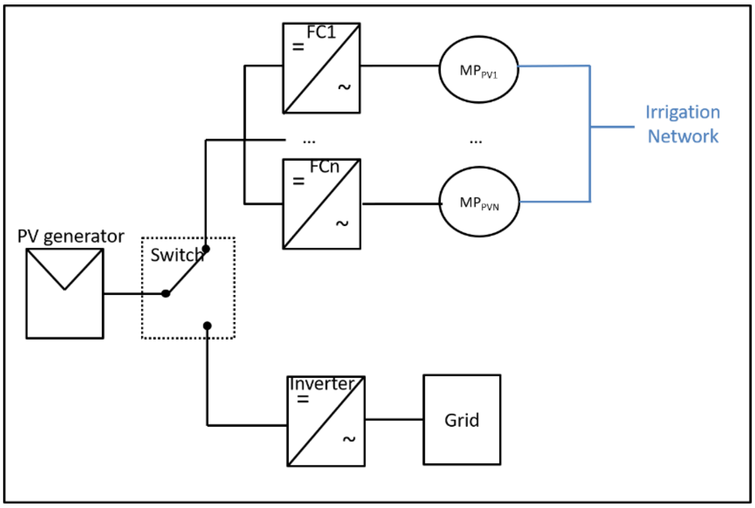

Figure 6 - Mixed systems: the system is a PVIS during the irrigation period, and a grid-connected system outside the irrigation period. The switch allows the change between the two operating modes and, in the case of this figure, the switch is in the PV irrigation system position.

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4. Key Performance Indicators for PVIS

It is very important to be able to assess the quality of a PVIS. The level of satisfaction of the end user, the irrigation community, is, in many cases, a good indicator of the correct functioning of the system. In any case, to properly assess the quality of the system it is necessary to have a set of objective indicators that go beyond the opinion of the irrigator that could mask what is really happening to the system. On the one hand, a PVIS requires an adaptation of the habits of an irrigator used to other types of irrigation systems, like those connected to the grid or to a diesel generator. The adaptation period can cause the irrigator a certain temporary discomfort that is not justified by a malfunction of the system. On the other hand, there are anomalous functioning of the system, imperceptible to the irrigation community and, therefore, compatible with a very high level of satisfaction, which can lead on to major breakdowns in the medium and long term if no corrective actions are taken.

4.1. Passing clouds

Clouds, by themselves, do not pose a risk to the PV irrigation system. If the cloud progressively covers the PV generator, the power available at its output decreases. Under these circumstances, it is possible that the generated power is less than the minimum required by the pumping system to pump water. If this happens during a certain period of time, usually one minute, the system stops. This type of stop is controlled by the system itself and does not pose a risk to any of its components. It is what is called a “controlled stop”.

Some clouds can partially or totally cover the PV generator in such a way that a quick intermittence of PV power occurs. This quick intermittence can carry out control instabilities, leading to a sudden stop of the frequency converter, encompassing water hammer and AC overvoltages that seriously threaten the integrity of both the hydraulic and electric components of the PVIS. It is what is called an “abrupt stop”.

To avoid those instabilities, ad-hoc control algorithms have been developed to support PV power instabilities without the need of batteries [17]. Therefore, the system must be able to withstand sudden intermittences of PV power caused by passing clouds.

To assess whether the system resists quick PV power intermittences due to passing clouds a passing-cloud resistance ratio (σ_{cloud}) is defined as the ratio of resisted clouds to the total number of clouds in a specific period of time. The “total number of clouds” takes into account clouds that cause quick PV power drops (intermittences), no matter whether they produce or not a frequency converter abrupt stop. In the same way, the “number of resisted clouds” considers just clouds that cause quick PV power drops that do not lead on to abrupt stops. The ”quick” adjective, in this context, is determined by the size of the PV generator, the design characteristics of the PV irrigation system and the weather conditions of the place where the PV generator is located. Abrupt stops are usually provoked by deep PV power drops in short periods of time. A good approximation for many of the systems would be to consider clouds that cause 50% irradiance decreases in a 3- or 4-seconds interval and associated to 40% PV power decreases.

It is reasonable to require values greater than 95% in a general specification of the passing-cloud resistance ratio in the framework of quality testing procedures.

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4.2. Performance Ratio for photovoltaic irrigation

To analyze the global performance of PV grid-connected plants it has been described the *performance ratio* (*PR*), which provides an indication of both the technical quality of the PV system's equipment and the efficient use of the available irradiation. It gives a good idea of how much of the ideally available PV energy has been used.

Due to the specificities of PVIS, it is interesting to distinguish between irradiation losses for three different reasons: the non-irrigation period – associated to the crop –, the intrinsic characteristics of the irrigation system design, and external circumstances that may affect the *PR* like the irrigation community habits or the different rainfall over time. To take them into consideration, the *PR* is factorized in four different factors (R.H. Almeida et al., 2018):

1. The PV Performance Ratio, PR_{PV}, is the *PR* considering only losses strictly related to the PV system itself. It is intrinsic to the technical quality of the PV component, the correct operation of the PLC control and its maintenance. Includes losses due to actual versus nominal peak power, dirtiness, DC/AC conversion and losses caused by the PLC malfunction (including those provoked by abrupt stops) and thermal losses.
2. The Utilization Ratio due to the Irrigation Period, UR_{IP}, is the ratio of the total irradiation throughout the irrigation period to the total annual irradiation. It is intrinsic to the irrigation period, which depends on water needs of the crop and the climatic conditions, in case of direct pumping, or on the relation between water needs, pumping capacity and pumped water storage capacity, in case of pumping to a water pool.
3. The Utilization Ratio due to the PV Irrigation System, UR_{PVIS}, is the ratio of the irradiation strictly required to keep the pump running, according to the conditions imposed by the irrigation system, to the total irradiation throughout the IP. It is intrinsic to the PVIS design and is highly dependent on weather conditions.
4. The Effective Utilization Ratio, UR_{EF}, considers irrigator's decisions like the irrigation scheduling. The irrigation habits acquired by de the irrigator are critical to keep this index at adequate values

To achieve a better performance of the PVIS, a good design of the system, good quality of its components and a proper use by the end user are required. The latter implies PV irrigation centred at midday, planning of maintenance tasks in cloudy days or during the night and a good management of water consumption.

Figure 7 to Figure 9 show an example of how a PV irrigation system has been used along several days. In all of them, the orange line represents the available irradiance, the black line the irrigation schedule and the green one the real time the system is pumping.

Figure 7 shows an irrigation schedule that goes from 9:30 to 12:40 and from 15:30 to the end of the day. Before 8:30 and between 12:40 and 15:30 there is no irrigation scheduled, so the system will not start, no matter whether there is or not enough irradiance to pump water. Even though the irradiance begins to grow at 8:30, the system does not start until 9:15 as there is not enough PV power available. The system stops at 12:40 and restarts at 15:30 due to the irrigation schedule, but it could be running in that time interval as there is enough irradiance to pump. As the available irradiance drops under a threshold at 15:45 and there is not enough PV power available, the system stops for 8 minutes and starts again when the irradiance rises. The system finishes pumping at 16:50, again due to lack of irradiance. The performance of the system would be better if the scheduled irrigation period covered all the hours of greatest irradiance (from 9:15 to 16:50).

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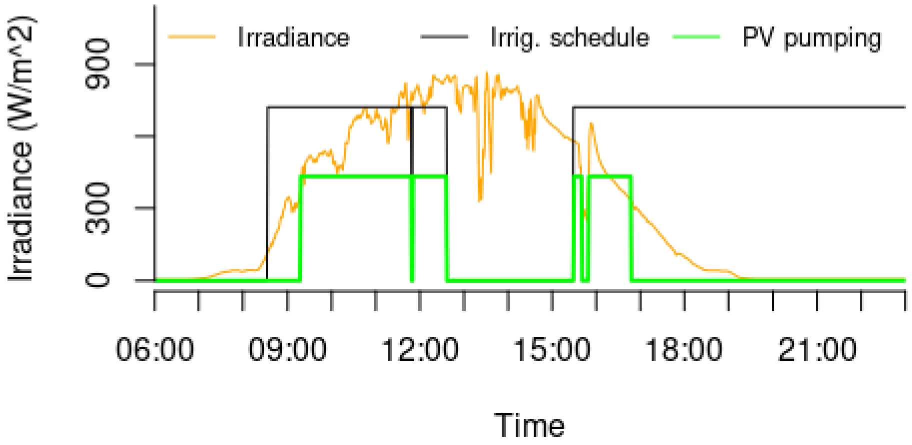

Figure 7 – Irradiance, irrigation schedule and PV pumping real time – Day 1

Figure 8 shows a day in which, despite being enough irradiance to make the system work, irrigation has not been scheduled and the system does not start. All the available irradiance is wasted.

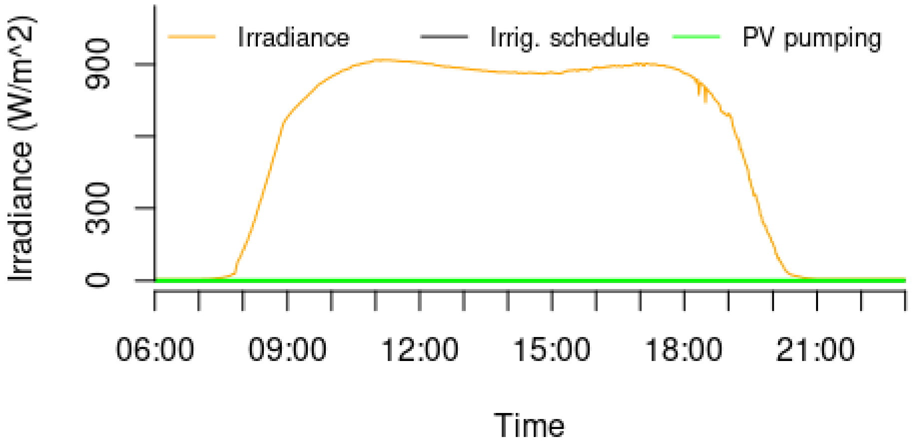

Figure 8 – Irradiance, irrigation schedule and PV pumping real time – Day 2

Finally, Figure 9 shows a day in which irrigation was initially scheduled properly, but the system was manually stopped for maintenance. To improve the performance, maintenance could have been planned for the evening or a cloudy day.

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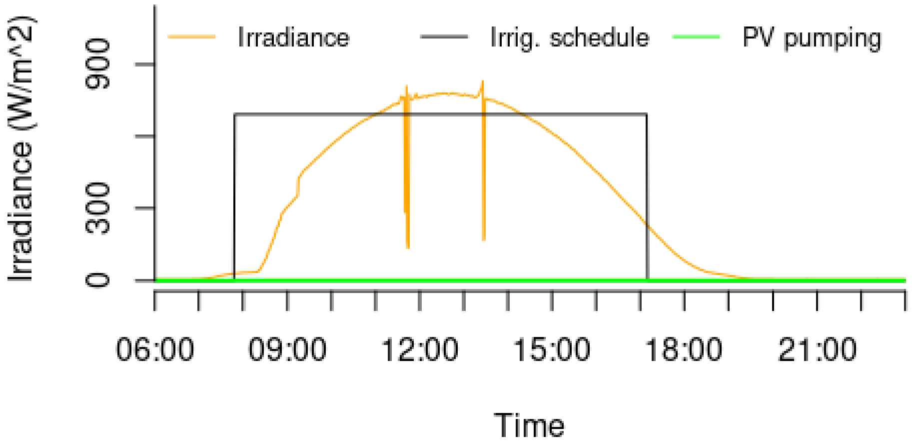

Figure 9 – Irradiance, irrigation schedule and PV pumping real time – Day 3

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5. Examples of large-power PVIS

The first six real-scale large-power PVIS with the previous solutions were installed in real farms of farmers, cooperatives, agro-industries and irrigator communities to show their reliability in real operating and their economic feasibility to introduce them into the market. These PVIS are:

1. A 360 kWp stand-alone PVIS pumping water from a deep-borehole to a water pool at a variable water flow (in Villena, Spain), see Figure 10 [18];

Figure 10 – Stand-alone PVIS in Villena, Spain.

2. A 160 kWp stand-alone PVIS with one pump elevating water from a borehole to an intermediate tank at a variable water flow and other pump to irrigate at a constant pressure through pivots (in Alaejos, Spain), see Figure 11 [19];

(a) (b)

Figure 11 – Stand-alone PVIS in Alaejos, Spain: (a) 160 kWp PV generator; (b) intermediate water tank.

3. A 40 kWp stand-alone PVIS with 2 pumps pumping from two different boreholes at a variable water flow to an intermediate tank and one pump to irrigate at a constant pressure through sprinkles (in Sardinia, Italy), see Figure 12 [20];

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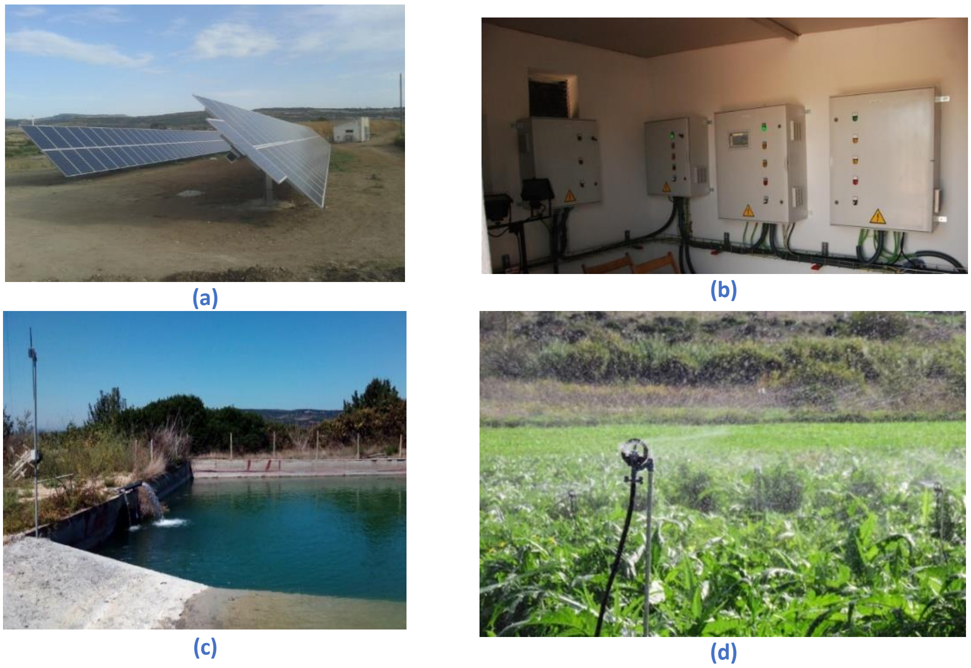

Figure 12 – Stand-alone PVIS in Sardinia, Italy: (a) 40 kWp PV generator; (b) engine room; (c) water pool; (d) low pressure sprinkles.

4. A 120 kWp hybrid PV-grid drip irrigation systems, with 2 pumps and hybridization in the electric part of the system (in Tamelalt, Morocco), see Figure 13 [21];

Figure 13 – Hybrid PV-grid drip irrigation systems in Tamelalt, Morocco: (a) 120 kWp PV generator; (b) engine room; (c) motor-pumps; (d) olive tree plantation.

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5. A 140 kWp hybrid PV-diesel drip irrigation systems, with 3 pumps and hybridization in the hydraulic part of the system (in Alter do Chão, Portugal), see Figure 14 [22].

Figure 14 - Hybrid PV-diesel system in Portugal.

6. A 213 kWp stand-alone system pumping from a channel to an elevated water pool (in Aldeanueva de Ebro, Spain), see Figure 15. UPM recorded a virtual visit to this system, which is available at https://www.youtube.com/watch?v=OQiRtQ4nCww&t=138s.

Figure 15 - Stand-alone PVIS in Aldeanueva de Ebro, Spain.

In addition to this solution, some other stand-alone and self-consumption projects have been installed in the Iberian Peninsula by different companies.

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6. Self-assessment tool

Under SolaQua project, the SolaQua Self-Assessment Tool has been developed. It is a Web App that allow **farmers** to obtain a **preliminary planning of a PVIS** based in the main characteristics of their farms.

The Self-Assessment Tool is freely available at www.sol-aqua.eu and it includes the most common configurations of irrigation systems: water pool and direct pumping systems.

The tool is user-friendly, and its main objective is to provide a general idea of the potential of PVIS in each case.

6.1. Inputs

To obtain the preliminary planning, farmers must introduce the location of their farm (latitude and longitude, as can be seen in Figure 16) and the main characteristics of their irrigation systems (see Figure 17). The needed characteristics of the irrigation system are:

- Type of pumping: water pool or direct pumping.
- The total head.
- The design flow.
- The irrigation period (first and last month of irrigation).
- The total target water flow for irrigation period.

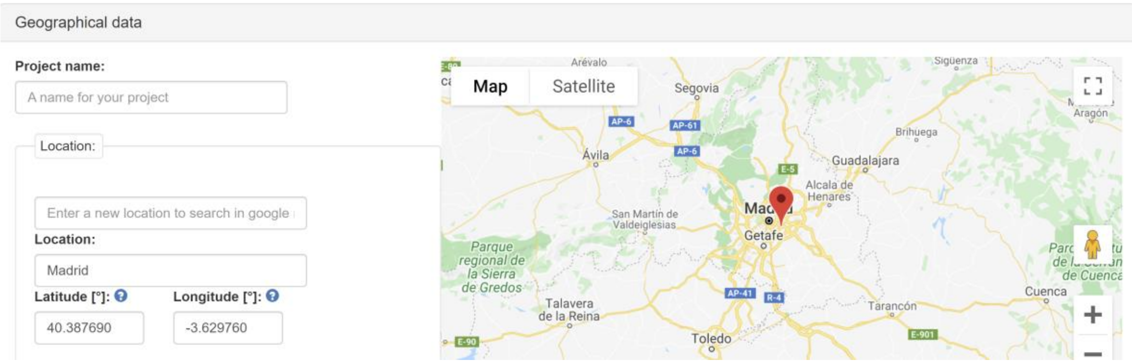

Figure 16 – Geographical data needed in the Self-Assessment Tool.

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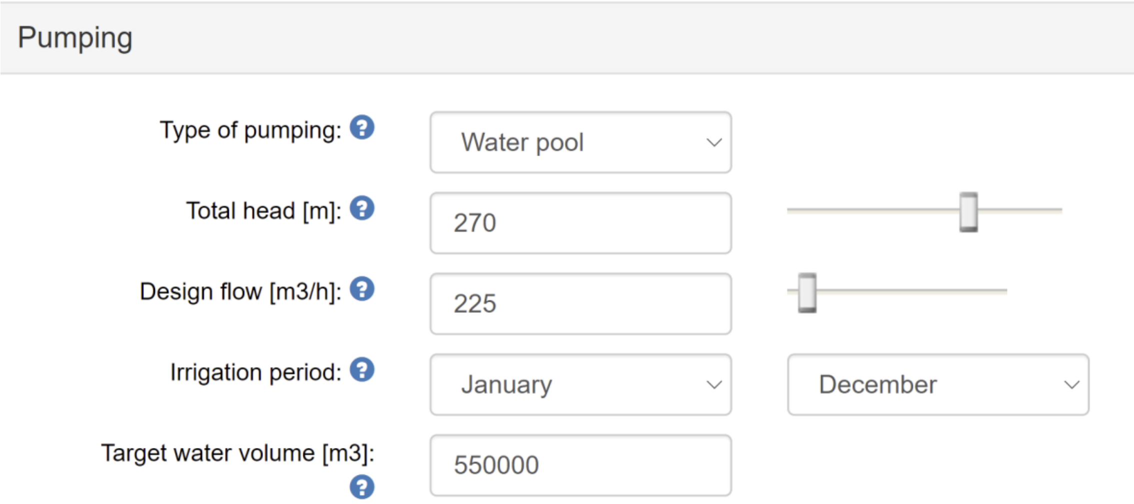

Figure 17 – Pumping system characteristics needed in the Self-Assessment Tool.

In addition to this information, if the Irrigation Community/farmer wants to have more information or to receive a more detailed simulation, name and e-mail must be included (see Figure 18).

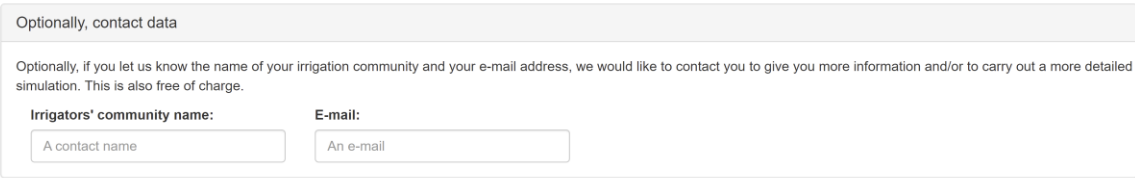

Figure 18 – Contact information.

6.2. Outputs

The results or outputs obtained from the SolaQua Self-Assessment Tool are the following:

- PV peak power.
- Yearly energy generated.
- Yearly water pumped.
- Required surface for the PV generator.

From the examples of Figure 16 and Figure 17, the following results are obtained (see):

- PV peak power: 367,2 kWp.
- Yearly energy generated: 694259 kWh.
- Yearly water pumped: 550000 m^3.
- Required surface for the PV generator: 5508 m^2.

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Below you can find the main results of the PRELIMINARY PLANNING FOR YOUR PV IRRIGATION SYSTEM (PVIS):

- PV peak power: 367.2 kWp
- Yearly energy generated: 604259 kWh
- Yearly water pumped: 550000 m3
- Required surface for the PV generator: 5508 m2

Figure 19 – Outputs of the self-assessment tool of SolaQua project.

It is important to keep in mind that these are preliminary results for a **PV irrigation system**. If one wants to perform a more detailed simulation, the SISIFO tool must be used. To highlight the fact that this is a preliminary result, the message of Figure 20 appears below the results of the tool.

Please, keep in mind that this is a preliminary result for your PV irrigation system. If you want to perform a more detailed simulation, you should use the SISIFO tool, which is freely available at www.sisifo.info. If you want to receive training on how to use the SISIFO tool, please visit www.sol-aqua.eu and apply to participate in one of our training courses.

If these preliminary results are interesting to you and you are seriously considering installing a PVIS, please send us an email to info@sol-aqua.eu for a more detailed project. Under SolaQua project, we want to introduce 100 MW of new PVIS projects!!! If you want to know more about PVIS systems and the SolaQua Project, please visit www.sol-aqua.eu.

Figure 20 – Message to highlight that this tool gives a preliminary result for a PV irrigation system.

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7. SISIFO tool

To perform a simulation with SISIFO – a software tool developed at UPM to simulate the energy yield of both PV grid-connected systems and PV irrigation systems[2] [23] – there is the need to fully know the characteristics of the irrigation system. These characteristics are fully detailed in section 4.1. of the Best Practices Manual developed under SolaQua project. The main characteristics are the ones that can be seen in the next tables:

IRRIGATION NETWORK									
Number of irrigation sectors									
Sector	1	2	3	4	5	6	7	8	…*
Working pressure of each sector [bar]									
Water flow of each sector [m3/h]									
Area of each sector [ha]									

PUMPING SYSTEM – ENERGY SOURCE			
Energy source			
If diesel group:	Power [kVA] Voltage [V] Maximum current [A] Specific consumption []		
If grid:	Contracted power [kW] Contracted tariff		

PUMPING SYSTEM – MOTORPUMP								
Pump type Number of pumps								
Pump								
8 points of the head-flow curve 8 points of the power-flow curve								
Minimum working frequency [Hz]								
Motor								
8 points of the efficiency curve								
Maximum current [A]								

PUMPING SYSTEM – FREQUENCY CONVERTER	
Frequency converter type	
Number of frequency converters	
Input voltage range [V]	
Maximum current [A]	
Maximum power [kW]	

[2] SISIFO is freely available at www.sisifo.info

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PUMPING SYSTEM - FREQUENCY CONVERTER								
Type Number of FC								
Efficiency curve								
8 points of the P2-efficiency								

During the training sessions of SolaQua, the trainees will learn how to use SISIFO tool.

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8. Business models

Under SolaQua, a Power Purchase Agreement (PPA) contract has been designed with the farmers to protect their interests. This PPA contract means that the farmer will:

- Save up to 60% of the electricity bill since day one;
- Have a fixed electricity cost for 20 years;
- Have an operation and maintenance contract for the PV installation along 20 years.

After this initial period of 20 years, the farmer can either extend the agreement or acquire ownership of the installation for 1€.

Under this PPA contract, it is estimated that the solar electricity to be paid by the end-users will vary between 3.9 c€/kWh (for systems with more than 1 MWp and average energy productivities close to 1800 kWh/kWp) and 9.0 c€/kWh (for smaller PVIS), see Table 1. It is important to highlight that these are estimated prices based on the PV peak power and energy productivity of the PVIS.

Table 1 – Type of systems, power and productivity range, and electricity price.

Type of system	Power range [kWp]	Average Productivity [kWh/kWp]	Estimated Electricity Price [c€/kWh]
A	100-300	1000-1400	6.1 – 9.0
B	300-500	1400-1700	5.1 – 7.5
C	500-1000	1500-1800	4.4 – 6.5
D	>1000	1600-2000	3.9 – 5.5

To exploit the results of the project and to trigger the PVIS market, SolaQua will facilitate a **joint promotion of more than 100 MW of reliable and affordable PVIS led by the farmers/ irrigators/ irrigator communities**. To do this, SolaQua will facilitate action-oriented dialogue among the relevant PVIS stakeholders.

Once the technical, economic and legal issues which are acting as barriers for the market uptake of PVIS are tackled, and once enough ISINPA are aware and trained, the objective of SolaQua will be to induce Action towards the introduction of PVIS. This will be done by presenting already interested ISINPA with a clear and ready-to-take path of action. That path of action will include activities that will create engagement among ISINPA in participating in a joint promotion of 100 MW of PVIS that will serve as a reference for the market uptake of the technology. This joint promotion will act as a flagship of PVIS, contributing to initiate a well-functioning market in Europe and Northern Africa. It will be a quality reference in PVIS for ISINPA.

Irrigators will be able to:

- Obtain 200 MW of PVIS preliminary projects, produced by self-assessment tool available at www.sol-aqua.eu;
- Obtain 150 MW of PVIS detailed projects, produced by 15 SMEs;
- Introduce 100 MW of new PVIS projects, with 10 SMEs executing the projects, and with investors and Public Administrations providing 120M€.

SolaQua consortium will conduct preliminary negotiations to secure letters of interest for at least € 150 MM in investments suited to the KEMT with approximately 15 investors. Once the

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database of PVIS preliminary projects will be available, preliminary financial and technical plans will be produced.

Those projects selected to the detailed planning will be object of a detailed financial analysis and presented to the investors to be funded using mechanisms suited to ISINPA needs and compatible with the EAFRD financial instrument designed during the project. SolaQua project will stablish a dialogue with European Commission’s DG-Agri to ensure that the PVIS financial instrument suits the policy and regulatory requirements. In addition, a risk assessment of the projects will be at disposition of farmers and SMEs during the planning process.

In the final process, SolaQua partners will coordinate the interaction between ISINPA to secure affordable and suited financing resources sufficient to produce at least 100 MW of PVIS projects under the model of PPA contracts.

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