


ECONOMIC ASSESSMENT METHODOLOGY FOR PV IRRIGATION

SolaQua

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- ABARCA COMPANHIA DE SEGUROS SA (ABARCA)
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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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Acronyms

AC	Alternate Current
CAPEX	Capital Expenditure
CAPM	Capital Asset Pricing Model
CBA	Cost Benefit Analysis
DC	Direct Current
DCF	Discounted Cash Flows
EIRR	Economic Internal Rate of Return
ENPV	Economic Net Present Value
EPC	Engineering, Procurement and Construction
EU	European Union
FC	Frequency converter
GHG	Greenhouse gases
IRR	Internal Rate of Return
ISINPA	Irrigators, SMEs, Investors and Public Authorities
KEMT	Key Enabling Materials and Tools
kWh	Kilowatt hour
kWp	Kilowatt peak
LCOE	Levelized Cost of Energy
MCM	Monte Carlo Method
MW	Megawatt
NPV	Net Present Value
O&M	Operation and Maintenance

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OPEX	Operational Expenditure
PR	Performance Ratio
PR_{PV}	PR considering only losses strictly associated to the PV system itself
PV	Photovoltaic
PVGIS	Photovoltaic Geographical Information System
PVI	Photovoltaic irrigation
RE	Renewable Energy
SME	Small and Medium Enterprise
STC	Standard Test Conditions
TEA	Techno Economic Analysis
Twh	Terawatt hour
UREF	Ratio of the irradiation required to keep PAC stable during the irrigation scheduling to the same irradiation during the IP
URPVIS	Ratio of the irradiation strictly required to keep PAC equal to the stable AC power requirement to the total irradiation throughout the IP
WACC	Weighted Average Cost of Capital

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Introduction

SolAqua in a nutshell

Irrigated agriculture accounts for 33% of freshwater use in Europe (estimated at 60 billion m3/year), while in southern regions, it consumes up to 80%. To pump this water from wells, EU farmers consume more than 24 TWh every year, mainly from the grid but also a significant part (20%) from diesel generators. Such an amount of energy causes greenhouse gases (GHG) emissions of more than 4 million tons of CO_2. In this context, combining the use of solar energy systems for irrigation and precision agriculture techniques represents the best alternative to conventional electric and diesel-based pumping systems. As in many other sectors, photovoltaic (PV) technology can be integrated into existing irrigation infrastructures to supply the required energy while dramatically reducing GHG emissions. The resulting solution, known as PV irrigation (PVI), is increasingly being used to supply energy for small-sized farms or for larger farms in combination with conventional technologies that serve as backup.

However, the use of PV in medium and large sized installations was, until recently, only suitable if a back-up was available to supply 100% of the power with batteries or grid connections. This technical requirement is needed because critical parts of large irrigation infrastructures work at high pressure and are very sensitive to sudden changes in the power supply. Relatively small variations in PV power can easily cause serious damage to the irrigation infrastructure due to overvoltages and water hammers, that reduce dramatically the lifetime of the electric and hydraulic systems, respectively. In order to prevent these problems, PVI had to add a set of batteries of equivalent size (up to 2 MWs) or a conventional power source that could instantly compensate any PV power fluctuation due to, for example, passing clouds. As a result of this intermittence and the related need for backup, PVI was not economically viable for the majority of irrigation infrastructures dominating the sector: the medium to large pumping systems.

The profitability of irrigated farming is extremely sensitive to the cost of electricity. As long as PVI systems rely on full scale backups it will not be possible to offer the solution at competitive cost. This problem has affected the attractiveness of PVI, increased its capital costs to uncompetitive levels and prevented large-scale uptake of the technology. However, a number of innovations that appear over the last few years, finally allows PVI systems of any scale to work fully independently of any back-up while guaranteeing the integrity of the infrastructure. These

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solutions can integrate the hydraulic part, the PV generators and the frequency converters in order to guarantee that the pressure parameters are always within the infrastructure operational values, even in the case that the PV power experiences a sudden drop. By ensuring the compatibility of directly-connected PV with irrigation infrastructures of any size farmers can finally build large scale PVI systems at competitive cost even in places without suitable grid connections or in areas where the existing grid is saturated. Nevertheless, even if the possibilities offered by these innovations can considerably increase the competitiveness of PVI, the cost of the resulting energy is not easy to determine and to compare with the cost of incumbent solutions. As high upfront payments are required to install PVI, the cost of the resulting energy must be calculated including the riskiness and time value of the investment over 25 years or more. In particular financial providers lack expertise and tools to assess the specific risks and returns of PVI projects and consequently PVI systems are not considered as suitable collateral. These factors are affecting negatively the market uptake of PVI.

Importantly, the large investment required to decarbonise irrigation, estimated at more than € 20 bn in Europe, means that access to capital markets will be needed to obtain sufficient funding at an affordable cost. Thus, in order to attract long-term, affordable capital for PVI expansion, PVI projects must have access as direct as possible to capital markets. This means that PVI assets must be considered valid collateral for mainstream financial instruments (FI), such as green bonds. For this to be possible, among other elements, a reliable and ready-to-use economic assessment methodology for PVI must be available based in industry standard valuation techniques. To provide such methodology is one of the objectives of the project SolAqua as part of its main goal of supporting the adoption of PVI.

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SolAqua is an initiative led by the Polytechnical University of Madrid aimed to facilitate the market uptake of PVI in Europe and beyond. The consortium of SolAqua, which represents more than 70% of European irrigators, includes all the relevant expertise and networking necessary to produce and disseminate the relevant information and solutions that are needed to unleash the potential of PVI. The members of Solaqua understand that, in order to fulfil the potential of PVI, it is necessary to overcome the existing barriers to its the market uptake, including the lack of a dedicated economic assessment methodology. In order to fill this gap, SolAqua has organized a multidisciplinary working group that has been focused in producing a dedicated economic assessment methodology for PVI. The result is one of the 7 **Key Enabling Materials and Tools (KEMT)** produced by SolAqua to support potential users in dealing with the technical, legal and economic aspects of planning, building and operating reliable and competitive PVI.

This document includes the description of such methodology, its theoretical foundations, the economically-relevant factors to be considered in PVI projects, the key indicators of economic and financial appraisal and the models that allow for their calculation. This document is complemented with a spreadsheet based on its methodology which can serve as a template to be used for the economic assessment PVI projects.

Purpose and scope

The economic assessment of PVI projects is not straightforward because they involve high up-front costs to design, install and build the systems that must be recovered over a long period so the cost of capital plays an important role. After considering all the factors, for some projects the resulting cost of energy is not competitive with incumbent solutions (higher LCOE). In fact, in order to facilitate the introduction of PVI, it is particularly relevant to allow ISINPA to produce comparations with conventional energy supplies, as securing a competitive cost of energy (lower LCOE than incumbent solutions) is the single most important reason for adopting PVI. One of the main aims of this methodology is to allow a direct comparation in economic terms between PVI and the alternatives including also the effect of the different cash-flow schedule and technical and financial risks that each present.

Producing accurate assessments of the cost of energy of PVI is relevant not only f at the "project level" but also to produce accurate assessments of the costs and benefits of PVI at other levels. PVI projects produce impacts that go beyond the farm affecting also the environment and the

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socio-economic development. These impacts are particularly relevant for policy makers and public authorities so it is important to support them with dedicated methodologies for PVI.

In order to support the different types of stakeholders involved in PVI, the methodology deals separately with the economic assessment at private level based on tecno-economic assessment, and at public level, where life cycle assessment is considered as the suitable theoretical framework.

This document is based on the know-how and experience of the partners of SolAqua in designing, building and operating SI systems and in the application to the case of PVIS of the mainstream methodologies applied in economic and financial appraisal. The resulting methodology can be used to assess the expected return of PVIS projects including the calculation of the most relevant indicators including NPV, IRR, WACC and LCOE. Furthermore, the TEA will be complemented with a cost-benefit analysis (CBA) methodology to facilitate the assessment of the impacts of PVI projects in welfare, allowing a complete appraisal of the projects for the different stakeholders.

About this document

After this introduction, Chapter 1 presents the elements that must be considered for budgeting a PVI at project´s level, based on the technical specifications of PVI projects presented in SolAquas´ KEMT 1. Chapter 2 focuses on the techno-economic assessment of PVI presenting a discounting cash flows-based methodology for PVI valuation. In order to introduce the specific riskiness of PVI projects, the capital assets pricing model is used to stablish the appropriate discount rate in each case. The methodology allows to calculate for PVI projects the key financial performing indicators including the cost of energy in terms of LCOE, which is the basis for comparison between PVI and the alternatives. Chapter 3 is focused on economic assessment of PVI from a socio-economic perspective. For this, a cost-benefit analysis for PVI will be presented. Chapter 4 presents the alternatives to carry out risk analysis of the economic performance of PVI projects and the limitations of assessing uncertainty in PVI projects. Finally, Chapter 5 includes a case study where the presented methodology is used to assess the economic suitability of replacing a grid connection with a PVI.

The next chapters present the different elements and instruments that allow for a comprehensive economic assessment of PVI systems:

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- Chapter 1 is about PVI´s capital budgeting.
- Chapter 2 is focused on PVI´s economic assessment at project level.
- Chapter 3 deals with PVI´s socioeconomic assessment.
- Chapter 4 presents alternative approaches to carry out PVI´s risk analysis.
- Chapter 5 is a case study that uses the proposed methodology to carry out the economic assessment of a PVI project.

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1. Capital budget of PVI

The first step to produce an economic assessment of any project is the estimation of the capital expenditure and the operational expenditure that must be paid in order to build and operate the system. Capital budget refers exclusively to the costs that have to be paid by the owners of the system, so any other aspects that may be necessary to execute the projects, such as consumption of public goods, are not included.

The different elements and activities required to be included in capital budgeting are grouped in two main categories: capital expenditure and operational expenditure. In a PVI project capital expenditure, also known as CAPEX, includes the equipment that compose the systems such as PV modules, variators and sun trackers. CAPEX also includes the necessary tasks to design the system and assemble the hardware such as the cost of engineering, procurement and construction (EPC). PVI systems are CAPEX intensive, so most of the capital budgeting will be used in CAPEX during the construction stage. The other main part of PVI´s capital budgeting is related to operational expenditure (OPEX) which includes items that are necessary during the operational life of the systems such as the maintenance and taxes. The costs of the different elements of PVI´s CAPEX and OPEX can be obtained from the market and can vary significantly over time, so the figures must be stablished for each project at the moment of its design. Here are presented the main cost elements that must be included in the capital budget of PVI.

1.1. Capital expenditure

PVI´s CAPEX is the most relevant element in order to assess the cost of the resulting energy. CAPEX in PVI projects is largely spent over the 6-12 months that takes to plan and build the systems but its amortization will take place during the 25 or more years that the system will last. The estimation of PVIs capital expenditure can vary significantly depending on a number of factors including system´s configuration, quality, location and suppliers. It is not straightforward for a customer to identify the differences between different offers which is a clear indicator of a dysfunctional market. This can lead to “lemon-markets” style agency problems because low-quality and poorly designed PVI systems are being introduced on the basis of lower prices resulting in disappointing results and a bad reputation for the technology. For this reason, it is important that ISINPA have tools to produce, analyse and compare PVI budgets. Following is a

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description of the components of PVI`s CAPEX and some relevant aspects that must be taken into consideration to stablish them:

Design and planning

Planning and designing a PVI involves more activities than those necessary when planning and designing a standard grid-connected PV system, therefore it results in an increased cost that can be up to 50% higher. The tasks that must be carried out when planning and designing a PVI system consists of:

- Choosing the type (stand-alone, hydraulically hybridized or electrically hybridized).
- Choosing and sizing the components.
- Estimating the energy balances over all the months of the year.
- Integrating the PVI and the irrigation infrastructure.
- Adapting, if necessary, the irrigation process to the particularities of the PVI.

The water requirements of crops change greatly throughout the year. They are usually very high in the spring-summer months and very low, or even non-existent, in the autumn-winter months. For the sake of economy, it is important that irrigation systems are designed in such a way that the volume of water they pump is matched as closely as possible to the needs of the crops.

A particularly convenient way to achieve this is to install the PV generators on mobile support structures that follow the movement of the sun by rotating around a horizontal axis oriented in the north-south direction. Indeed, this form of tracking is the one that leads to the greatest difference between the volumes pumped in summer and winter.

Two things are very important to consider when planning a PVI. On the one hand, that the monthly pumped volumes estimated by a simulation exercise are precisely the basis of the expectations placed on the project. On the other hand, when the project is implemented and operating, the experimental data will have to be analyzed to decide whether the reality meets these expectations and, if not, to diagnose the cause, propose a solution and settle the responsibility.

The whole difficulty of the exercise lies in the fact that the real operating conditions, in particular solar radiation and pumping head, are not governable but are imposed by the environment. This

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means that a procedure must be devised to transfer or correct experimental values measured in reality to values corresponding to the reference conditions established in the design. This will require a throughout analysis of the existing irrigation infrastructure and practice in close collaboration with the irrigators. Capex must include a sufficient budget allocation for this task that can occupy up to 200 hours of work of qualified staff for a typical 1 MW installation.

The photovoltaic generator

This is the most important hardware element of a PVI and a relevant centre of cost. PV technology has achieved maturity and PV modules are almost a commodity in terms of availability, market and price. PV panels´ cost experimented a deep cost reduction over the two decades previous to 2020 but since then it has been stabilized or even increased. In any case the capital budget of the PV generator must be on the basis of the following points:

1) Each PV generator must consist of modules of the same manufacturer, type and model.

2) The PV modules must be conventional and of crystalline silicon.

3) The PV modules must be IEC 61215 certified.

4) The PV modules must be IEC 61730 certified.

5) The PV modules must be resistant to PID (Potential Induced Degradation).

6) The actual power of the PV generator measured at the input of each frequency converter must be equal to or greater than 93% of the nominal value. In other words, the sum of the losses due to initial degradation, characteristic dispersion and DC wiring must not exceed 7%.

7) The PV modules must not exhibit any "hot spots" when there are no shadows on them and the frequency converter is feeding the pump normally.

8) The range of values expected at operating conditions of the PV generator voltages and currents (VOC, ISC, VMPP and IMPP) due to variations in PV module temperature and operating modes must be compatible with the technical specifications of the frequency converter.

There are many more aspects to consider for the choice of the PV generator, but those described are the most relevant.

In a PVI system it is possible to distinguish between three values of nominal electrical power:

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- Photovoltaic generator power ("$\mathbf{P_G}$"), which is its power in the so-called Standard Measurement Conditions and which is usually used to refer to the nominal power of the whole system.
- Frequency converter power, PI_{MAX}, which is the maximum power it can deliver at its output in steady state. It is also the maximum power that the system can deliver to the motor pump and, in the case of systems that are electrically hybridised with the grid, it defines the power of the grid connection. Typically, it is between 5% and 35% lower than PG, depending on whether the PV generator is tracked or static.
- The motor power that driving the pump, $P_{1, NOM}$. It can be up to 30% lower than that of the frequency converter. In other words, the motor pump can operate at higher than nominal power, especially if, as is common in relatively large systems, the system incorporates a motor temperature control protection.
- That of the pump itself, $P_{2, NOM}$, which is the mechanical power that the motor delivers to the pump.

Therefore, when calculating the number of PV modules needed for a PVI system, it is necessary to know how the pre-existing irrigation system works in order to correctly match the needs derived from the crop and the production of the PV plant.

PV modules can be purchased on the market from multiple companies, with prices varying from one company to another depending on whether they are local suppliers, large plants or simply for small self-consumption. There is no price database where you can find the current price, it is necessary to compare prices between several suppliers.

Particularly if the manufacturer is not a highly reputed company, It should be included an external quality control before acquiring the PV modules. Sometimes it can be the same company that performs the inspection, reviews and/or drafts a contract of purchase and sale of the PV modules, and includes a clause that can reject the product during the product warranty if any of the values with which the .pam file is created are not complied with. It is important to note that most of the PV module manufacturers are located in Asia and it is advisable that the terms of the contract are subject to laws that sometimes differ greatly from those in the West.

One of the most relevant indicators of quality is the output guarantee of the modules. Nevertheless, most manufacturers guarantee a PV module output power based on a degradation curve, but the guaranteed powers are measured under laboratory conditions, 25°C

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cell temperature and 1000 W/m2 radiation. A random number of PV modules should be selected and sent to an approved laboratory for power testing, PID testing and EL testing. This increases slightly the CAPEX but it will reduce the risk of acquiring modules of a lower quality than expected and will allow to anticipate future problems and to be able to make claims during the product warranty period.

Once the PV modules arrive at their final destination, it will be necessary to check that the seal is not broken and at least re-measure the power of the PV modules once they have been installed and carry out random electro-luminiscence tests to check that the modules have not been damaged during transport and/or assembly.

In the O&M phase, it is important to dedicate time to periodically check the PV modules In fact the PV generator should be measured at least once a year to obtain its I/V curve. With the help of new technologies, for example with the use of drones, thermography tests can be performed more frequently.

The market of PV modules is quite volatile so any economic assessment must include timely quotations. In Spain by September of 2021 a price of 229.30 €/kWp has been estimated based on objective parameters obtained from the database of different suppliers consulted.

Frequency converter

Frequency inverters or frequency converters are systems that are located between the PV generators and motor-pumps. They are used to regulate the rotational speed of alternating current (“**AC**”) motors of the pumps.

Certain characteristics of the frequency converters (FC) must be taken into account when selecting the FC for the PV system:

1. The rated power of the FC should preferably be equal to or greater than 65% of the rated power of the PV generator under standard conditions:

$$P_{VFD}^{N} \geq 0.65\, P_{N}^{*}$$

2. In order to preserve the quality of electrical service, the FC must comply with IEC 61000-6-2 and IEC 61000-6-4 (EMI), with EN 50178 (power quality requirements) as well as with specific

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national regulations. The use of ferrites/filters at the output of the FC to avoid electromagnetic noise is highly recommended.

3. As far as possible, the FC should include an insulation fault detection and protection system according to IEC 60364-7-712.

4. The FC should preferably be located inside a room intended for electrical equipment with appropriate ventilation (exhaust fans) or air circulation systems in order to avoid high temperature operating conditions. The entrance door to the room should have a locking system to prevent possible damage due to wind gusts when the door is left open.

5. The FC must be able to withstand a sudden power drop of the PV generator caused by passing clouds.

These and some other more technical specifications are important to consider when choosing the FC to be installed in our PV irrigation system. Under these conditions, the reference price in Spain by September 2021 was around 76.40 €/Kwp.

Suntracker

Such as has been mentioned in the “Capital expenditure” chapter, the water requirement for crops varies throughout the year. For this reason, it is very important that the PV irrigation system may be designed to cover the real need of water in each season. A solution for that is to install the PV generators on mobile support structure that follow the movements of the sun This element is known as Suntracker.

One consideration is that horizontal axis trackers are intrinsically more robust than any other type of tracker. This is a consequence of the fact that, as they rotate on a horizontal axis, these trackers are normally very close to the ground, which greatly reduces wind loads and thus facilitates all structural and foundation requirements. Therefore, single-axis horizontal tracking systems present an optimal match between the energy produced by the PV generator and the energy demanded by the irrigation needs.

The International Electrotechnical Commission (IEC) has recently issued the IEC 62817:2014 Ed.1 standard "Photovoltaic systems - Qualification of solar tracker design" for the definition of the tests that must be applied to a complete suntracker (tracker + key components), in order to obtain its certification. The activities proposed in this standard have two main objectives:

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- Review of the technical specification sheet of the suntracker provided by the manufacturer, to check that all the technical parameters that allow a correct description of the product are included.
- Application of the proposed test procedures, with the aim of validating the technical specifications of the product sheet and its performance and identifying any degradation or possible premature failures.

For this purpose, the IEC 62817:2014 Ed.1 standard contains the procedures for measuring and checking the parameters indicated in the technical data sheet, and establishes the acceptance and rejection criteria with which the results of the tests carried out are assessed, according to which it is possible to subsequently qualify the product.

In the market, despite the large number of suppliers, there is not a great variety of prices between one and the other, with prices in Spain by September 2021 between 0.12-0.15 €/ Wp.

Engineering. Procurement and Construction (EPC)

EPC is a particular type of contracting that allows for the efficient management of all aspects and stages of the PV plant construction process, from licensing, design and engineering, through the construction and development of the PV system, to commissioning. Building a PV system has become easier than in the past, but there are several issues that can derail a project such as delays, material procurement problems and inconveniences during the final stage of construction. If the EPC methodology is chosen, it is extremely important to find a reliable partner.

There are various opportunities within the PV EPC contract, the main difference lies in the nature of the general contractor's business structure:

- The General Contractor is a management company with financial and coordination, planning and control capabilities, which assumes full responsibility towards the client, manages the project, but delegates the execution to several contractors for engineering, procurement and construction.
- The General Contractor is an engineering company, which has management and engineering skills, but no construction skills; it assumes full responsibility towards the client, manages the project, directly executes the engineering and procurement and relies on a specialised construction contractor.

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- The General Contractor is a construction company that executes directly to site using third party engineering and bid coordination; this scheme is often weak in terms of management.
- The General Contractor is the true and legitimate general engineer of the construction company, who executes, directly, the majority of the project.

Responsibility in all stages of the Photovoltaic EPC:

1. Pre-feasibility study of the project
2. Environmental Impact Assessment.
3. Social Impact Assessment.
4. Archaeological Permit.
5. Engineering Studies:
    a. Indicative study.
    b. System impact study.
    c. Installation's study.
6. Legal and Technical Consultancy.
7. Future Flows Study.
8. Project management and legalisation.
9. Local permits (change of land use and building permit).
10. Basic and Detailed Engineering.
11. Civil works (trenches, pile driving, roads, etc.).
12. Electrical works for medium and high voltage evacuation.
13. Installation of mechanical and electrical works.
14. Commissioning.

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Bearing in mind these responsibilities, they must be clearly defined in the contract to be carried out.

Based on data from different PVI plants, we can establish that the approximate cost of this type of contract is around 371.90 €/KWp.

1.2. Operational expenditure

The operational expenditure (OPEX) of PV irrigation systems (PVI) is significantly lower than that of incumbent alternatives as no fuel or grid connections are required. This reduced OPEX is key to achieve a competitive LCOE for PVI and to attract ISINPA to the solution. Nevertheless, a well designed and implemented operation and maintenance (O&M) and risk hedging is absolutely necessary to ensure the reliability and the longevity of PVIs, so sufficient resources must be anticipated to carry out the tasks. In order to estimate a realistic budget for OPEX, the following elements must be considered:

Operation and Maintenance

Within PVI OPEX, O&M activities are the most important cost centre as it involves regular expenses in tasks that must be carried out by specialized staff or contractors. In this regard O&M activities of PVI can be divided into preventive maintenance, corrective maintenance, predictive management and extraordinary management that are described below.

Preventive maintenance

This includes all the activities that must be executed regularly and independently of the performance of the system. For this an Annual Maintenance Plan must be available including the different activities and the schedule of their implementation. Among other aspects preventive maintenance must allow for detecting possible hot spot in the PV modules or to prevent mechanical problems in sun trackers. A well-executed preventive maintenance can substantially reduce operational cost in the long term so a compliance mechanism must be also implemented. The annual maintenance plan must include, at least, the following activities:

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1. Cleanliness. This is the main maintenance to be taken. Its intensity depends on the conditions of the system such as location and weather circumstances. As a central scenario, at least 100 hours/person/MWp/year must be budgeted for this task.
2. Protection from vegetation. This is important to ensure the correct operative of the PV module and to maintain the expected level of production. At least 50 hours/person/MWp/year must be budgeted for this task.

3. Periodical confirmation of the tracking algorithm. This can be done remotely by a specialized contractor. Deviation of the tracking algorithm can have an important impact in the reduction of the energy yield of the system.
4. Regular meter readings.
5. Maintenance of buildings, fence and security equipment. This should be supported by remote surveillance in order to ensure the optimal state of the infrastructure. As a central scenario, at least 100 hours/person/MWp/year must be budgeted for this task.

This maintenance must be done by technical specialists and the main cost is related to staff. As an indication the cost of the described activities in Spain in September 2021 is estimated to be between € 6,000 and € 9,000 MWp/year depending on the specific conditions of the PVI system.

Corrective maintenance

Alongside the preventive maintenance, the OPEX must also include the activities related to the corrective maintenance of the system during its lifespan. Corrective maintenance refers to the activities that must be implemented after failure detection. It is very important that effective failure detection mechanisms are implemented through the remote monitoring, by the plant operator or by the annual maintenance plan. Three main activities can be performed under corrective maintenance: fault diagnosis, temporary repair, and repair.

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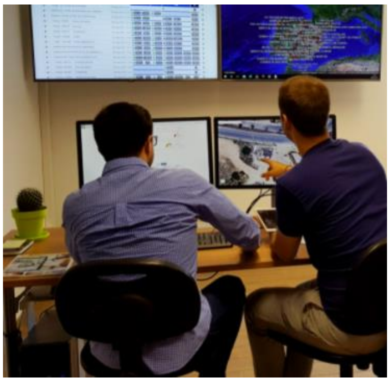
Fault diagnosis is the process of identification of the fault, temporary repair is the repair to restore the function or item for a limited period of time (until repair is carried out), and repair is the restoration of the function or item permanently. As the stop of production of energy can be very costly in particular during the irrigation season, it is highly recommendable to stablish long-term contracts with local suppliers in order to ensure the prompt execution of corrective maintenance. Furthermore, the corrective maintenance must be done during night-hours (to avoid influencing the PV generation) so the related costs can be higher than normal technical assistance. Temporary repair can be often necessary to limit the loss of energy production while a complete reparation is carried out.

Predictive maintenance



As PVI is a recent technology, there is a limited track record of its performance in real conditions over the lifespan of the systems. Furthermore, each PVI system has specific design and operational conditions that can require specific maintenance activities that cannot be anticipated. Predictive maintenance includes those activities that allow for the identification and execution of maintenance activities that address project-level characteristics. In order to carry out predictive maintenance is needed that a suited monitoring system has been included in the PVI including a data connection to communicate the data with the analysts. The entity responsible to operate the systems and to deliver O&M will analyze key performance indicators such as the historic yield assessment and the occurrence of failures in order to design and implement predictive maintenance activities. Predictive maintenance can support important O&M decision including when it is needed to substitute elements such as frequency converters or the motor-pumps. An optimal decision over these

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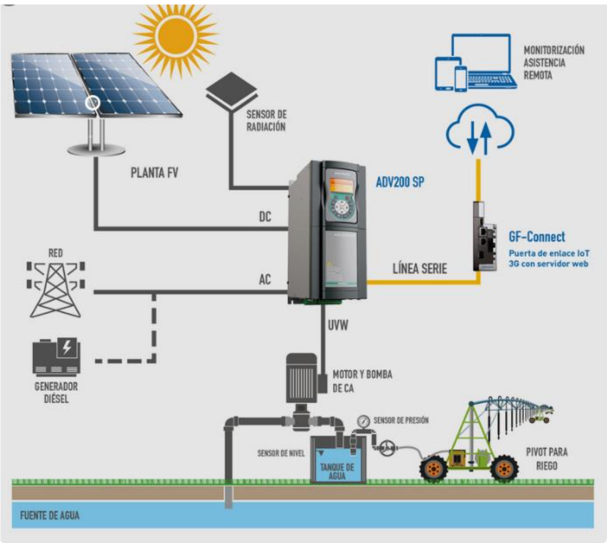

important activities requires several factors must be considered regarding both mechanical and electrical installation. Predictive maintenance must be executed based on a very specialized support service that is not fully developed in the current market. It is expected that as the PVI market develops so be the availability of predictive maintenance. As a reference, a complete preventive maintenance service in Spain in September 2021 has a cost around € 2,000 MWp/year.

Extraordinary maintenance

As in any other infrastructure, a number of unexpected events negatively affecting the assets must be considered to happen at any time. These unexpected events can have many forms including storms, fire (particularly in the FCs), theft or vandalism and endemic failures among others. Most of these contingencies can be somehow hedged by subscribing insurance policies but, even in that case, they can severely affect the performance of the system if quick and effective remediation actions are not carried out to mitigate them. Furthermore, unforeseen events can also create the need to include maintenance activities that have not been initially considered and budgeted, as can be the case of new requirements done due to a change in the regulatory framework.

A particularly frequent cause of extraordinary maintenance results from the systems suffering equipment deterioration at a faster path than anticipated. If there is the need to repower the PV modules, special attention is needed in what concerns PV modules support and electric installation.

The cost of PVIs extraordinary maintenance is difficult to assess, but based on the track record of equivalent PVI installation, a provision of at least € 1,200 MWp/year should be added to the OPEX budget to account for this concept.

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2. Techno-economic assessment (TEA) of PVI

Alongside OPEX and CAPEX, any investment such as PVI has an “opportunity cost” as the money used there could have been invested instead in alternative assets and produced a return. The higher the opportunity cost is the higher the riskiness of the project, so an appropriate “discount factor” must be estimated to calculate the cost of the project in real terms. The discount factor that is used for a project is consistent with its weighted average cost of capital (WACC), that is, the level of return that investors and debt providers require from a project in a specific context and which is the basis of a TEA´s valuation and cost calculations.

TEA combines process modelling, engineering and construction design, and economic evaluation in order to assess the viability of a system or to compare it with alternative solutions. In this regard TEA is mainly oriented to support economic assessment at project level in order to identify the potential return in financial terms for its owners. In the context of PVI, TEA can be used by irrigators in order to simultaneously analyse several alternatives that can produce energy and, in particular, in order to compare the use of a diesel generator and/or electricity supplied by the public grid versus a solar photovoltaic system to power irrigation water pumps. Also, investors can use TEA to evaluate the risk-return profile of PVI assets in order to assess the suitability of investing there. The main advantage of using TEA for the economic assessment of PVI projects is that it allows to include the time-value of money and other elements to assess the riskiness of the project and the risk-adjusted cost of the energy. In particular TEA allows to estimate the LCOE of the three different alternatives for supplying energy to irrigation systems (PVI, grid connection and diesel generation) so a direct comparison can be carried out in order to support decision making.

Time value of money and riskiness must also be included in PVI economic assessment because farmers and investors prefer projects whose expected returns will be obtained earlier in time and with less uncertainty. As a result, the cost of capital increases when projects have longer payback times and greater uncertainty over the results. Then if the riskiness of using PVI is higher than relying in an electricity grid, the expected return from PVI must be higher to compensate (the LCOE of PVI must be lower than the cost of electricity from the grid). From this perspective, an economic assessment methodology for PVI must allow to assess the riskiness of the technology and to stablish the impact of this riskiness at LCOE level. The Modern Portfolio

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Theory provides the framework for the economic analysis of risk (Markowitz 1991) and the capital asset pricing model (CAPM) allows for the relation of this riskiness and the cost of capital of each single project (Sharpe 1964).

2.1 Cost of capital of PVI

The economic riskiness of a PVI project can be assessed using the CAPM model in order to estimate its WACC. WACC is the price that is required by lenders and owners to disburse the necessary funds for its execution. The WACC of a specific project is not directly observable so it must be calculated for each project using the appropriate methodology and data reflecting market conditions. A higher WACC reflects higher costs of capital meaning that projects must produce a relatively high level of return to be considered as economically viable, because they bear risk. In terms of cost of energy (LCOE), the higher the WACC the higher the LCOE will result. WACC can be calculated following Eq (1):

$$WACC = w_d k_d (1 - t) + w_e k_e \qquad \text{eq. 1}$$

where

w_d is the proportion of debt to be used to fund the project.

k_d is the before-tax marginal cost of debt.

t is the project´s tax rate.

w_e is the proportion of equity to be used to fund the project.

k_e is the marginal cost of equity.

The variables that are needed to calculate the WACC of a project do not include CAPEX or OPEX which are considered during capital budgeting. Instead WACC reflects general market conditions of the economy, the systematic risk of the project and the financial structure that is envisaged to fund the investment (what are the proportions of debt and equity that will be used to pay for the CAPEX). In this regard the estimation of the systematic risk of PVI is a key part of a dedicated economic assessment methodology for the technology and a necessary element to facilitate its market uptake. In order to estimate the WACC of a PVI project it is necessary to carry out the following actions:

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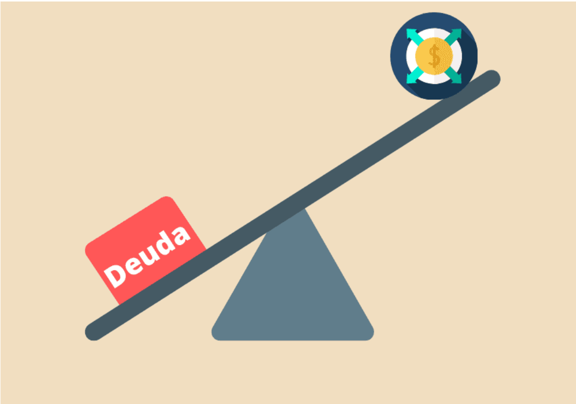
1. Identify the cost of debt for the project.
2. Identify the cost of equity of the project. This involved the following actions:
   2.1 Identify the systematic risk (beta) of the project.
   2.2 Identify the risk-free rate of the economy.
   2.3 Identify the premium return of the market in the country where the project is based.
3. Stablish the proportion of debt and equity which will be used to fund the project.

The cost of debt

Projects can be funded using debt, equity or, most commonly, a mixture of both. The cost of debt is the return that money lenders such as banks require from debtors. The cost of debt that



will be asked for a PVI project includes the cost for the lender to obtain the money from capital markets plus a premium that reflects the riskiness of the project. There are a number of different methodological approaches to stablish the cost of debt and many different debt financial instruments. If a project can produce a predictable and steady cash flow, it is possible that lenders accept the project itself as the sole guarantee of the loan. For this to happen the details of the project including its technology, business model and a historical track record of similar projects must be available. At this stage such elements are not available for PVI projects so in practical terms, the cost of debt for a PVI project is that which the bank will demand after analysing the riskiness of the borrower and the collateral or guarantees provided for repayment. The promoter of the project has to secure a loan with the required maturity of a PVI project, which is typically 20 years and negotiate the specific conditions. Interest on debt is tax deductible; therefore, the cost of debt must be adjusted to reflect this deductibility.

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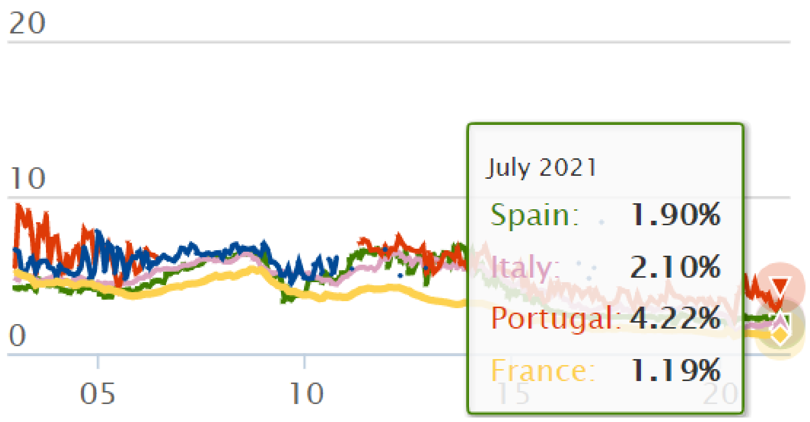

Figure 1: Evolution of the cost of bank loans to corporates in some of the countries suited to PVI in the euro area (Jan 2003-July 2021). Loans are of less than € 3M with maturities longer than 5 years. Eurostat.

The cost of equity

The equity of a project is the money that owners have disbursed to execute it. In exchange of their investments equity holders expect to obtain a financial return coherent with the level of riskiness assumed. The CAPM is the reference methodology to stablish the cost of equity of any asset. CAPM states that the expected return on equity is the sum of the risk-free rate of the economy plus a premium that compensates the systematic risk of the asset. The model is presented in Eq(2):

$$E(R_i) = R_{Fc} + b_i\,[E(R_M) - R_{Fh}] \qquad \text{eq. (2)}$$

Where R_{Fc} is the spot risk free rate of the economy for a maturity equivalent to that of the project, b_i is the return sensitivity of asset *i* to changes in the market return (known as beta), $E(R_M)$ is the expected return on the market and R_{Fh} is the historical risk-free rate during the period used to estimate $E(R_M)$. $E(R_M) - R_F$ is the expected market risk premium or equity risk premium which is the extra return that investors receive on average in order to invest in risky assets. Each of the elements that must be considered to estimate the cost of equity of a PVI project are described below:

Calculating the systematic risk (beta) of a PVI project

The underlying assumption of CAPM is that any project has two types of risks. First are the unsystematic risks that includes events that may affect negatively the expected return of a

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project which take place at project level. Unsystematic risks of PVI includes technical failures such as hot spots, unforeseen costs for example because of the need of a more intensive maintenance than original planned or lower capacity factor than planned because of water scarcity. Many unsystematic risks which introduce uncertainty over the results of PVI projects can be hedged by using insurance products or diversified out. Nevertheless, PVI projects are also affected by systematic risks that cannot be avoided by investors/owners. This is because the systematic risks of PVI projects result from events which affect the entire economy when occurring. This is the case of economic downturns, changes in the level of the interest rates or in the political framework or unexpected events such as a pandemic or a social unrest.

As mentioned, unsystematic risks can be eliminated by appropriate hedging and diversification (for example by investing in more than one PVI) but systematic risks cannot be eliminated because they cannot be diversified out, as its occurrence affect all the assets in the same direction. Thus, the only type of risks that must be considered to calculate the cost of equity of PVI are its systematic risks, this is, how much the value of a PVI system is affected by changes that affect the entire economy.

Different asset classes present different systematic risk as they are not equally affected when unforeseen events that trigger this type of risks take place. This is because the performance of some asset classes is more affected than others by changes in the overall economic conditions. For example, if the general level of rent is negatively affected by an economic shock, the demand of non-essential and investment goods such as holidays or houses will be more affected than basic goods such as energy or food. At project level, the systematic risk increases with the level of debt used to fund it. This is because equity acts as a buffer to absorb risks and the smaller it is the more affected the asset will be in case of negative events taking place. The sensibility of the value of a specific asset to systematic risks is measured by a variable named beta, which is higher the higher the systematic risk of the asset and equals 1 if the asset´s systematic risk is exactly the average of the economy. In order to stablish the beta of an asset it is necessary to compare (regress) the evolution of the value of such asset with the average value of all the risky assets the economy (using as a proxy the evolution of the stock market of the country). Then, in order to calculate the riskiness of a PVI project it is needed first to obtain the beta of the asset class PVI and then leverage it by introducing the proportion of debt and equity which is foreseen for the project. In the case of PVI, it is not possible to observe its beta directly because there are not “pure” PVI assets traded in a public market so no data is available on how the asset class performs in comparison with the rest of the asset classes.

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As the asset class PVI is not available in the market it is required to obtain first the beta of a comparable and then "unlever" the part of the beta that corresponds to the asset class (Damodaran 2002). A comparable is normally a company or a set of companies in the same sector and with similar business models to those of the asset class that we are assessing. It is also required that comparables are traded in a public market. A comparable for PVI includes publicly traded companies with a line of business that matches as close as possible that of PVI projects. As high frequency quotations of publicly traded companies are available it is possible to regress the evolution of its value against the evolution of the overall economy. In the case of PVI, in order to estimate beta, it is necessary to observe how companies focused in producing photovoltaic energy in a given country are affected when an economic downturn happens. For example, suitable comparables for PVI in Spain includes companies that are focused in operating photovoltaic systems such as SolarPack, Solaria and Grenergy. The beta of the comparable company or companies can be used to estimate the beta of the asset class on which the company rely, for example PV systems.

In order to calculate the beta of an asset class using the beta of a comparables it is required to eliminate the effect on the beta of the comparable of its specific financial structure and tax rate. As mentioned, the beta observed in a public traded asset is reflecting not only the systematic risk of the business/sector but also the level of debt of that specific asset. To estimate the beta of the underlying asset class it is necessary to unlever the beta of the comparable. This can be done using eq (3).

$$\beta_{\text{asset}} = \beta_{\text{equity}\,comparable} \left[\frac{1}{1+\left((1-t_{comp.})\frac{D_{comp.}}{E_{comp.}}\right)} \right] \qquad \text{eq. 3}$$

Where t_{comp} is the tax rate of the comparable, D_{comp} is the amount of debt used to fund the comparable and E_{comp} is the amount of equity used to fund the comparable. The value of these variables can be obtained from the financial statements of the comparable.

Once the beta of the asset class is obtained it can be leveraged again into the new project to include its specific financial structure and tax rate. This is done following the calculation of eq. (4):

$$\beta_{\text{equity}\,project} = \beta_{\text{asset}} \left[1 + \left((1 - t_{proj.}) \frac{D_{proj.}}{E_{proj.}} \right) \right] \qquad \text{eq. 4}$$

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Asset betas (unleveraged) for PVI projects are observed to be low (<0.5) meaning that the systematic risk of PVI projects is low.

When estimating the cost of equity of a PVI project, beta is the only variable which requires project-specific inputs including the expected proportion of debt and equity to be used to fund the project and the tax rate. The rest of the variables needed are obtained from the market and are the same for any asset in a given economy. For this reason, its obtention is straightforward and the only adjust that must be applied is to use the value of the variables with the same maturity as the planned lifespan of the PVI.

The risk-free rate

CAPM introduces in economic assessments the concept of the risk-free asset and its related return: the risk-free rate of return. The risk-free rate is the return that any investor can obtain in a given economy without bearing any asset-specific risk. As increased levels of risk must present higher returns, the risk-free rate is also the minimum return that any asset must offer. Asset other than the risk-free asset must consequently present higher returns to attract investors. The extra return of non-free assets must be consistent with their systematic risk (beta) and the risk premium of the economy where this asset is located. When estimating the cost of equity of projects of a given maturity in a specific country, the risk-free rate is the same for all of them regardless of the business model, technology used, leverage or any other factor. As debt issued by the government is normally assumed to be the safest asset in a given country, sovereign bonds are considered as the risk-free asset of that country and its yield is assumed as the risk-free rate. Small changes in the risk-free rate can have important effects on the WACC and, consequently in the LCOE of PVI. The risk-free rate is tightly correlated with the inflation rate and expectative of a given economy. In developed economies such as European countries the risk-free rate tends to be low, a feature that facilitates the suitability of PVI projects as the lower the risk-free rate, the lower the WACC and LCOE of PVI and the more competitive the technology is. Nevertheless, the risk-free rate can have important variations in a very short period of time, meaning that in order to stablish its value it is necessary to use a sample of quotations sufficiently long, for example by averaging the daily quotations of the last year. The risk-free rate also incorporates the country-risk as it is higher in countries that investors consider as structurally riskier because of local socioeconomic and institutional conditions. For that reason, PVI projects with similar expected cash inflows and outflows will have different LCOEs in countries with different risk-free rates.

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The premium return

The premium return of a country is the extra return that risky assets offer in average to investors in that country. The premium return is normally obtained as the difference between the (average) return of risky assets (stocks) and the corresponding return of the risk-free asset (historical risk-free asset). As in the case of the calculation of the risk-free asset, in order to estimate the premium return that we must use when estimating the cost of equity of a PVI it is necessary to use a time-series covering a period long enough as to smooth the important volatility inherent to markets. Countries with a high premium return tend to be developing economies where investors are only interested in projects with high return and short paybacks.

By multiplying the beta of our project by the premium return of the country where it is based, we can obtain the extra return that our PVI project must produce over the risk-free rate to be considered financially suitable. The cost of equity of the project is obtained by adding its extra return and the risk-free rate with the same maturity as our project lifespan (typically between 20 and 30 years for PVI).

Stablishing the proportion of debt and equity

The financial structure of a PVI project affects its value and, consequently, the resulting PVI. This is caused because, as we have presented, debt and equity have different costs and its proportions are relevant for the calculation of WACC. Debt has priority over equity to be repaid so it is considered as less risky and, consequently is cheaper. Furthermore, debt is tax deductible while dividends on equity are taxed. As a result, project promoters tend to maximize the level of debt to fund their projects and to use as little equity as possible. Nevertheless, highly leveraged projects are very risky from both the debtor and the borrower perspective as small reductions on its value have a large negative effect on the return for the owners increasing the risk that the project ends up defaulting. For that reason, the proportion of debt and equity is normally established in order to accommodate the risk-return expectative of the equity within the boundaries stablished by the debt provider.

In the case of PVI, debt providers are not used to accept the system itself as collateral, so the promoter has to assume the debt within its own balance sheet. If this is the case, the level of debt of a PVI project can be assumed to be the average level of indebtness of the equity providers. In the case that the project can be isolated and is possible to obtain debt exclusively secured for it (for example by stablishing a special purpose vehicle to own the system), the

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financial structure of the PVI will be independent of that of the owners and the WACC will be calculated accordingly.

2.2 The cost of energy of a PVI project

By producing a capital budget and an estimation for the WACC, PVI promoters can use TEA for the calculation of a large variety of indicators which allows them to carry out an economic assessment of the projects. In the case of projects oriented to produce energy, such as PVI, the LCOE is considered the standard metric to assess the cost of producing energy at system level (Short, Packey, Holt 1995). Estimating LCOE allows promoters and investors to establish the break-even level of the projects by comparing the resulting cost of energy with other alternatives (Hansen 2019). LCOE is also popular among policy makers to design effective supporting schemes (Ouyang and Lin 2014). Its calculation consists of estimating the total cost of constructing and operating an electricity generating plant divided by the expected total electricity production. The future costs and the production is “discounted” using a discount rate that reflects the cost of capital and the riskiness of the project. As we have presented, WACC is the appropriate discount rate for this purpose. LCOE can be stablished using the following eq. (5):

$$LCOE = \frac{\sum_{t=1}^{n} \frac{CAPEX_t + OPEX_t}{(1+WACC)^t}}{\sum_{t=1}^{n} \frac{EnGen_t}{(1+WACC)^t}} \qquad \textit{eq. 5}$$

where *n* is the number of years of lifespan of the system; $EnGen_t$ is the amount of energy produced in year *t* and WACC is the weighted average cost of capital of the project. The obtention of the LCOE of a specific PVI project allows for direct comparisons with incumbent solutions and also to assess different scenarios when planning projects. Alongside LCOE, the economic assessment of PVI must also include a valuation of the project and also stablishing its expected return.

2.3 Valuing a PVI project from the owners´ perspective

The use of TEA to value PVI projects is relevant because it is based in the most widely used valuation techniques; those based on discounted cash flow (DCF) methods. The investment

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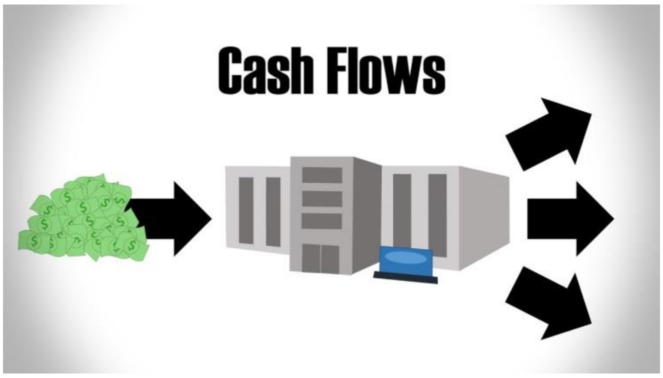
appraisal based on DCF includes the calculation of the net present value (NPV) and the internal rate of return (IRR) and the payback. The combination of this indicators is the basis for the economic assessment of a project from the owners´perspective (irrigators and/or investors).

Estimating the cash flows



DCF methods require the estimation of the cash outflows and inflows that are expected to take place during the lifespan of the project. In order to stablish its time-value it is also required to identify the moment when this cashflows will take place. Cash outflows of a PVI include all the payments that are required to fund CAPEX and OPEX, as established in our capital budgeting. The cash inflows that can be obtained from a PVI project can arise from a number of sources. The first cash inflow to be considered is the cost of the energy that has been saved by installing the PVI. If the PVI were not installed, the irrigator would have to get this energy from alternative sources such as a grid connection or a diesel generator. In order to determine the amount of this inflow it can be used the price of cheapest alternative source available multiplied by the amount of energy produced by the PVI and consumed by the irrigator. In order to introduce in the model the cash inflows resulting from obtaining by self-consuming the energy from the PVI instead of depending on grid/diesel during period t we can use eq. (6):

$$Cash\ inflows\_selfcom_t = [Cc_1 * (1+R)^{t-1}] * Es_t \qquad \text{eq. 6}$$

Where Cc_1 is the price for consumers of the cheapest alternative to PVI to supply energy to the irrigation system at the time of the start of the operations of the PVI, R is the rate increase in electricity costs in percent per year and Es_t is the energy self-produced and self-consumed from the PVI.

A second potential inflow from installing a PVI is the commercialization of energy surpluses produced by the system but not consumed by the irrigator. PVIs are primarily designed to produce energy to power irrigation systems but often part of the energy production cannot be self-consumed. This can occur because the irrigation season is limited to part of the year or

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because the level of humidity of the land is sufficient without irrigation due to rain. If the PVI is connected to the public electricity grid and the legal and regulatory framework allows it, the energy produced by the PVI during those moments can be injected in the grid and receive an economic compensation as a result. For some PVI configurations selling surpluses to the grid can be necessary to ensure its financial viability, in particular in those situations where the irrigation season is relatively short and the capacity factor of self-consumption is low. In order to estimate the cash inflows from commercialization in period t we can use eq. (7):

$$Cash\ inflows\_grid\_com_t = [Cp_1 * (1+R)^{t-1}] * (E_t - Es_t) \qquad \text{eq. 7}$$

Where Cp_1 is the price of energy for producers injecting into the grid and E_t is the total amount of energy produced by the systems during year t.

Finally, investments in agriculture can often opt to publicly funded support schemes including grants and subsidies. These instruments can take a large number of different forms but often consist in direct payments to project promoters based on CAPEX, OPEX or other relevant indicators. If these payments are a direct result of carrying out a PVI project they must be included in the calculations of NPV and IRR as inflows and in the case of LCOE reducing CAPEX and/or OPEX.

The total value of the cash inflows at time t can be obtained with the following eq. (8):

$$cash\ inflows_t = \frac{cash\ inflows\_selfcom_t + cash\ inflows\_grid\_com_t + cash\ inflows\_grant_t}{(1+r_t)^{t-1}} \qquad \text{eq. 8}$$

Where r_t is the risk-free rate with maturity at t.

The net present value of a PVI project

NPV is the risk-adjusted value that can be created by executing a project in absolute terms (how much money we are expected to earn). From the perspective of irrigators and investors it will not make sense to carry out a PVI project if the estimated NPV is negative, as they will lose money. On the other hand, a positive NPV indicates the financial suitability of the project. To calculate the NPV of a project we must obtain the difference between the summation of the present value of future cash inflows and cash outflows from the project discounted at its WACC. The NPV of a PVI project is determined by eq. (9):

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$$NPV = \sum_{t=1}^{n} \frac{Cash\ inflows_t - Cash\ outflows_t}{(1+WACC)^t} \qquad \textit{eq. 9}$$

where WACC is the weighted average cost of capital of the project; *n* is the number of years of lifespan expectancy of the system.

The internal rate of return and payback period

Another key indicator of DCF is the internal rate of return IRR, a measure of the relative performance of the project (what is the return that is expected to result from its execution). The IRR of a project is equivalent to its yield, so the higher the IRR the most suitable its execution is. In order to calculate the IRR of a project we must find the discount rate at which NPV=0 as presented in eq. (10) below.

$$0 = NPV = \sum_{t=1}^{n} \frac{Cash\ inflows_t - Cash\ outflows_t}{(1+IRR)^t} \qquad \textit{eq. 10}$$

If the value of IRR estimated for a project is lower than its WACC then the NPV will be negative. This is because the cost of capital of the project is higher than its expected return so promoters will be losing money by executing it. As a consequence, such project should not be considered appropriate for investment purposes.

The third indicator that is normally used for economic assessment at project level is the payback period or simply payback. The payback is the amount of time required for an investment to recover its initial cost. Based on the payback rule, an investment is better the shorter the payback is. The payback period can be calculated by determining the amount of time required for the cumulative value of the cash inflows to exceed the CAPEX of the PVI system. That is, the payback year is the lowest value of n that satisfies eq. (11)

$$\sum_{t=1}^{n} (cash\ inflows_t - OPEX_t) \geq CAPEX \qquad \text{eq. 11}$$

As a rule of thumb, if the LCOE of a PVI is higher than the price of the cost of energy of the cheapest alternative (for example the cost of electricity from the grid) then the NPV and the IRR of the PVI project will be negative and it will be not considered as a suitable investment. Nevertheless when stablishing the cost of energy of alternatives to PVI it is important not to simply use the cost observed during the few last period (for example taking as a reference the

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spot price at the time of the assessment) but to consider the prices observed during a long enough period (for example averaging spot prices over at least the last two years) and also by introducing costs related with the uncertainty of the future evolution of the price (for example the cost of hedging electricity prices over the next years).

A number of academic papers have used TEA to evaluate the use of photovoltaic irrigation and its suitability over incumbent alternatives in different configurations and countries. Most of the published studies present positive NPV, indicating the suitability of the solution in a wide range of contexts (Carrêlo et al. 2020) (Sarkar and Ghosh 2017) (Niajalili et al. 2017). Regarding PVI´s LCOE, the existing literature present a large variation in the estimated cost of energy, depending on the availability of local providers and the abundance of the energy resource. These differences indicate the difficulty of extrapolating the TEA results from PVI projects from different locations and times so any new project must carry out its own TEA to ensure the accuracy of the results.

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3. Socioeconomic assessment

TEA allows to assess the costs, expected returns and uncertainties related to building and operating PVIs at project level. This type of economic assessment includes only the private perspective of the owners of the PVI systems. Nevertheless, a comprehensive economic assessment of PVI should include not only the perspective of farmer/investors, but also the different direct and indirect impacts on society as a whole as a result of producing and operating PVI. For this, a widened focus must be applied in order to include costs and returns that are not necessarily assumed directly by its owners including environmental impacts, externalities, the use of public goods and any other element that will result of installing such systems (Strantzali and Aravossis, 2016). Such economic assessment provides useful information for policy makers and public institutions, including academics, that seek to understand all the implications that producing and introducing large scale PVI may have on a wide number of aspects.

The different methodologies available for estimating the social costs of projects are included in the socio-economic analysis. This type of analysis is based on the assumption that any enterprise or project has ramifications that affects not only its promoters or "shareholders" but also the rest of society. In the case of natural resources being involved the environment is also affected and these affections can also be valued economically even if the owners will not have to bear the resulting costs or obtain potential benefits. Among the conceptual framework of socio-economic analysis that can be used in the socioeconomic analysis of projects two most frequent approaches used are cost-benefit analysis (CBA) and life-cycle assessment (LCA). As LCA for PVI is the subject of KEMT 2, in this KEMT a CBA methodology for PVI will be proposed

3.1 Cost-benefit analysis of PVI projects

CBA identifies and estimates the cost and benefits of projects in relation to any change in welfare that would result from its execution. In order to do this, it is required to identify and to carry out an assessment at project level (for example by carrying out TEA) that will be complemented with a valuation of the impact on the overall economic and natural environment. CBA includes factors that are not included in economic assessment at project level such as

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the existence of imperfect markets, the consumption of public goods by the project, or the impact in value chains. By aggregating the results, an estimation of the net social gain or loss of undertaking a PVI project is possible. The results of CBA are economic indicators that are complementary to those estimated by TEA including the economic net present value (ENPV) and the economic internal rate of return (EIRR) which are the “social” versions of NPV and IRR respectively. The use of CBA in the context of policies oriented to the reduction of GHG is particularly relevant as it often occurs that the estimated NPV of a clean energy project is negative while the ENPV is positive, mainly as a result of introducing the economic value of avoided emissions.

The positive externalities of PVI projects are not only related to GHG reductions. As they rely in locally-based production facilities they create economic opportunities in the vicinity of the project that are not directly captured by its promoters but have a positive impact. Furthermore, by avoiding direct or indirect consumption of fossil fuels in irrigation activities, PVI reduces energy imports improving the commercial balance of the country. Given these potential socioeconomic benefits of PVI, public authorities may introduce subsidies to compensate the promoters in case that the NPV results negative at project level but the ENPV is positive. By carrying out a CBA it is possible to determine the adequate level that these subsidies in order to maximize social welfare (Johansson and Kriström, 2019).

A CBA of PVI requires the analysis of social, economic, political and institutional context in which the project will be produced. For example, the space required to install a PVI will have a larger cost in an area suited for greenhouse agriculture than in an olive plantation. It is not always straightforward to identify all these indirect impacts and to assign a monetary value to them, particularly when considering impacts on non-tradable goods. In any case a CBA for PVI must consider at least the following aspects.

(1) Identification of gainers and/or losers; Switching from electricity grid and diesel generation will affect negatively energy and utility companies and local providers of related goods and services. On the other hand, PVI will increase the demand for companies and professionals in related areas. The environmental and economic benefits of reducing fossil fuel consumption will benefit the overall economy.

(2) Identification of impacts (job creation, landscape destruction); Each MWp of PVI requires a total investment of around €1M. In terms of job creations, it is estimated that installing a MW of PVI creates 17.9 direct jobs-year. Its O&M creates 7.5 direct jobs-year

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assuming a lifespan of 25 years. The calculation of indirect jobs created can be obtained by using a factor of 0.45 over the direct jobs created. The impact of PVI includes land occupation of around 2 ha per MWp which can negatively affect the natural landscape. In 2021, producing a MW of electricity for the public grid implies CO2 emissions of 0.15 tons that will be totally avoided by using PVI. A CBA of PVI must consider the impact of switching from centralized production of energy to a decentralize model, a particularly important issue for energy planners. In particular the reduction of the costs of transmission and distribution losses should be included (Holtmeyer et al., 2013)

(3) Identification of the impacts with economic significance; It is estimated that 40% of the investment needed to produce a PVI is spent at local/regional level. At national level PVI will reduce the turnover of energy and utility companies and tax collection. PVI can reduce the energy dependency and improve the trade balance of the country.

(4) Physical identification and schedule of relevant impacts; Most of the economic impacts are produced during the first 12 to 24 months which is the period when most PVI CAPEX is used. Energy savings, O&M costs and environmental effects take place over the lifespan of the project, typically 25 years.

(5) Monetary valuation of impacts; It is estimated that for each MWp of PVI €400k are spent at local level. Jobs created by PVI are of higher qualification than the average being the average salary around €35K year in Spain in 2021. As a proxy of the economic value avoided emissions the EU´s Emissions Trading System (EU ETS) can be used. The average price of ETS during the first 8 months of 2021 was around € 50 per ton.

(6) Estimation of a discount rate and cash flows; The discount rate of PVI for project-level analysis must be its WACC. For socioecomic analysis the discount rate must be the economy´s risk-free rate as it reflects the time value of money in that country.

(7) Estimation of ENPV and EIRR

(8) Sensitivity analysis. This is particularly relevant to evaluate the total economic return of PVI supporting policies such as public co-financing of CAPEX and or OPEX of projects when NPV<0 but ENPV>0.

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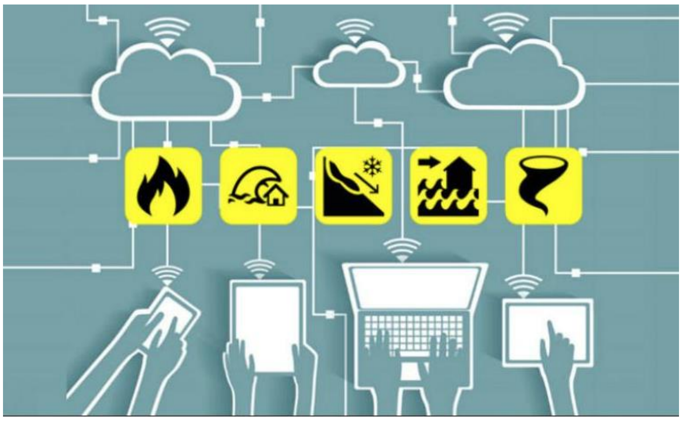
4. Risk analysis of PVI projects

In order to apply the proposed methodology, it is required to specify values for each of the inputs. Some of the values are easy to obtains and have a small level of uncertainty such as the expected yield of a system or the cost of commoditised elements of the CAPEX. Nevertheless, other elements are not so easily valued and/or present a high level of uncertainty regarding the actual value. This is the case of inputs which present a high volatility and/or that will affect the valuation in a future period such as future prices of alternative sources of energy or the future level of interest rates. The actual value that these inputs end up presenting have a significant impact in the economic performance of PVI so a comprehensive economic assessment must include an analysis of the different scenarios and its likelihood. This can be done using several techniques in order to quantify the components of the project that can deviate the actual results from the expected results. In the case of PVI uncertainty is inherent to its economic assessment as the expected cost and returns will unfold over decades of operation.



4.1 Sensitivity analysis

A first alternative for risk analysis of PVI is to carry out a sensitivity analysis. Sensitivity analysis consists of varying the values of variables considered particularly relevant and quantifying their influence on the main indicators of the project, such as LCOE or GHG emissions. In the case of PVI projects a sensitivity analysis must be performed to stablish the impact in LCOE, IRR, NPV and ENPV of at least:

1) Price and evolution of alternative sources of energy.
2) Capacity factor.
3) WACC components, in particular proportion and cost of debt, risk free rate and beta.
4) Intensity of grants and subsidies if considered as inflows of the model.

Sensitivity analysis presents useful information but has limitations. In particular it is a deterministic approach that fails to recognise key factors to understand uncertainty, including

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endogeneities among variables (for example a reduction of the capacity factor as a result of a reduction in the price of electricity from the grid) and, crucially, the probability of the occurrence of significant events such as an economic crisis. In order to include these issues, risk assessment models with probabilistic methods allow for the introduction of factors such as probability distributions and correlations between variables (Hasan, Preece, Milanović Invalid date).

4.2 Probabilistic analysis

The most frequently used probabilistic approach to assess risk and uncertainty in economic assessment is the Monte Carlo method (MCM). It consists of assigning a random value to the variable containing uncertainty and then running the model and recording the result. The process is repeated in order to obtain a set of results that can be used to assess the probability of the evolution of the variable to follow a given path. MCM can be applied in order to consider simultaneous variations in several parameters of a project and their impact on the expected cost and return. For example, the MCM allows simultaneous changes in parameters that present uncertainty such as operation and maintenance costs, electricity generation and variability, and obtaining in this manner a probability distribution function for the value of IRR instead of a single value.

These probabilistic approaches require the selection of probability distributions for uncertain input factors based on observed cases such as data records or surveys. As the track record of large scale PVI systems is currently very limited the application of probabilistic models is not possible. Nevertheless, it is expected that in the near future sufficient data will be available to carry out PVI risk analysis based on such models.

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5. Case study

In order to facilitate the application of the economic assessment methodology for PVI, a case study is presented in this section. It consists in assessing for the suitability of introducing a PVI in order to substitute an existing connection to the electricity grid. For this, project´s LCOE will be calculated and compared with the cost of the electricity obtained from the grid (P_e). As the promoters are assessing the system exclusively from its perspective if the LCOE > P_e then the project will not be executed.

The expected future cost of the electricity from the grid, P_e, has been calculated on the basis of the analysis of the bills charged by the electricity company over the last five years and the analysis of future market trends. The resulting expected future price of the electricity from the grid is estimated to be 68 €/MW. This price will be compared with the LCOE of the PVI project in order to assess the economic suitability of substituting the grid connection by a PVI. To quantify the LCOE of the project, estimations are required for its expected energy production over the expected lifespan of the system (t), CAPEX (€), OPEX (€) and the discount rate. The discount rate will be the WACC of the project (see equation 3 above).

1. Estimating energy production.

The energy production of a PVI system is determined by its capacity, normally expressed in kilowatt-peak (kWp). The size of the system is planned in order to meet the expected energy demand of the pumps. The other main determinant of the energy production of a PVI system is the solar radiation available at its location expressed in annual peak sun hours[1]. The value of this variable can be obtained using one of GIS-based tools available such as the SISIFO simulation tool (https://www.sisifo.info/en/default). Other elements that must be considered to estimate the production of a PVI system is the power efficiency of the panels and inverters and also to the existence or not of a tracking mechanism to optimize the orientation of the solar panels towards the movement of the sun across the sky. These elements are introduced in the model using factors accounting for losses of efficiency. An “availability ratio” must also be included in order to include production pauses caused by technical reasons. Finally, the lifespan of the system and the degradation rate of the solar panels were also estimated, based on the

[1] One “peak sun hour” is equivalent to 1000 W/m^2 of the sun's radiation collected in 1 hour.

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information provided by the manufacturer. In this case the variables that determine the expected energy production are presented in Table 1.

Table 1. Parameters for the technical description of an on-farm PVI system

Parameter and symbol	**Value**	**Unit**
Capacity of the system (*S*)	200	kWp
Solar radiation (*Sun*)	2,245	Peak sun hours
System efficiency (*Sys_eff*)	77%	
Lifespan	25	Years
Annual panel degradation (*Deg*)	0.6%	W/yr
Availability factor (*Av*)	96%	% of total time

The energy yield of the system (*Ey*), expressed in MWh, for a given period of time t is given by eq. (12):

$$\boldsymbol{Ey_t = S * Sun * Sys\_eff * Av * (1 - Deg)^t} \qquad \text{eq. 12}$$

The resulting *Ey* is presented for the first 6 years of the life of the system in Table 2. Nevertheless, the estimation of electricity generation over the entire operational life of the system (25 years) was used in the calculations.

Table 2. Annual electricity (MWh) expected to be generated by the solar PV system over the first 6 years of operation.

Year	1	2	3	4	5	6
Ey (MWh)	276.1	275	273.9	272.8	271.7	270.6

2. Capital budgeting

The capital expenditure of a PVI is concentrated during the planning and construction phase. CAPEX includes hardware elements such as solar panels and converters, as well as the

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engineering, procurement and construction (EPC) activities. The EPC budget includes contractors hired to design and install the different components. The frequency converters have a special treatment on CAPEX because their lifespans are shorter than the rest of the system and must be replaced every 10-15 years. Monitoring systems and the cost of taxes and permits related with construction and entering into operation must be included in the estimation of CAPEX. In this case, the cost of the site was considered to be zero as it was provided by the project owner. If the appraisal is also intended at socio-ecomic level an opportunity cost reflecting the use of the land should be estimated. If the system is designed to inject energy surpluses into the grid, inverters should also be included. The economic value of the aforementioned elements is obtained and included into the model at market prices (Table 3). The summation of these costs for each year *t* is $CAPEX_t$.

Table 3. Components of the capital expenditure (CAPEX €) of a 200 kWp solar photovoltaic system designed to power water pumps for an irrigation scheme.

Item	*Cost per unit €(kWp)*	*Total cost (€)*
PV modules	229.3	45,860
Frequency converter	76.4	15,280
Frequency converter (replacement year 12)	96.89	19,378
Sun-tracker	108.2	21,640
Monitoring	60.2	12,040
Engineering, procurement, construction	484.1	96,820
Civil engineering works	129.6	25,920
Taxes and permits	60.6	12,120
Total (converter replacement excluded)	1,148	229,680

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Once the CAPEX has been stablished the OPEX of the system has also to be determined. In this case study, OPEX will be paid at a constant rate during the entire operational lifetime, measured as € /kWh produced. The calculation of OPEX includes more uncertain than that of CAPEX because of it has to be paid for in the future. In this regard inflation must be considered. After assessing market quotations for the different goods and services included in the OPEX and the expected inflation rate over the period we can produce Table 4.

Table 4. Components of the operational expenditure (OPEX €/KWp) of a 200 kWp solar photovoltaic system designed to power water pumps for an irrigation scheme.

OPEX		Total OPEX per year					
Item	Unit cost (€kWp)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Maitenance	11.38	2,276	2,303	2,331	2,358	2,387	2,415
Management	7.69	1,538	1,556	1,575	1,594	1,613	1,632
Monitoring	7.50	1,500	1,518	1,536	1,554	1,573	1,592
Security	1.89	378	382	387	391	396	401
Insurance	2.50	500	506	512	518	524	530
Total	30.96	6,192	6,266	6,341	6,417	6,494	6,572

The total OPEX of the system in nominal terms over its 25 years of operation is estimated to be € 171,039.

3. Estimating the discount rate.

LCOE provides a measure of the cost of energy that takes into consideration the cost of capital given the riskiness of the project. The discount factor used in techno economic assessment the weighted average cost of capita. The WACC is calculated based on the systematic risk of the project (beta) and the proportion of debt and equity used to fund the investment. To estimate the cost of equity, the CAPM will be used in a basic version as presented in eq. (13) (Sharpe 1964):

$$\boldsymbol{k_e = r_f + \beta * (R_M - r_f)} \qquad \text{eq. 13}$$

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where r_f is the risk-free rate (normally the return of government bonds of the country where the project is based with a maturity equivalent to the lifespan of the system); β is the systematic risk of the project (which can be obtained using comparables (Damodaran 2002)); and R_M is the return of the risky asset of the country (normally the historical return of its stock market). The project is expected to be carried out with a bank loan covering 50% of the investment and 50% with equity of the owners. The bank has offered a 25 years loan guaranteed by the PVI at a year interest rate of 2.7%. In order to obtain the beta of the asset PVI, three comparables have been selected among companies operating PV systems and listed in the Spanish stock market (Solarpack, Grenergy and Solaria). The resulting beta of the asset and of the project has been obtained applying eq. (3) and eq. (4). The value of the relevant variables to estimate the cost of equity of a PVI project located in Spain are presented in Table 5 below.

Table 5. Parameters included in the calculation of the cost of equity for use in predicting the LCOE for a 200 kWp solar PV project to power irrigation pumps on a farm in Spain.

Variable	Value	Description
Risk free rate (r_f)	0.98%	Yield of Spanish 25 years bond
Tax rate	25%	Income tax in Spain
Systematic risk of the asset PVI (β_{PVI})	0.35	Average unlevered beta of Solarpack, Grenergy and Solaria
Systematic risk of the project ($\beta_{project}$)	0.61	For a PVI project using 70% debt and 30% equity
Return for risky asset (R_M)	8.04%	Historic annual return of Spanish stocks
Cost of debt	2.7%	Annual interest rate
Cost of equity (eq.13)	4%	Annual yield
WACC (eq. 1)	3.01%	Annual return

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Using the estimated discount factor, the summation of the expected energy yield discounted at WACC over the lifespan of the project is:

$$\sum_{t=1}^{25} \frac{EnGen_t}{(1+WACC)^t} = 4,744.7\ MWh \qquad \text{eq. 14}$$

As presented, PVIs CAPEX is mainly paid for in two years, most of it being spent during construction in year 1, with the remainder in year 12 when frequency converters are expected to be replaced. The resulting value of CAPEX discounted at WACC is:

$$CAPEX_1 + \frac{CAPEX_{12}}{(1+WACC)^{12}} = 229,680€ + 12,100€ = 241,781€ \quad \text{eq. 15}$$

In order to estimate the resulting cost of the energy for the system the estimated values of CAPEX, OPEX and the energy yield of the system are considered and discounted at WACC. Therefore, applying eq. 5 the LCOE of the project is:

$$LCOE = \frac{241,781+122,070}{4,744.7\ MWh} = €\ 76.69\ MWh \quad \text{eq. 16}$$

The estimated LCOE from the solar PV system is higher than the current price of the energy obtained from the electricity grid (€ 68 /MWh), so in this case, the decision should be to not carry out the PVI project and continuing obtaining the energy for the irrigation system from the public grid. Nevertheless, a sensitivity analysis can produce relevant information to support or revise this decision. In particular, a project´s investor may consider:

a) to fund part of the project with debt in order to reduce WACC and consequently the LCOE of the project; and/or

b) to change the configuration of the irrigation system in order to increase the PVIs energy output used.

4. Sensitivity analysis.

A sensitivity analysis can estimate the LCOE for different levels of debt and capacity use of the system. The original scenario in this case study was based on a level of debt for the project of 50% and a 65% employed capacity. Increasing the levels of these variables gives a reduction of LCOE. So the objective of the sensitivity analysis is to assess if it may be possible to reduce LCOE

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below the €68 MWh price expected to be paid in the future to the power company for grid electricity. The resulting values of the LCOE are shown in Table 6.

Table 6. Sensitivity analysis of the LCOE ($/MWh) of solar PV in relation to the proportion of debt used to fund the CAPEX (base case = 50%) and the efficiency of the system (base case = 65%). LCOEs that are lower than the alternative cost of the electricity (€68/MWh) indicate scenarios were changing to a solar PV system is economically viable (shown in bold types).

		Capacity use of the system					
		65%	67.5%	70%	72.5%	75%	77.5%
% of debt	50%	76.7 €	73.8 €	71.2 €	68.8 €	***66.5 €***	***64.3 €***
	55%	76.3 €	73.5 €	70.9 €	68.4 €	***66.1 €***	***64 €***
	60%	75.9 €	73.1 €	70.5 €	68 €	***65.8 €***	***63.7 €***
	65%	75.5 €	72.7 €	70.1 €	***67.6 €***	***65.4 €***	***63.3 €***
	70%	75 €	72.2 €	69.6 €	***67.2 €***	***65 €***	***62.9 €***
	75%	74.5 €	71.7 €	69.2 €	***66.8 €***	***64.6 €***	***62.5 €***
	80%	74 €	71.3 €	68.7 €	***66.3 €***	***64.1 €***	***62.1 €***
	85%	73.5 €	70.7 €	68.2 €	***65.9 €***	***63.7 €***	***61.6 €***

The sensitivity analysis shows that by combining higher capacity use and an increased level of debt used to fund the project, the LCOE can become less than the retail price being paid for electricity from the grid. Increasing the capacity of the system is particularly effective to reduce the LCOE of the system to competitive levels. However, increasing the capacity use of the system will probably require an increase in CAPEX that will result in an increase in LCOE. This possibility can be assessed with another sensitivity analysis.

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References

Carrêlo IB, Almeida RH, Narvarte L, Martinez-Moreno F, Carrasco LM. 2020. Comparative analysis of the economic feasibility of five large-power photovoltaic irrigation systems in the Mediterranean region. Renewable Energy 145:2671-82.

Damodaran A. 2002. Relative valuation. Investment Valuation.

Hansen K. 2019. Decision-making based on energy costs: Comparing levelized cost of energy and energy system costs. Energy Strategy Reviews 24:68-82.

Hasan KN, Preece R, Milanović JV. Invalid date. Existing approaches and trends in uncertainty modelling and probabilistic stability analysis of power systems with renewable generation. Renewable and Sustainable Energy Reviews 101:168-80.

Markowitz HM. 1991. Foundations of portfolio theory. The Journal of Finance 46(2):469-77.

Niajalili M, Mayeli P, Naghashzadegan M, Poshtiri AH. 2017. Techno-economic feasibility of off-grid solar irrigation for a rice paddy in Guilan province in Iran: A case study. Solar Energy 150:546-57.

Ouyang X and Lin B. 2014. Levelized cost of electricity (LCOE) of renewable energies and required subsidies in China. Energy Policy 70:64-73.

Sarkar MNI and Ghosh HR. 2017. Techno-economic analysis and challenges of solar powered pumps dissemination in Bangladesh. Sustainable Energy Technologies and Assessments 20:33-46.

Sharpe WF. 1964. Capital asset prices: A theory of market equilibrium under conditions of risk. The Journal of Finance 19(3):425-42.

Short W, Packey DJ, Holt T. 1995. No title. A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies.

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Annex I

Factors and indicators relevant in the economic assessment of PVI

Item	Unit of measure	TEA	LCOE	CBA
Technical				
Efficiency		✓	✓	✓
Reliability		✓	✓	✓
Resource availability	Equivalent sun hours	✓	✓	✓
Installed capacity	MWp/kWp	✓	✓	✓
Safety				✓
Lifespan	Years	✓	✓	✓
Economic				
CAPEX	€MWp/€kWp	✓	✓	✓
OPEX	€MWh/€kWh	✓	✓	✓
Cost of energy from alternative sources	€MWh/€kWh	✓	✓	✓
Cost of capital	Annual return (%)	✓	✓	
IRR	Annual return (%)	✓	✓	
EIRR	Annual return (%)			✓
NPV	€	✓	✓	
ENPV	€			✓

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Payback period	years	✓		
Environmental				
CO_2 emissions	Tons of CO_2			✓
Land use	Ha per MWp			✓
Impacts on ecosystems				✓
NOx emissions				✓
SOx emissions				✓
Social				
Job creation	Direct/indirect jobs/year			✓
Social acceptability				✓
Social benefits				✓
Visual impact				✓
Local development				✓
Impacts on health				✓
Income from jobs				✓

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