MODULE 2

Photovoltaic energy

Open Educational Resources for online course of renewable energy for local development

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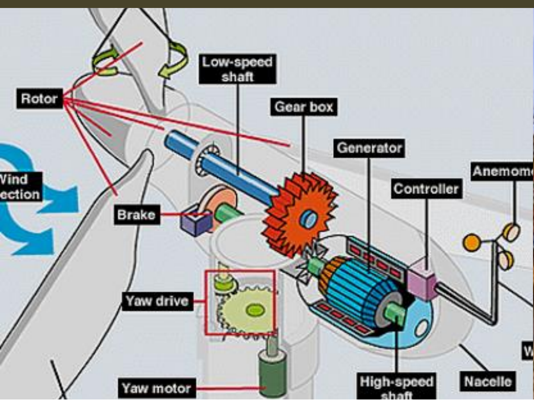
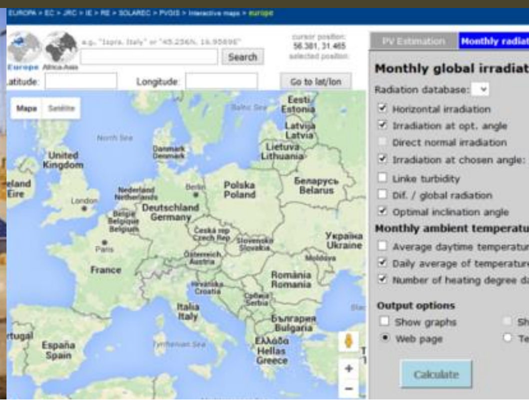
Authors: José Segarra, Juan Jorro and Zsuzsanna Kray





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MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 1. Technical aspects

Subchapter 1.1 - Principles concerning the use of photovoltaic energy. Conditions for efficient exploitation

José Segarra Murria, Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

Summary: To start this PV module the main uses of photovoltaics will be detailed in order to get an idea of the possibilities that this technology offers for the development of modern living. Once the technological possibilities offered by this technology are known, the main factors that determine the efficiency of photovoltaic systems such as radiation, inclination, shade, losses and efficiency will be dealt with.

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1. Photovoltaic solar energy

* The use and transformation of solar radiation into electricity is called Photovoltaic Solar Energy.

Photovoltaic Solar Energy is the term used to refer to the use and transformation of solar radiation into electricity by means of the photovoltaic effect.

It is considered a renewable energy resource because it uses a natural energy source such as solar radiation in order to produce electricity.

It is a clean energy source which does not produce greenhouse effect emissions. Therefore, it does not contribute to climate change or global warming.

The transformation of solar radiation into electrical energy is possible because of the photovoltaic effect. This phenomenon occurs when solar radiation photons impact on a semiconductor surface. If the photon hits the semiconductor surface with enough energy, it releases an electron that leaves enough space for the electrons to move and generate an electric current as a consequence.

1.1. Photovoltaic solar energy uses

After some years of technological development, photovoltaic solar energy applications have expanded into various fields:

- **Rural electrification**: photovoltaic solar energy enables the electrification of buildings located at a significant distance from the electrical grid, or buildings which can not afford the high grid connection prices. These buildings have habitually been obtaining their energy needs from disesel/gas generators.

- **Electrification of boosters, maritime beacons, and road signposting:** temporary low-power supplies. Their electrification through the electrical grid would involve an unreasonable cost.

- **Electrification of independent homes or industries:** these are buildings that are independent from the electrical grid and self-sufficient in terms of electricity. These self-sustained buildings satisfy the energy requirements for homes, farms or industries.

- **Pump unit and agricultural irrigation electrification:** the photovoltaic panels are used to supply the pump units without battery use. Pump equipment is sized according to daily irrigation needs.

- **Water desalination:** photovoltaic solar energy provides electricity to electrodialysis systems which desalinise water for human consumption or irrigation. This process of desalination occurs in remote areas or coastal zones with access to saline aquifers. Electrodialysis systems have low maintenance costs due to the lack of accumulators, regulators and invertors.

- **Ventilation**: a forced ventilation system by means of photovoltaic solar energy is used to expel hot and used air from the room with neither maintenance nor operational costs.

- **Diverse military and medical uses:** photovoltaic solar energy can be used to provide energy to field hospitals, and provisional and emergency posts.

- **Caravans electrification:** photovoltaic panels and the rest of components provide electric supplies to electric household appliances such as microwaves, refrigerators or televisions.

- **Electrification of ships, boats and vessels:** installing solar equipment enables increased or even complete autonomy to supply electricity for basic electrical appliances. These systems avoid using generators, which create a disturbing noise.

- **Electrification of space satellites:** space satellites were one of the first large applications of photovoltaic energy that are still in use today.

- **Other applications**
  - **Small appliances**: calculators, flashlights…
  - **Battery chargers**
  - **Toys**




2. Conditions for efficient exploitation

The production and performance of a photovoltaic installation depends on a number of factors.

To obtain the optimal calculation and result of a photovoltaic installation various norms must be taken into consideration because they will affect the performance of the installation. Some of these factors are:

- Radiation
- Inclination
- Losses due to shades
- Losses due to dirt
- Cell temperature
- Equipment efficiency
- Solar panel deterioration

All these factors account for the overall losses of the installation and, therefore, they impact its efficiency. This is called the Performance Ratio (PR) of the installation.

The official definition of PR according to IEC, STANDARD 61724 is '*the ratio of the measured System Energy to the Hypothetical Energy that would be produced had the System been operating at its rated power under the Reference Irradiance'*.

The installation PR tends to have values which range from 0,6 to 0,8 depending on the type of installation and its characteristics.

These various factors are described in detail below.

1.2. Radiation

The energy emitted by the Sun is transmitted to the Earth as electromagnetic waves.

The wavelength is a characteristic of the waves. It is defined as the distance between two consecutive crests of the wave and it is related to the frequency (v) of the wave. This last concept determines the energy transported by a wave and does not change when moving from one medium to another.

Electromagnetic waves travel at the speed of light (c) in a vacuum. The relationship between the wavelength (λ) and the frequency (v) is determined by the expression:

$$\lambda \cdot \nu = c$$

The energy transported by the wave is defined as:

$$E = h \cdot \nu$$

h being Plank´s constant with a value of $6{,}63 \cdot 10^{-34}$ Js

Solar radiation is made up of groups of electromagnetic waves with different frequencies and, therefore, different energies.

The representation of the energy of radiation according to the wavelength, or the frequency, is known as the spectrum.

The following figure is a representation of the solar radiation spectrum, as it achieves the Earth.

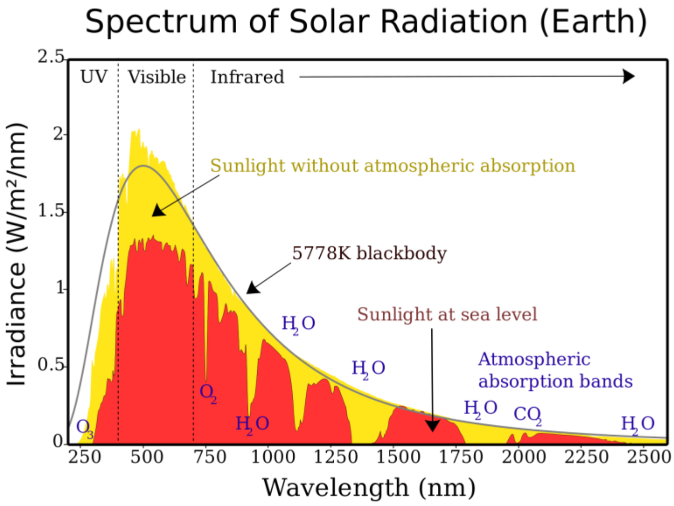

Figure 1: Solar Radiation Spectrum, by Robert A. Rohde via Wikipedia.

From the solar energy transformation perspective into another type of energy, the spectrum is not useful in its entirety, given that for some wavelengths the energy flow reaches the Earth's surface at such a low level that no further transformation is possible.

The only important radiation is the one concretely located in the visible range (390 a 750 nm), part of the corresponding Ultraviolet radiation (UV) zone and part of the Infrared radiation (IR) zone. This is because the amount of radiation in this spectrum range is large enough to be received and used. Also, the energy of this radiation can interact with the materials used in the panels.

1.2.1. Direct and diffuse radiation

As already introduced in the first module of this course, not all the Sun´s solar radiation reaches the Earth's surface given that a part is absorbed when it goes through the atmosphere, while another part is dispersed by the atmospheric constituents and suspended particles. On average, only 53% of the solar radiation in the upper atmosphere reaches the Earth's surface. This is named as global solar radiation. This type of radiation is divided into two subtypes according to the interaction of radiation with the atmosphere. Thus, global radiation distinguishes between direct radiation and diffuse radiation.

Direct radiation has an uninterrupted trajectory. This radiation component has not changed its direction from leaving the Sun. Direct radiation can be noticed because it casts shadows over the objects affected by it.

Diffuse radiation is produced as a consequence of the phenomena of reflecting and refracting radiation caused by atmospheric components.

Solar energy collector systems can absorb energy coming from both types of radiation or even reflected radiation, Figure 2.

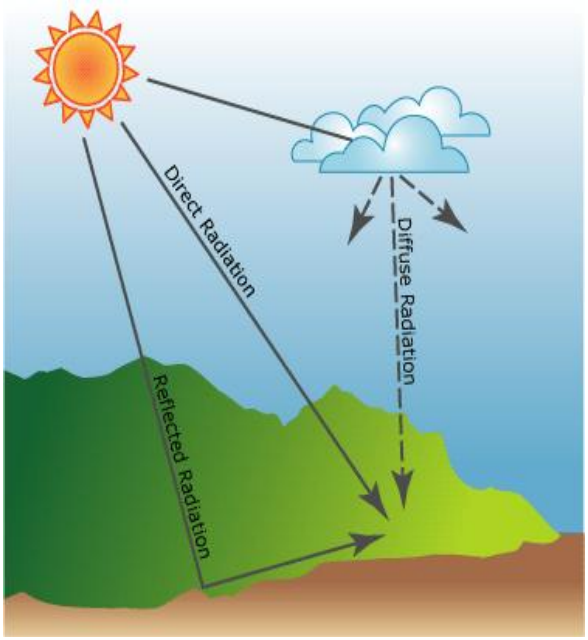

Figure 2: Radiation's type World map by SolarGIS Source: http://www.biofuturo.net/

1.2.2. Variation in solar energy flow

Variation occurs not because of solar variations but due to environmental factors in the Earth's surface. These factors are:

- ***Geographical sunlight variation (Latitude):*** Depending on latitude, the irradiation values will be distinct because not all areas of the Earth receive equal amounts of solar radiation.

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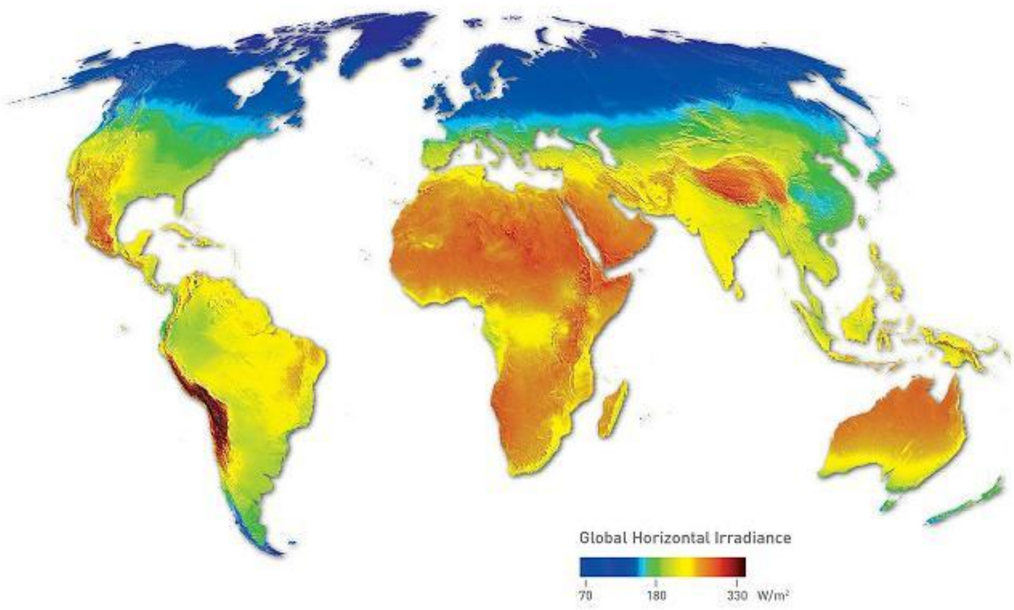

Figure 3: Geographical sunlight variation. By Kristina Ivonne A. Via InCyTDe (Instituto de Ciencia y Tecnología para el Desarrollo)

- ***Diurnal light variation:*** due to the Earth's rotation around its own axis and its trajectory around the Sun, the angular height with which the radiation passes through the atmosphere and its air mass changes. This daily variation produces changes in the solar radiation on a surface throughout the day and the months of the year.

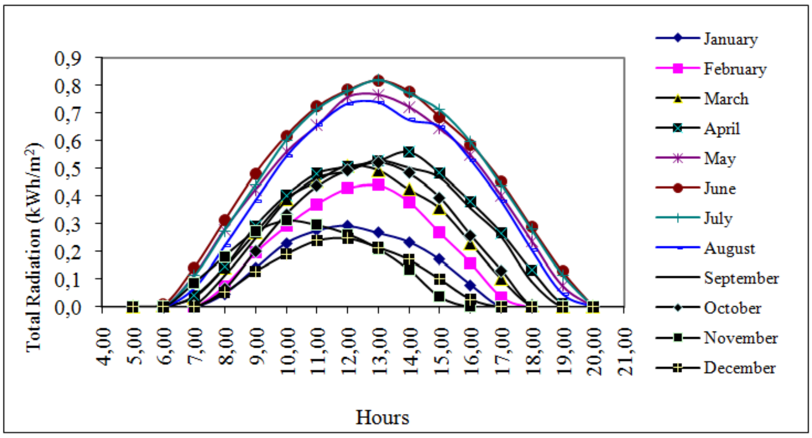

Figure 4: Diurnal light variation

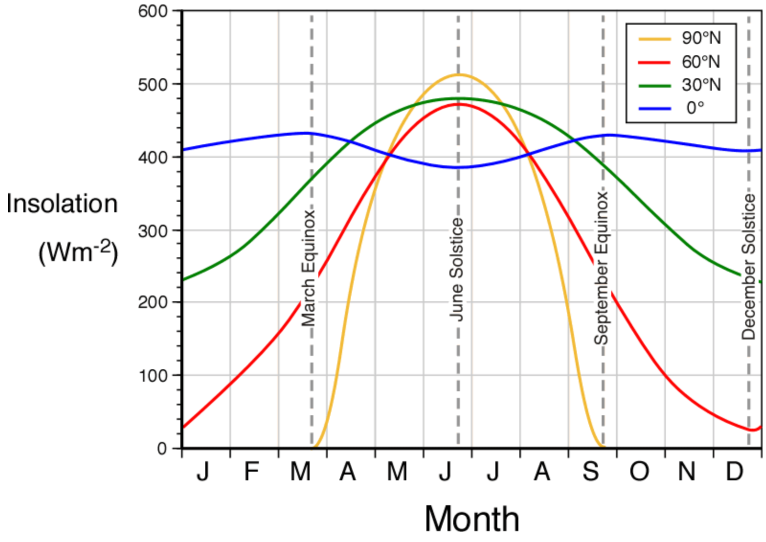

Figure 5: Monthly values of available isolation in Wm^{-2} for the equator, 30, 60 and 90º North. Source: www.phisicalgeography.net

- ***Elevation:*** the elevation above sea level is another important factor. Direct radiation increases when the radiation collector point is more elevated as the thinner atmosphere absorbs and disperses the sunlight less than in areas of lower elevation.

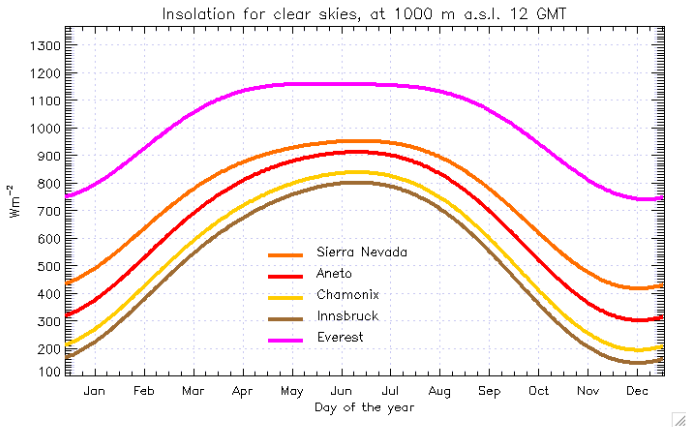

Figure 6: Solar Radiation at difference elevations

1.3. Inclination

The surface collector inclination, in relation to the horizontal, modifies the collected radiation due to solar rays' angle of incidence on the surface.

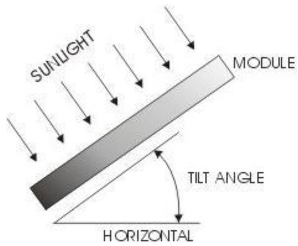

Figure 7: Inclination solar panel

The optimal collector surface inclination to optimize the annual use of the incident solar radiation depends on the installation's location. Three situations are generally differentiated according to the need of greater solar production.

- Annual demand: $\beta_{opt} = \phi - 10$

- Summer demand: $\beta_{opt} = \phi - 20$

- Winter demand: $\beta_{opt} = \phi + 10$

β_{opt} being the optimal inclination angle and ϕ being the location's latitude.

Occasionally, it is not possible to apply the maximum possible capture criteria to determine the inclination because these is limited by regional and climate factors. Inclinations of around 90º are required in areas where it frequently snows to avoid the accumulation of snow on the panels' surface. A minimum inclination of 40º is required in desert areas to avoid sand accumulation on the surface and a minimum inclination of 30º is required in tropical rainy areas.

1.4. Shade loss

Surrounding shades produce radiation losses on a surface. These losses are expressed as percentages of the global solar radiation that would attain the surface in the absence of any shade.

Losses may be caused by the shaded outlines of the photovoltaic installation, or may be caused by remote obstacles such as buildings or trees.

The minimum separation distance between lines of panels in order to avoid shade losses among them is usually calculated in the following way:

$$a = H / tg\ (61^{o} - \text{place latitude})$$

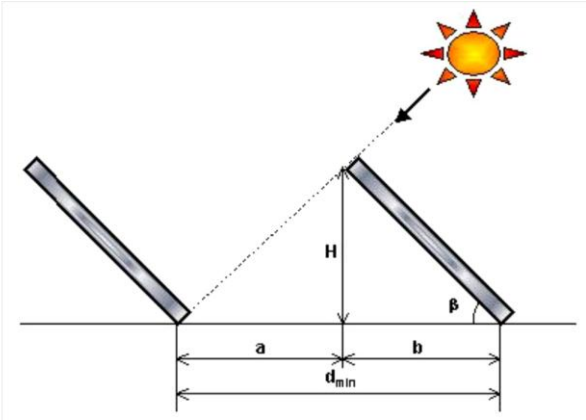

Figure 8: Separation distance between lines of panels

There are methods to calculate and determine the losses due to remote obstacles shade which relates their height to the distances that separate them.

1.5. Losses by dirt

Dirt and dust accumulate on the panels as a consequence of their outside location.

Losses due to dirt are estimated to be 5% in normal environments. This percentage increases in busier environments such as installations close to dirt roads or heavy industry areas.

1.6. Temperature modules

Photovoltaic modules lose around 4% of their power for every 10ºC increase in their operating temperature. This percentage changes slightly depending on the technology. The photovoltaic module operating temperature depends on environmental factors such as the irradiance, the ambient temperature and the wind speed, as well as the position of the module or the ventilation at its rear part. This implies that even though the incidental solar irradiation is identical, the same photovoltaic system will produce less energy in a warm place than a cold place.

1.7. Losses by wiring

Wiring losses are due to energy losses caused by voltage drops both in the direct current (DC) and the alternating current (AC), when current flows down a conductor made of a determined material and placed in a determined section. These losses are minimised when the cabling section is measured correctly. Even so, DC loss may be as high as 1,5% and AC loss can reach 3%.

1.8. Equipment efficiency

All the equipment that forms the photovoltaic solar installation also has an efficiency which influences the installation. The performance data of the equipment is made available by the producer.

Therefore, power inverters (device that converts direct current to alternating current) tend to have an efficiency of around 94 to 96% and the maximisers (battery charge controller with Maximum Power Point Tracking technology) tend to have an efficiency of around 98%.

Moreover, the global efficiency of a battery bank can be calculated in the following way:

$$R = (1 - K_b) \cdot \left(1 - \frac{K_a \cdot N}{DOD}\right)$$

Where:

K_b: loss coefficient due to accumulator efficiency.

- 0,05 in systems which do not demand powerful discharges.
- 0,1 in high discharge systems.

K_a: coefficient of daily self-discharge.

- 0,002 in low self-discharge batteries (Ni-Cd)
- 0,005 in stationary batteries (Pb-Ac)
- 0,012 in high self-discharge batteries (car starter batteries)

DOD: being the daily *Depth Of Discharge* (DOD). It will not exceed 80% - it refers to the nominal accumulator capacity.

N: number of days of autonomy.

1.9. Solar panel deterioration

Photovoltaic panels lose their efficiency over the years in such a way that after 20 years they will have lost approximately 20% efficiency.

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MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 1. Technical aspects

Subchapter 1.2 - Technical alternatives and installation types for photovoltaic installations applicable for rural development.

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Summary: The aim of this subchapter is for the student to know the main characteristics of the components that form part of a photovoltaic system and the main current technologies for them. Descriptions of the main types of PV installations depending on their purpose and location that determine the components necessary for each kind follow.

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1. Components of a photovoltaic installation

A photovoltaic installation is mainly formed of a solar radiation collector field (PV or photovoltaic panels) and the equipment that transforms the DC electricity generated by the panels into energy to be stored (in case of using batteries or another storage technology in an isolated installation) used in local appliances, or injected into the grid.

Depending on the type of installation, the equipment used for these purposes are:

- Photovoltaic panels
- Supporting structures for photovoltaic panels
- Regulator / Maximiser
- Batteries
- Power inverters

This equipment is described in detail along the following points.

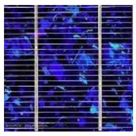
1.1. Photovoltaic panels

Collector fields are formed by photovoltaic panels. Each of them, these panels are formed by groups of photovoltaic cells which produce the photovoltaic effect and generated electricity (current and voltage).

Commercially available photovoltaic cells present different technologies:

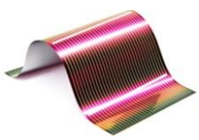
- **Monocrystalline silicon:** consisting of just one silicon crystal that provides a performance of around 14-18% and a relation of 150 W/m^2 providing more installed power on a small surface.

- **Polycristalline silicon:** consisting of a number of silicon crystals, each with a different shade of blue. Their performance tends to be 12-14% with a relation of 100 W/m^2. This type of panel is cheaper than the monocrystalline silicon.



- **Amorphous silicon**: is the non-crystaline form of silicon used as a deposit on different surfaces. They are also called thin film panels. These panels have lower efficiency (6-10%) and are the cheapest available. They can be flexible and used in curved or irregular surfaces.

- **CIS and CISG cells**: these cells are formed of copper, indium, selenide, and by adding gallium the latter type of cell may be obtained (CISG). They are used in thin film modules.



- **CdTe cells:** they are formed of cadmium telluride and they are also used in thin-film panels.
- **Other types:** various lines of investigation on photovoltaic cells are being followed nowadays. Some of them may be organic cells, solar paint…

Monocrystalline and polycristalline panels are the most commonly used worldwide due to their cost and performance, both in big installation and also in small ones usually developed in rural areas.

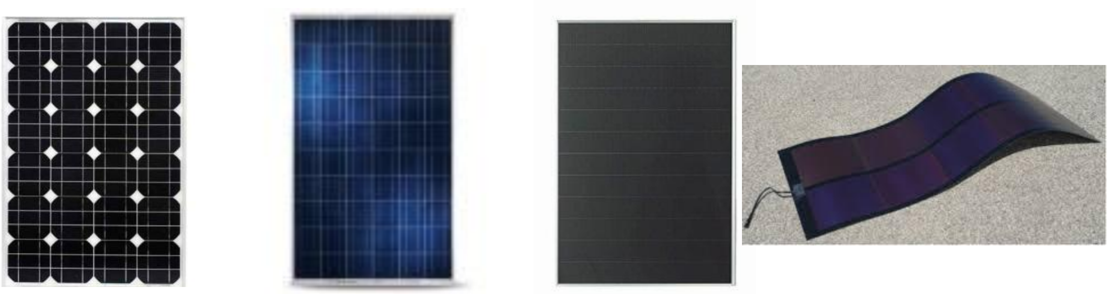


Figure 1: Monocrytalline Polycrystalline Thin-film

1.2. Supporting structures for solar panels

The structure supports the photovoltaic module and it gives the necessary inclination to achieve the optimal efficiency. It is also in charge of fixing the PV modules against wind gusts and offer support to the wiring interconnections.

The most commonly used supporting structures for photovoltaic panels are made of anodised aluminium or galvanised steel. The supporting structures made of anodised aluminium weigh less and are easier to transport.

There are different types of structures:

- Fixed
- Solar tracking

1.2.1. Fixed structure

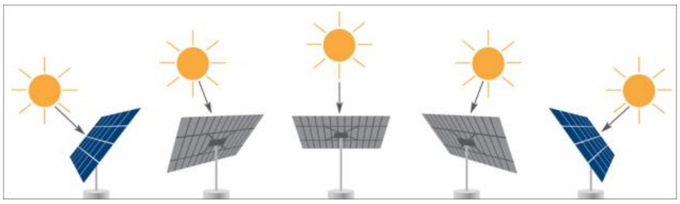
These coplanar and inclined types of structures are permanently fixed in place.

- The ***coplanar*** structures are situated in parallel with the surface where the panels are installed in order to optimise their integration. It is always advisable to leave certain space in between the surface and the structure in order to allow a good ventilation of the panels, avoiding overheating.

- ***Inclined structures*** give the ideal inclination for the installation. Eventually, these structures may have two positions that allow changing the inclination angle mannually in winter or in summer.

1.2.2. Sun tracking structure

This type of structure can track one axis, with the movement only along one axis. (e.g. from East to West for a day), or two axes to also change the inclination.



Sun tracking structures increase the photovoltaic production up to 40% (depending on the tracking structure) in comparison to a fixed installation, Figure 2.

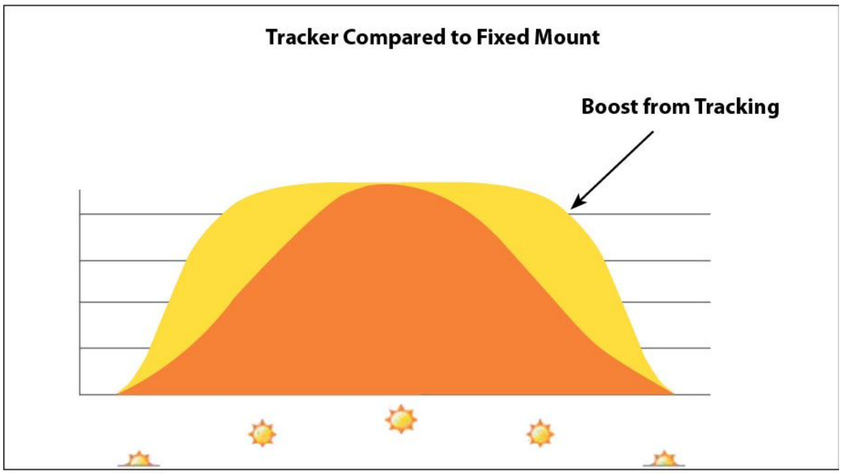


Figure 2: Daily Power Production. Tracker Compared to Fixed Mount. Source: First Solar

1.3. Regulator/maximiser

Regulators are the electronic equipment that controls the battery charge. Thes, they impede the batteries to have a charge that is too high or too low. Regulators also try to optimize the sensitive battery life. They tend to have input voltages of 12 or 24V, what limits their use with certain types of panels.

Maximisers (Maximum Power Point Tracking - MPPT) are an evolution from traditional charge controllers. These power converters analyse the energy flow of the photovoltaic panels and compare it with their internal algorithm to make the best use available of it. They enable the use of panels usually employed in grid connecting installations without problems, and they can even reach an input voltage of 150Vcc.

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1.4. Batteries

A battery is an energy storage system and they allow using the stored energy when there is no Sun.

Nowadays, there are various types of batteries which depend on their application. The most commonly used for solar installations are the following:

- ***Monobloc battery:*** it is used in low demand applications such as weekend homes, ships or caravans. Their lifetime is about 400 cycles to 75% of discharge. They are economical and require low-maintenance.

- ***GEL and AGM monobloc batteries:*** these batteries can be made of gel or lead acid VRLA. They are low maintenance because they recombine gases and do not produce water loss. Their main advantage is their low self-discharge, hence they can be maintained at maximum charge for 6 months with no important charge losses. Due to their slower sulphating in regard to the conventional lead-acid batteries, they lose less capacity during their lifetime. These types of batteries are perfect for ships, caravans or solar installations because they do not emit gases during operation.

- ***Semi-stationary monobloc batteries:*** they are used in solar energy and high-cycle application. There are two technologies: flat plate or tube plate. The difference between them is that tube plate technologies duplicate the flat plate's lifetime.

- ***CPZS batteries:*** these are batteries with an opac polypropylene container. They are appropriate for intensive uses due to their resistance to deep discharges. Their lifetimes are 1500 cycles at 80% of discharge and they tend to be commercialised in 2V cells.

- ***OPZS batteries:*** these are the most commonly used in photovoltaic solar installations due to their low-maintenance and, also, because the electrolyte level can be seen through their walls. They are prepared for deep discharges (1500 cycles at 80% of discharge) but if they are not appropriately sized they can lose half of that lifetime.

- ***OPZV batteries:*** these are tube plate batteries and their electrolyte is in the form of a gel. They are sealed, therefore, they can be installed in any position. Due to its low sulphating, they have a higher efficiency during their lifetime. This type of batteries is perfect for telecommunications facilities or places where the water level is not controlled. They are more expensive than the OPZS batteries but they have higher energy efficiency.

- ***Nickel-iron batteries:*** they were patented by Edison in the 20th century to be used in the electric car. They are long lifetime batteries that can last 50 years due to the electrolyte in them which does not destroy the battery. By only changing it every 7 or 8 years, the battery is renewed. They present a low energy cost even though their price is higher than the previous ones. Nowadays, grapheme researchers are focused on this type of batteries, in which the loading charge (2 minutes) and discharge (30 seconds) times are reduced.

- ***Lithium-ion batteries***: the advantages of this type of batteries are their low weight-volume ratio with their high storage capacity and their low self-discharge rate. Lithium-ion batteries are the most commonly used in electronical appliances (mobile phones and computers) and, lately, in the development of the electric vehicle and compact equipment which allow housing to be self-efficient. Some disadvantages are their high costs, their lifetime is not long enough and their low number of charges.

1.5. Power inverters

Power inverters transform stored energy form the batteries or generated energy DC current from the photovoltaic panels at 12, 24 or 48V into alternating current at grid voltage and frequency.

A distinction can be drawn between:

- ***Grid-tie inverters:*** this type of inverters requires the grid signal presence to transform the generated energy into the same characteristics of the grid. Current power rating can range from 20-300Wp for inverters embebed in the photovoltaic modules, to medium and central inverters with more than 100kW.

- ***Stand-alone inverters:*** this type of inverters transform energy into preselected values and, according to the quality of the wave they emit, can be distinguished between:

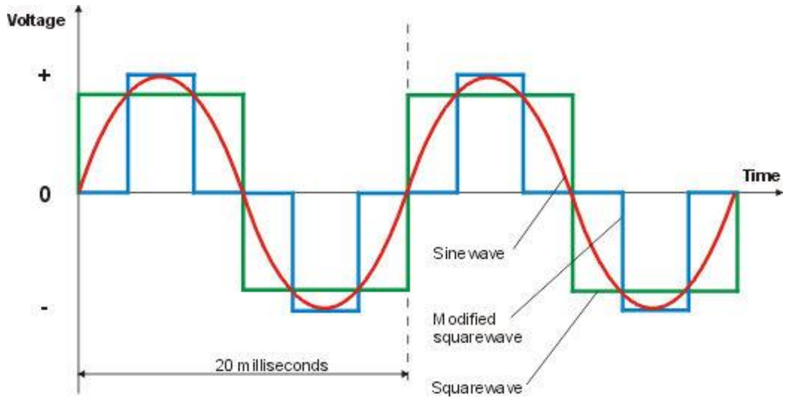

Figure 3: Different waves

- *Square wave inverters*: they emit a sudden signal. They are the cheapest ones but also the least efficient. They produce too many harmonics which cause interferences (noise) and, as a consequence, they are not suitable for induction motors. These inverters can only be used to feed a television, a computer or a small electric device.
- *Modified sine wave inverters:* the wave width is modified to bring it closer to the sine, even when it is not. They have the best price and quality to feed lighting, television or variable-frequency drives.
- *Pure sine wave inverters:* this type of inverters produces a pure sine wave. In order to do that they need complex technology that makes the equipment more expensive.

Some stand-alone inverters have a charger function. This faction enables the charge of the batteries from an external generator such as a diesel one. It is used to keep the batteries in a good charge condition after strong discharges.

2. Types of photovoltaic installations

There may be three different types of photovoltaic installations depending on the installation's purpose and location:

2.1. Off-grid

Off-grid photovoltaic installations are not connected to the distribution network. The installation generates and stores the energy for its deferred use.

These types of installations are common in places where there is no access to the distribution network or in places where creating a distribution network implies an important economic cost.

The basic diagram of this type of installations is:

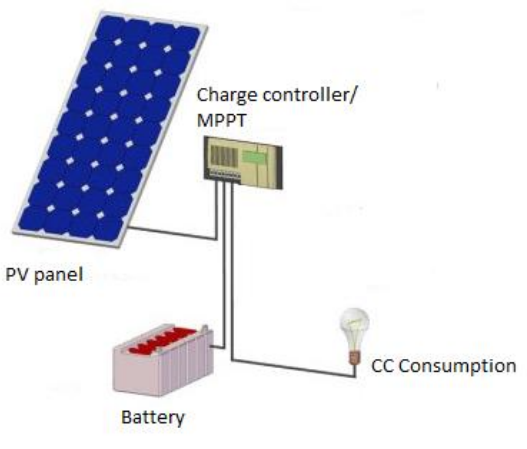

Figure 4: Diagram off-grid installation

The panels generate the energy that via the regulator either charges the batteries or is taken for direct consumption by a direct current load. When there are alternating current loads, an inverter is also needed and this one removes the required energy from the batteries via the regulator.

Thus, stand-alone installations consist of:

- Photovoltaic panels
- Regulator / maximiser
- Battery bank
- Inverter / Charger

The applications for this installation system are the electrification of isolated houses, industries, hotels and rural areas.

Some examples of applications of these installations are road lighting and electrification markers.

There are also installations which do not store energy and work only when there is photovoltaic production. Boreholes solar pumps, solar irrigation, swimming pools purifiers or ventilation equipment are all examples of this type of installation.

2.1.1. Pumping and solar irrigation

Solar pumps and irrigation are based on a photovoltaic field that, through a water-resistant borehole pump controller regulates the irrigation or fill up a deposit.

There are pumps which have the controller incorporated -solar pumps- and other pumps that have external controllers.

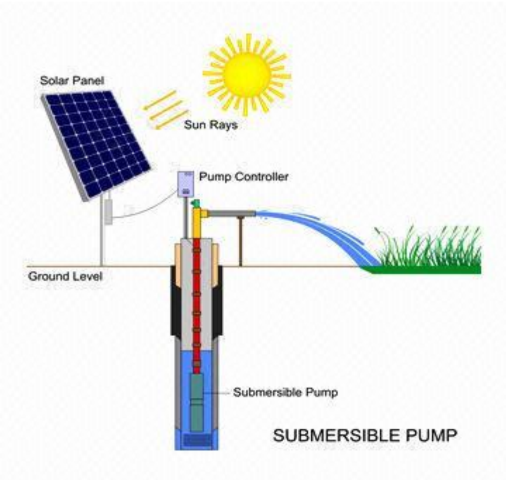

Figure 5: Diagram of pumping solar irrigation

2.1.2. Solar purification of swimming pools

The basic drawing of a swimming pool solar purification installation is identical to the solar pump installation. The energy generated by the photovoltaic panels goes through a pump controller to regulate how it works.

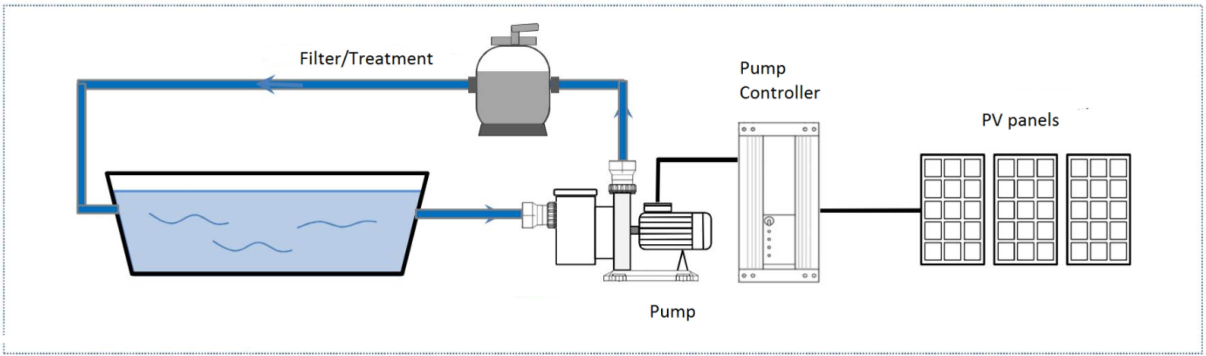

Figure 6: Diagram of solar purification of swimming pools

2.2. Grid-tie installations

Grid-tie installations are photovoltaic installations which discharge all the energy generated to the distribution network.

It is a type of installation devoted to sell as much energy as possible to the electrical market and, therefore, it is not dependent on the power consumption that there may be at the point of discharge.

The components of grid-tie installations are photovoltaic panels and grid-tie inverters

These can be observed in the following diagram:

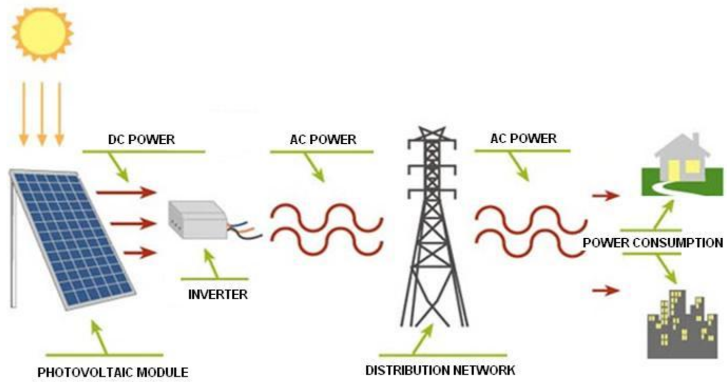

Figure 7: Diagram of grid-tie installation. Source: www.eco-systems.es

2.3. Photovoltaic self-consumption installations

This type of installations mixes both types of installations mentioned previously. They generate energy using photovoltaic panels, then they consume the necessary energy at the point of delivery and they discharge the surplus production to the grid.

There are two types of self-consumption:

2.3.1. Direct self-consumption

The energy generated from these installations is directly and instantly consumed by the local charges, and the surplus production is discharged to the grid. In some countries this surplus is paid. In others a net balance exists where the energy discharged is compensated with that consumed by the user installation in non-productive hours of the PV plant. In contrast, in other countries the surplus is not paid.

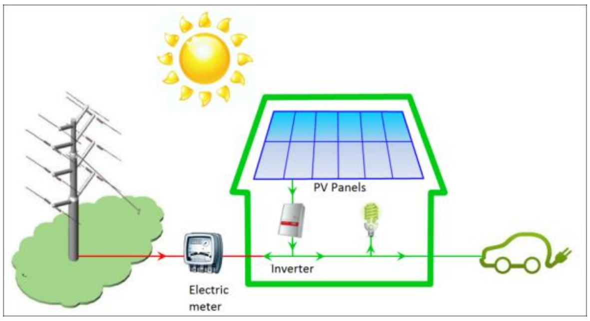

Figure 8: Diagram of self-consumption

The next graphic represents the production and self-consumption curve of a direct self-consumption installation. In it, the blue part represents the surplus production that will be discharged to the grid.

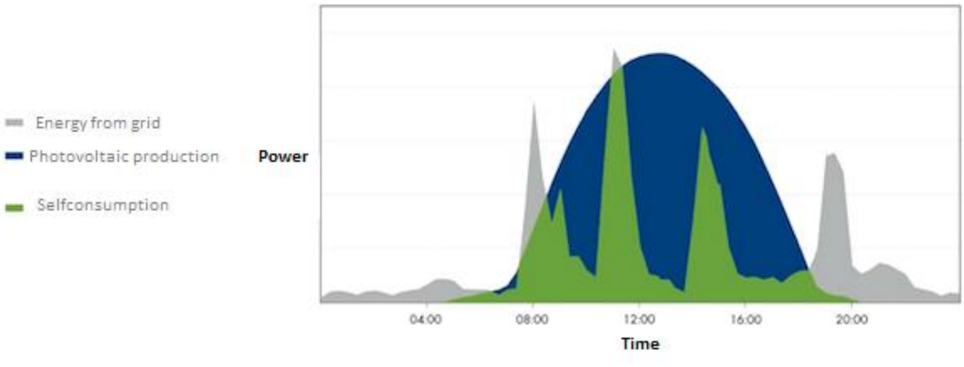

Figure 9: Diagram of the energy's house in one day

2.3.2. Self-consumption with accumulation

In this type of installation, the surplus production is stored into batteries in order to keep that energy till the time is more useful. Therefore, it requires a pack of batteries and some additional equipment to manage the battery charging and discharging.

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MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 1. Technical aspects

Subchapter 1.3 - Calculations and design.

José Segarra Murria, Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

Summary: An accurate installation sizing is crucial for an optimal long-life operation of the equipment. Once the main equipment required for a photovoltaic system is known, this subchapter describes the basis for a correct PV system sizing. This includes as the calculation of energy needs, system losses, and the dimensioning of each installation component. With this, the student will be able to carry out a basic PV system design and sizing according to its end use and location requirements.

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1. Calculation of the energy needs

To start designing the photovoltaic system it is necessary to know the daily consumption of energy required. To do so it will therefore be necessary to list the energy consuming equipment and the daily number of operating hours. If there is no up to date performance data, this can be estimated from the basis of the data provided in the following table:

Table 1: Power consumption of different equipment. Source: own elaboration.

Appliance	Power Consumption	Running hours /day
Fridge class A+	80W	10h
Led TV	70W	3h
Washing machine A+ (Wash cold water)	350W	1,5h
Microwave	900W	0,3h
Blender	200W	0,25h
Computer	200W	2h
Kitchen/dining room lighting	26W x 6 Uds	3h
Room lighting	26W	1h
Small consumption (chargers, standby…)	4W	24h

The daily energy required in Wh/day is obtained by multiplying the rated power by the operating hours of the equipment to add all the concepts.

$$Ed\ (Wh) = \sum(P\ (W) \cdot h_{func}) \qquad \textit{(Eq. 1)}$$

2. System losses

The energy generated by the panel is calculated by taking into account the radiation at the defined angles of inclination.

As has been explained in subsection 1,1 of this module, system losses are called Performance Ratios (PR) and they encompass all losses. A PR of 0,6 is usually established if there is a battery accumulation system and a value of 0,8 if it is a direct generation system.

In order to obtain the exact calculation the PR is calculated as:

$$PR = 1 - (Loss_{orient} + Loss_{shade} + Loss_{dirt} + Loss_{cable} + (1 - Perf_{inv}) + (1 - Perfreg+1-Perfbat+Lossdeter) \qquad \textit{(Eq. 2)}$$

Where:

$Loss_{orient}$: losses due to orientation. They will be 0 for South orientations.

$Loss_{shade}$: losses by shadows

Lossdirt:	losses by dirt. These are estimated to be around 5%, increasing in charged environments.
$Loss_{cable}$:	losses by wiring. These are estimated to be around 3%.
$Loss_{inv}$:	performance of the inverter. It is estimated to be between 94-96%. It is obtained from the technical data-sheet.
$Perf_{reg}$:	performance of the Regulator/Maximiser. It is obtained from the technical data-sheet. For a Maximiser this sum is calculated to be 98%.
$Perf_{bat}$:	performance of the batteries. It is calculated according to the formula provided in the sub-section 1.1:

$$R = (1 - K_b) \cdot \left(1 - \frac{K_a \cdot N}{DOD}\right)$$

$Loss_{deter}$:	loss due to deterioration of the panels. It is defined in the technical sheet of the panel. Normally, the panels lose 20% of the production in 20 years.

3. Dimensioning the photovoltaic field

In order to define the number of PV panels to be installed, it is compulsory to know apart for the previously defined variables (the daily energy that must be supplied and the system losses), the characteristics of the panel to be installed (e.g. Monocrystalline, polycrystalline, amorphous) as well as their nominal peak power.

The irradiation of the area is obtained from official databases available for each country or region. These usually provided the radiation in the inclined surface of the panels that will be installed.

The total daily and monthly energy generated values are also available in some of those databases. One excellent example is the web PVGIS (Photovoltaic Geographical Information System) in which the PV production can be estimated by entering the required parameters. Check: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php

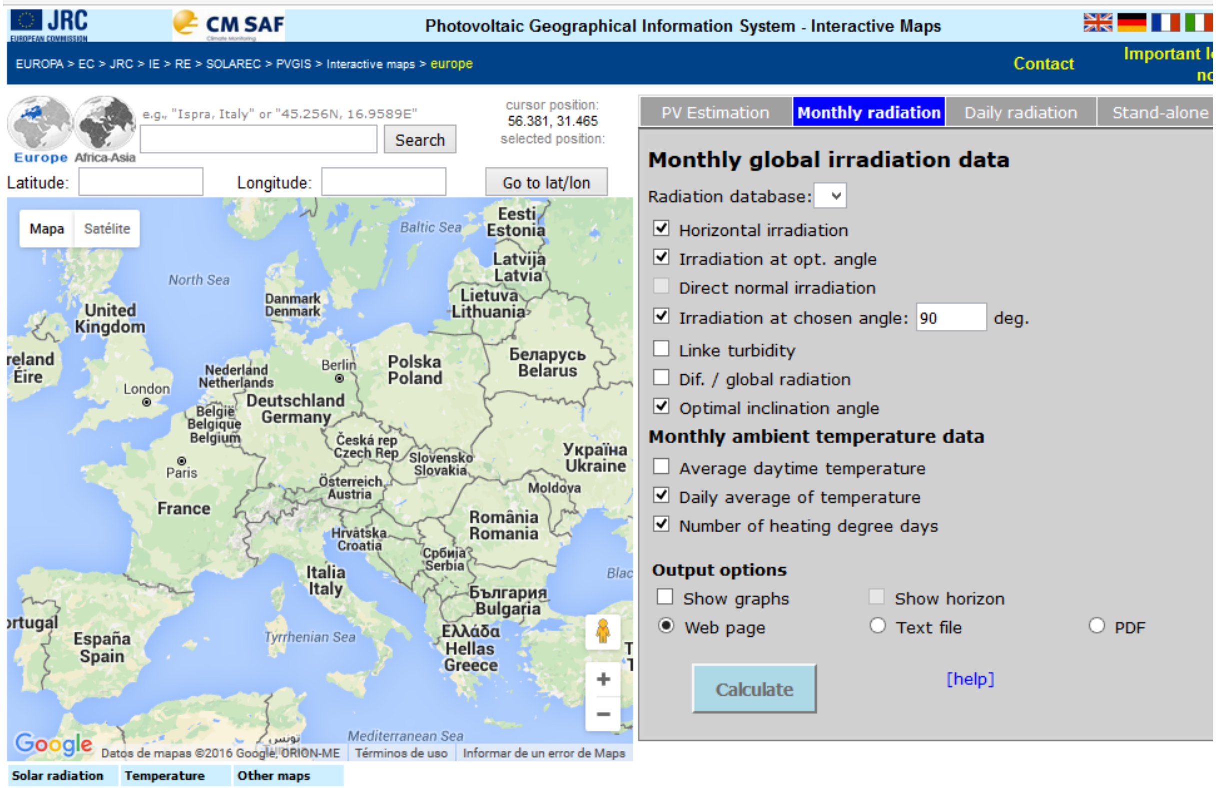

Figure 1: Web view. http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php

Click on the tab "Monthly radiation", then select the location of the installation in the map and on the right side click on "Irradiation at chosen angle: deg" to define the angle of installation of the panels.

Click on calculate and a new window with the following data will open:

Monthly Solar Irradiation

PVGIS Estimates of long-term monthly averages

Location: 40°4'0" North, 0°15'49" West, Elevation: 332 m a.s.l.,

Solar radiation database used: PVGIS-CMSAF

Optimal inclination angle is: 36 degrees
Annual irradiation deficit due to shadowing (horizontal): 0.8 %

Month	H_h	H_{opt}	$H(45)$	I_{opt}	T_{24h}	N_{DD}
Jan	2240	3870	4090	63	8.2	220
Feb	3230	4930	5120	56	9.1	168
Mar	4710	5980	6010	43	11.7	98
Apr	5500	5990	5820	28	14.4	46
May	6460	6270	5920	15	17.6	3
Jun	7300	6730	6270	8	22.0	1
Jul	7250	6850	6410	12	24.6	1
Aug	6240	6500	6250	23	24.7	1
Sep	4830	5790	5750	38	21.0	7
Oct	3660	5160	5290	51	17.3	43
Nov	2500	4150	4370	61	12.2	181
Dec	1960	3530	3760	65	8.6	233
Year	4670	5480	5420	36	16.0	1002

H_h: Irradiation on horizontal plane (Wh/m^2/day)

H_{opt}: Irradiation on optimally inclined plane (Wh/m^2/day)

$H(45)$: Irradiation on plane at angle: 45deg. (Wh/m^2/day)

I_{opt}: Optimal inclination (deg.)

T_{24h}: 24 hour average of temperature (°C)

N_{DD}: Number of heating degree-days (-)

Figure 2: web results. PVGIS Screenshot.

This indicates that the optimal inclination of this installation is 36º. Column H(45) shows the irradiation in Wh/m^2/day at the angle previously indicated for each month of the year.

These values will be used for calculating the power to be installed.

The real energy that will be used will be the result of multiplying the efficiency of our system (performance ratio calculated with the *EC.2*) by this obtained irradiance (H(45)).

$$H(45) \times PR = H(45)PR \quad [kWh/m^2/day] \quad (Eq.\ 3)$$

Note a new concept, **Peak Sun Hours (PSH)**, that is commonly used in photovoltaics. This concept is defined as the amount of time (in hours) of hypothetical solar irradiation of 1000W/m^2. This is understood as the equivalent number of hours of solar irradiation that are used per day.

This value will vary monthly according to the radiation of the area.

$$1\ P.S.H = \frac{1000W \cdot 1h}{m^2} \cdot \frac{3600s}{1h} \cdot \frac{1\,{}^{J}/_{s}}{1W} = 3.6\,{}^{MJ}/_{m^2}$$

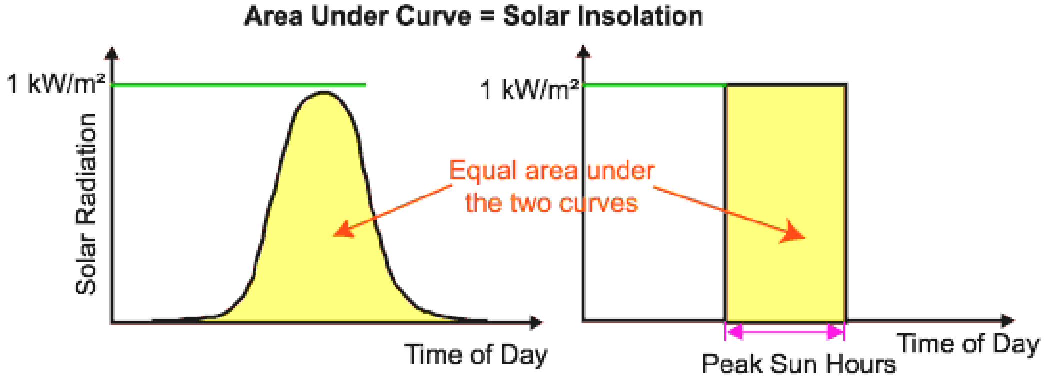

Figure 3: PSH's graphic representation. Source: www.pveducation.org

Going back to the calculation of the panels required, the actual usable energy as calculated according to *Eq.3* is equivalent to the monthly PSH.

$$H(45)PR\_month\_i = PSHmth\_i \quad (Eq.\ 4)$$

If you divide the energy required to supply the loads (E_d) by the monthly PSH of each month, it will have the power to be installed (P_i) for the month *i*.

$$P_i\ [W] = \frac{E_d[Wh]}{HSP_{month_i}[h]} \quad (Eq.\ 5)$$

To find the number of panels (n_p) to be installed, P_i will be divided between the peak power (Wp) of the panels selected. The division is rounded up to the nearest integer.

$$n_p = \frac{P_i}{W_p} \qquad (Eq.\ 6)$$

Usually, the number of panels to be installed will be based on the least favourable month of the year, i.e. the one which needs most panels to supply the consumption.

In specific cases in which there are support diesels or small wind generators, these values can be reduced according to the indications of the technician who performs the calculation.

Thus, once the number of panels to be installed is known, the reverse process can be done in order to know what production will be obtained monthly to compare it to the daily needs.

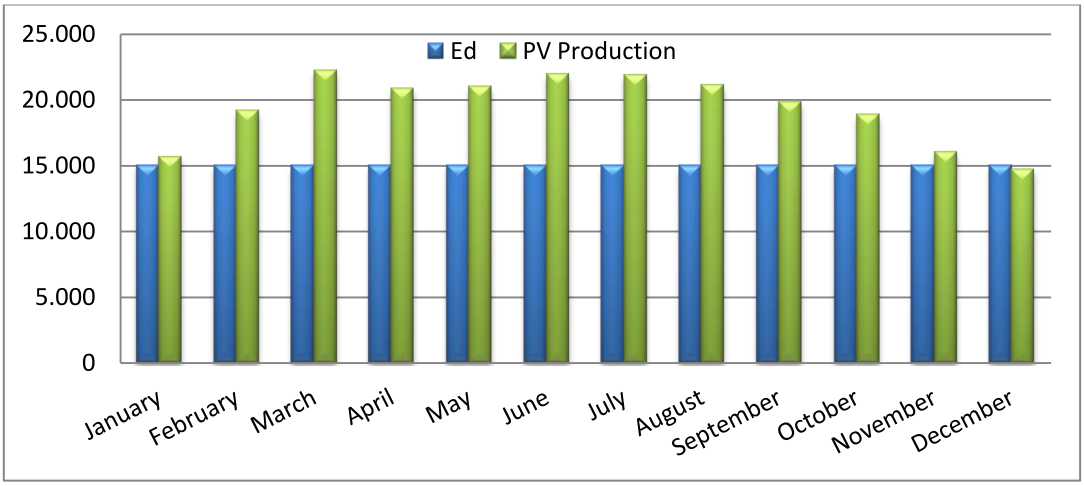

Figure 4: Graphic representation Ed vs. PV production. Source: Own elaboration.

4. Calculation of the regulator/maximiser MPPT

Regulators and maximisers are characterised by the load current at the regulator output and the output voltage at the batteries.

The load current will be calculated by different methods depending on whether it is a charging regulator or a maximiser MPPT.

The output voltage of the regulator or the maximiser will be the one of the bank of installed batteries.

4.1. Regulator calculation

Typically, a regulator must be selected to be able to resist a simultaneous overload on:

- The ***regulator input current***: this will be calculated as 25 % higher than the short-circuit current of the generator.

$$I_{input} = I_{SC} \times N_{PP} \times 1{,}25 \quad (Eq.\ 7)$$

Where,

I_{SC}: Short-circuit current at the panels.

N_{pp}: Number of series of panels fitted in parallel.

- The ***regulator output current:*** this must be at least a 25 % higher than that of the load under maximum consumption conditions.

$$I_{output} = I_{max\_cons} \times 1{,}25 \quad (Eq.\ 8)$$

Where,

I_{max_cons}: is the load current maximum consumption. It is calculated as the maximum power demanded by the local loads divided by the voltage of the batteries (regulator output voltage).

$$I_{\max\_cons} = \frac{Power\ consumption(W)}{Voltage\ (V)} \qquad (Eq.\ 9)$$

4.2. Calculation of the regulator MPPT

An MPPT regulator will have to be capable of withstanding the load current and tension of the PV field.

- The ***current*** is calculated as:

$$I_{MPPT} > \frac{P_T\ (W)}{V_{bat}\ (V)} \cdot 1{,}25 \qquad (Eq.\ 10)$$

Where:

I_{MPPT}: Maximum Intensity supported by the regulator MPPT [A]

P_T: installed power in the generator field [W]

V_{bat}: voltage of the battery bank or exit from the regulator [V]

- The ***voltage*** is calculated as:

$$V_{MPPT} > n_{ps} \cdot U_{OC} \cdot 1{,}25 \qquad \textit{(Eq. 11)}$$

Where,

V_{MPPT}: maximum voltage to withstand the regulator MPPT at input [V].
n_{ps}: Number of panels connected in series.
U_{OC}: open circuit voltage of the panels according to the technical sheet [V]

5. Calculation of the batteries

To calculate the capacity that the batteries have to present to supply the consumption of the installation, the following formula is applied:

$$C_{bat}[Ah] = \frac{1{,}1 \cdot N \cdot E_d}{V_{bat} \cdot DOD_{max}} \qquad \textit{(Eq. 12)}$$

Where:

C_{bat}: is the required capacity of the batteries.
N: Days of autonomy. Values are taken between 2 and 5 days depending on the needs. In dwellings that have support diesel generators 4 days for homes, 3 days, and seasonal for homes throughout the year, 5 days can be taken.
E_d: daily energy demanded by the house [Wh]
V_{bat}: the voltage of the battery bank [V]
DOD_{max}: Maximum depth of batteries discharge. For lead-acid batteries values between the 60-80% are taken.

6. Calculation of the inverter

The power of the inverter the installation needs is calculated as:

$$P_{inv}[W] = \left(\sum P_{eq\ sim}\right) \cdot 1{,}25 \qquad \textit{(Eq. 13)}$$

Where,

P_{inv}: power of the inverter to be installed [W]
$P_{eq\ sim}$: power of the simultaneously connected equipment [W]

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MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 2. Economical aspects

Subchapter 2.1 - Estimation cost of the investment

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Summary: To estimate the PV system investment costs of a photovoltaic system, a summary of developments in the photovoltaic to understand the evolution of prices will be introduced.

After learning the general evolution of prices in the photovoltaic market, the main investment costs of a photovoltaic system will be broken down so that the student may have a rough idea of the investment costs necessary to carry it out.

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1. Current global PV market

Photovoltaics (PV) are one of today´s fastest growing renewable energy technologies. It is expected they will play a major role in global electricity production in the future. Driven by attractive policy incentives (e.g. feed-in tariffs and tax breaks), the global installed PV capacity has multiplied by approximately fifty times in the last decade from 3,7 GW in 2004 to 177 GW at the end of 2014, a growth rate of 47% per year, Figure 1.

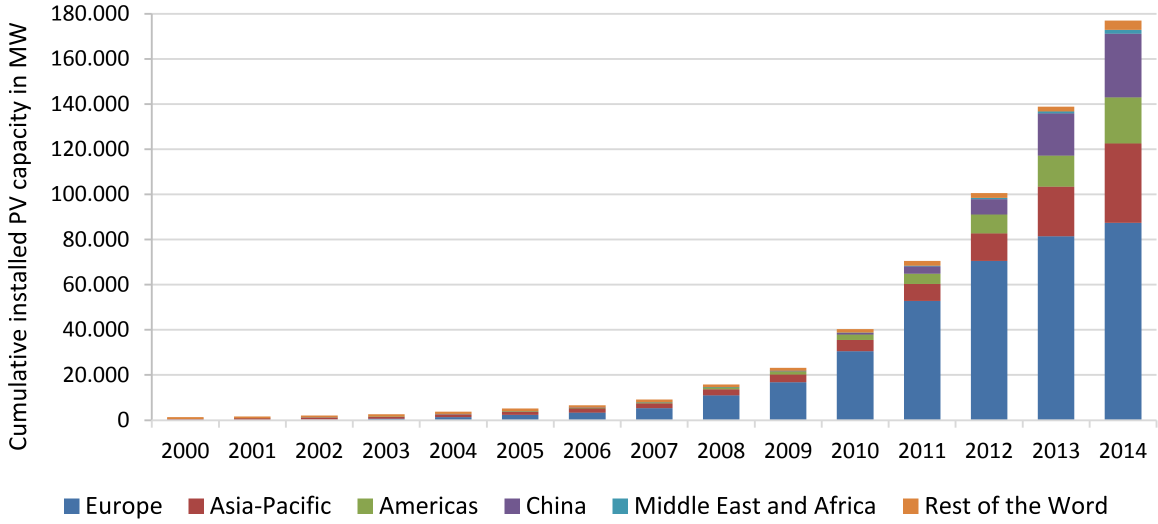

Figure 1. Worldwide growth of photovoltaics. Cumulative capacity in megawatts [MWp] grouped by region. Source: Own elaboration based on SolarPower Europe data.

However, although presenting more than **177 GW installed globally by the end of 2014,** the PV market experienced that year a limited global expansion. Thus, reported market data shows a still growing market in 2014 that was below expectations, with around 38,7 GW of PV systems installed and connected to the grid worldwide. Among the top 10 countries, there are 4 Asian Pacific countries (China, Japan, India and Australia), three European countries (Germany, Italy and France), two countries in the North American region (USA, Canada) and one African Country (South Africa).

Asia is confirmed as the first world region for PV, reporting around 60% of the global PV market with the stabilisation of the Chinese PV market with more than 10 GW and the rapid growth of the Japanese PV market (after the Fukushima disaster) which reached more than 9,7 GW. Next to these two giants, other markets like Australia, Korea or Taiwan have confirmed their maturity, and others are also showing signs of potential rapid PV development in coming years.

In North America, the US market continued to grow, and reached 6,2 GW in 2014. Canada (632 MW) and, to a lesser extent, Mexico (64 MW) are also progressing. Chile has installed close to 400 MW, becoming de facto the leading PV country in South America.

The market in Europe has decreased significantly from 22 GW in 2011 to around 7 GW in 2014. The European market continued to decline, despite the growth of the UK market that led development in Europe with 2,27 GW in 2014. Germany experienced another market decline to 1,9 GW, with extremely competitive incentives. France grew again to close to 1 GW while the Italian market, as all markets where feed-in tariffs were phased-out, decreased to a rather low level (400 MW). Some medium-sized European markets continued to progress, such as the Netherlands or Switzerland, while others declined (Austria, Denmark and Romania) but stayed at reasonable levels. Former gigawatt (GW) producing markets experienced a complete shutdown, with between nothing and a few MW installed: Spain, Czech Republic, Belgium, Greece and Bulgaria.

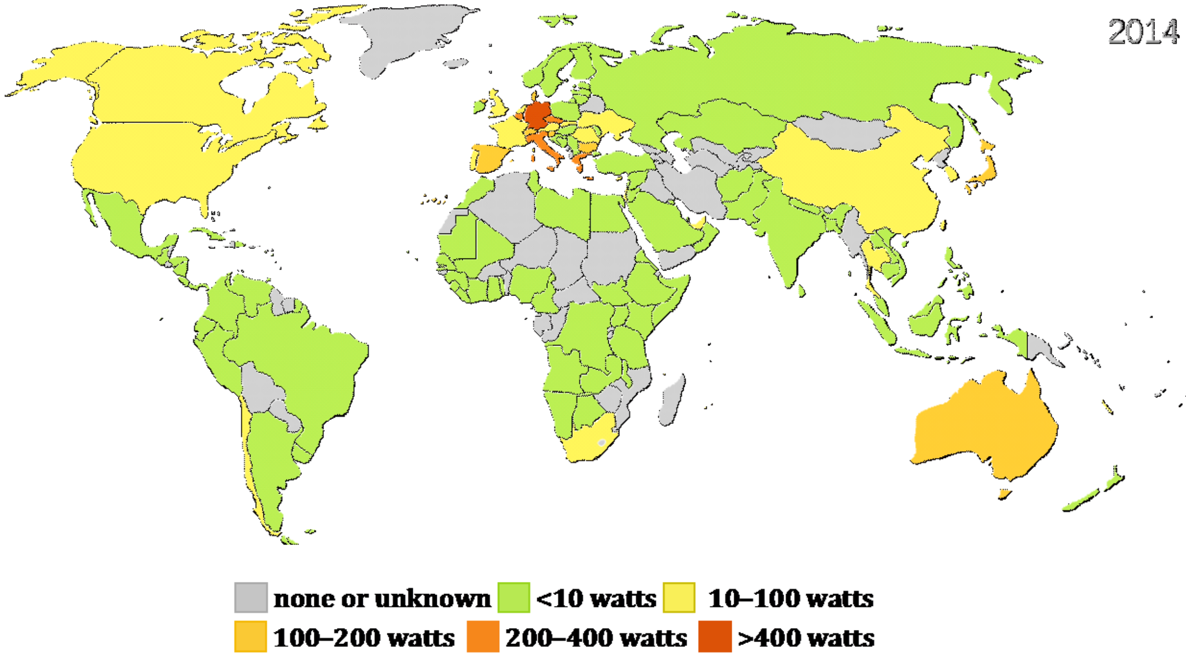

Figure 2. Worldwide installed PV capacity in “watts per capita” 2014. Source: Wikipedia “Growth of photovoltaics”

2. PV costs

PV is a mature, proven technology that is rapidly approaching grid parity. It is a renewable, safe and secure energy source with very high plant reliability and is not exposed to any fuel price volatility. PV has made remarkable progress in reducing costs, as until recently grid parity still seemed years away. Only a few years ago, PV electricity was four to five times more expensive than fossil fuels. However, with increases in fossil fuel prices and continuing cost reductions in PV modules, grid parity is being reached since 2012 in sunny regions of USA, Japan and Europe. Other regions with lower electricity production costs and/or more moderate solar resources may achieve grid parity as early as 2020. That is without taking into account that PV is often already competitive for peak power production, for generation in grid-constrained areas, and for many off-grid applications.

The following content refers to:

A. PV module costs
B. Balance of System Costs (BOS)

2.1. PV module costs

The PV module cost is currently between a third and a half of the total capital cost of the PV system. This depends on the size of the project and the type of PV module.

The cost and price dynamics of technologies are often quantified following the experience curve approach. This relates the cumulative produced quantities of a product and the drop in unit costs (production costs). The concept is based on learning effects, which were first described by Wright as early as 1936 in a mathematical model for production costs of airplanes. It was later generalised by Henderson of the Boston Consulting Group to the price development of a globally traded product. The central empirical observation is that the costs (price) of a specific product change (most often decrease) by an individual percentage-number (price experience factor) every time the cumulative produced volume doubles. Mathematically this is expressed by:

$$\boldsymbol{C(x_t) = C(x_0) \cdot \left(\frac{x_t}{x_0}\right)^{-b}}$$

The cumulated production x_t and cost (or price) $C(x_t)$ at time t in relation to the corresponding values x_0 and $C(x_0)$ is at an arbitrary starting point. The central parameter b is called the **learning parameter**. Applying the logarithmic function to the equation allows a linear experience curve with b as the slope parameter to be drawn. Note that the price experience curve usually refers to the price of a product, whereas the term learning curve is used when the concept is applied to cost. The main outcome of this analysis is usually the learning rate (LR) or the progress ratio (PR), which is defined as:

$$\boldsymbol{LR = 1 - 2^b = 1 - PR}$$

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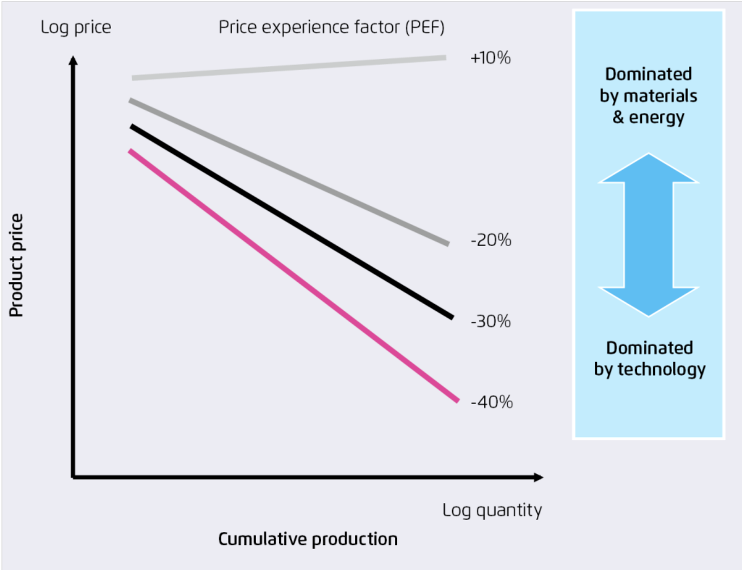

Figure 3. The price experience curve. Methodology explanation. Source: Agora Energiewende.

The price dynamics of PV modules have followed price experience curves since 1980 (Figure 4). It is important to note that the learning rate depends on the time period, which is used for fitting the trend line. From the starting trend line in 1980, the PV module experience curves lead to a high **learning rate of 22%** that has been experienced over time.

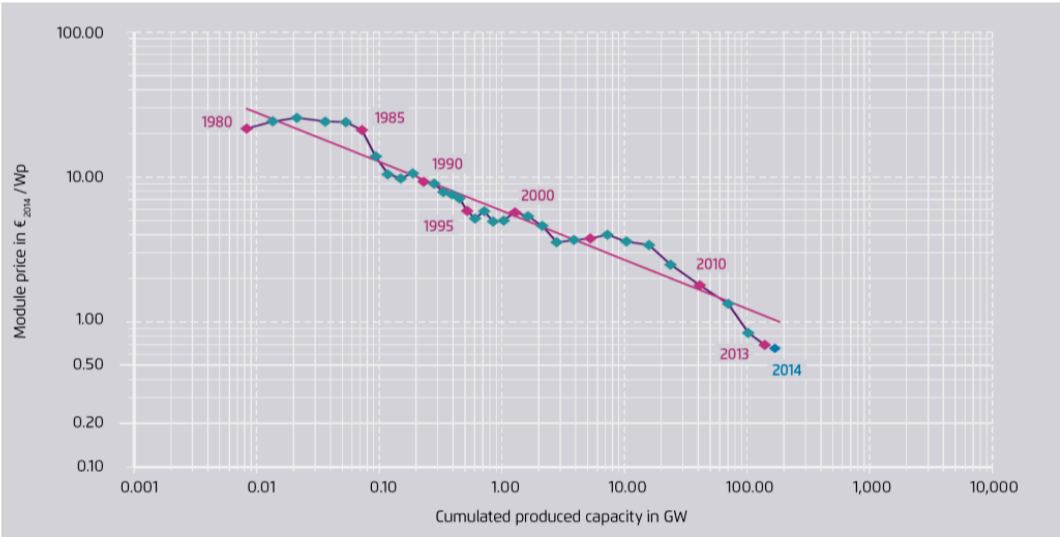

Figure 4. Historical price experience curve of PV modules since 1980. Source: Agora Energiewende.

2.2. Balance of system costs (BOS costs)

The BOS costs and installation comprise the remaining capital costs of a PV system. The BOS costs largely depend on the nature of the installation. For utility-scale PV plants, it can be as low as 20% (for a simple grid connected system) or as high as 80% (for an off-grid system), with 40% being representative of a standard utility-scale ground-mounted system.

For residential and small-scale systems, the BOS and installation costs comprise 55% to 70% of total PV system costs. The average cost of BOS and installation in PV systems is in the range of 1,0 €/W to 1,85 €/W, depending on whether the PV system is ground-mounted or rooftop, and whether it has a tracking system or not.

BOS and installation costs include:

- The inverter, which converts the direct current (DC) PV output into alternating current (AC);
- The components required for mounting and racking the PV system;
- The combiner box and miscellaneous electrical components;
- Site preparation and installation (i.e. roof preparation for residential systems, or site preparation for utility-scale plants), labour costs for installation and grid connection;
- Battery storage for off-grid systems;
- System design, management, installer overhead, permit fees and any up-front financing costs.

Rooftop-mounted systems have BOS costs around 0,25 €/W more than ground-mounted systems. This is primarily due to the additional cost of preparing the roof to receive the PV modules and its slightly more costly installation. In absolute terms, the electric system costs are roughly the same in both systems and account for around one-third of the BOS costs in ground-mounted systems. This proportion is somewhat less in residential rooftop systems due to the higher BOS costs.

2.2.1. PV Inverter

An impressive progress has been achieved over the last couple of decades not only at the module/cell level of photovoltaics, but also in the inverter technology: costs came down from over 1 €/Wp in 1990 to almost 0,10 €/Wp in 2014; efficiencies and power density have increased significantly. Main drivers for this development were improved power semiconductors and new circuit topologies. At the same time, inverters became “smarter” by offering advanced monitoring and communication interfaces that help to improve PV installation performance and availability.

The learning rate of PV inverters is 18,9% (Figure 5). The historical price data is only available for inverters with less than 20 kW rated power. These have higher specific costs than large scale inverters with several-hundred kilowatt rated powers.

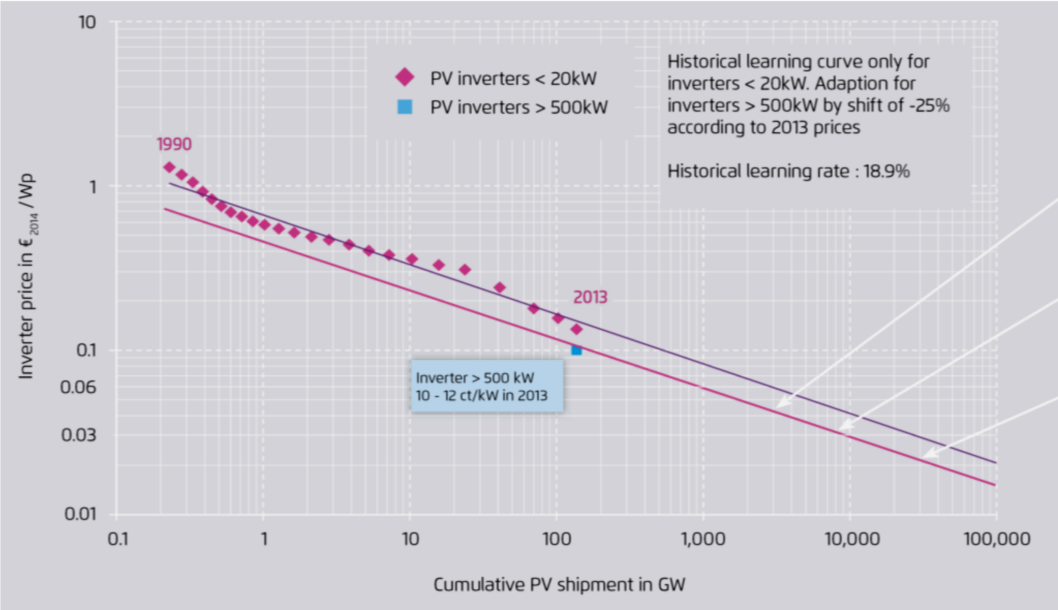

Figure 5. Extrapolation of the price experience curve of PV inverters since 1990. Source: Agora Energiewende.

Inverter sizes range from small textbook-sized devices for residential use to large container-sized solutions for utility-scale systems. The size and numbers of inverters required depend on the installed PV capacity and system design options. Inverters are the primary power electronics components of a PV system and typically account for 5-10% of total installed system costs.

Currently, inverter cost varies greatly from 0,10 €/W to 1,00 €/W, depending on the system size. Larger systems tend to have lower inverter costs per unit of capacity, with systems in the 10 to 100 kW range having costs of between 0,23 to 0,57 €/W. However, some of the most competitive inverters for small-scale applications (<5 kW) can rival those costs, as the range in 2014 was 0,31 to 1,00 €/W.

2.2.2. Mounting structures and racking components

Mounting structures and racking hardware components for PV modules are typically pre-engineered systems of aluminium or steel racks. They account for approximately 6% of the total capital cost of PV systems. Mounting structures vary depending on where the PV systems are sited, with different solutions for residential and commercial systems, for roof types and ground-mounted systems. Because of their low value and substantial weight, mounting and racking structures are generally produced and/or assembled locally, as shipping would be prohibitively expensive, except from countries where labour costs are so low that they can offset transportation costs.

2.2.3. Combiner box and miscellaneous electrical components

These include all remaining installation components, including combiner boxes, wires/conductors, conduits, data monitoring systems, and other miscellaneous hardware. Combiner boxes are the only PV system-specific product included in this category and they are sourced from dedicated manufacturers who supply pre-engineered systems. Other miscellaneous electrical hardware (e.g. wires, electrical conduits, over current protection) are commodity products and can be sourced virtually anywhere. Combiner box and miscellaneous electrical components can represent around 10 to 30% of the total cost of the installation.

2.2.4. Site preparation and system installation

These are one of the major components of the BOS and installation costs. They include site preparation (roof or ground-based), any physical construction works (e.g. electrical infrastructure), installation and connection of the system. Labour costs make up the majority of the installation costs, and these vary largely by project and country.

2.2.5. System design, management and administrative costs

This includes system design, legal fees, permits, financing and project management costs. For residential and small-scale PV systems, these costs are typically included in the total PV installed prices quoted by companies. For large-scale installations these costs might be managed directly by the promoter or sub-contracted to a service provider. PV system costs are typically included in overhead costs and profit margins. These soft costs can depend significantly on local conditions.

2.2.6. Electricity storage systems for off-grid PV systems

Electricity storage systems enable electricity use at night or during cloudy periods. As already introduced in the previous module, it exists an important variety of electricity storage systems, but most of them are expensive and tend to be more suited to large-scale applications. For small-scale systems, standard lead-acid, and potentially lithium-ion batteries, are the technology of choice.

Batteries increase the cost of the PV system, but much less than grid connection in remote areas. They are needed not only for remote residential and commercial applications, but also for off-grid repeater stations for mobile phones, radio beacons, etc.

Lead-acid batteries are the oldest most widely applied electricity storage technology and are a proven option. Deep-cycle lead-acid batteries are a proven choice, with much longer lifespan than car batteries. However, even deep-cycle batteries will last longer if the discharge rate is kept low. For instance, limiting the discharge to 50% or less can allow the battery to last for ten years. The trade-off is higher initial costs, as 2 kWh of battery storage is needed for every 1 kWh of electricity used from storage.

In sunny Spanish conditions, a 1 kW PV system may supply 1500 kWh per year (4 kWh/day). Assuming half of this energy is needed in the evenings, this means 2 kWh of useful storage is needed, requiring 4 kWh of battery storage if battery life is to be optimised. This represents an investment of 600 € (150 €/kWh), to which a battery charge controller must be added if this is not included in the PV system. The addition of storage, assuming the PV system costs around 3000 €/kW, increments 17% the PV system cost (total 3600 €/kW).

Batteries are connected to the PV array via a charge controller to protect against overcharging or discharging. This controller can provide information about the state of the system. Off-grid PV systems can be hybrids (e.g. in conjunction with wind and electricity storage) and / or be combined with a back-up power system (e.g. a biomass or diesel generator) to ensure a more reliable supply of electricity or to allow higher loads.

2.3. Total PV system costs

The total cost of a PV system is made up of the costs of the PV modules, BOS and installation. The overall PV system cost also depends on the size of the system, and on whether the system is ground or roof mounted.

To analyse costs, PV systems can be grouped into four main end-use markets:

- **Residential PV systems,** typically do not exceed 20 kW and are usually roof-mounted.
- **Large-scale building PV systems,** typically do not exceed 1 MW and are placed on large buildings or complexes, e.g. commercial buildings, schools, hospitals, universities.
- **Utility-scale PV systems,** are larger than 1MW and are generally ground-mounted.
- **Off-grid applications,** vary in size from small systems for remote beacons or relay stations to mid-size systems for homes or businesses not connected to the grid, all the way up to large-scale PV systems that provide electricity to off-grid communities.

The following table shows current price ranges for the four main end-use markets:

Table 1. PV system price ranges for the four main end-use markets. Source: Own elaboration based on experience.

END-USE MARKET		**<20 kW**	**20-1000 kW**	**>1000 kW**
Residential	TOTAL COST [€/Wp]	1,5 - 3,5		
Large-scale building	TOTAL COST [€/Wp]		1,1 - 1,7	
Utility-scale	TOTAL COST [€/Wp]			0,7 - 1,1
Off-grid	TOTAL COST [€/Wp]	3,5 - 5,5		

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MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 2. Economical aspects

Subchapter 2.2 - Other costs

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Summary: In addition to the initial investment costs of a photovoltaic system, special attention should be paid to the lifetime costs of the operational and maintenance activities of the facility to achieve an optimized plant performance while minimizing operating costs. Thus, this subchapter develops the main aspects for PV system operations and maintenance activities as well as the main reasons for power losses and failures of photovoltaic installations during their lifetime to be considered.

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1. Other costs

As well as the initial investment costs of a PV installation, special care must be taken to study the operation and maintenance (O&M) costs of the installation during its useful life in order to carry out a realistic profitability studies.

An effective O&M program enhances the likelihood a system will perform at or above its projected production rate and cost over time. It therefore reinforces confidence in the long-term performance and revenue capacity of an asset. O&M practices and approaches are not standard and are implemented according to the methods of their owners. Doing this increases the cost and the perception of risks to funding sources and investors. It also reduces the ability to pool solar assets to offer as financial security, known as securitization. Specific consequences of variations in O&M practices include:

1. Performance metrics are defined differently. A system characterized by a guarantee to deliver 1.000 MWh/year would be difficult to compare and bundle with another that has a guarantee to be operational 90% of the time. Investors need clear performance metrics and evaluation methods.
2. Practices and delivery of O&M services also differ, and investors need to know that an existing system has been maintained according to standard definitions and criteria.
3. Differences in types of systems and also geographic location and climate conditions can also confound securitization. Investors want to know how much it will cost to perform required O&M and secure the performance of the investment. Cost estimates must be uniform and predictable so that they can be bundled, yet they should reflect the factors that cause O&M costs to vary from site to site.

Many investors are more interested in reducing risk than maximizing internal rate of return (IRR). Investors would prefer 5% IRR with 100% certainty over 10% IRR with 50% certainty, although the two are of statistically equivalent value. Investors will make an investment decision based on mitigating performance risk with effective O&M, as then the financing rates are determined mainly through competition from other banks. Standardization of O&M practices will facilitate both investor analyses of risk factors as well as securitization of PV asset cash flows. Risk reduced by effective O&M will enable banks to qualify more projects, and that will eventually increase competition and reduce borrowing costs.

1.1. The PV O&M plan

The PV O&M plan is the only long-term operations plan for a PV system. The O&M manager retains and archives all the initial planning, warranty, design, and other system specification documents in the plan. He also revises the plan as the system is constructed, maintained, and modified over time. The O&M plan provides the specific measures to achieve the level of performance specified by the Key Performance Indicators (KPIs) in the Performance Work Statement.

An O&M plan can accommodate different system configurations by including all the descriptions and measures for systems and adding the terms “if applicable”—for example, “lubricate tracking ring gear, *if applicable*.” However, the scope of work and cost estimate for suppliers should itemize the measures to be performed based on system details affecting maintenance. Examples of these are the number and types of different inverters, fixed rack vs. tracker, rooftop vs. ground mount, etc. A documented PV system O&M plan for a system or fleet of systems should include the following (depending on system size, complexity, and investment):

- List of responsible personnel. This contact information includes the site owner and off-taker of power, as well as emergency numbers.
- System descriptions with as-built drawings, specifications, site plans, photo records and any special safety considerations. Documents should include single line (overview) and detailed (schematics, drawings and installed components: “cut sheets” and warranties) identification for easy access.
- Performance estimates and insulation/shade studies, including a description of nominal conditions to make it easier to see malfunctions or deviations.
- Chronological O&M log: work order and task tracking to include initial commission report, inspection reports, and ongoing O&M history.
- Descriptions of operational indicators, meters, and error messages; description of any physical monitoring setup and procedures by which performance data is to be archived and reported; and procedures by which data are regularly examined for system diagnostics and analytics.
- List of preventative maintenance measures that need to be performed to maintain warranties and to optimize system energy delivery, and the schedule for each; this should include details such as cost and current supplier of each preventative maintenance measure and special instructions such as hours that work is to be performed, access to site, and locations where vehicles may be parked and equipment staged.
- Procedure for responding to alerts from monitoring diagnostics, error messages, or complaints from the building owner.
- Troubleshooting guide with common problems and sequence to approach solving each problem.
- Criteria to decide to repair or replace a component (refer to specific replacement parts in “list of all equipment and suppliers of each”). Criteria to decide whether to “cannibalize” a string of modules to source replacement modules or to order new parts instead.
- Procedures for re-acceptance testing following a repair.
- List of all equipment by manufacturer, model, and serial numbers and map of placement in system (to spot trends in manufacturing defects); for each piece, a supplier of replacement part (vendor) should be listed.

- Inventory of spare parts kept onsite, or easily accessed by maintenance crew, and process for determining when other spare parts need to be ordered based on component failure history.
- Operator manuals associated with any of the equipment, including emergency shut-down and normal operating procedures.
- All warranties from system installer and equipment manufacturers.
- Reports from commissioning, inspection and ongoing work orders, and repair.
- Contracts for preventative maintenance, service, and other operations documents, including contacts for each, and specified response times and availability (24 x 7).
- Budget for O&M program including costs for monitoring and diagnostics, preventative maintenance, corrective maintenance, and minimum exposure (line of credit) if replacement of inverter or more expensive corrective maintenance is needed.

1.2. PV operations

PV Operations include the following five areas

1. ***Administration of Operations***: Ensuring effective implementation and control of O&M activities including archival of as-built drawings, equipment inventories, owners and operating manuals, and warranties. It also includes keeping records of performance and O&M measures, preparing scopes of work and selection criteria for service providers, contracting with suppliers and service providers, paying invoices, preparing budgets, and securing funding and contingency plans for O&M activities.
2. ***Conducting Operations***: Ensuring efficient, safe, and reliable process operations including making decisions about maintenance actions based on cost/benefit analysis. This includes serving as a point of contact for personnel regarding PV system operations; coordinating with others regarding systems operation; inspection work and invoice approval. Meanwhile, operations include any day to day operation of the system to maximize power delivery, manage curtailments, or adjust settings such as the power factor.
3. ***Directions for the Performance of Work***: Specifying the rules and provisions to ensure that maintenance is performed safely and efficiently, including the formalization and enforcement of: safety policies (including training for DC and AC safety, rooftop safety, minimum manning requirements, arc flash, lock-out tag-out, etc.); working hours; site access, lay down areas, and parking; and any other stipulations under which work is performed. This includes confirming and enforcing qualifications of service providers and compliance with any environmental or facility-level policies regarding handling controlled materials such as solvents, weed killer, and insecticide.
4. ***Monitoring***: Maintaining monitoring systems and analysis of resulting data to remain informed on system status. This includes comparing results of system monitoring to benchmark expectation and providing reports to facility stakeholders.

5. ***Operator Knowledge, Protocols, Documentation***: Ensuring that operator knowledge, training, and performance will support safe and reliable plant operation. Information such as electrical drawings, part specifications, manuals, performance information, and records must be deliberately maintained.

1.3. PV maintenance

PV Maintenance includes the following four types of maintenance procedures:

1. ***Maintenance Administration***: Ensuring effective implementation, control, and documentation of maintenance activities and results. Administration includes establishing budgets and securing funds for preventive maintenance, establishing reserves or lines of credit for corrective maintenance, planning activities to avoid conflict with systems operation or operations at the customer site, correspondence with customers, selection and contracting with service suppliers and equipment manufacturers, record keeping, enforcement of warranties, providing feedback to designers of new systems, and reporting on system performance and the efficacy of the O&M program.
2. ***Preventive Maintenance***: Scheduling the frequency of preventive maintenance is set by the operations function. This is influenced by a number of factors, such as equipment type, environmental conditions (marine, snow, pollen, humidity, dust, wildlife, etc.) of the site, and warranty terms. Scheduled maintenance is often carried out at intervals to conform to the manufacturer´s recommendations. Following them is a requirement of the equipment warranties.

   Preventive maintenance maximizes system output, prevents more expensive failures from occurring, and maximizes the life of a PV system. Preventive maintenance must be balanced by the project financial cost. Therefore, the goal is to manage the optimum balance between the cost of scheduled maintenance, yield, and cash flow during the lifetime of the system. Preventive maintenance protocols depend on system size, design, complexity, and environment. The major elements of PV preventive maintenance are:

   - Panel cleaning (~1-2 times/year or as needed)
   - Vegetation management (~1-3 times/year)
   - Wildlife prevention (variable)
   - Water drainage (variable)
   - Retro-commissioning (1 time/year)
   - Upkeep of data acquisition and monitoring systems (e.g., electronics, sensors) (frequency: undetermined)
   - Upkeep of power generation system (e.g., inverter servicing, BOS inspection, tracker maintenance (~1-2 times/year)
3. ***Corrective Maintenance***: Required to repair damage or replace failed components. It is possible to perform some corrective maintenance such as inverter resets or

communications resets remotely; also. Less urgent corrective maintenance tasks can be combined with scheduled, preventative maintenance tasks.

Lost revenue builds up while a system is down or when output is reduced. Repairs should be delayed only if there is an opportunity to do the repair more efficiently in the near future. Response time for alerts or corrective action for the O&M function should be specified as part of the contract, but will be typically 10 days or less for non-safety related corrective maintenance service. For small residential systems, a fleet operator may make repairs only when enough work has accumulated to justify the logistical cost to the area, or at the next regularly scheduled preventative/inspection of a site.

The main elements of PV corrective maintenance are:

- On-site monitoring/mitigation
- Critical reactive repair: Address production losses
- Non-critical reactive repair: Address production degradation
- Warranty enforcement (as needed)

4. ***Condition-based Maintenance***: Condition-based maintenance is the practice of using real-time information from data loggers to schedule preventative measures such as cleaning, or to head off corrective maintenance problems by anticipating failures or catching them early. As the measures triggered by condition are the same as preventative and corrective measures, they are not listed separately. Rather, condition-based maintenance affects when these measures occur, with the promise of lowering the frequency of preventative measures and reducing the impacts and costs of corrective measures.

   The main elements of PV condition-based maintenance are:

   - Active monitoring—remote and on-site options
   - Warranty enforcement (planned)
   - Equipment replacement (planned)

1.4. Inverter

Inverter reliability continues to increase, with 10-year warranties now commonly available and 20-year extended warranties/service plans also gaining prevalence. However, a sound O&M plan should account for inverter failure because it is one of the most frequent causes of PV system performance loss.

Additional steps:

1. Decide whether inverters are to be replaced or repaired based on inverter size, type, and associated cost. Replacement is preferred over repair when spare parts availability and lead time trigger an upgrade.

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2. Include remote monitoring to confirm inverter status, reset inverter, and diagnose problems.
3. In remote locations, it is advisable to stock component replacements onsite, especially for equipment commonly in need of repair, such as driver boards. Replacement micro-inverters should also be stored onsite.

1.5. PV module degradation rate

When comparing measured performance to predicted performance, it is important to consider the expected degradation in PV module output over time in the prediction. Before 2000 this performance was highly variable and unpredictable. Nowadays, degradation rates are more uniform among types and manufactures. Typically, they are around 0,5% per year. This is not to be confused with the failure rate of modules. PV module failures are rare, with reported failure rates of 0,025% per year to 0,1% per year, depending on the source.

Compare measured and predicted performance using a module degradation value given by manufacturer. If no value is available, assume default value of 0,5% per year for new crystalline silicon products.

Degradation is calculated based on the age of the system at the time of evaluation, but for life cycle cost analysis a degradation factor of 0,94% provides an estimate of the degradation levelised over a 25 year lifetime with a 5% discount rate.

1.6. Current PV O&M cost

The management, maintenance and repair costs (O&M) are the third largest cost factor (before cost of capital and modules as seen in the estimation cost of investment chapter). At 1,5 – 2,5 €ct/kWh these cover the foreseeable repairs and exchange costs of components like the inverter, as well as the annual degradation of the solar modules as specified by the manufacturers. O&M costs have a special significance in relation to operation beyond the period of 20 years used to pay back the initial capital investment.

Other sources estimate PV O&M cost around 1,5% of the initial cost per year, about half of which amortizes inverter replacements. For small off-grid systems with batteries, the average annual O&M cost is 2% to 6% of the initial capital cost. Travel time and mileage account for about 40% of the unscheduled maintenance cost of these remote systems.

These heuristics inform an expectation of PV system O&M cost. The PV O&M Cost Model allows a customized, if not entirely accurate, estimate of system costs based on system types and components and environmental conditions too. Survey data on cost and backup services providers is correlated with model test data to “calibrate” the cost model. The cost model can also lay out year-by-year fluctuations in O&M cost. This cost is based on scheduled intervals for preventative measures, failure distributions that increase with age, and inflation in the cost of O&M services.

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MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 2. Economical aspects

Subchapter 2.3 - Analysis of economic efficiency and profitability

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Summary: This subchapter presents three basic methods for evaluating the profitability of a photovoltaic system. The methodologies explained will take into account all the operating income (or savings if any), as well as all the implementation, operation and maintenance costs of the PV system.

The first methodology explained will be the LCOE parameter, usually used to make a comparison between PV installations and other type of energy source installations. Subsequently, three concepts widely used for the feasibility analysis of all types of investments will be introduced. Finally, it will end with an example of a PV system feasibility study.

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1. Levelised Cost of Electricity (LCOE)

The method of levelised costs of electricity (LCOE) makes it possible to compare the cost of electricity produced in power plants of different generation, technologies and cost structures. It is important to note that this method is an abstraction from reality with the goal of making different sorts of generation plants comparable and it does not include other aspects such as the ability to react to the demand for electricity. The method is not suitable for determining the financial feasibility of a specific power plant. For that, a financing calculation must be completed taking into account all revenues and expenditures on the basis of a cash-flow model.

The calculation of the average LCOE is done on the basis of the net present value (NPV) method, in which the expenses for investment and the payment streams from earnings and expenditures during the plant's lifetime are calculated based on discounting from a shared reference date. The cash values of all expenditures are divided by the cash values of power generation. Discounting the generation of electricity seems, at first glance, incomprehensible from a physical point of view, but it is simply a consequence of mathematic transformations. The idea behind it is that the energy generated implicitly corresponds to the earnings from the sale of this energy. The farther these earnings are displaced in the future, the lower their net present value. The LCOE is calculated using the following formula:

$$LCOE\ \left(€/_{kWh}\right) = \frac{I_0 + \sum_{t=1}^{n} \frac{M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where:

I_0 = Investment
M_t = operations and maintenance expenditures in year t
F_t = fuel expenditures in year t, which is zero for photovoltaic electricity
E_t = electricity generation in the year t
r = discount rate
n = investment period considered in years

The above approach provides the LCOE of a given generator and is strictly appropriate only when the electricity can be used directly at source i.e. self-consumption. It does not fully describe the cost in the context of the overall electricity supply system, since profile cost (including flexibility and utilisation effects), balancing costs and grid costs are not considered.

We use the following assumptions to calculate the LCOE:

- A system price of 1,7 €/kWp for a residential rooftop system of less than 20 kWp
- 5% cost of capital (discount rate in the formula above)
- Operating and maintenance costs are fixed at 1,5% of the capital cost.

- 20 years financial lifetime: this value corresponds to the current minimum performance duration warranty offered by module manufacturers.
- The annual energy yield (kWh per kWp installed) is taken for each location using the methodologies explained along “Chapter 1: Technical Aspects”.

Next tables show the resulting LCOE of PV generated electricity for the residential system with the characteristics just introduced (a system price of 1700 €/kWp ex. VAT, 1,5% operation, maintenance and repair (O&M) cost and financial lifetime of 20 years for a ROI of 5%) at the three locations involved in the IN2RURAL project.

Table 1. LCOE for CASTELLÓN (Spain) PV installation – 1490 kWh/kWp/year. Source: Own elaboration.

	Contributions to LCOE				LCOE
Item	Cost [EUR/kWp]	Amortizable cost/energy produced [EURct/kWh]	Capital for ROI 5% [EURct/kWh]	O&M 1,5% [EURct/kWh]	Total [EURct/kWh]
PV Module	600	2,0	1,2	0,6	3,8
Inverter	150	0,5	0,3	0,2	1,0
Balance of Systems	420	1,4	0,9	0,4	2,7
Engineering & Construction	370	1,2	0,8	0,4	2,4
Fees, permitting, Insurance…	160	0,5	0,3	0,2	1,0
Total	1700	5,7	3,5	1,7	10,9

Table 2. LCOE for GYÖNGYÖS (Hungary) PV installation – 1060 kWh/kWp/year. Source: Own elaboration.

	Contributions to LCOE				LCOE
Item	Cost [EUR/kWp]	Amortizable cost/energy produced [EURct/kWh]	Capital for ROI 5% [EURct/kWh]	O&M 1,5% [EURct/kWh]	Total [EURct/kWh]
PV Module	600	2,8	1,7	0,8	5,4
Inverter	150	0,7	0,4	0,2	1,3
Balance of Systems	420	2,0	1,2	0,6	3,8
Engineering & Construction	370	1,7	1,1	0,5	3,3
Fees, permitting, Insurance…	160	0,8	0,5	0,2	1,4
Total	1700	8,0	4,9	2,4	15,3

Table 3. LCOE for BACĂU (Romania) PV installation – 1070 kWh/kWp/year. Source: Own elaboration.

	Contributions to LCOE				LCOE
Item	Cost [EUR/kWp]	Amortizable cost/energy produced [EURct/kWh]	Capital for ROI 5% [EURct/kWh]	O&M 1,5% [EURct/kWh]	Total [EURct/kWh]
PV Module	600	2,8	1,7	0,8	5,3
Inverter	150	0,7	0,4	0,2	1,3
Balance of Systems	420	2,0	1,2	0,6	3,7
Engineering & Construction	370	1,7	1,0	0,5	3,3
Fees, permitting, Insurance...	160	0,7	0,5	0,2	1,4
Total	1700	7,9	4,8	2,4	15,1

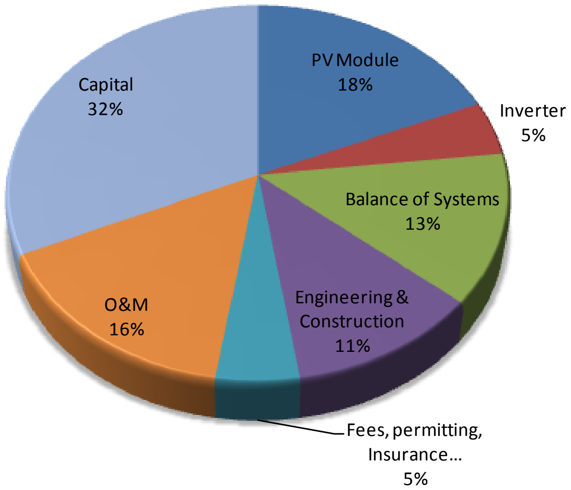

Figure 1. LCOE cost breakdown. Source: Own elaboration.

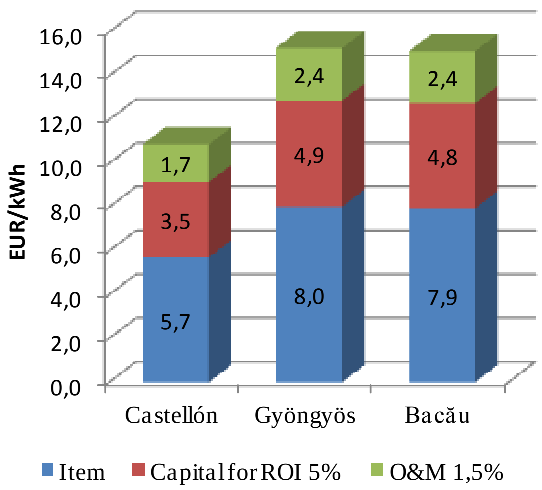

Figure 2. LCOE cost distribution. Source: Own elaboration

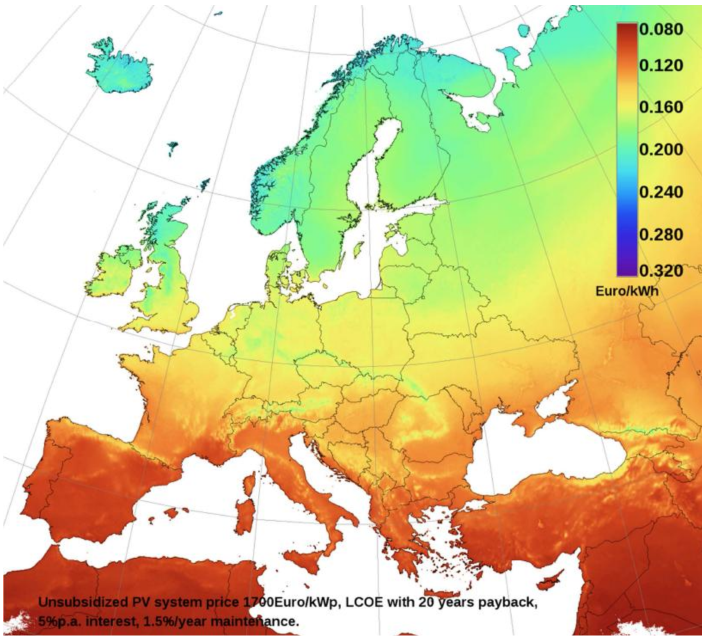

Figure 3. Distribution of the levelised cost of PV electricity in Europe. Source: European Commission. Joint Research Centre.

2. IRR, NPV & PAYBACK

There are several financial parameters that can be used to determine the economic profitability of a project. The most common methods used to examine the profitability of a PV project are payback period (PB), the net present value (NPV) and the internal rate of return (IRR).

2.1. Payback period

Payback period is defined as the expected number of years required to recover the original investment. If all factors remain constant, projects with shorter payback periods are considered better projects because investors can recover the capital invested in a shorter period of time. Besides, shorter payback periods mean greater project liquidity. Since cash flows expected in the distant future are generally riskier than short-term cash flows, the payback is often used as an indicator of a project's riskiness.

However, there are some limitations to using payback periods to measure the project's effectiveness in an investment. The first limitation of a payback period is it ignores any benefits that occur after the payback period and does not measure profitability. Payback period stresses the aspect of capital recovery rather than profitability. It does not take into account the returns from the project after its payback period.

Besides, a payback period does not give any consideration to the time value of money. Cash flows occurring at any point of time are simply added and treated as having equal value. It is a contravention of the basic principle of financial analysis which agrees to compound or discount those cash flows that might arise at different points of time.

$$Payback\ Period = \frac{Cost\ of\ investment}{Annual\ cash\ flows}$$

2.2. Net Present Value (NPV)

Net present value (NPV) is applied in capital budgeting to analyze the profitability of an investment or project. Its formula is sensitive to the reliability of future cash inflows that an investment or project will yield. NPV compares the value of money received today and the value of that same amount of money in the future. It does so by taking inflation and rate of return into account. NPV is defined as the difference between an investment's market value and its cost.

NPV is based on discounted cash flow (DCF) techniques with three basic steps:

- The first step is to find the present value of each cash flow, including all inflows, outflows, and discounted at the project's cost of capital.
- Secondly, all of these cash flows are added up. This amount is defined as the project's NPV.

- The last step is to determine which project to select. If the NPV is positive, the project should be accepted, while if the NPV is negative, it should be rejected. In some cases, two projects will show positive NPVs, so the one with higher NPV should be selected.

When using NPV criterion for evaluating projects, we need to pay attention to the following:

- All relevant and related cash flows[1] of a project should be included in the computational of this NPV;
- The project's NPV directly reflects its contribution to the present value of the business for investors;
- The NPV of a project is inversely related to its discount rate (i.e. required rate of return);
- The required rate of return used to discount project's cash flows should reflect the project's cost of capital and risk.

The net present value of a project can be expressed as follows:

$$NPV_0 = +PV\ cashinflows - PV\ cashoutflows$$

$$NPV_0 = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} - I_0$$

$$NPV_0 = -I_0 + \frac{C_1}{(1+r)^1} + \frac{C_2}{(1+r)^2} + \frac{C_3}{(1+r)^3} + \cdots + \frac{C_n}{(1+r)^n}$$

Where:

NPV_0 = Net present value of the project

C_t = (after tax) cash flow to be received in period t (remember this means end of period t)

n = the number of total periods for discounting or the expected years of life of the project

r = the discount rate (i.e. required rate of return)

t = the number of period during which the discounting occurs

I_O = initial outlay (or the cash flow at t_0)

The decision rules based on the NPV criterion are defined in Table 4:

[1] Cash flow: Cash Flow is the net amount of cash and cash-equivalent moving into and out of a business. Positive cash flow indicates that a company's liquid assets are increasing. Negative cash flow indicates that a company's liquid assets are decreasing.

Table 4. NPV_0 value-based decision criteria

Criteria	Explanations
$NPV_0 = 0€$	- Accept the project with conditions - PV of project's cash inflows is equal to PV of project's cash outflows - No change to the intrinsic value to the business as well as the health of the shareholders - If the firm does not have any other investment opportunities, rejecting the project implies the firm will have to suffer opportunity loss on the unused funds.
$NPV_0 > 0€$	- Accept the project - PV of project's cash inflows is greater than PV of project's cash outflows - Acceptance of project will increase value of the firm and create wealth for shareholders which is consistent with the firm's financial objective - The value of the firm will be increased by an amount which equals the NPV of the project - The firm will earn a rate of return on the project which is higher than the project's discount rate
$NPV_0 < 0€$	- Reject the project - PV of project's cash inflows is less than PV of project's cash outflows - The project yields a return which is less than the firm's required rate of return - The project will not increase the firm's value and the shareholders' wealth - Accepting the project will lead the firm to suffer a loss in value which is equal to the project's negative NPV

2.3. Internal rate of return (IRR)

The internal rate of return (IRR) criterion is an evaluation approach which is very similar to the NPV method discussed in the previous section. It also discounts the cash inflows and cash outflows of the project. The main difference between NPV and IRR approaches is that the latter discounts a project's cash flows at a rate so as to equate the present value of cash inflows to the present value of the cash outflows. That is, the IRR approach sets a precondition such that when the project's NPV equals zero, the discount rate used to discount the project's cash flow is equal to its internal rate of return.

In the next figure, the intersecting point, threshold discounting rate, is actually the project's IRR.

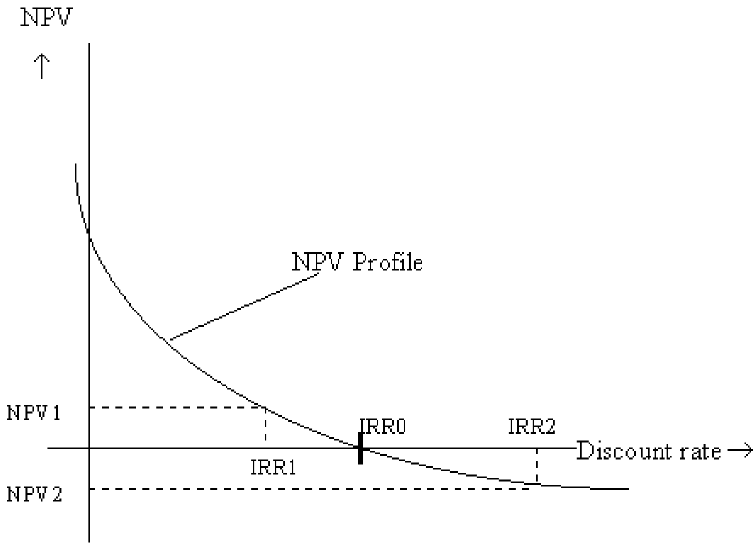

Figure 4. Graphical illustration of the IRR concept. Source: P.V. Viswanath

Symbolically, the internal rate of return is the discount rate, IRR, in the following equation:

$$NPV_0 = 0 = +PV\ cashinflows - PV\ cashoutflows$$

$$NPV_0 = \sum_{t=1}^{n} \frac{C_t}{(1+IRR)^t} - I_0 = 0$$

$$NPV_0 = -I_0 + \frac{C_1}{(1+IRR)^1} + \frac{C_2}{(1+IRR)^2} + \frac{C_3}{(1+IRR)^3} + \cdots + \frac{C_n}{(1+IRR)^n} = 0$$

Where:

NPV_0 = Net present value of the project

C_t = (after tax) cash flow to be received in period *t* (remember this means end of period *t*)

n = the number of total periods for discounting or the expected years of life of the project

IRR = the project's internal rate of return (or the discount rate)

t = the number of period during which the discounting occurs

I_O = initial outlay (or the cash flow at t_0)

As for the previous parameter, the decision rules based on the IRR criterion are enumerated in Table 5:

Table 5. IRR value-based decision criteria

Criteria	Explanations
IRR = r Where, IRR-project's internal rate of return r= the firm's required rate of return	- Accept the project. - Project's NPV is equal to zero. - When the project's IRR equals the firm's required rate of return (r), acceptance of the project will neither increase nor decrease the value of the firm. - Rejection of the project will lead to opportunity loss on the firm's unused funds, causing a comparable decrease in the market value of the firm. The rate of opportunity loss on the unused funds is equal to the firm's required rate of return.
IRR > r	- Accept the project. - Project's NPV is greater than zero. - Acceptance of the project will lead to an increase in the market value of the firm as well as the shareholders' wealth. - The magnitude of increase in the value of the firm is equal to the project's NPV.
IRR < r	- Reject the project. - Project's NPV is less than zero. - Rejection of the project will help the firm prevent a loss on the intrinsic value of the firm as well as the shareholders' wealth. The loss is equal to the project's negative NPV.

3. Conclusions – Profitability

This final section presents a profitability calculation example for a PV installation designed for self-consumption with the following principal characteristics:

PROJECT PARAMETERS	
INSTALLATION DATA	
LOCATION	Castellón (Spain)
POWER (kWp)	20,00
UNIT COST (€/Wp)	1,70
CAPITAL COST (€)	**34.000**
PRODUCTION	
PEAK SUN HOURS - PSH (kWh/kWp/year)	1.490
ESTIMATED ELECTRICITY PRODUCTION (kWh/year)	29.800
ANNUAL LOSSES (%)	**0,60%**
COSTING DATA	
GRID ENERGY COST (€/kWh)	0,20
ELECTRICITY ANNUAL INCREASE (%)	3,00%
ESTIMATED CONSUMER PRICE INDEX (CPI)	2,00%
DISCOUNT RATE (%)	**5,00%**
OPERATING AND MAINTENANCE (O&M)	
O&M COST (% of the capital cost)	1,50%

This economic analysis shows the results of calculating the parameters described throughout this subchapter for a 20kW photovoltaic system for direct consumption located in Castellón (Spain).

With design parameters considered, as well as the comparative costs of the energy network, the following results are obtained:

PAYBACK: 6 years

NPV: 45.828,79 €

LCOE: 0,11 €/kWh

YEAR	ESTIMATED ENERGY PRODUCTION [kWh/year]	GRID ENERGY COST [€/kWh]	ESTIMATED SAVINGS [€/year]	O&M COST [€/year]	CASH-FLOW [€]	CUMULATIVE CASH-FLOW [€]	PAYBACK [€]	NET PRESENT VALUE – NPV [€]
0					-34.000			
1	29.800	0,200	5.960	510,00	5.450	5.450	-28.550	-27.438
2	29.621	0,206	6.102	525,30	5.577	11.027	-22.973	-22.620
3	29.443	0,212	6.247	541,06	5.706	16.733	-17.267	-17.926
4	29.267	0,219	6.396	557,29	5.839	22.572	-11.428	-13.351
5	29.091	0,225	6.548	574,01	5.974	28.546	-5.454	-8.893
6	28.917	0,232	6.704	591,23	6.113	34.659	659	-4.548
7	28.743	0,239	6.864	608,97	6.255	40.915	6.915	-314
8	28.571	0,246	7.028	627,24	6.400	47.315	13.315	3.811
9	28.399	0,253	7.195	646,05	6.549	53.864	19.864	7.832
10	28.229	0,261	7.366	665,43	6.701	60.565	26.565	11.750
11	28.060	0,269	7.542	685,40	6.857	67.422	33.422	15.568
12	27.891	0,277	7.722	705,96	7.016	74.437	40.437	19.288
13	27.724	0,285	7.906	727,14	7.178	81.616	47.616	22.914
14	27.557	0,294	8.094	748,95	7.345	88.961	54.961	26.447
15	27.392	0,303	8.287	771,42	7.515	96.476	62.476	29.890
16	27.228	0,312	8.484	794,56	7.689	104.165	70.165	33.245
17	27.064	0,321	8.686	818,40	7.868	112.033	78.033	36.514
18	26.902	0,331	8.893	842,95	8.050	120.083	86.083	39.700
19	26.741	0,340	9.105	868,24	8.237	128.319	94.319	42.804
20	26.580	0,351	9.322	894,29	8.427	136.747	102.747	45.829
TOTAL	563.220	0,269	150.451	13.704	136.747	136.747	102.747	45.829

PAYBACK	6	YEARS
NET PRESENT VALUE (NPV)	45.828,79	€
INTERNAL RATE OF RETURN (IRR)	17,31	%
LCOE	0,11	€/kWh

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MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 3. Social and environmental aspects of photovoltaic systems for rural development.

Subchapter 3.1 - Environmental impact emissions and life cycle assessment of photovoltaic systems

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Heliotec 2006 S.L., Spain

Summary: The student is supposed to know about the basic technical and economical aspects of photovoltaic systems. This chapter treats the social and environmental aspects of the learnt photovoltaic systems and its impact on rural development. It is considered essential to enter more into the details in two main areas: firstly, understand the sources of emissions and secondly, learn about Life Cycle Assessment. It is important to know about the natural resources needed for producing photovoltaic systems (such as water, energy or material demand) and the material (air pollution, waste) emitted to the environment through production, usage and disposal. Life Cycle Assessment analyse the whole life cycle of solar panels with regard on the sustainability with ecological mindset. The subchapter 3.1 talks about the main phases and the most commonly used software, GaBi.

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1. Environmental impacts of photovoltaic systems

This section analyses the environmental impacts of photovoltaic systems from two main aspects. Firstly, what of the Earth´s limited natural resources are needed to develop the photovoltaic technology? Secondly, what sort of strains are put on our environment and what the environmental emissions are that escape into the environment while producing, using and decommissioning photovoltaic systems?

1.1. Natural resources

Photovoltaic solar systems are considered to be a green way of producing eco-friendly energy, for the reason that they produce no greenhouse gas or other gas emissions while producing energy. Also, they do not pollute the natural bodies of water and there is no environmental noise impact. Also, it is the entire PV panel life cycle that must be looked at to consider the global effects of the technology on the Earth.

To look at the use of natural resources, we will consider the space and land demand of the installation, the primary materials needed for production, as well as the energy and water demand during the production, transportation, installation and maintenance.

1.1.1. Space, landscape and soil demand

PV solar plants receive major criticisms when they are installed on a harvestable or agriculturally usable territory. Energy production and food production should not compete with each other, as both are crucial nowadays. This is one of the reasons why the area considered suitable for photovoltaic plants must be chosen carefully

Solar panel capacity is bigger on a larger surface. Therefore, if more energy production is a requirement, more modules are to be installed next to each other. Hence, large PV plants need huge surfaces, but locally roof-installed household systems do not bother the ecosystem that much. Additionally, if the building possesses an air conditioning system, shade cover on the roof (Kis, 2005) makes energy usage more efficient.

1.1.2. Material demand for production

Regarding the PV panel production, the hazards of a standard mining operation and the inputs of diesel fuel and machinery used for extracting silicon must be taken into account. Also, the main emission from the metallurgical grade silicon conversion process is silica dust, which can cause lung disease, and uses high levels of energy consumption.

PV panels need highly purified silicon, and this purification can involve hazardous materials such as silane, whilst silicon composition involves the administration of toxic chemicals such as diborane and phosphine in small diluted quantities in an inert gas. Nonetheless, these materials have been traditionally used in the microelectronics industry and their monitoring and control is well established.

Indium, tellurium and gallium are elements that are rare on the surface of the Earth, so mining them puts a heavy strain on the environment. In cadmium-telluride panels, the toxic heavy metal cadmium is used.

Regarding the materials for the construction of the structure of the PV system, other than the PV modules, these are steel, aluminium and concrete. These have a number of associated standard industrial hazards.

Batteries are needed for isolated PV systems and the environmental impact of their components also has to be taken into account.

The following table (Aguado-Monsonet, 1998) shows that the highest environmental impact is the waste management during the technology production and the waste management after the PV system useful life because batteries contain heavy metals (cadmium, lead, etc). For example, a lead-acid battery is the most common in developing countries and they are less expensive than PV batteries.

Table 1. Environmental impacts detected during the life of the batteries (Aguado-Monsonet, 1998)

	Mining	**Technology production**	**Decommissioning**
Exhaustion of raw material		Medium	
Energy needed	Medium	Medium	Low
Global warming	Low	Medium	Low
Waste	Medium	High	High
Land use	Low	Low	Medium (if it is not recycled)

The chart below (Pehnt, 2005) shows the required material, fossil energy and the caused greenhouse gas effect and acidification compared to the current (2010) energy mix (=100%, see the red line). The chart shows that PV systems need more material (iron ore, bauxite; mainly for construction) than conventional systems. It is necessary to note that other environmental impacts associated with materials supply are included, e.g. ecosystem degradation caused by mining. Also note that the quantities and types of directly input material directly depend on local conditions (e.g. aluminium input for photovoltaics depending on roof or facade integration, etc.).

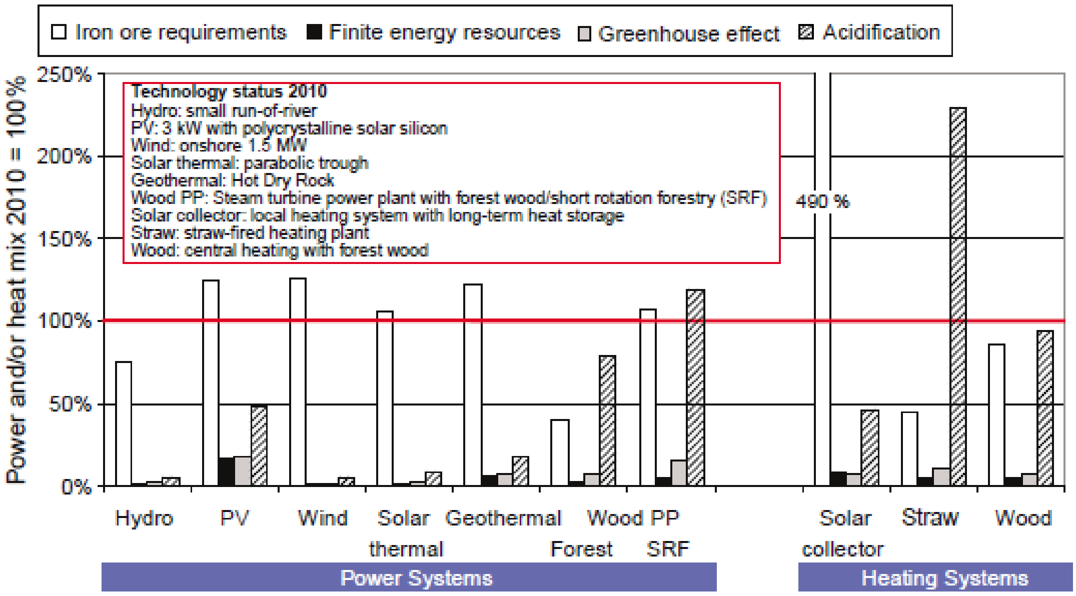

Figure 1. Normalized LCA of selected renewable energy systems for selected impact categories. Source: Pehnt, 2005.

1.1.3. Water demand

Compared to other renewable energy production systems, neither photovoltaic panel production, nor its operation require significant quantities of water consumption.

1.1.4. Energy demand

As we have seen in the chart mentioned above (material demand section), the finite energy sources needed for RES are in every case significantly lower than for the current (2010) fossil based-systems (Pehnt, 2005).

Of course, in an ideal future, RES systems would be produced using renewable energy sources.

1.2. Environmental strains and emissions

1.2.1. Visual impact

Although aesthetic questions can be highly subjective, most towns have regulations and/or restrictions about PV panel installation on protected buildings and monuments. Some historical buildings are a part of the national heritage and the solar panel installation is prohibited or permitted only on the inner side of the roof.

In bigger cities, installing PV panels on the top of industrial or commercial buildings, where they do not significantly influence the visual impacts negatively is a common practice.

On the other hand, solar panels can be used as an exterior vertical panels on modern buildings (for example Kyocera headquarters).in what is called ¨architectural integration¨.

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Nevertheless solar parks installed in the middle of natural places, can look quite artificial and removed from nature; their installation must be carried out in an environmentally friendly way. This is particularly true when the surface of the solar panels acts like a mirror, and its reflection in hours of high radiation can bother or frighten birds and animals (Kis, 2005) and even airplanes.

1.2.2. Noise impact

During the entire solar panel life cycle, noise pollution is only produced during manufacturing and construction. Photovoltaic systems do not produce any noise whilst under normal operation. (Kis M., 2005).

1.2.3. Air pollution and greenhouse gas emissions

Taking into account the whole life cycle of the modules, the most significant air pollution originates from the production phase. Compared to this, the emission is only 0.1-1% during the transportation. Among the various PV panels, monocrystalline and polycrystalline module manufacture requires the most complicated technology and emits most significant amount of air pollution in that time (Tsoutsos, 2005).

In case of accident or fire, CIS and CdTe solar panels can let small quantities of pollution into the air.

Under normal operation, solar panels are emission free.

Again, as cited in the material and energy demand sections above, under German atmospheric conditions, producing a polycrystalline solar-grade Silicon photovoltaics system leads to greenhouse gas emissions of 100 g CO_2 equiv./kW (Pehnt 2005). Among renewable systems, PV has the highest GHG effect and is still notably lower (50%) than conventional systems'. The greenhouse gases that are higher than in other RES systems are CO_2, CH_4, as well as dust/particles. SO_2 has to be mentioned as it is a cause of acid rain (Pehnt, 2005).

1.2.4. Water and soil pollution (surface, subsurface water bodies, land and soil)

Whilst running normally, PV systems do not directly pollute water bodies or soil, although careless storage can damage the natural environment. (Kis M., 2005)

1.2.5. Ecosystem disturbance

Roof-top PV systems do not affect ecosystems significantly, especially because these household systems are mostly installed in cities, where the original ecosystem has been historically changed and damaged because of urbanization.

Solar plants require relatively large area of land and space compared to the energy produced by them. As long as photovoltaic parts do not occupy protected areas, natural parks, forests or agriculturally precious territories, their impact on the environment can be considered as medium in these territories (Géza, Simon Andrea - Dr. Pálvölgyi Tamás - Mészáros, 2012).

1.2.6. Waste production and management

During the 20-30 year lifetime, normally operating grid-connected photovoltaic panels neither produce pollution, nor waste. The lifetime of batteries connected to isolated panels is around 10 years, which requires changing them twice or three times.
Appropriate waste management principles for the disposal of panels must be ensured.

Since 2012, in Europe, the WEEE[1] Directive describes the conditions of electrical and electronic waste. And since 2014, the same Directive describes the management of solar panels too. Producers have to take back and recycle PV panels. The PV CYCLE Association[2] consists of PV manufacturers and commercial businesses that operate 316 collection points across Europe to manage used solar panel recycling.

Nowadays, the majority of installed solar panels are still in service inside the 20-30 years useful lifetime. However, large number of used PV panels will be needed to be collected and recycled in the future. Estimations of EPIA[3] indicate that the amount of photovoltaic panel waste could reach 35000 tons by 2020. Therefore, a detailed plan has to be elaborated well before. It is the responsibility of the producers to use less toxic components and build modules that are easy to be recycled.

2. Life Cycle Assessment (LCA)

2.1. Definition, importance in sustainability

Life Cycle Assessment (LCA) is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle. LCA provides an adequate instrument to support environmental decisions. Reliable LCA performance is crucial to achieve a life cycle economy.

A product’s life cycle consists of the mining and preparation of the raw material needed, through the production and usage, up to the post-usage phase and time of waste management. All aspects of environmental impact, natural resource use, ecosystem status and human health have to be considered.

[1] Waste Electrical and Electronic Equipment
2 http://www.pvcycle.org/

3 European Photovoltaic Industry Association

The goal of Life Cycle Assessment[4] is to define the product's relation with the environment and to be able to express the material and energy needs numerically, as well as calculate the damages caused during the entire lifetime of a product or service. When realizing the LCA, we need to know the energy and material inputs and outputs, and the losses and emissions to assess and weigh them up. LCA plays an important role in the definition of critical points, the original source of most pollution and emissions, to help us manage to reduce these impacts, leading to a more environmentally friendly product or service.

2.2. ISO standards in LCA

The International Organisation for Standardisation (ISO) is a world-wide federation of national standard bodies which has a standardised framework for LCA collected within the series ISO 14040.

ISO 14040[5] describes the principles and framework for LCA including:
- definition of the goal and scope of the LCA,
- the life cycle inventory analysis (LCI) phase,
- the life cycle impact assessment (LCIA) phase,
- the life cycle interpretation phase,
- reporting and critical review of the LCA,
- limitations of the LCA,
- the relationship between the LCA phases, and
- conditions for use of value choices and optional elements.

And ISO 14044 specifies these requirements and provides guidelines for the LCA.

The ISO 14040 and 14044 standards provide a framework for LCAs. However, this framework opens the door to the individual practitioner with a range of choices that can affect the validity and reliability of the results of such a study. The current IEA guidelines were developed to provide guidance on assuring consistency, balance, and quality to enhance the credibility and reliability of the results from photovoltaic (PV) LCAs. The guidelines represent a consensus among the authors, PV LCA experts in North America, Europe, and Asia, for assumptions made on PV performance, process input and emissions allocation, methods of analysis, and reporting of the results. All PV LCA studies should be accomplished according to the ISO standards 14040 and 14044. Deviations from the nomenclature, procedures and methodologies compared to these standards for LCA should be stated clearly (V. Fthenakis, R. Frischknecht, M. Raugei, H. C. Kim, E. Alsema, M. Held and M. de Wild-Scholten, 2011).

4http://www.unep.org/resourceefficiency/Consumption/StandardsandLabels/MeasuringSustainability/LifeCycleAssessment/tabid/101348/Default.aspx

5 http://www.iso.org/

2.3. The four main phases of LCA

1. Goal and scope definition
2. Inventory analysis
3. Impact assessment
4. Interpretation

All four steps are interrelated and influence the results of the other three.

2.3.1. Goal and scope definition

The first step is to define the goal and scope of the analysis that makes the context of the study clear. We have to define the functional unit, its functions and boundaries, as well as the reference flow (material and energy flow input and output from the system and between the elements of the system).

In the case of PV systems, the system boundary shall include in the product's system the panels, the mounting system, the cabling, the inverters, and all further components needed to produce electricity and supply it to the grid. Also, we have to include the energy- and material- flows caused by manufacturing and storage, climate control, ventilation, lighting for production halls, on-site emissions abatement, and onsite waste treatments. On the contrary, it is required to exclude commuting (transportation to and from work), administration, sales, distribution and research and development (R&D) activities that are typically not included in the LCAs of conventional power generation systems. Such activities should, therefore, also be excluded from the LCA of PV systems, lest misguided comparisons are made. Alternatively, if included, their contribution shall be analysed and reported separately from that of the manufacturing phase.

2.3.2. Inventory analysis

The second step defines the Life Cycle Inventory (LCI). This analysis involves creating an inventory of flows from and to nature for a product system. Inventory flows include inputs of water, energy, and raw materials, and releases into air, land, and water. In LCI we define the inputs and outputs of the material and energy flow numerically.

2.3.3. Impact Assessment

The third step is the Life Cycle Impact Assessment (LCIA).

This phase of LCA is aimed at evaluating the significance of potential environmental impacts based on the numerical LCI flow results.

Specifically in the case of PV LCA we use the previously defined life cycle inventory indicators, such as radionuclide emissions, nuclear-waste generation, and air-pollutant emissions (NO_x, SO_2, PM2.5, PM10).

We employ mid-point indicators, greenhouse-gas emissions, cumulative energy demand, acidification potential (AP), ozone depletion potential (ODP), human toxicity, ecotoxicity, and ionizing radiation. The greenhouse gas (GHG) emissions during the life cycle stages of a PV system are estimated as an equivalent of CO_2 using an integrated 100-year time horizon using the most recent global warming potential factors published by the IPCC.

The Cumulated Energy Demand (CED) describes the consumption of fossil, nuclear and renewable energy sources along the life cycle of a good or a service. This includes the direct uses as well as the indirect (grey) consumption of energy due to the use of materials (e.g. plastic or wood in construction), consumables necessary in manufacturing (e.g., solvents, gloves, packaging) and raw materials.

Acidification potential (AP): acidification describes a change in acidity in the soil due to atmospheric deposition of sulphates, nitrates and phosphates. Major acidifying substances are NO_X, NH_3, and SO_2.

(Abiotic) Resource Depletion:
The existing method of impact assessment for resource depletion is considered problematic by some of the participants because data sources for rare metals, like silver, indium, tellurium, and gallium, carry considerable uncertainty. Instead, cumulative energy demand might be suitable, which takes minerals into account as well as energy resources (V. Fthenakis, R. Frischknecht, M. Raugei, H. C. Kim, E. Alsema, M. Held and M. de Wild-Scholten, 2011).

2.3.4. Interpretation

The fourth step is the Life Cycle Interpretation, a systematic technique to identify, quantify, check, and evaluate information from the results of the LCI and/or the LCIA. The results of the inventory analysis and impact assessment are summarized during the interpretation phase. The outcome of the interpretation phase is a set of conclusions and recommendations for the study.

Especially in the case of solar systems, some of the impact indicators described above may further be processed into energy payback time (EPBT), energy return on investment (EROI) or impact mitigation potentials (IMP).

The energy payback time is defined as the period required for a renewable energy system to generate the same amount of energy (in terms of primary energy equivalent) that was used to produce the system itself.

The energy return on investment is a key determinant of the price of energy, as sources of energy that can be tapped relatively cheaply will allow the price to remain low. The ratio decreases when energy becomes scarcer and more difficult to extract or produce[6]. This may comprise the mitigation potentials for climate change. Today's European electricity mix, or the national electricity supply mix clearly reference the impact assessment method applied and specify the reference system used.

2.4. LCA softwares - GaBi

Different software platforms are available to work out the Life Cycle Assessment. The most commonly used is the GaBi software. The name stands for "Ganzheitliche Bilanz," which in German means Holistic Balance. The software is in line with the Global Guidance Principles for Life Cycle Assessment Databases released by UNEP SETAC[7].

The advantage of this software is that it contains a large database. Even so, in the case of really specific PV data needs, the extended database may be the best purchase.

The GaBi software works with the following definitions:

- The *plan* means the life cycle that we would like to evaluate.
- *Processes* are inside the plan and define the phases of the product and
- *Flows* link the processes as the figure below (Fruzsina, 2013):

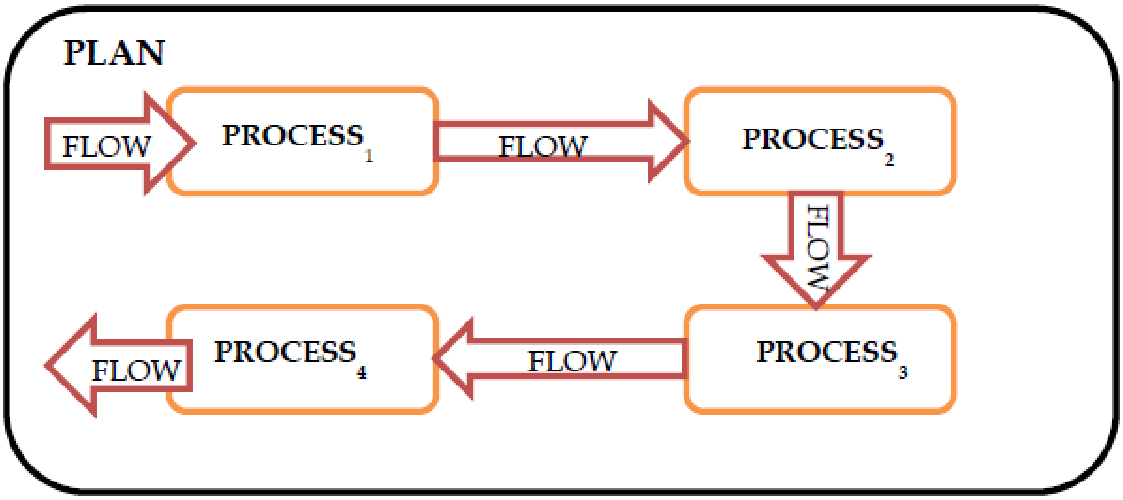

Figure 2. GaBi software Flows. Source: Fruzsina,2013.

[6] http://www.investopedia.com/terms/e/energy-return-on-investment.asp

[7] http://www.unep.fr/shared/publications/pdf/DTIx1410xPA-GlobalGuidancePrinciplesforLCA.pdf

GaBi software works with the following indicators:

ADP: Abiotic Resource Depletion
EP: Eutrophication potential
GWP: Global-warming Potential
POCP: Photo-oxidant Formation
HTP: Human-Toxicity Potential
AP: Acidification Potential
ETP: Ecotoxicity Potential

2.5. Barriers, challenges and critics of LCA

LCA is a powerful tool for analysing commensurable aspects of quantifiable systems.

- Not every factor, however, can be reduced to a number and inserted into a model. Rigid system boundaries make accounting for changes in the system difficult. This is sometimes referred to as the boundary critique to systems thinking.
- The accuracy and availability of data can also contribute to inaccuracy. For instance, data from generic processes may be based on averages, unrepresentative sampling, or outdated results.
- Additionally, social implications of products are generally lacking in LCAs. Comparative life cycle analysis is often used to determine a better process or product to use. However, because of aspects like differing system boundaries, different statistical information, different product uses, etc., these studies can easily be swayed in favour of one product or process over another in one study and the opposite in another study based on varying parameters and different available data.
- There are guidelines to help reduce such conflicts in results but the method still provides a lot of room for the researcher to decide what is important, how the product is typically manufactured, and how it is typically used[8].

[8] https://en.wikipedia.org/wiki/Life-cycle_assessment#Criticism

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MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 3. Social and environmental aspects of photovoltaic systems for rural development.

Subchapter 3.2 - Social and rural development impact

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Heliotec 2006 S.L., Spain

Summary: In this subchapter three main areas are covered. Firstly, the different types of installations (in regard to the isolated or grid-connected sites) and their social and economical advantages or inconveniences are discussed. Secondly, we talk about the rural development caused by photovoltaic systems, with special emphasis on energy security, climate change mitigation and economic development. Thirdly, we consider the possible socio-economical, administrative and cultural barriers and challenges in relation with solar systems.

INDEX

1. Different types of installation regarding social and economical aspects

1.1. Isolated

We speak about isolated solar energy production when the site is not connected to the grid. The site can be a small village, a farmstead or an industrial site, even a research station. The common attribute to all these installations is that the site is able to cover all its energy demand and there is no need or (feasible or viable) option for grid connection. This has two main consequences: the collected/produced amount of energy is limited and dependent on the weather and therefore has to be stored by the help of batteries for those periods when the energy source is not available.

Isolated photovoltaic sites are important in rural regions where the grid connection is impossible due to geographical reasons or the expenses of the infrastructure are too high. In some communities, the isolation is voluntary and desired. For instance, *Mas de Noguera*[1] is an educational centre for schoolchildren and also for adults. Disconnection from the grid is becoming more and more popular among young people as a lifestyle choice and forms an important part of environmental education as well.

Although photovoltaic energy is able to supply all the required energy to any use or energy demand, in most cases the necessary high economic investment makes it unprofitable. The main problem is that if the aim is to supply all the energy needed during winter days, where there are fewer sunlight hours, this implies oversizing the installation. This causes high surpluses and losses of energy in the installation during the summer months. Many authors suggest installations should be supported by wind energy systems in order to compensate the lack of sunlight during cloudy and rainy days. *„…it is worth installing wind turbines and sun-collectors together, because if the weather is sunny, then the sun collectors can produce energy in the most effective way – this is often the case with calm weather, however, if the weather is cloudy, but windy, in that case wind turbines can provide us with the necessary amount of energy.”* (Rázsi András – Csabai Edina – Kovács Attila, 2014)

Isolated industrial sites can also be supplied by solar panels. However, the security of the continuous energy supply or the economic viability is many times insufficient because the risk factors are high. On the other hand, smaller, temporary stations (for example isolated research sites in national parks, container offices or flats on a construction site) can rely on energy produced by solar panels. As soon as workstations are reachable in rural, isolated areas, the employment of local workforce is an important aspect to be highlighted.

1.2. Self-consumption (individual)

In this document, individual self-consumption installation refers to a photovoltaic system which is not isolated but connected to the grid and generally it is battery-free.

This installation concept is interesting in those cases when the electric energy generated by photovoltaic modules could be more profitable and viable than the use of all the energy supplied directly from the grid.

The photovoltaic system is located on the roof of houses, offices or other types of buildings. They use individually and exclusively the energy produced by the panels.

There are various reasons to install self-consumption systems:

[1] http://www.masdenoguera.coop

- Economic reasons are mainly considered because in many cases the energy generated by photovoltaic modules could be cheaper than the energy used from the grid.
- Other reasons can be technical aspects. PV modules can supply electricity in places where the grid connection is not available or the supply is deficient.
- Another potential reason is environmental responsibility and environmental awareness because photovoltaic production is more sustainable and environmentally friendly.

The advantage of the self-consumption mode is that the accumulation of energy is not required. Therefore, the cost of the installation is considerably lower since batteries have higher prices. On one hand, when there is sunlight there is also direct energy generation which is instantly used from the photovoltaic system. On the other hand, when there is no energy generation from the Sun, i.e. at night, the energy is directly provided by the electric grid.

The following cases are possible:

1. There is solar energy generation and production equals demand. In this case, all the energy is used by the photovoltaic system, there is no energy surplus and additional supply from the electricity grid is not required.

   There is solar energy generation and production is higher than demand. In this case, all the energy needed by the consumer is supplied by the photovoltaic installation, and there is also a PV produced energy surplus. This surplus can be injected into the grid as a surplus. The injection of the surplus will depend to a great extent on the regulation and legislation of the country. Some possibilities are selling the surplus energy, compensating the energy as a 'net balance' even though in some cases legislation forbids this.

1. A different option would be to earmark the energy for any extra or additional use which could be programmed or activated automatically.
2. The last option would be to store energy in batteries, although due to the high costs, it is not considered profitable with current available technology.
3. There is solar energy generation and production is lower than demand. In this case, all the energy from the photovoltaic system is used, but it also needs an extra contribution from the electricity grid to finish covering the demand.
4. There is no solar energy generation. In this case, all the energy must be supplied from the electricity grid to cover the demand.
5. Although this course is not focused on the legal and regulatory aspects, there is current strong controversy concerning this type of installation in many countries of the European Union and there are strong restrictions, limitations, and even prohibitions in place.

1.3. Self-Consumption (Collective)

Collective self-consumption corresponds to the same case described previously but the photovoltaic system supplies to different consumers which are interconnected.

Collective self-consumption is when a little village or a community decides to produce their own electricity. The local grid connects the energy producers and users.

In the future, independence from electricity companies and systems with locally produced energy for collective self-consumption can be a solution for rural areas. These will be the so-called microgrids, which are gaining more and more attention in the international research community.

1.4. Grid connection / production for selling

This is the most extended and the largest installed capacity mode throughout Europe and the world.

These are systems with rated power varying from 1 kW to more than 100 MW. These produce energy in order to inject it to the grid and get economic compensation in return. Therefore, these installations are created for doing business to obtain economic benefits by selling the energy or obtaining financial reward from it.

These installations are usually regulated by different European countries. Currently, there is no common legislation and each country has its own regulation and legislation.

These installations are oriented to investors and business people. From a rural developmental perspective, grid connection is not the most interesting type of installation. However, in many cases this type of installations is placed in rural areas and could be interesting for the local community which owns the land and could receive financial benefits that compensate the land usage and maintenance costs.

It is also possible to do small installations of photovoltaic systems in some countries. Consequently, small local investors from rural areas could benefit from this type of investments.

2. Impact in rural development

To analyse the impact in rural development originated by photovoltaics, three categories are considered for classification: A.) Energy security, B.) Climate change mitigation, and C.) Economic development (job creation). This classification is in the same line that the renewable energy policies in the OECD study (OECD, 2012).

2.1. Energy security

Our computer-based and over-consuming society’s energy dependence is unarguable. One of our policy makers’ main concerns is to grow the level of energy security in the EU.

Photovoltaic plants contribute to improved energy security with a positive impact in different ways: rural electrification, improvement of electrical infrastructures that might imply energy independence and sovereignty in the future.

2.1.1. Rural electrification

Rural electrification consists of obtaining electricity in rural areas where this has not previously existed.

It can be installed by the “classical” way, which consists of taking the cable from the grid that receives electricity from fossil fuel sources. Another option is to install PV panels and batteries in remote areas. It has to be highlighted that in many cases the costs of the electrical grid extension can be considerably higher than the installation of photovoltaic panels with their adequate energy storage.

Although, almost 99% of the households are connected to the electricity grid in Europe, there are still rural or remote areas lacking electrification. For instance, in Hungarian rural areas 100 000 persons are not connected to the network (EnergetikaiKözpont). As a general rule, we can say that the grid density corresponds to the population density. Rural electrification has its importance, not only in general development but also in potentially creating temporary jobs, such as building photovoltaic installations or small electrical infrastructures (EurElectric). The maintenance of photovoltaic or electricity systems can create permanent jobs in the area.

2.1.2. Improving electrical infrastructures

Photovoltaic installations are not only important when there is no network connection at all, but also as complementary systems, especially in rural areas.

Since climate change affects our common life, we experience more and more often extreme weather conditions. Storms or extremely low temperatures can damage cables and cause power cuts or blackouts in remote areas. Batteries filled up by photovoltaic panels can work as complementary energy sources in periods of electricity shortage.

Also, in remote areas, there is only one line of cable that provides electricity to a town and the line originates from a nearby larger city. In case there is a high consumption in peak hours, the city has its priority and the low voltage causes electricity cuts and shortages in the remote village. Delivering interconnections between lines and grids has a large potential in rural development through by offering the population energy security.

2.1.3. Energy independence and sovereignty

Currently, more than 2400 electricity distribution companies work in the European Union. These sources say that decentralized energy production and consumption is the future for supplying the 260 million connected customers (EurElectric).

On the household level, ***energy independence*** means–a person or a household could be absolutely independent from energy suppliers. This can be independently or through an intermediary energy company which ensures the electricity through solar plants and also decides prices and provides maintenance. The individual is independent, but not sovereign.

‘’***Energy sovereignty*** is the right of conscious individuals, communities, and people~~s~~ to make their own decisions on energy generation, distribution and consumption in a way that is appropriate to their ecological, social, economic and cultural circumstances, provided that these do not affect others negatively.” as per the Catalan Network for Energy Sovereignty (Pablo Cotarelo - David Llistar - Alfons Pérez - Àlex Guillamon - Maria Campuzano - Lourdes Berdié, 2014).

Photovoltaic systems possess other advantages in providing energy independence or sovereignty in rural areas. Solar panels work in a modular system, so communities or individuals can install a few panels on their roof and later the system can be extended. Flexibility makes PV the most competitive on the RES market in comparison with wind or biomass. Solar panels are viable on a small scale too. Panels can be installed on an individual house, without the agreement or permission of the community.

2.2. Climate change mitigation

2.2.1. CO_2 emissions reductions

The energy sector accounts for approximately 75 % of the total carbon dioxide emissions in the world (Manish S. - Indu R. Pillai - Rangan Banerjee , 2006).

The amount of carbon dioxide emissions that can be mitigated by a renewable energy technology such as solar power in a given period, usually a year, depend on three main factors:

- **Carbon intensity of solar electrical energy**
  Carbon intensity of electricity production measures the carbon emissions per unit of electricity generated in a given year (Ce). They vary from country to country (UNESCO).

  Carbon is spent through the energy used in manufacture and transport and the embedded energy in the materials used. This quantity is influenced by the solar resource (typically 1000-2000 kWh/Wp/year, depending on location, obviously sunnier places are more worthy) and the system lifetime is of typically 25 years.

- **Carbon intensity of displaced power**
  The carbon intensity of grid power varies between locations. For instance, when solar power is used in off-grid situations, then the carbon intensity of the displaced fuel and any related plant should be used. For example, the high embedded energy in kerosene lamps (paraffin lamps) makes it effective to replace kerosene with solar lighting despite the relatively high carbon intensity of off-grid solar systems that include battery storage.

- **The amount of solar capacity deployed depends on**
  - The cost of the PV electricity relative to locally available alternatives
  - PV technology availability: depends on the availability of system components (such as inverters and batteries), as well as on the infrastructure and skills to install and maintain systems in the available area;
  - Regulatory issues, such as building and planning regulations, and policy measures such as incentives stimulate the market and/or place obligations on suppliers to provide solar generation (Ekins-Daukes, 2014).

The CO_2 emission mitigation appears on an individual level too. Although, renewable sources are not the only component of ecological footprint calculations[2],[3] by using photovoltaic, or other renewable sources instead of fossil energies, everybody can reduce their personal, or household ecological footprint.

Photovoltaic energy usage on a community level is an efficient tool for awareness raising and the harmonious cooperation among stakeholders, decision makers, and everyday people. PV energy interconnects businesses and communities through environmentally conscious solutions. Those communities that already decided and implemented RE systems are developing the best practices in the EU.

[2] http://footprint.wwf.org.uk
[3] http://www.footprintnetwork.org/en/index.php/GFN/page/calculators

2.2.2. Awareness raising and education

One of the most important EU priorities is the realization of a knowledge-based society. This is the synergy of business, research and the sphere of higher education to lead the transformation into making the knowledge triangle more real[4].

Education and awareness raising on every level is key for the future. In a modern society, environmental education is part of education from kindergarten, through primary and secondary school to higher education and later in adult or professional education. There is no doubt that adults can easily be influenced by their children. Pedagogues have the responsibility of teaching the basics of sustainable and climate conscious behaviour. Experts say that in many cases children initiate changes in families that positively affect the environment.

Adults are targeted through awareness raising campaigns such as campaigns related to new implementations in town. Solar panels on the top of the municipality are exemplary for the local population. They have the double benefit of producing energy for the community buildings and promoting an environmentally conscious lifestyle. Local government can help residents with incentives for renewable energy installations.

From another point of view, the renewable energy sector draws those workers who are computer-literate because new technologies work with ICT more (smart grids, smart meters, etc.) (N., 2011). This tendency requires more ICT knowledge in the region that potentially increases the amount of professional training and/or the frequency of such education as well.

2.3. Economic development

2.3.1. Economical saving. Competitiveness

Photovoltaic energy may have an important impact on rural development from an economic perspective since it may involve an important economic saving in bills or in energy use.

The current situation of photovoltaic energy is close to Grid Parity.

Grid Parity occurs when the costs of the energy produced by photovoltaic power technology becomes equal to the cost of the energy obtained from the electrical grid.

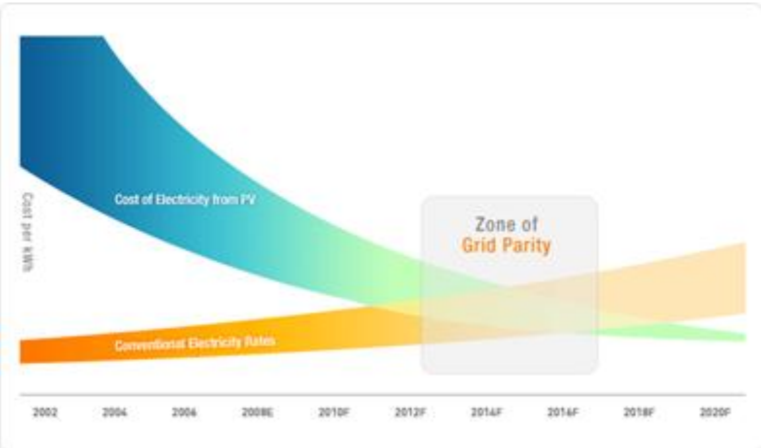


Figure 1. Graphical illustration of grid parity concept. Source: Make Wealth History.

[4] http://ec.europa.eu/education/policy/higher-education/knowledge-innovation-triangle_en.htm

Grid Parity has reached many European countries such as Spain, although it has not totally reached other countries such as Romania and Hungary due to their low solar radiation. When Grid Parity is reached, photovoltaic energy becomes a de facto competitive energy source which provides economic savings compared with other sources of energy supply. In this way, economic savings may be achieved in private houses, and also in businesses, industries and agricultural holdings which will allow them to be more competitive in their business area.

Economic savings are not only achieved in cases of Grid Parity. Photovoltaic energy may involve an increase in the competitivity of other situations. An example would be the substitution of isolated energy sources which are expensive. For instance, if a water pumping well on an isolated agricultural holding that works by a fossil fuel generator is substituted by a photovoltaic system, significant economic savings may be achieved.

Grid Parity will involve the creation of a new energy model in the forthcoming years. Why should we depend on electricity companies and fossil fuels when energy may be generated locally at the same or lower price and also be more sustainable?

Photovoltaic energy may be the key to changing the current energetic model. This would enable energy to be generated individually in small communities for their own use. Going one step further, it is worth mentioning distributive energy system based upon renewable energies. Different photovoltaic systems and other renewable technologies established in different locations which belong to different users or communities may be interconnected in this energetic model. In this way, a small supply network is created that enables higher efficiency and a greater level of security which becomes gradually more grid-independent, autonomous and self-governed.

Nevertheless, despite the fact that this model is technically and economically viable in many regions of Europe, current regulation and legislation policies are not helping to make the transition to this new decentralized energy model.

2.3.2. New jobs and business opportunities

As was mentioned, the RE sector provides temporary, as well as continuous jobs on the labour market.

Particularly, photovoltaic market offers short term/contractual based jobs in the following fields:

- The planning and engineering phase ensure jobs for engineering offices.
- The installation works draw a less skilled workforce for the period of implementation.
- After the installations, the next step is validation that offers jobs for auditors.

After installation, solar panels require permanent maintenance. This increases local employability and mainly for manual workers. Further extensions on the solar farm require again engineering work, or if the developments are financed by European or national projects, project managers, officers, translators are employed to realize extensions.

Environmental protection and sustainability issues have become more and more important in the past decade. Thanks to these changes, a new type of approach appeared in the labour market: nowadays, besides the well-known classification (blue collar workers or white collar employees), the concept of green-collar worker has appeared as someone employed in the environmental sectors of the economy. Environmental green-collar workers (or green jobs) satisfy the demand for green development. Generally, they implement environmentally conscious design, policy, and technology to improve conservation and sustainability. Formal environmental regulations, as well as informal social expectations, are pushing many firms to seek professionals with expertise with environmental, energy efficiency, and clean renewable energy issues. They often seek to make their output more sustainable, and thus more favourable to public opinion, governmental regulation, and the Earth's ecology.

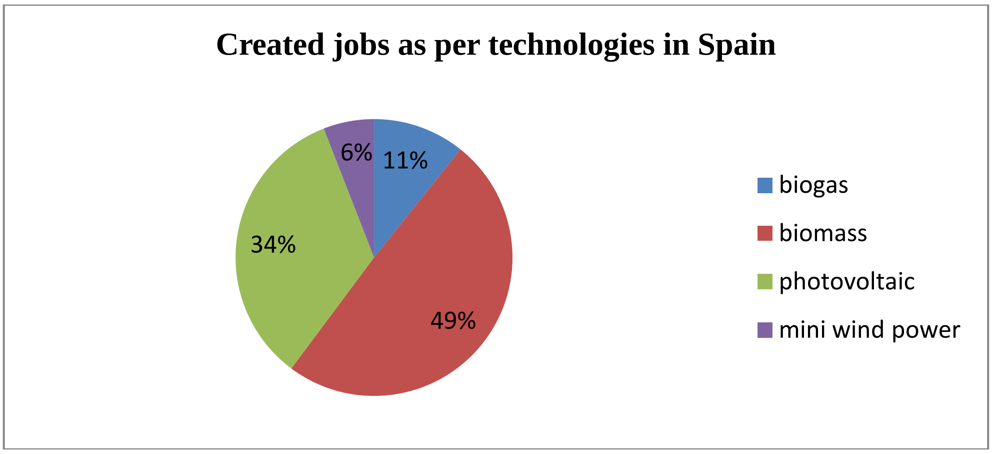
In numbers: in 2013, approximately 240000 people were employed in the Electricity sector in the EU. Worldwide, these jobs related to photovoltaic panels may reach 3.7 million by 2030 and 5 million by 2050 (EurElectric).

In Spain, as per the study (Díaz), the photovoltaic sector is aiming to reach 11261 MW potential in the next 10 years. 44% of this potential would affect residential buildings and households and 56% affect industrial buildings. These developments will surely increase rural area employability too.

Based on these plans, the above-mentioned study forecasts that photovoltaic sector will create 31715 direct jobs and 14272 indirect jobs in Spain. The photovoltaic sector is the second strongest "job creator" in the RES, seeing total numbers. It can be deduced that approximately 2/3 of the employment will affect workers in the manufacture and 1/3 the longer term operational and maintenance works.

Table 1. Directly and indirectly employment outcomes associated with the development potential of the Study "El autoconsumo energético y la generación distribuida renovable como yacimiento de empleo" in Spain.

Technology	**Employment**				**Total**
	Manufacture and installation	**Operation and maintenance**	**Total direct jobs**	**Total indirect jobs**	
biogas	721	6485	7205	7385	**14590**
biomass	23350	12375	35725	31438	**67163**
photovoltaic	22224	9491	31715	14272	**45987**
mini wind power	3526	941	4466	3573	**8040**
total	49820	29291	79111	56668	**135779**



Spanish researchers (RIO, 2009) consider that due to the low population density, a declining dependence on agriculture and high unemployment rates, the success of RES in rural development is guaranteed.

Another study (CALDÉS, 2009) analyses the photovoltaic panels' socio-economical impacts, namely a solar power plant (50 MW) and a solar tower (17 MW).

Table 2. Photovoltaic panels' socio-economical impacts. Source: CALDÉS, 2009

Technology	Solar power plant (50MW)	Solar tower (17 MW)
direct employment	5 553	3 213
indirect employment	4 030	2 278

2.3.3. Specialisation and capacity building

In small regions, there is potential in the RES to generate new jobs (Gábor, 2014). To make this real, reinforcing the level of knowledge in the general population with greater awareness raising campaigns and environmental education to retain the local population and give chances to professional workers in the region and provide skilled jobs for every level is necessary. These steps would generate further development and would attract back young people to their hometowns.

Capacity building is training that works in a synergetic way in many cases. For instance the solar farm installed in Sellye (South-Hungary) provided a significant amount of work for local entrepreneurs in the implementation phase, although the permanent manning requirement is minimal. The biggest success is that further businesses and stakeholders were drawn to the region thanks to the news that appeared in the media and was highlighted by the Mayor (Viktor, 2014).

2.3.4. Diversified activities. Energy production.

Innovation can appear in the sense of multi specified jobs. Decentralized energy systems and grid connection may assure the possibility to run more businesses at the same time. For example, in Spain, farmers install PV panels on the top of sheds. The energy generated is much more than the energy used by the farm, so the owner sells the energy to the grid/neighbours.

In this way, with some investment we can easily become energy producers, a future possibility to maintain and connect businesses.

3. Barriers and challenges

3.1. Socio-economical barriers

- Lack of resources and financial difficulties
- In Spain, there is an extra capacity in the electric power park, which acts as a barrier to enter new technologies, even though this would involve a reduction of costs.

- There are not enough support mechanisms through incentives and public grants for research, development and innovation in RES to reduce costs and promote new applications
- Economic difficulties of Spanish households that lower the chance to install RES in their homes
- In some European countries governments still keep the grants and incentives for fossil energy and nuclear energy. For example, in Spain, the incentives are for Combined Cycle Power Plants.
- Small and Medium Enterprises (SMEs) are important in the renewable sector especially from the point of view of renewable energies. The challenge for these companies is to negotiate a good price with their suppliers, as big companies obviously can get better prices with bigger orders.

3.2. Administrative barriers

- Lack of an elaborate administrative procurement about how to connect to the grid. In many cases there are individual permissions but does not exist a uniform, national/European legislation to regulate the energy supply to the grid
- Big electricity companies determine and rule the way to connect. For that reason they are not interested in opening the doors to alternatives (so people buy more electricity from them) and the costs remain extremely high.

3.3. Cultural and social barriers

- The awareness about energy efficiency and energy saves is still not enough, neither about renewable energies. Society still needs to increase the level of awareness.
- The information related to energy and in particular renewable energies from the media is inadequate, incomplete and in some cases significantly influenced by certain interest groups.

Nowadays, producing sufficient energy from renewable sources is not the challenge. How the grid reacts to the decentralized and continuously changing potential and distribution of power input at any given moment, and the cost of producing energy is. (István, 2014).

Another challenge is the quick, short term, changes to the grid that make longer term (hours, days) forecasting nearly impossible.

A possible solution to resolve efficient energy storage is to increase capacity and make it cost-efficient, either with new generation batteries, or other storage cell innovations. For this reason, it is important to promote R+D+I in every level and develop national strategies.

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MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 3. Social and environmental aspects of photovoltaic systems for rural development.

Subchapter 3.3 - Vision for future. Ideas and new suggestions.

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Summary: To summarize the conclusions from subchapters 3.1 and 3.2 in this subchapter various scenarios, visions and suggestions can be found for the future. Namely, we highlight the importance of education and awareness raising on every level and through every channel and put the emphasize on the responsibility of universities and knowledge centres in research, development and innovation. Changes in the general, common mindset and in legal process are crucial from the point of view of renewable energies. Rural participation plays a significant role through local development actors; also, the technical and the policy makers' aspect has to be considered. Finally, the subchapter inform us about the distributive generation model and closes the thoughts by conclusions.

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1. Introduction

Currently, there are more than 2400 electricity distribution companies working in the European Union. Many of them are convinced that decentralised energy production and consumption is the future for supplying its millions of connected customers.

The European Commission's Advisory Council indicates that PV has the potential to deliver electricity on a large scale at a competitive cost and states that, if appropriate measures are taken, PV could generate up to 4% of the total electricity demand or even more by 2030. In relative terms, it looks reasonable, but in absolute terms, this represents, for Europe alone, a huge step forward of several orders of magnitude (RUIZ).

Solar PV power is a commercially available and reliable technology with a significant potential for long-term growth in nearly all world regions. As per the IEA's estimation, PV will provide around 11% of global electricity production and avoid 2.3 gigatons (Gt) of CO_2 emissions per year by 2050 Figure 1 (OECD/IEA, 2010).

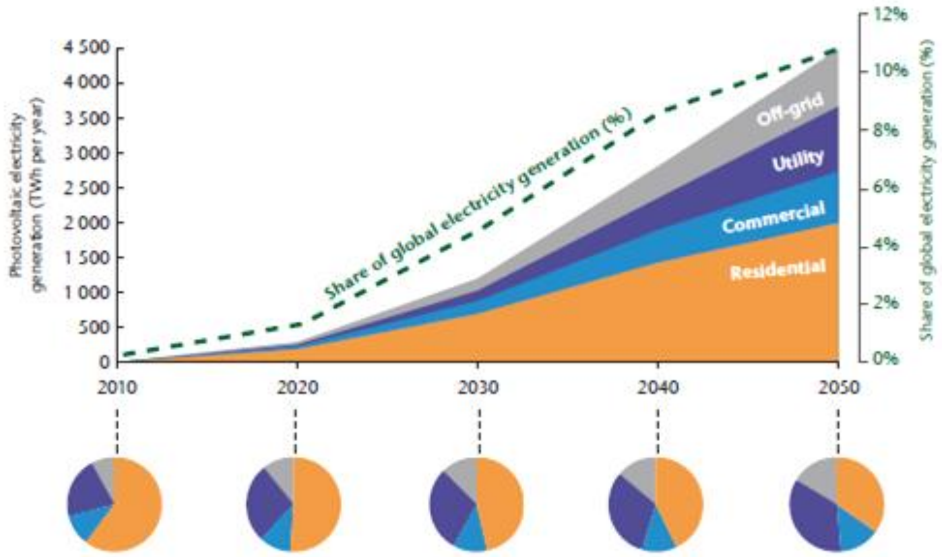

Figure 1. Evolution of photovoltaic electricity generation by end-use sector. Source: International Energy Agency (IEA)

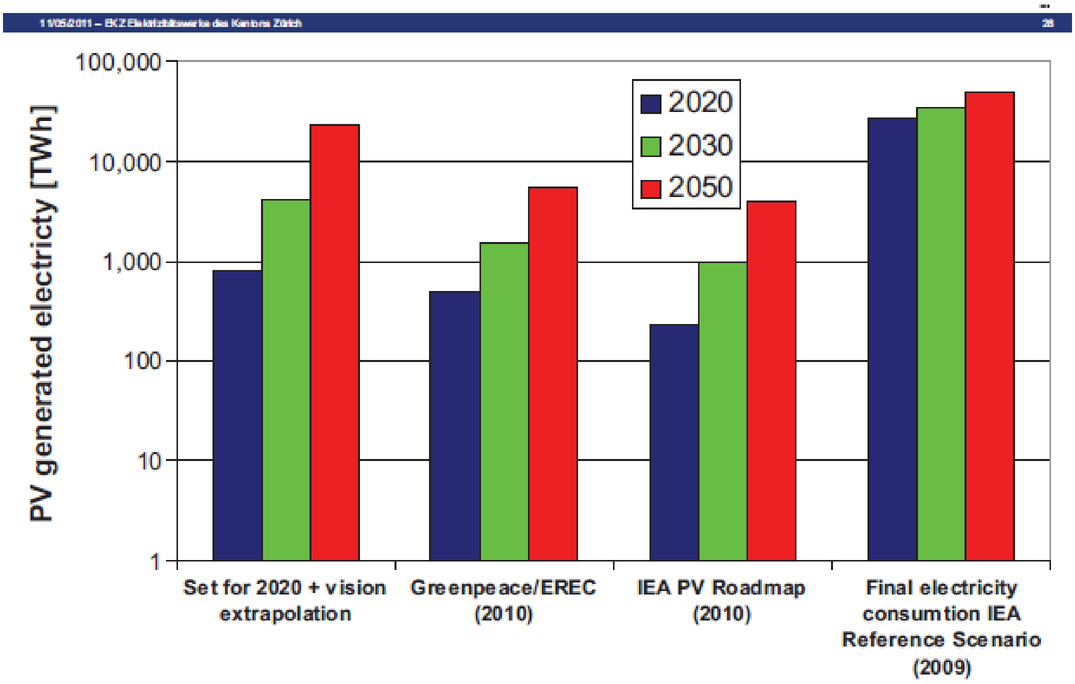

Figure 2. Scenario comparisons of global PV electricity production. Source: Join Research Center of European Commission.

In this chapter we will discuss the future visions, scenarios and suggestions as per the following structure:

A. Education and awareness raising
B. Research, innovation
C. Changing paradigm and mindset on different levels
D. Regulation and legal changes
E. Rural participation, decentralization
F. Policy makers aspect
G. Technical aspects
H. Distributive generation model

2. Visions, scenarios and suggestions

2.1. Education and awareness raising

As discussed in subchapter 3.2, educational reforms and changes must be performed at every level of the educational system. Awareness raising should affect society and provide all of its sectors with the necessary and adequate level of knowledge and information. People in a knowledge-based society can take environmentally conscious decisions for the benefit of future generations and sustainability.

Although dissemination activities take part in every European project, their real impact can hardly be measured. For successful RES project communication professional disseminators and communicators are needed with specialized knowledge: firstly a reasonable level of professional knowledge is required, and secondly, the person needs sophisticated communication skills. In remote rural areas people welcome new persons with new ideas and find them interesting, which is an effective strategy in the first phase of dissemination. However, implementing the new ideas into everyday lives, needs a regular "feed in impact" (children speaking about environmental topics that they hear about in school, local examples like PV panels on a town hall or council building. Local action groups are often the best, e.g. local green NGOs that define common community goals.

2.2. Research, Innovation and Development

Universities and research centres are playing key roles in the fight against climate change through research, innovation and sustainable development. Universities need funding and financial security to be able to deliver the newest technological innovations and provide our societies with ecological solutions in climate change mitigation.

Policy makers and the stakeholders in the industrial sphere are the actors who can help in this battle. They have to increase R&D efforts to reduce costs and ensure PV readiness for rapid deployment while also supporting longer-term technology innovations (OECD/IEA, 2010).

The following future criteria and vision could be targeted on short-, medium- and long-term initiatives according to the International Energy Agency:

- The industry needs to improve the technical performance and cost efficiency of solar cells, modules, and system components, (both for existing as well as for new solar cell technologies) to make things more achievable at a typical person level.

- Encouraging producers from the consumer and the governmental side to consider the results of life-cycle assessment studies and reduce the environmental strains of PV systems. The importance of developing and implementing recycling solutions for different PV technologies has to be mentioned.

- Designing PV as a building material and architectural element to meet technical, functional, and aesthetical requirements, as well as cost targets.

For example, in 2014 in Krommenie, Netherlands the government built the first bike path made of solar panels. The 70 meters long path produces now more electricity than it was planned originally[1].

[1] http://en.solaroad.nl/

2.3. Changing paradigm and general mindset

Nowadays, one of the most important EU policies is promoting active citizenship, involving local communities. We are living changing and turbulent times; bottom-up initiatives (when a small community, NGOs stand up for an environmental, social or political change and start to act on a local level) are more and more successful, professional and accepted. Renewable energy policies must keep taking into account the demand for more and more active participation by rural dwellers. Citizens demand direct involvement in key decisions about their territory, particularly when they concern large installations or infrastructure.

In a number of rural regions, a top-down and large-scale approach to renewable energy is causing communities to oppose installations. Then any bad feeling created might go on to undermine the development of other, more appropriate initiatives in the future.

Often, policy makers have tried to simplify renewable energy policy by putting a focus on large-scale installations and a limited number of key actors supported by automatic incentives. However, viewing renewable energy through a lens of "hard" industrial policy limits the ability of hosting communities to feel some ownership for the interventions and share in their overall vision. Moreover, with this type of policy, many hosting communities feel they have to deal with all the negative consequences while the investors and workers from outside the region get all the benefits. Many hosting communities have started opposing renewable energy installations and voting against further deployment.

Also, a new paradigm says that the target sector has been extended and the focus from agriculture is moving towards a number of other sectors such as rural tourism, manufacturing and the ICT industry. Although in the old approach the main tool was the help of subsidies, nowadays governmental bodies participate in different roles and levels (European, national, regional and local), and investment is the new trend. Beside the different governmental levels, the key actors are the stakeholders from public and private companies, NGOs (OECD, 2012).

2.4. Regulation and legal changes

RES will bring new paradigm in the electricity market as well. New actors will appear on the market with different roles and remuneration needs. A new business model will take over the old monopoly vs. curbed market idea instead. As well as the "insider-outsider" approach, diversified and internalised actors will be present on the local mini-market instead.

2.5. Rural participation

Emerging major economies are already investing substantially in PV research, development and deployment. However, more is needed to be done to foster rural electrification and capacity building. Multilateral and bilateral aid organisations should expand their efforts to express the value of PV energy in low-carbon economic development (OECD/IEA, 2010).

Participation of local decision makers plays a crucial role in the future of rural areas. The smallest is a village; its welfare is the strongest connection with the Mayor's personal and professional ambitions and skills. In most cases, mayors and leaders are the initiators of renewable energy projects. They make the new directions and regulations to other local government members or parties more acceptable. However, in nearly all cases the sustainability directives do not influence and directly lead the local authorities, because renewable energy projects are first considered beneficial from a financial point of view. Environmental advantages have also been used as a marketing tool in political campaigns or provided help to obtain a regional or national grant.

2.6. Policy makers aspects

Policy makers are responsible for the development and implementation of appropriate financing schemes, in particular for rural electrification and infrastructures in areas in need.

Governments have to create financing models and training and education to promote market facilitation and transformation; improve international collaboration to allow for accelerated learning and knowledge transfer among the stakeholders. Implement effective and cost-efficient PV incentive schemes on a European level and decrease over time so as to foster innovation and technological improvement.

On one hand, setting effective, predictable, long-term and clear financial incentive schemes and regulatory frameworks as PV installations require high capital investments and expensive manufacturing plants. Additionally, establishing standards and codes, due to standards, codes and certificates help create confidence and better handling of PV products.

On the other hand, in most areas of the world, PV has not yet achieved an electricity generation share larger than 1%, and can currently be absorbed by existing grids without any problems. However, with an increasing number of PV systems in place, interconnection and load management will become important issues. For this reason, the government has to establish regulatory frameworks that facilitate large-scale PV grid integration.

Lastly but not least, the creation of a skilled PV workforce that is well-trained workforce is necessary to ensure technology development, quality installations, cost reductions, and consumer confidence in the reliability of solar installations (OECD/IEA, 2010).

As previously has been mentioned, policy makers should open up to public-private partnerships. If this new concept is followed by acts, they might be considered a valuable tool to provide the added value needed to enhance the chances of photovoltaics and lead to a harmonious balance of co-operation in the sector (RUIZ).

2.7. Technical aspects

Achieving this roadmap vision will require an effective, long-term and balanced policy effort in the next decade to allow for optimal technology progress, cost reduction and ramp-up industrial manufacturing for mass deployment. Governments will need to provide long-term targets and supporting policies to build confidence for investments in manufacturing capacity and deployment of PV systems.

As PV matures into a mainstream technology, grid integration and management and energy storage become key issues. The PV industry, grid operators and utilities will need to develop new technologies and strategies to integrate large amounts of PV into flexible, efficient and smart grids (OECD/IEA, 2010).

As a technological outlook, the further development and wider usage of bifacial solar panels offer a promising future benefit.

Bifacial PV modules are able to use light not only from the front, like classical PV modules but also from the back. Hence, the area-related efficiency can be increased in a power plant when these modules generate additional electricity from the light reflected from the ground to the other side of the modules.

This system can reach higher efficiency when it is supported by 1.) a light coloured flat roof or 2.) a ground mount system or 3.) a desert area (albedo is higher than in the case of earth and soil) 4.) the installation of a special reflective foil. Another possible application for bifacial solar modules would be the vertical installation in an east-west direction which shifts the production peak from noon to the morning and afternoon hours.

2.8. Distributive generation model

PV will achieve grid parity, i.e. competitiveness with electricity grid retail prices, by 2020 in many regions. As grid parity is achieved, the policy framework should evolve towards fostering self-sustained markets, with the progressive phase-out of economic incentives, but maintaining grid access guarantees and sustained R&D support (OECD/IEA, 2010).

Nowadays, in 2016, Grid parity is a reality in a lot of European countries. The high number of sun hours in South European Countries and the evolution of technology and competitiveness of prices, make the grid parity a reality in countries like Spain or Italy.

Grid Parity will involve the creation of a new energy model in forthcoming years. Why should we depend on electricity companies and fossil fuels when energy may be generated at the same or lower price and also be more sustainable?

In this sense, photovoltaic energy may be key to changing the current energetic model. This is the easiest technology that enables energy to be generated individually in small communities for their own use.

To sum up, the International Energy Agency states the Solar Vision for 2050 is the following:

- The produced solar energy by 2050 will be 2.6 TW
- Photovoltaics will cover 7.8% of Total Primary Energy Supply and
- 45 % of electricity.

3. Conclusions

- However, the growth of PV electricity installations is much faster than predicted by most scenarios, for the next decade solar PV will still need support. Only increasing markets ensure that PV electricity prices are continuously declining.
- The adaptation of current grid structures is needed to accommodate a larger share of decentralised RES to enable a large scale use of PV electricity.

Nevertheless, the most important is to make sustainable steps at the same level in the same direction for everyday to start to take changes in their life and accept responsibility. Market actors should decide to consider the environment and not only financial aspects and governmental bodies have to facilitate the legislative background and give support with environmentally conscious initiatives and incentives. Synergetic actions may help to implement further positive steps towards a low carbon economy.

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MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 4. Fully developed case study of application of photovoltaics for rural development

Subchapter 4.1 – Introduction and technical aspects of the case study

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Heliotec 2006 S.L., Spain

Summary: In chapter 4 of this module, a specific case study application of photovoltaic technology for supplying energy to a rural hotel in Alfondeguilla (Castellón) is developed to follow the chapters throughout this module.

Thus, in this subchapter a description of the end-use of the facility, the design parameters, and calculations will be performed for sizing the installation.

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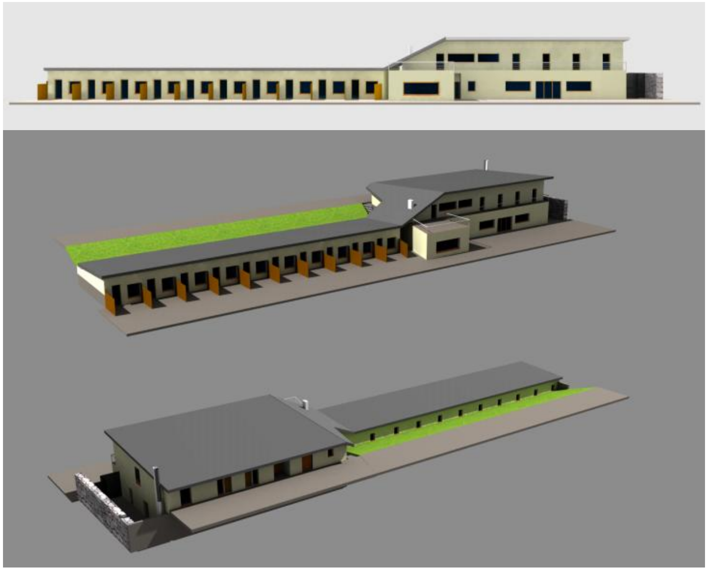
1. Introduction

This chapter presents a case study of a solar PV installation for supplying power to a rural hotel isolated from the grid with the help of a gas-fired electricity generator.

This particular project is called "Mar de Fulles" Eco-ethical tourism. It deals with an eco-touristic complex located in an area of great ecological value and interest next to the Sierra de Espadán Natural Park, in Castellón (Spain). The complex is very close to an area of special protection for birds that is part of the Red Natura 2000 network, lying at the heart of a centennial cork forest in an area of 160000 m^2 and great biodiversity.

The complex is made up of:



1. A hotel with ten 30m^2 bedrooms that have 20m^2 terraces.
2. A hostel: five rooms for 8 occupants with a terrace.
3. A 2000 m^2 private garden in front of the terraces.
4. A panoramic swimming pool.
5. 30 conditioned woodland spaces.
6. 5 conditioned group spaces in the forest.
7. Parking.
8. A restaurant with an indoor dining room for 60 to 150 diners and an outdoor dining space for more than 150 diners.
9. Multipurpose rooms.
10. A reception with tourist information and guidance.
11. An ecological food garden.

Principal characteristics of the complex:

- Bioclimatic construction.
- PVC free.
- Energy self-sufficient.
- Integrated landscaping.
- Integrated water management.
- Integrated waste management.
- Woodland management.
- Ecological agriculture.

2. Technical aspects of the case study

2.1. Location

Location:	Alfondeguilla, Castellón (Spain)
Geographic Coordinates:	39º 49’ 01’’ North
	0º 17’ 23’’ West
Elevation:	305 m a.s.l.

2.2. Design parameters

PV module location: The PV modules are placed in a coplanar arrangement on the roof of the hotel bedrooms. The roof has an inclination of 12º with a south-facing location. Things have been done this way to improve the architectural integration and minimize the visual impact of the installation.

Type of installation: Given the distance from the grid network and the prohibitively high cost of connecting to it, the owner decided to develop a remote renewable power system with the support of a gas-fired generator

2.3. Calculations and design

2.3.1. Energy requirements

For the calculation of the energy consumption of the complex, a detailed study of the forecast of energy needed from each of the resort facilities according to parameters depending on season and occupancy days and time curves for the use of facilities was carried out. Both of them modify the daily load curves of the facility.

The complexity curves showing the daily energy needs of the complex to be developed directly depend on the occupancy of the accommodation and the facility usage hours depending on the time of year. This starting data for sizing the installation requirements is summarized in the following Table 1.

Table 1. Summary of estimated daily maximum power and energy demands

SERVICE	Maximum Power [kW]	Daily energy consumed [kWh/day]
Hotel	32	38
Hostel	25	42
Restaurant	28	21

Air-conditioning	18	15
Irrigation pumps	5	4
TOTAL	108 kW	120 kWh/day

2.3.2. System losses

As "Chapter 1: Technical Aspects" of this module explains, the Performance Ratio of the system needs calculating.

To do so, the following performances and losses are calculated:

- Orientation loss: There will be no orientation loss effect given that the PV installation is placed on a south facing roof with a horizontal angle (azimuth) of 0º.
- Shade loss: As the PV modules are fitted with a coplanar assembly on the hotel roof and there are no nearby objects that could cast a shadow shade loss will be inexistent.
- Dirt loss: Loss through dirt accumulation is estimated to be 5%.
- Cabling loss: Performance losses through wiring reach 3%.
- Inverter performance: The inverter performance is 96%.
- Charge regulator/maximiser performance: This performance is estimated to be 98%.
- Battery performance: The performance of the battery bank is considered to be 82%.

Therefore the Performance Ratio of the system will be:

$$PR = 1 - \big(0{,}05 + 0{,}03 + (1 - 0{,}96) + (1 - 0{,}98) + (1 - 0{,}82)\big) = 0{,}68$$

2.3.3. Photovoltaic field sizing

In this area, special attention was paid to the sizing of the installation and its cost, so that its profitability was suitable for the end-user.

On the one hand, if the installation was sized to cover 100% of the energy demand, we would obtain a remote PV installation with a high initial investment cost. On the contrary, if this was sized to cover a low percentage of the energy demand, it would lead to a high consumption from the gas-fired generator to provide the energy necessary to cover the needs of the complex. An adequate balance was aimed for between the investment cost, the energy produced and the consumption of gas for the generator.

During the in-depth study of the installation, a number of sizings and installation budgets were obtained that covered the energy needs of the complex, analysing the costs of each case in turn, the balance of energy produced by the PV installation and the cost of the energy necessary to be supplied by the electricity coverage support.

After this number of installation sizings, it was concluded that the optimum sizing of the installation, by which an adequate balance between investment, produced energy and energy demanded from the electricity coverage, was the following:

Table 2. Photovoltaic power

PV modules	136 x Atersa A305P (305Wp)
Inclination	12º
Orientation	Sur
Peak Power	41480 Wp

Starting from the power to be installed and the parameters described, the data on radiation, generated daily energy and generated monthly energy were obtained from the PVGIS (Photovoltaic Geographical Information System) website.

Monthly Solar Irradiation

PVGIS Estimates of long-term monthly averages
Location: 39°49'1" North, 0°17'23" West, Elevation: 305 m a.s.l.,
Solar radiation database used: PVGIS-CMSAF
Optimal inclination angle is: 35 degrees
Annual irradiation deficit due to shadowing (horizontal): 1.2 %

Table 3. Monthly Solar Irradiation

Month	**H_h**	**H_{opt}**	**H(12)**	**I_{opt}**	**T_{24h}**	**N_{DD}**
Jan	2130	3510	2700	61	9,3	232
Feb	3150	4700	3810	55	9,8	184
Mar	4720	5960	5310	43	11,8	114
Apr	5590	6070	5940	27	14,0	58
May	6570	6380	6710	14	17,1	7
Jun	7380	6820	7420	8	21,2	3
Jul	7290	6900	7390	11	23,8	1
Aug	6310	6560	6610	22	24,2	2
Sep	4880	5840	5390	37	21,2	12
Oct	3640	5050	4260	50	18,0	53
Nov	2420	3890	3030	59	13,2	193
Dec	1810	3070	2330	63	10,1	241
Year	4670	5400	5080	35	16,1	1100

H_h: Irradiation on horizontal plane (Wh/m^2/day)

H_{opt}: Irradiation on optimally inclined plane (Wh/m^2/day)

H(12): Irradiation on plane at angle: 12deg. (Wh/m^2/day)

I_{opt}: Optimal inclination (deg.)

T_{24h}: 24 hour average of temperature (°C)

N_{DD}: Number of heating degree-days (-)

From the Monthly Solar Irradiation results, it can be seen that the optimal inclination of the photovoltaic modules for the installation site would be 35º. However, since complete architectural integration for the installation was a requirement, a coplanar mounting for the roof with an angle of 12º was finally designed. Under these installation conditions, the PV plant production will be that indicated in Table 4.

Table 4. Monthly PV generation

Month	H(12) kWh/m2/day	PR	$H(12)_{PR}$ kWh/m2/day	Energy production per kW [PSH]	Production for peak power 41,48 kWp	
					Daily energy produced kWh/day	Monthly energy produced kWh/month
Jan	2,70	0,68	1,84	56,92	76,16	2360,88
Feb	3,81	0,68	2,59	72,54	107,47	3009,06
Mar	5,31	0,68	3,61	111,93	149,78	4643,06
Apr	5,94	0,68	4,04	121,18	167,55	5026,38
May	6,71	0,68	4,56	141,45	189,26	5867,21
Jun	7,42	0,68	5,05	151,37	209,29	6278,74
Jul	7,39	0,68	5,03	155,78	208,45	6461,80
Aug	6,61	0,68	4,49	139,34	186,44	5779,77
Sep	5,39	0,68	3,67	109,96	152,03	4560,97
Oct	4,26	0,68	2,90	89,80	120,16	3724,94
Nov	3,03	0,68	2,06	61,81	85,47	2563,96
Dec	2,33	0,68	1,58	49,12	65,72	2037,35
Year	5,08		3,45	1261,19	143,28	**52314,13**

On the basis of the calculated production values and the energy demand of the complex, the following chart was compiled.

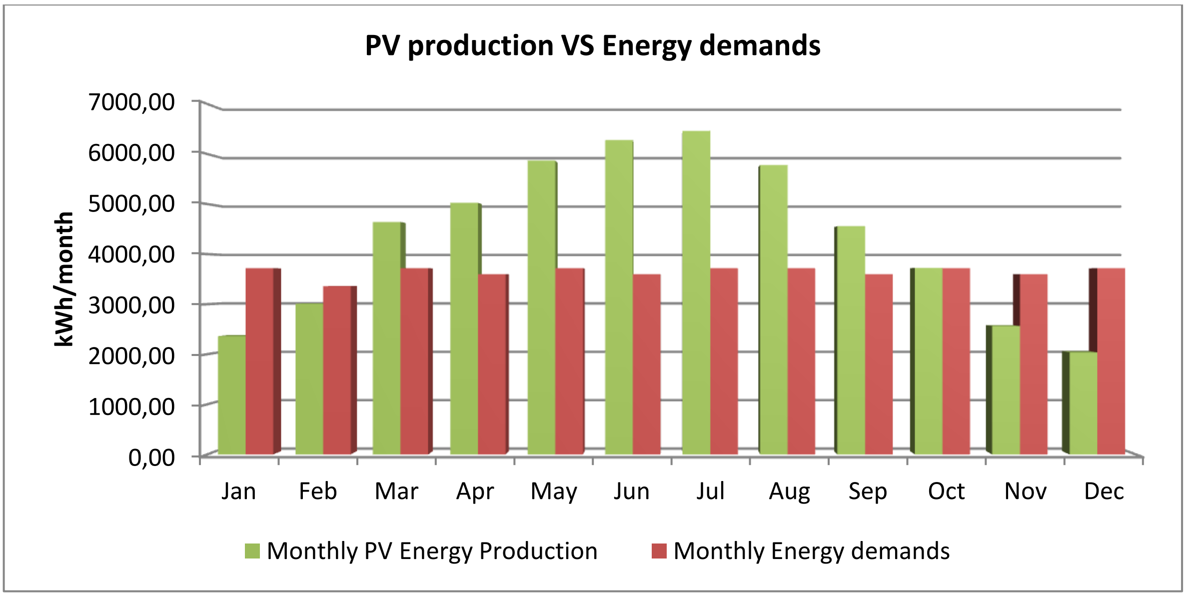


Figure 1. Monthly PV production VS Energy demands

2.3.4. Selection of MPPT charge controller

In the first place, for the selection of the charge regulator, the voltage of the battery bank, which in this case will be 48V, was defined. This higher voltage insures there is less power loss than 24V or 12V systems.

On the other hand, the final configuration of the installation was carried out in the following way:

Taking the voltage of the battery bank and the total power of photovoltaic modules available:

$$I_{MPPT} > \frac{P_T\ (W)}{V_{bat}\ (V)} \cdot 1{,}25 = \frac{41480}{48} \cdot 1{,}25 = 1080{,}2\ A$$

In this case a system of 8 Studer VarioString VS-120 charge regulators with the following characteristics was chosen:

- Maximum power: 7000W
- Maximum input current: 13A
- Maximum open circuit voltage: 900V
- Maximum output current 120A

Table 5. PV module configuration

PV modules	
Nominal power	305 Wp
Imp	8,27 A
Vmp	36,88 V
Isc	8,78 A
Voc	45,97 V
Strings	
Nº of modules per string	17
Voc	781,49 V
Isc	8,78 A

Using the selected regulators, photovoltaic modules will be configured in series of 17 modules, to form a total of 8 strings of 17 modules of 305 Wp, with a connection of 2 strings per regulator.

2.3.5. Choosing the batteries

The following battery bank was calculated for this installation.

Table 6. Battery bank configuration

Batteries	
Producer and model	Rolls Solar Series 5000 2YS31P
Voltage	2V
Capacity C100	3426 Ah
Depth of Discharge (DOD)	50%
Battery Bank	
Total no. of units	96 units
Units in series	24 units
Parallel series	4
Battery bank voltage	48 V
Total Capacity	13704 Ah

Taking the total capacity of the battery bank, the system voltage, and the daily demand, the following autonomy was obtained:

$$A = \frac{V_{bat} \cdot C_{bat} \cdot DOD_{max}}{1.1 \cdot E_d} = \frac{48 \cdot 13704 \cdot 0{,}5}{1{,}1 \cdot 120000} = 2{,}5\ days$$

2.3.6. Selecting the inverters

According to the above data, the maximum power of the installed equipment on the site of the complex is 108 kW. Given that the energy consuming equipment will not all be simultaneously running, the detailed study carried out a simultaneity coefficient for the equipment of 60%. This means that the estimation that the maximum amount of equipment that could be running at once would require 60% of the maximum installed power (~65 kW).

Considering the energy demand of the equipment that is running at the same time, the power necessary from the inverters is calculated to be the following.

$$P_{inv}[W] = \left(\sum P_{eq\ sim}\right) \cdot 1{,}25 = 65 \cdot 1{,}25 = 81{,}25\ kW$$

In this case, given the high power required to service the simultaneously connected equipment, it was decided to provide the most of this power with inverters, and at certain times of greater power demand, to make use of the generator to supply this extra power.

Thus, it was finally decided to install the following inverters:

Table 7. Inverter configuration

Inverter	
Producer	Outback Power
Model	Radian Series GS7048E
Continuous Output Power	7 kW
DC Input Voltage	48 V
AC Output Voltage	230 VAC

Inverter Group	
Total Units	10 units
Total Power	70 kW

2.3.7. Generator

As mentioned previously, to support the designed PV system and the supply of certain peaks of power to the resort, a generator of the following specifications was installed:

Table 8. GAS Generator

GAS Generator	
Continuous Power	97 kW
Emergency Power	121 kW
Fuel	LPG
Motor start	Automatic by inverters signal
Fuel Consumption	26,5 kg/h

MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 4. Fully developed case study of application of photovoltaics for rural development

Subchapter 4.2 - Economical aspects of the case study

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Summary: Following the structure of the previously developed chapters in this module, this subchapter develops the key economic parameters explained for the case of the photovoltaic system for isolated remote power supply to the rural hotel Mar de Fulles.

In this way, the LCOE, Payback, IRR and NPV indicators from the installation investment cost to the O & M financial parameters will be calculated.

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1. Introduction

This section provides a survey of the most important economic aspects of the project.

To do so, the total budget of the PV system must be known. This is shown below.

Table 1. PV Installation cost of capital

DESCRIPITON	UNITS	TOTAL COST	€/Wp
PV MODULES	136	29.036,00 €	0,7
BOS COST			
INVERTER	10	38.500,00 €	0,9
STRUCTURE	136	8.840,00 €	0,2
COMBINER BOX & ELECTRICAL COMPONENTS	1	12.890,00 €	0,3
SITE PREPARATION AND SYSTEM INSTALLATION	1	17.845,00 €	0,4
CHARGE CONTROLERS	8	14.328,00 €	0,3
BATTERIES	96	71.328,00 €	1,7
DESIGN, MANAGEMENT AND ADMINISTRATIVE COST	1	18.150,00 €	0,4
GAS GENERATOR	1	19.560,00 €	0,5
TOTAL COSTS		**230.477,00 €**	**5,6**

2. Leveliced Cost of Electricity (LCOE)

According to the previously mentioned LCOE calculation formula:

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

The LCOE of the presented PV system design is calculated as well as the LCOE connection to the grid.

For the PV system the following design values are considered:

Table 2. Data for PV investment and operation costs.

I_0 (Investment)	230.477,00 €	
M_t (O&M)	1.5%	3.457 €/year
F_t (Fuel expenditures)	4.428 kWh/year	1.062,72 €/year
E_t (Electricity generation)	52.314,13 kWh/year	
r (discount rate)	5%	
n (investment period)	20 years	

- O&M costs include the costs of O&M of the gas generator.
- For the cost of the fuel generating set, the energy required to supply the complex in the months in which the production of photovoltaic energy is lower than that demanded, was calculated using a LPG price of 0,508 €/litre.

Within these parameters, a $LCOE_{PV}$ is obtained for the photovoltaic installation:

$$\boldsymbol{LCOE_{PV} = 0,44\ €/kWh}$$

Similarly, to compare the price of the energy produced by the photovoltaic system with a possible connection to the mains grid, one must perform the same calculation for the case of networking, having the following design values:

Table 3. Data for Grid connection investment and operation costs. Electricity cost: 0,18 €/kWh.

I_0 (Investment)		120.000 €
M_t (O&M)	0,1%	120 €/year
F_t (Electricity expenditures)	43.800 kWh/year	7.884 €/year
E_t (Electricity consumption)		43.800,00 kWh/year
r (discount rate)		5%
n (investment period)		20 years

Resulting in a LCOE value of:

$$\boldsymbol{LCOE_{GRID} = 0,40\ €/kWh}$$

From the LCOE values calculated, the price of energy obtained with the isolated photovoltaic installation is slightly higher than the price obtained by connecting to the grid, but it is important to note that with these values:

- Remote PV systems in many European countries can get grants from European funds for their development, having obtained in the case of this study a grant of 60.000 €. Discounting this initially invested amount, we get a $LCOE_{PV}$ of 0,35 €/kWh.

- On the other hand, if the LCOE is analyzed for a period of investment of 25 years (regardless of any aid), we get a $LCOE_{PV}$ of 0,40 €/kWh, compared to $LCOE_{GRID}$ of 0,38 €/kWh.

- Considering the aid of 60.000 € and analyzing the LCOE for a period of investment of 25 years, a $\boldsymbol{LCOE_{PV}}$ **of 0,32 €/kWh** is obtained.

3. Payback, IRR and NPV

To carry out the installation profitability study, the following considerations are taken into account:

- Capital Cost: From the cost of the installation, the grant received by the Valencian Institute of Business Competitiveness (IVACE) of 60.000 € to carry it out is deducted.

- Grid energy cost: To perform the profitability study of the investment, the $LCOE_{GRID}$ network energy prices obtained in the previous section are taken into account. This is the price of the investment needed to connect the complex to the grid according to the technical specifications of the distribution company.

PROJECT PARAMETERS	
INSTALLATION DATA	
LOCATION	Aldondeguilla (Spain)
POWER (kWp)	41,48
CAPITAL COST (€)	230.477
GRANT AND SUBVENTIONS (€)	60.000
FINAL CAPITAL COST (€)	170.477
PV PRODUCTION	
PEAK SUN HOURS - PSH (kWh/kWp/year)	1.261
ESTIMATED ELECTRICITY PRODUCTION (kWh/year)	52.314
ANNUAL LOSSES (%)	0,60%
COSTING DATA	
GRID CONNECTION CAPITAL COST (€)	120.000
GRID ENERGY COST (€/kWh)	0,18
GRID CAPITAL COST (€/kWh)	0,22
ELECTRICITY ANNUAL INCREASE (%)	3,00%
ESTIMATED CONSUMER PRICE INDEX (CPI)	2,00%
DISCOUNT RATE (%)	5,00%
OPERATING AND MAINTENANCE (O&M)	
PV O&M COST (% of the capital cost)	1,50%
LPG GAS CONSUMPTION (€/year)	1.062,72

From these considerations and the input data presented, the following table indicates the installation profitability values that can be compared with the costs of connecting to the grid.

	PV SAVINGS				OPERATION COSTS			PROFITABILITY			
YEAR	ENERGY PRODUCTION [kWh/year]	GRID ENERGY COST [€/kWh]	GRID CAPITAL COST [€/kWh]	ESTIMATED SAVINGS [€/year]	O&M COST [€/year]	LPG GAS COST [€/year]	TOTAL COST [€/year]	CASH-FLOW [€]	CUMULATIVE CASH-FLOW [€]	PAYBACK [€]	NET PRESENT VALUE – NPV [€]
0								-170.477			
1	52.314	0,180	0,220	20.926	510,00	1.062,72	4.519,88	16.406	16.406	-154.071	-147.479
2	52.000	0,185	0,220	21.081	525,30	1.083,97	4.644,84	16.436	32.842	-137.635	-133.280
3	51.688	0,191	0,220	21.242	541,06	1.105,65	4.773,35	16.469	49.310	-121.167	-119.732
4	51.378	0,197	0,220	21.409	557,29	1.127,77	4.905,49	16.503	65.814	-104.663	-106.801
5	51.070	0,203	0,220	21.582	574,01	1.150,32	5.041,38	16.540	82.354	-88.123	-94.458
6	50.763	0,209	0,220	21.761	591,23	1.173,33	5.181,12	16.580	98.934	-71.543	-82.675
7	50.459	0,215	0,220	21.946	608,97	1.196,80	5.324,82	16.621	115.555	-54.922	-71.426
8	50.156	0,221	0,220	22.138	627,24	1.220,73	5.472,60	16.665	132.220	-38.257	-60.683
9	49.855	0,228	0,220	22.336	646,05	1.245,15	5.624,57	16.711	148.932	-21.545	-50.424
10	49.556	0,235	0,220	22.541	665,43	1.270,05	5.780,85	16.760	165.692	-4.785	-40.624
11	49.259	0,242	0,220	22.753	685,40	1.295,45	5.941,58	16.811	182.503	12.026	-31.263
12	48.963	0,249	0,220	22.972	705,96	1.321,36	6.106,87	16.865	199.368	28.891	-22.319
13	48.669	0,257	0,220	23.198	727,14	1.347,79	6.276,86	16.921	216.289	45.812	-13.773
14	48.377	0,264	0,220	23.431	748,95	1.374,74	6.451,69	16.979	233.268	62.791	-5.606
15	48.087	0,272	0,220	23.672	771,42	1.402,24	6.631,49	17.040	250.308	79.831	2.200
16	47.799	0,280	0,220	23.920	794,56	1.430,28	6.816,42	17.104	267.412	96.935	9.663
17	47.512	0,289	0,220	24.176	818,40	1.458,89	7.006,61	17.170	284.581	114.104	16.797
18	47.227	0,298	0,220	24.440	842,95	1.488,06	7.202,22	17.238	301.819	131.342	23.619
19	46.943	0,306	0,220	24.713	868,24	1.517,83	7.403,40	17.309	319.129	148.652	30.142
20	46.662	0,316	0,220	24.993	894,29	1.548,18	7.610,32	17.383	336.512	166.035	36.382
TOTAL	988.738	0,242	0,220	455.228	13.704	25.821	118.716	336.512	336.512	166.035	36.382

PAYBACK	11 YEARS
NET PRESENT VALUE (NPV)	36.381,93 €
INTERNAL RATE OF RETURN (IRR)	7,49 %
LCOE (25 years)	0,32 €/kWh

MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 4. Fully developed case study of application of photovoltaics for rural development

Subchapter 4.3 – Environmental, social and rural development impact of the case study

José Segarra Murria, Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

Summary: In this subchapter the main environmental, social and rural development impacts, as outlined in chapter 3, for the case of the photovoltaic system to supply energy to the rural hotel Mar de Fulles will be developed.

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1. Environmental impacts

Following the analysis scheme detailed in "Chapter 3: Social and the environmental aspects of photovoltaic systems for rural development", the environmental impact of the installation is analyzed from two main aspects: Natural resources and environmental pressures; and emissions produced.

1.1. Natural resources

Within the natural resources concerned, it is important to analyse the natural space, the energy, and the water demand during the installation and the routine operation and maintenance procedures of the plant.

1.1.1. Space, landscape and soil demand

The installation is an eco-resort situated in an area of great ecological value by the Natural Park of the Sierra de Espadán (Castellón - Spain) and is an area of special interest for birdlife which is part of the Red Natura 2000 network, in the heart of a highly bio-diverse centuries-old cork forest in an area of 160000 m^2.

Given the great ecological value of its location, the PV system considered the main aspects are integrated landscaping and the effective use of landspace.

Thus, the PV system is planned for coplanar roof installation, using this unused space of 272 m^2, without affecting the ecosystem and in turn creating an air ventilated covering for the benefit of the air conditioning needs of the building.

As for the other elements of the system, these were projected to be installed in the room adjacent to the construction site. They only need a space of 22m^2.

1.1.2. Water demand

The water demand for the PV installation arises because of the need to clean the PV modules. This need was calculated as being annual.

1.1.3. Energy demand

The energy demand of the facility is considered null as only a small amount of energy will be required for the machine assembly (drills, electric screwdrivers, ...) supplied by the work generator during the initial system installation.

The required energy for maintenance work is also very small (pressure washer to clean modules), and it comes from the PV system itself.

Finally, the complex will need during the support of a LPG-fuelled generator with an estimated energy requirement of 4428 kWh/year for the months with the least sunshine.

1.2. Environmental strains and emissions

1.2.1. Visual impact

The design of the photovoltaic system has been carried out using the premise of minimising the visual impact as much as possible. Thus, as discussed above, the installation of coplanar modules on the hotel roof it was chosen at the expense of production and for the benefit of minimising the visual impact.

In addition, given the structural characteristics of the eco-resort, the roof covering angles away from the main facade, that completely covers the installation at the front of the complex.

1.2.2. Noise impact

The photovoltaic system is soundless, so the only existing noise impact from the installation is created by the generator when it runs during its hours of operation.

The generator is installed in a purpose designed room that is soundproofed in order to minimize any noise impact.

1.2.3. Air pollution and greenhouse gas emissions

To calculate the greenhouse emissions only the emissions produced by the generator should be taken into account.

To this end, the emission factor for stationary LPG-fuelled combustion equipment indicated by the Ministry of Agriculture, Food and Environment of the Government of Spain are used.

$$\text{LPG Emission factor} = 1{,}656\ \text{kg}CO_2/\text{litre}$$

From this, the annual LPG generator emissions for powering the operation of the generator set are obtained.

Table 1. Annual generator emissions.

GENERATOR ANNUAL EMISSIONS	
Generator annual output (kWh/year)	4.428
LPG annual consumption (litres/year)	2.092
Emission factor (kgCO_2/litre)	1,656
CO_2 emission (kgCO_2/year)	3.464

On the other hand, it is worth making a comparison between the emissions produced by the photovoltaic system and those that would predictably be produced in the event that the complex was grid-connected.

Emission calculations from the complex in the case of national power grid connection should be based on the emission factors of the electrical system. These are the emission factors published in the draft document recognized by the Institute for Diversification Energy Saving and Efficiency (IDAE), part of the Ministry of Industry, Energy and Tourism of Spain. The proposed peninsular conventional electricity emission factor is:

$$\text{Grid electricity emission factor} = 0{,}372\ \text{kg}CO_2/\text{kWh}$$

From the annual emission factors and energy needs of the eco-tourist resort, the following emission values are obtained.

Table 2. Annual emissions in the case of being connected to the mains electricity grid

GRID CONNECTED ANNUAL EMISSION FACTORS	
Annual electricity consumption (kWh/year)	43.800
Emission factor ($kgCO_2$/kWh)	0,372
CO_2 emissions ($kgCO_2$/year)	16.294

The following chart shows the accumulated emissions that result over 20 operating years of the PV installation and the hypothetical connection to the national grid. It can be seen from the chart that emissions from the connection to the mains grid are five times the emissions generated by the generator supporting the PV system over a 20 years horizon.

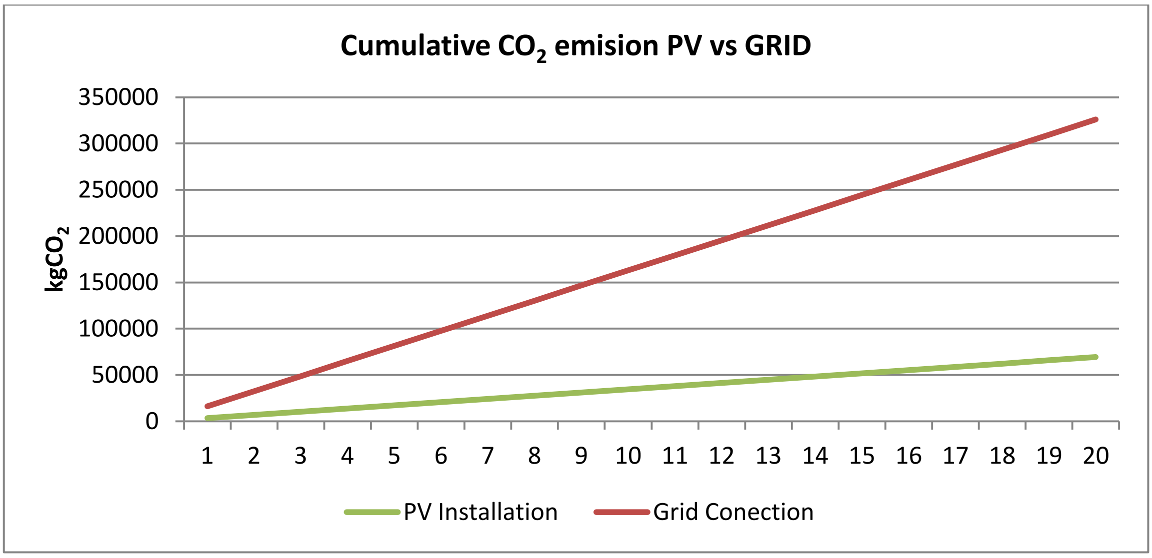

Figure 1. Cumulative CO_2 emissions. PV vs. GRID. Source: Own elaboration.

1.2.4. Water and soil pollution

The photovoltaic system produces no direct pollution of water or soil. In the case of batteries, some accidental spill could occur. The proper design of the installation facilities and an adequate system maintenance plan will avoid or minimize spills of these electrolytic solutions.

1.2.5. Waste production and management

During their 20 to 30 year long lifetime photovoltaic panels do not produce either waste or pollution. Installed battery lifetime is around 15 years.

In that time any component or equipment replacement will be treated adequately by the approved recovery and recycling managers.

2. Social and rural development impacts

The following classifications will be considered to analyze the social impact and rural development produced by the remote PV system in this study: 1. Energy Security, 2. Climate change mitigation and 3. Economic development.

2.1. Energy security

The photovoltaic installation presented contributes to improved energy security by having a positive impact on rural electrification and energy autonomy and sovereignty.

- Rural electrification: The installation carried out can generate electricity in a rural area where there is no main grid, and the cost of extension and connection of the network represents a major investment.
- Energy independency and sovereignty: The installation that contributes to decentralized energy production contributes to energy supplier independence and autonomy. Also, this type of installation affects the direct control of the generation and energy consumption that affects greater autonomy.

2.2. Climate change mitigation

The installation that is the subject of analysis in this chapter, as calculated above, contributes to a reduction in CO_2 emissions of nearly 80% compared to emissions from the power consumed from the Spanish grid. So, for 20 years, the saving of CO_2 emissions will be 256600 kg.

It is also important to note that usually in places where there is a photovoltaic system for power supply, a greater awareness of the efficient use of energy is possible. This can result in the use of highly efficient systems for the use of energy and the increased habit of rational use. Overall, this contributes to a lower global energy use.

Also, the eco-resort plans expects visits and planned activities that will contribute to a greater awareness and education about the benefits that improved energy efficiency and renewable energy offer to the environmental and economic development in rural areas.

2.3. Economic development

- Economical saves. Competitiveness

Firstly, the photovoltaic installation directly impacts on the cost savings for the eco-tourist complex derived from the energy needed for its operation. As calculated in previous chapters, the installation obtains a saving of 8 ct€/kWh compared to the grid connection and the use of energy from it. In this way a Payback on investment is reached in 11 years.

The resulting energy savings of the PV system have a direct impact on the greater economic viability and competitiveness of the eco-resort, functioning as an engine to promote rural and economic development in the area.

- New jobs and business opportunities

The International Renewable Energy Agency (IRENA) estimates that attaining universal access to modern energy services by 2030 could create 4,5 million jobs in the off-grid renewable-based electricity sector alone. Many of these jobs can be created within rural communities, as most skills can be developed locally.

In this regard, the installed photovoltaic system has contributed to the use of:

- Technical staff for the design and development of the proposed installation.
- Qualified personnel for the construction and installation of the system.
- Qualified personnel for the regular operation and maintenance of the facility.

The PV plant contribution to indirect jobs can be classified as follows:

- Manufacturers of photovoltaic components such as manufacturers and distributors of PV modules, inverters, batteries, structure, regulators, electrical equipment and so on.

- Resort employees. Since the installation enables the economic viability of the eco-tourist project, it indirectly affects the jobs created to run the resort and indirect jobs resulting from its function.

- Specialization and capacity building

Most of the resort's current employees are from the rural areas surrounding Alfondeguilla. They are currently being trained to properly use and operate the renewable energy system used as a power supply. This direct expertise of the resort staff will allow the wider dissemination of knowledge to the end users of the facilities and the residents of this rural area.

In addition, the complex will serve as an example and broadcast centre for eco-tourism, organic farming, and energy self-sufficiency by organizing information days. These events will achieve the same function for end users and local residents as those mentioned above.

MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.1 – Case Study 1

José Segarra Murria, Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

1. CASE STUDY 1

An operation and management company of sewage treatment plants requires the installation of a waste water treatment plant in Benafigos, a Spanish village of a population of 156 inhabitants. The facility is located away from the conventional electricity grid and that is why the costumer decides to study the possibility of installing an isolated photovoltaic system to supply the power required by the installation.

1.1. Input data

LOCATION

Village: Benafigos (Spain)

Coordinates: 40º 16’ 25’’ North
0º 12’ 20’’ West

The plot where the waste water treatment plant is located has the enough space to install photovoltaic modules on the ground with the required inclination and orientation.

ENERGY NEEDS

The energy needs of the treatment plant are simplified as follows:

SYSTEM	POWER [W]	DAILY OPERATION [h/day]	DAILY ENERGY DEMANDED [Wh/day]
Biodisc Reactor	**1000 W**	**20,0 h**	**20.000 Wh**
Sieve	**400 W**	**0,5 h**	**200 Wh**
Pump	**400 W**	**0,5 h**	**200 Wh**
TOTAL	**1800 W**		**20.400 Wh/day**

1.2. Considerations for the study

- To consider Atersa A250P photovoltaic modules for calculation (manufactured less than 200km away).
- Minimum coverage of 75% of the energy required in December. The remaining power will be supplied by a generator.
- The minimum battery life is 2 days (autonomy).

- For the economic analysis, a price of connection to the electricity grid 25000 € and the cost of energy consumption of 0,19 €/kWh should be considered.
- The cost of the installation shall be calculated by the student based on the ratios indicated in the course syllabus.
- Workers at the treatment plant must be trained to understand the functioning of the photovoltaic system.

MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.2 – Case Study 2

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1. Case Study 2

Azuebar, a city from Castellón, places an order to construct a covered structure for the sports and event courts in order to improve their use and enjoyment by the town's inhabitants. In order to carry out the project, a study of the use of the new cover to install a photovoltaic plant connected to the grid with power sales is proposed. The project generates an economic, environmental, and social benefit for the town.

1.1. Input data

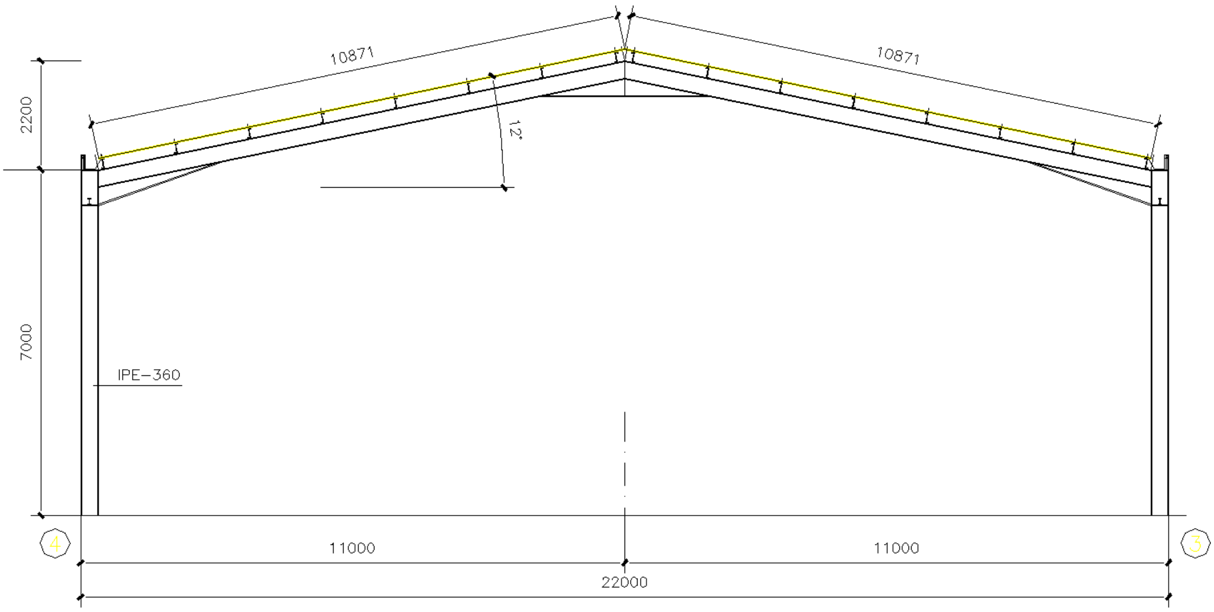
LOCATION

City: Azuebar (Spain)

Coordinates: 39º 49' 57'' North
0º 22' 04'' West

CONSTRUCTION FEATURES

The structure will consist of a gabled roof with a slope of 12º. The covered surface will be 968 m^2 (44x22m).



The orientation of the gable of the roof is from east to west, so the azimuth of these will be -90 ° and 90 ° respectively.

1.2. Consideration for the study

- To maximise the annual energy production using the available cover surface suitable for the photovoltaic module installation.
- The photovoltaic modules shall be installed on the covering in an integrated way, thus minimising the installation's visual impact.
- To consider photovoltaic modules of technology of microcrystalline silicon Thinfilm and amorphous U-EA120 from Kaneka Solar Energy for the calculation.
- To consider a selling price of the energy produced of 0,39€/kWh for the economic analysis.
- The installation cost will be calculated by the student based on the ratios indicated in the course syllabus.

MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.3 – Case Study 3

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Heliotec 2006 S.L., Spain

1. Case Study 3

A small agricultural cooperative in the province of Castellon has a grocery store which is generally open every day of the week and on Saturday mornings. On Saturday afternoon and on Sunday it is closed.

This food business is connected to the electricity grid but it consumes electricity at an average price of 0,195 €/kWh, considering both fixed and variable costs. After several conversations with a renewable energy rural company, they have realised that the installation of self-consumption photovoltaic panels interconnected to the electricity grid could be an interesting economic saving since it is expected to obtain an electricity price of less than 0,12 €/kWh from photovoltaics.

The average annual electric consumption is 60 kWh per day and the distribution of the average daily consumption is distributed according to the attached chart. Saturday is in orange and Sunday is in light-blue.

In order to carry out the self-consumption installation, the exploitation of all energy generated must be considered. This means that all the energy produced by the photovoltaic installation must be instantly consumed by the business. Therefore, it is always convenient that the measured installation does not produce more energy than the energy consumed by the installation. It should be remembered that energy peaks can be covered with energy from the grid as the self-consumption system of the photovoltaic plant is interconnected to the grid.

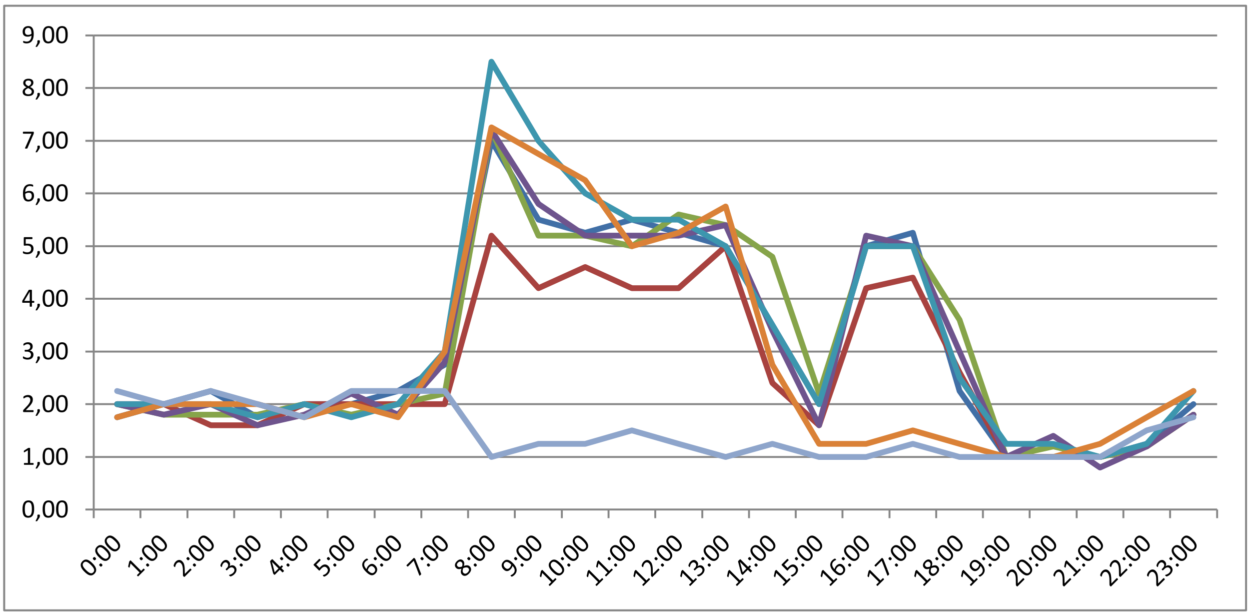

Figure 1. Distribution of the average daily consumption in kWh.

1.1. Input data

LOCATION

Town: La Vall d´Uixó (Spain)

Coordinates: 39º 49’ 26’’ North
0º 13’ 12’’ West

1.1.1. Considerations for the study

- Considering the Atersa A250P photovoltaic modules for the calculation (manufactured at a distance of less than 200km).
- It is enough to consider the average daily consumption, but it is recommended to do a daily analysis for an average day of the year, to better define the study.
- Two options are suggested for the economic analysis. The first one is to suppose an LCOE of 0,12 €/kWh as is quoted in the statement. The second one is to obtain the maximum cost of the installation for this price or to determine, based on the ratios indicated in the course, an installation cost and calculate the LCOE for that installation cost.
- Workers of the cooperative store shall be trained to know how the photovoltaic installation works.
- The cooperative will start a publicity campaign for all the members of the cooperative.

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MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.4 – Case Study 4

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Heliotec 2006 S.L., Spain

1. Case Study 4

The Mas de Noguera hostel is in a rural setting near to Caudiel (Castellón) which has been working in isolation with photovoltaic modules so far. The hostel is greatly concerned with environmental education and its relationship with nature, which are its hallmarks. Due to an expansion of the facilities, a higher power supply is required and, therefore and a renewable energy rural enterprise to install new photovoltaic panels has been contacted. The type of installation is isolated and the proposal is that the new solar panel location should be on the hostel's own land.

1.1. Input data

LOCATION

Address: PD. Mas de Noguera S/N, 12440

Town: Caudiel (Castellón)

Coordinates: 40º 00' 09'' North
0º 35' 57'' West

The hostel has enough space to install the photovoltaic modules on the plot of land with the required inclination and orientation.

ENERGY NEEDS

The extra energy needs of the place to be covered are simplified in the following table:

SERVICE	UNITS	POWER [W]	OPERATION [h/day]	CONSUMPTION [Wh/day]
Milking machine	1	736	2	1472
Pumping	1	736	1,5	1104
Windmill	1	736	0,5	368
PC	4	100	5	2000
Washing machine	2	400	3	2400
Fluorescent tube	20	18	6	2160
Inside lighting	50	11	6	3300
Outside lighting	30	20	6	3600
TOTAL				**16404 Wh/day**

1.2. Considerations for the study

- Consider Atersa A235P polycrystalline Silicon photovoltaic modules for calculations (their manufacture would be at a distance of less than 200km).
- The minimum autonomy of the batteries will be of 3 days.

- In order to carry out the economic analysis, the cost of the connection to the electrical grid of 40000€ and the cost of the power consumed of 0,19 €/kWh should be considered.
- The installation cost shall be calculated by the student based on the ratios indicated in the course syllabus.
- The reduced CO_2 impact avoided thanks to the installation should be taken into account.
- Decide and give reasons why the installation must have a battery storage system or not.
- The hostel workers know how the photovoltaic installation works and they show it to schools and visitors.

MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.5 – Case Study 5

José Segarra Murria, Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

1. Case Study 5

The Mas de Noguera hostel is a rural place located near to Caudiel (Castellón) which has been working in isolation with photovoltaic modules so far. The hostel is greatly concerned with environmental education and its relationship is one of its hallmarks. It is necessary to install a submersible centrifugal pump DC powered using solar energy for an irrigation application. This pump will raise an average daily flow of 80 m^3/day between two ponds with a slope of 18m. Once the flow is raised, the irrigation is done by means of gravity. The hostel contacts with a renewable energy rural enterprise to determine the photovoltaic system needed to carry out the pumping application.

1.1. Input data

LOCATION

Address: PD. Mas de Noguera S/N, 12440

Town: Caudiel (Castellón)

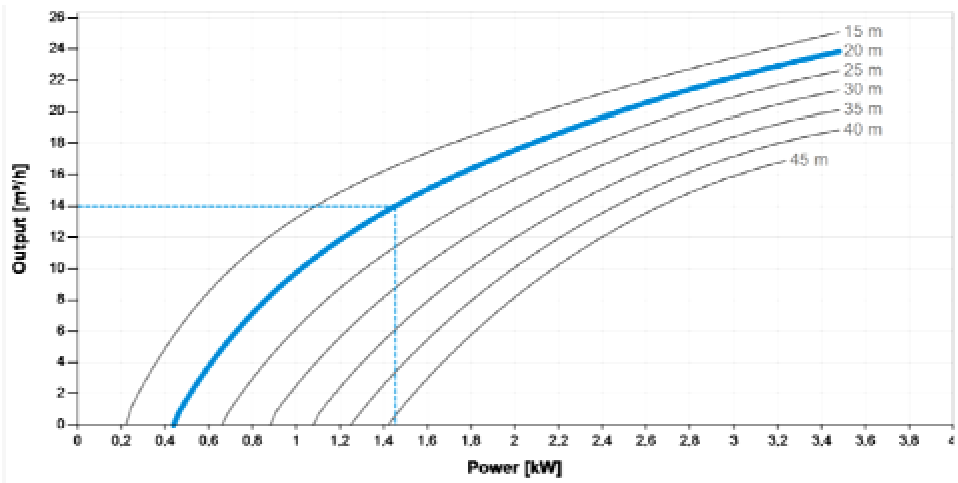
Coordinates: 40º 00’ 09.3’’ North
0º 35’ 57.3’’ West

The hostel has enough space to install the photovoltaic modules on the plot of land with the required inclination and orientation.

ENERGY NEEDS

In order to get an average flow of 80m^3/day, the average power consumption is 10,25 kWh/day.

The maximum flow during the day is considered to be 14m^3/h, equivalent to an approximate power of 1,45 kW.



1.2. Considerations for the study

- Consider Atersa A235P polycrystalline Silicon photovoltaic modules for calculations (their manufacture would be at a distance of less than 200km).
- Input data:

Average daily flow	80 m^3/day
Total equivalent altitude	18 m
Pipe length	145 m
Pond voume 1	250 m^3
Pond volume 2	1600 m^3

- In order to carry out the economic analysis, the 40000€ cost of the connection to the electrical grid and the cost of the power consumed of 0,19 €/kWh should be used.
- The installation cost shall be calculated by the student based on the ratios indicated in the course syllabus.
- The reduced CO_2 impact thanks to the installation should be taken into account.
- Say and give reasons if the installation must have a battery storage system.
- The hostel workers know how the photovoltaic installation works and they show it to schools and visitors.

MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.6 – Case Study 6

José Segarra Murria, Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

1. Case Study 6

Santa Engracia del Jubera is a rural town located in the province of La Rioja (Spain) and it has a population of 181 residents. A few years ago, they decided to change the installation of the streetlights by exchanging 50 mercury vapor lamps for 50 LED lamps. With this, they pretended to improve the energetic efficiency of the light system and to reduce the electricity bill by about 60%. The new lamps have a power of 50 W, being a total installed power of 2,5 kW.

Nowadays, an installation of photovoltaic modules is proposed in order to supply the streetlight power demand. For this purpose, an adjacent area near the town is considered.

1.1. Input data

<u>LOCATION</u>

Town: Santa Engracia del Jubera (La Rioja)

Coordinates: 42º 18’ 53’’ North
2º 18’ 22’’ West

There is enough space to install the PV modules on the plot of land with the required inclination or orientation.

<u>ENERGY NEEDS</u>

- Installed power: 50 LED lights of 50 W; total power of 2,5 kW.
- Consumed energy in 10 daily hours (3650 h/year): 9125 kWh/year.

1.2. Considerations for the study

- Consider Atersa A235P polycrystalline Silicon photovoltaic modules for calculations (their manufacture would be at a distance of less than 200km).
- As consumption is at night, an isolated installation with an accumulation battery system with a minimum autonomy of 3 days is required.

- In order to carry out the economic analysis, it should be considered that the cost of the connection to the electrical grid of 30000€ and the cost of the power consumed of 0,19 €/kWh should be considered.
- The installation cost shall be calculated by the student based on the ratios indicated in the course syllabus.
- The reduced CO_2 impact thanks to the installation should be taken into account.
- Explain why an isolated installation with an accumulation battery system is the best option.
- The local government will try to attract young people to the town by offering jobs in the service of installation maintenance.

MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.7 – Case Study 7

José Segarra Murria, Juan Jorro Ripoll

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1. Case Study 7

A family want to build a house in the suburbs of the town of Segorbe (Castellón). In order to obtain electricity, they decided to install PV modules with the idea of supplying all the household consumes. In addition, they doubt between an isolated installation or a self-consumption installation. The PV panels will be placed on the roof of the house, where there is an area of 75 m^2 and an inclination of 5º.

1.1. Input data

LOCATION

Town: Segorbe (Castellón)

Coordinates: 39º 51’ 07’’ North
0º 29’ 22’’ West

The roof has an inclination of 5º and an area of 75 m^2.

ENERGY NEEDS

- The average daily consumption is 5000 kWh/day. This consumption includes all the parts of the household: kitchen, lights, air conditioning, TV, etc.

1.2. Considerations for the study

- Consider Atersa A250P polycrystalline Silicon photovoltaic modules for calculations (their manufacture would be at a distance of less than 200km).
- A study between the cases of isolated connection and self-consumption is required.
- With self-consumption possibly covering up to 80% of the energy demand. The cost of the connection to the electrical grid is 5000 € and the energy costs are 0,16€, including fixed and variable costs.
- Consider using batteries in the case of isolated connection.
- The household must have a minimum autonomy of 3 days.
- The installation cost shall be calculated by the student based on the ratios indicated in the course syllabus.
- The reduced CO_2 impact thanks to the installation should be taken into account.

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MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.8 – Case Study 8

Zsuzsanna Kray, José Segarra Murria

Heliotec 2006 S.L., Spain

1. Case Study 8

The solar park was built between 2012-2013 and it was the biggest grid connected park in that time. The 499,8 kW installed capacity consists of 50 turning solar tables, each with 42 modules with 1,6 m^2 surface.

The solar park lies on 2,5 hectare of land. The tables can reach 7-8 metres in height and in case of special weather conditions they move appropriately. Although, the size is not huge on a European level, the technology used was one of the newest in that time. The investors employed a local workforce, and since 2013 October, the whole system works automatically.

1.1. Input data

<u>LOCATION</u>

Village: Sellye, Hungary

Coordinates: 45°51'50.3"N
17°50'19.6"E

<u>ADDITIONAL INFO</u>

The installed capacity of the solar park is 499,8 kW

The average electricity price for grid connection installations in Hungary is 32,14 HUF/kWh (10,7 € cent/kWh)

The total cost is 310 million HUF (roughly 1 000 000 EUR)

The workforce during the construction was made of 30 people.

The Mayor of Sellye is Attila Nagy.

1.2. Considerations for the study

- Consider the benefit of this construction for rural development.
- Consider the social impacts and the benefit of this construction for the local land owners (an agricultural co-operative) if the rental price is 500 €/hectare.
- The constructors guaranteed a 25 years long lifetime for this solar park.
- For the construction, a 60% of cost European grant was used.
- The electricity produced in smaller than 20 MW solar parks (in Hungary) can be sold for 32.14 HUF/kWh (without VAT).

MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.9 – Case Study 9

Zsuzsanna Kray, José Segarra Murria

Heliotec 2006 S.L., Spain

1. Case Study 9

In this case study, practice your critical thinking skills.

Fotó: MTI - Komka Péter

The solar park in Visonta was built in 2015 by the thermal power station (Mátrai Erőmű ZRt.). The power plant has been collecting its refuse close to the land the plant is on, in a 30 hectare waste bank. This re-vegetated, flat area was a perfect choice for the solar park that operates with 15MW power and cost 6,5 billion HUF (21 670 000 EUR). The solar park consists of 72480 panel of 255W power each and 20 inverters.

Fotó: MTI - Komka Péter

1.1. Input data

LOCATION

Village: Visonta

Coordinates: 47°47'14.5"N
20°03'39.2"E

ADDITIONAL INFO

Kioto Solar 255 Wp panels are in use in this solar park.

The panels consist of poly-crystal cells.

The nominal power of the park is 18,5 MW.

SMA (0,8MW each) inverters were used.

The average electricity price for connected grid installations in Hungary is 32,14 HUF/kWh (0,107 EUR/kWh).

1.2. Considerations for the study

You are free to practice your censoriousness while elaborating this case study.

- Consider making comments on the price of the installation.
- Bear in mind the learnt technical, social and environmental aspects in this chapter.
- Mátrai Erőmű ZRt. is one of the biggest regional employer: It employs 2500 people from the surrounding cities, the prepared solar park provides continuous work for 6 people.

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MODULE 2: PHOTOVOLTAIC ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.10 – Case Study 10

Zsuzsanna Kray, José Segarra Murria

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1. Case Study 10

Nagypáli is an ecovillage in Zala County, Hungary.

The village is engaged with further RES investments leading to future energy independence. The solar park was built for the benefit of local community: it provides electricity to the local government, local companies, NGOs and residents.

In relation with the solar park project, an **Innovative Renewable Energies Ecocenter** was built; with 140 m^2 roof surface.

1.1. Input data

<u>LOCATION</u>

Village: Nagypáli

Coordinates: 46°54'29.9"N
16°50'44.5"E

<u>ADDITIONAL INFO</u>

The consumption of the Innovative Renewable Energies Ecocenter is 15 MWh/year, 70% of it is covered by the solar panels and the rest (30%) from the grid.

The energy need of municipal buildings is covered up to 70% by renewable energies. There is a Tourist Centre operating, where training and community meetings take place. Nagypáli participates in several European, national and regional projects.

The Energy Park not only consists of solar panels, but a small scale meteorological station, solar power fed LED lighting system (2 kW) and a small scale (1,5 kW) wind turbine

A cogeneration and a biogas plant are planned, that makes the village interesting from a rural development and RES point of view. Nagypáli's success can be an exemplary village in the In2rural project as well: since 1996 the population of the village has almost doubled, the average age decreased by 16 years and there are three times more SMEs in the village than before.

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1.2. Considerations for the study

- The average electricity price in Hungary for consumption is 40 HUF/kWh (0,133 €/kWh).
- The investment was carried out in the framework of local development strategies (LEADER) with 50% grant support.
- Consider the sociological aspects and rural development impact of the installation.
- The Ecocenter is available for local trainings and courses.
- Choose the solar panel branch you consider more sustainable for this installation.
- Consider the number of solar panels used on the roof.

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