Inter-American Development Bank

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Practical Guide for the Implementation of Photovoltaic Systems in Social Infrastructure Projects

Mauro Passos
Arturo Alarcon
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Infrastructure and Energy Sector

Social Sector

TECHNICAL NOTE Nº IDB-TN-1459

August 2018

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Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library

Passos, Mauro.
+ Sun + Light: Practical guide for the implementation of photovoltaic systems in social infrastructure projects / Mauro Passos, Arturo Alarcón, Wilhelm Dalaison.
p. cm. — (IDB Technical Note ; 1459)
Includes bibliographic references.
1. Photovoltaic power generation-Latin America. 2. Solar energy-Latin America. 3. Buildings-Environmental aspects-Latin America. 4. Climate change mitigation-Latin America. 5. Infrastructure (Economics)-Social aspects-Latin America. I. Alarcón, Arturo. II. Dalaison, Wilhelm. III. Inter-American Development Bank. Infrastructure and Energy Sector. IV. Inter-American Development Bank. Social Sector. V. Title. VI. Series.
IDB-TN-1459

Codes JEL:I00, O13, O18, Q42
Key words: social infrastructure, photovoltaic systems, PV, renewable energies, health and education.

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Social Infrastructure

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Practical guide for the implementation of photovoltaic systems in social infrastructure projects

Mauro Passos – Arturo Alarcon – Wilhelm Dalaison

IDB

Index

Background

In 2017, the management of the Infrastructure and Energy Sector (INE/INE) and the management of the Social Sector (SCL/SCL) of the Bank, agreed to create the Social Infrastructure Unit to provide specialized technical support for the programs and projects financed by SCL/SCL containing infrastructure components.

The Social Infrastructure Unit has the following objectives: (i) Strengthen the social sector teams, and through them, the executing units, offering technical expertise for the preparation, execution, and supervision of the infrastructure components included in the portfolio of operations; and (ii) Generate knowledge aimed at promoting good practices in planning, procurement, design, construction and supervision of social infrastructure.

One of the difficulties encountered during the execution of social infrastructure projects was that, in many cases, the only way to solve the lack of electricity was by means of photovoltaic systems, also known as PV systems. In order to do so, an integral and straightforward instrument allowing rapid analysis and evaluation of most appropriate solutions is needed at the time of the decision-making processes.

+ SUN + LIGHT provides to anyone, through an accessible language and format, the answers to many of the concerns regarding PV systems: what they are, how they work, why to use them, how to calculate their cost, where to use them, what is required to use them, how to size them, how to install, operate and maintain them.

+ SUN + LIGHT is organized in a series of modules aimed at the different actors interested to know and use PV systems in social infrastructures, including infrastructure managers; administrators; technicians in architecture, engineering and electricity; teachers; parents; students or users in general.

+ SUN + LIGHT, an initiative of Cristian Santelices, is the product of collaborative work between the Energy Division (INE/ENE) and the Social Infrastructure Unit at INE/INE.

This guide was developed based on the contents prepared by the engineer Mauro Passos with the support of Kathlen Schneider and André Cechinel, technical supervision of Arturo Alarcón (INE/ENE) and coordination and general edition of Wilhelm Dalaisón (INE/INE).

This guide counted with the invaluable collaboration of Virginia Snyder (INE/ENE) and the members of the Social Infrastructure Unit: Marcos Camacho, Livia Minoja, Iciar Hidalgo Roca and Juliana de Moraes (INE/INE), who collaborated in the revision and complementation of the document.

Originally written in Spanish, this guide was translated to English by Fabiana Santos and edited by Juliana de Moraes.

Introduction

The energy generated through sources considered inexhaustible or self-generating is known as renewable energy. Within the group of renewable energy, there are: solar, wind, hydroelectric, geothermal, tidal and biomass.

Solar energy is also considered clean energy because it does not generate waste (or generates very little in comparison with other systems) when it is produced or used.

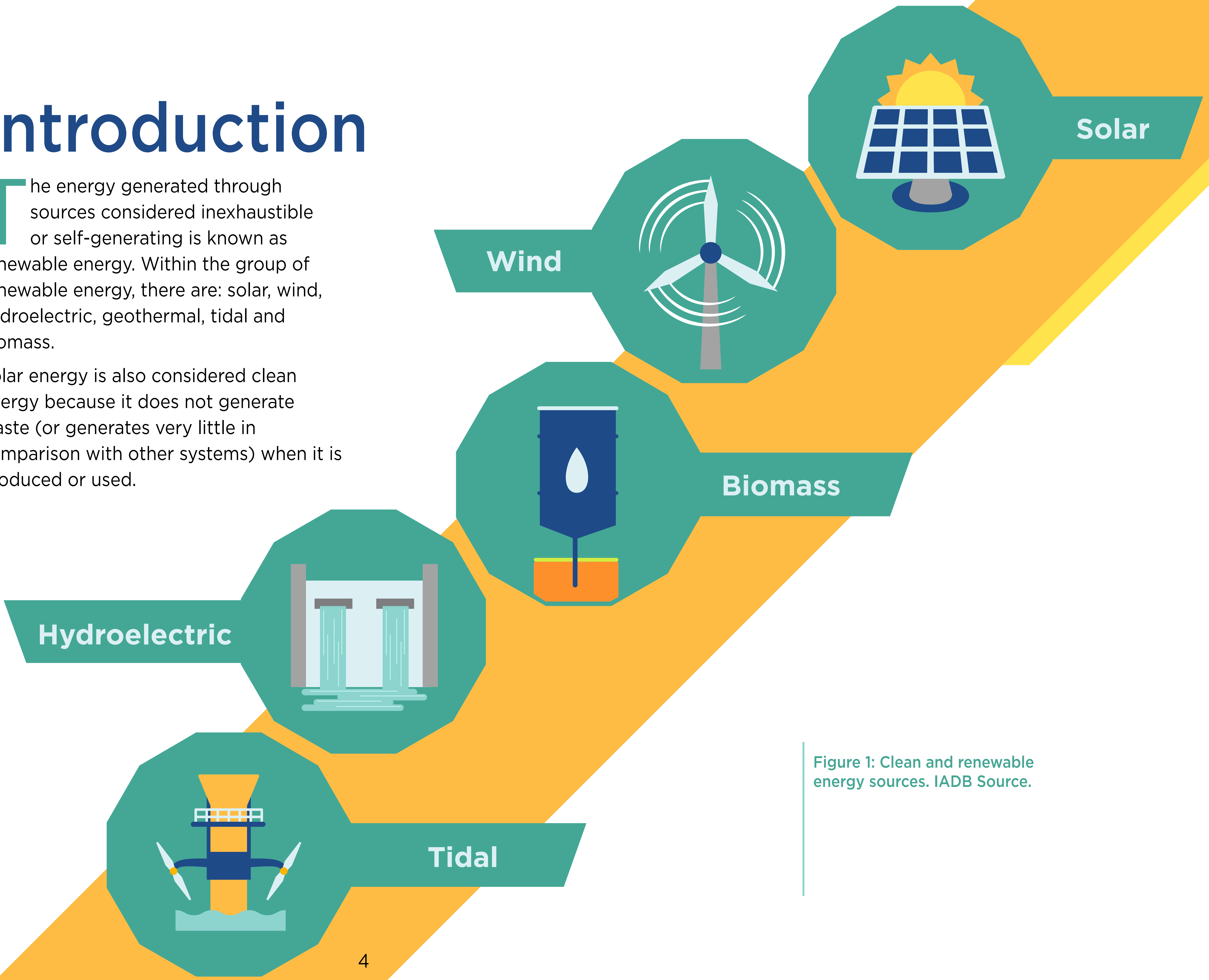


Figure 1: Clean and renewable energy sources. IADB Source.

Solar energy is used mainly for two purposes: (i) to provide space heating and hot water, mostly commonly known as solar thermal energy; and (ii) to generate electricity directly from sunlight, known as solar PV energy.

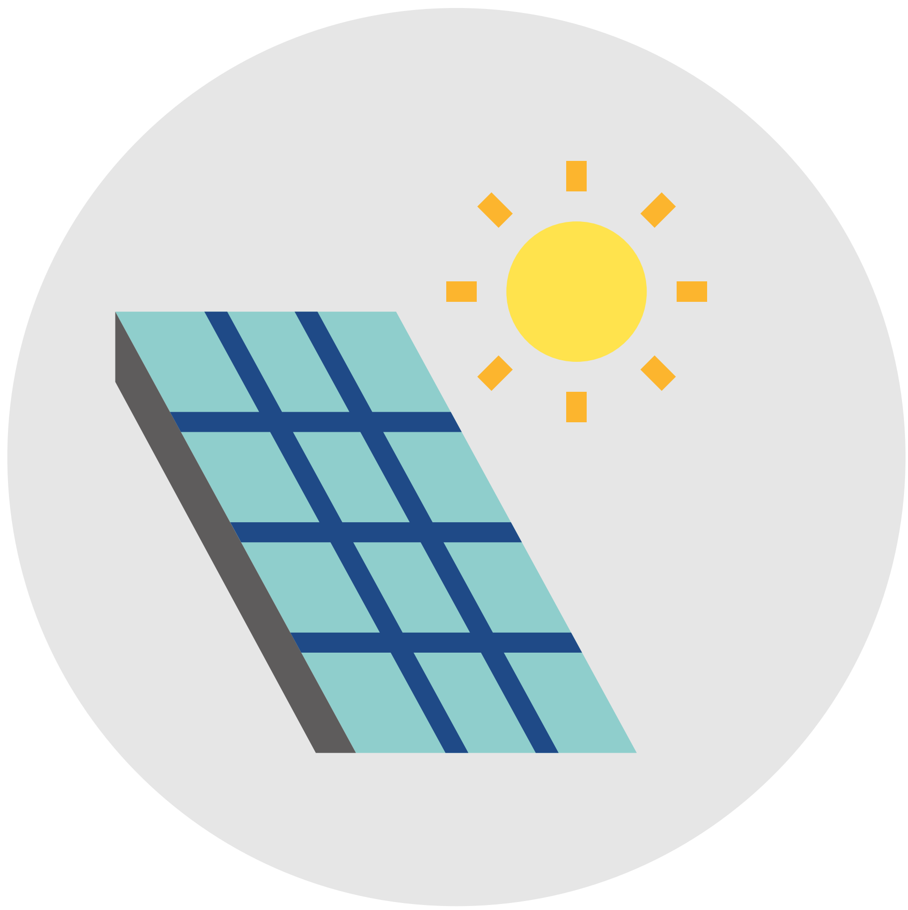
In addition to the supply of electricity, essential for the operation of an infrastructure, the use of photovoltaic (PV) solar energy can respond to economic and environmental goals through the reduction of energy costs and the replacement of polluting energy with clean energy.

While used in schools, the use of PV systems can be a teaching instrument for basic principles and concepts on the use of renewable energies to new generations and ways it can change lives in Latin America and the Caribbean (LAC). For that reason, the use of PV systems in schools represents much more than just the supply of energy.

The different thematic modules of this guide cover introductory information anyone interested in learning and using **PV systems** can utilize. It also includes application examples and standards norms.

It is necessary to note that the contents of the modules are informative and were made to introduce the different users to the topic and facilitate decision making. The specific activities for design, size, installation, maintenance, and operation must be carried out by a professional trained in these types of systems to guarantee safe procedures and optimal results.

Finally, it is important to mention that, although the contents and examples are aimed at installations of PV systems in schools, the methodology may be applied to any other type of social infrastructure at a low level of complexity, including single-family homes.



Photovoltaic Systems

M1: What are they?

M2: How do they work?

M3: Why use them?

M4: How to calculate their cost?

M5: What is required to use them?

M6: Where is it possible to use them?

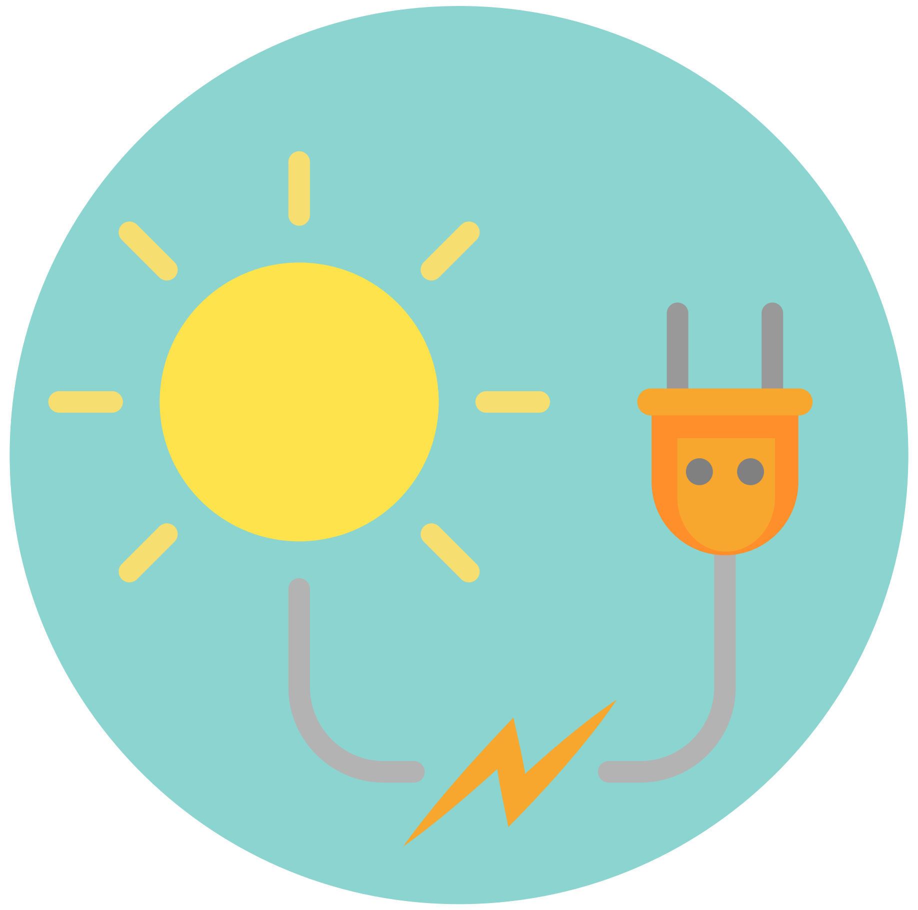
M7: How to size them?

M8: How to install them?

M9: How to operate and maintain them?

M1

What are Photovoltaic Systems?



The sun has a constant presence in our lives and the use of radiant energy is accessible and relatively simple. Solar energy is clean, renewable, practically infinite and can be applied in several ways.

The conversion of solar energy into electricity is possible due to the photovoltaic (PV) effect, which occurs when semiconductor materials receive sunlight, causing the photons of light to energize the semiconductor electrons, which in turn generates electricity in the form of direct current.

The **photoelectric cell** was created using these semiconductor materials and is the basic unit of photovoltaic solar generation. It is necessary to connect the cells inside a cabinet, called a **photovoltaic panel**[1], which generates more reliable energy and takes full advantage of the photoelectric cells. The panels can also be connected to create an **array of panels**[2], which increases output considerably by adding the power of all panels. Arrays can be formed with panel connections in series, parallel, or both.

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1 It can also be known as a photovoltaic module.

2 Array of panels is the set of individual photovoltaic panels interconnected to form the photovoltaic system that generates energy.

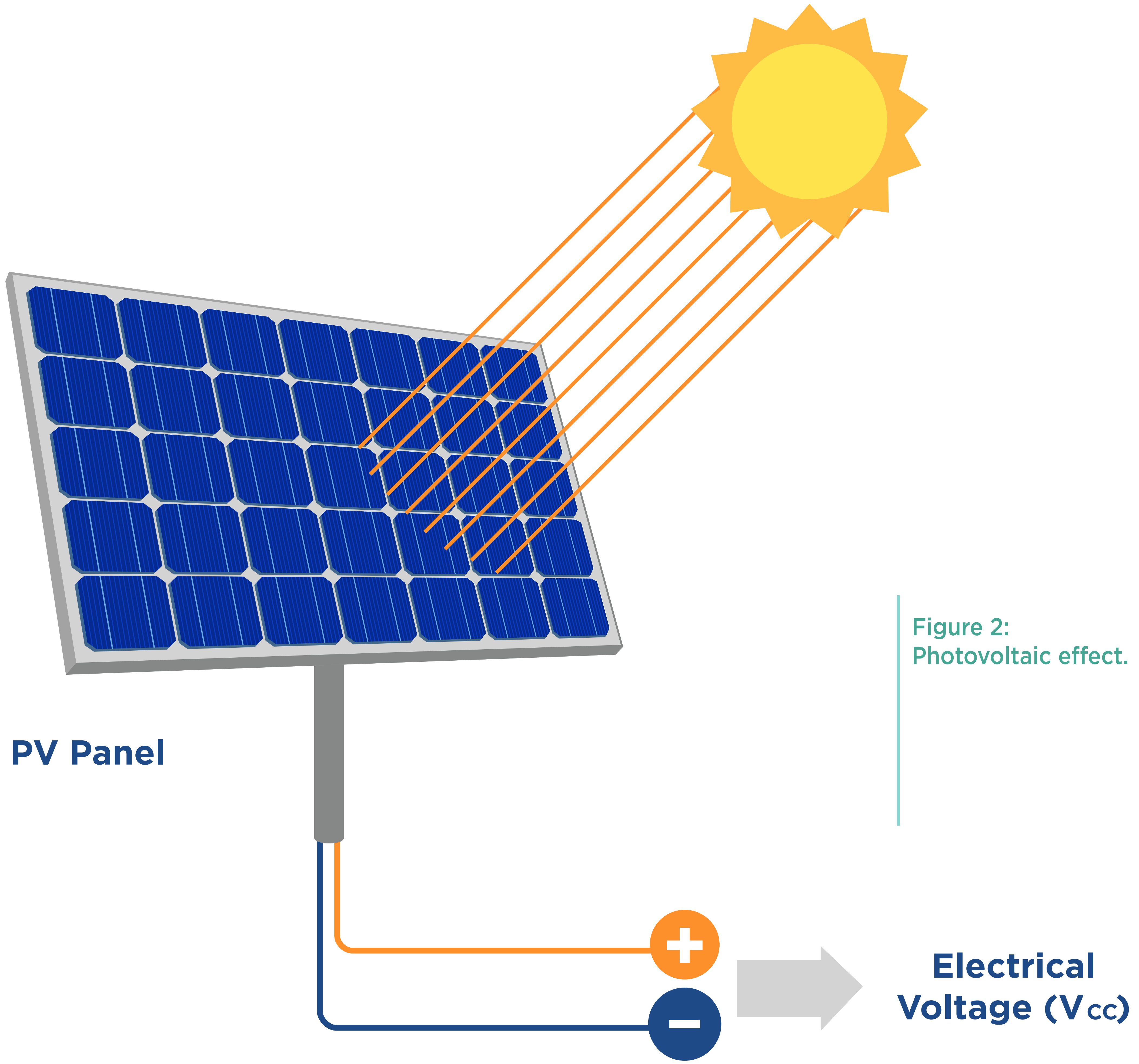


Figure 2: Photovoltaic effect.

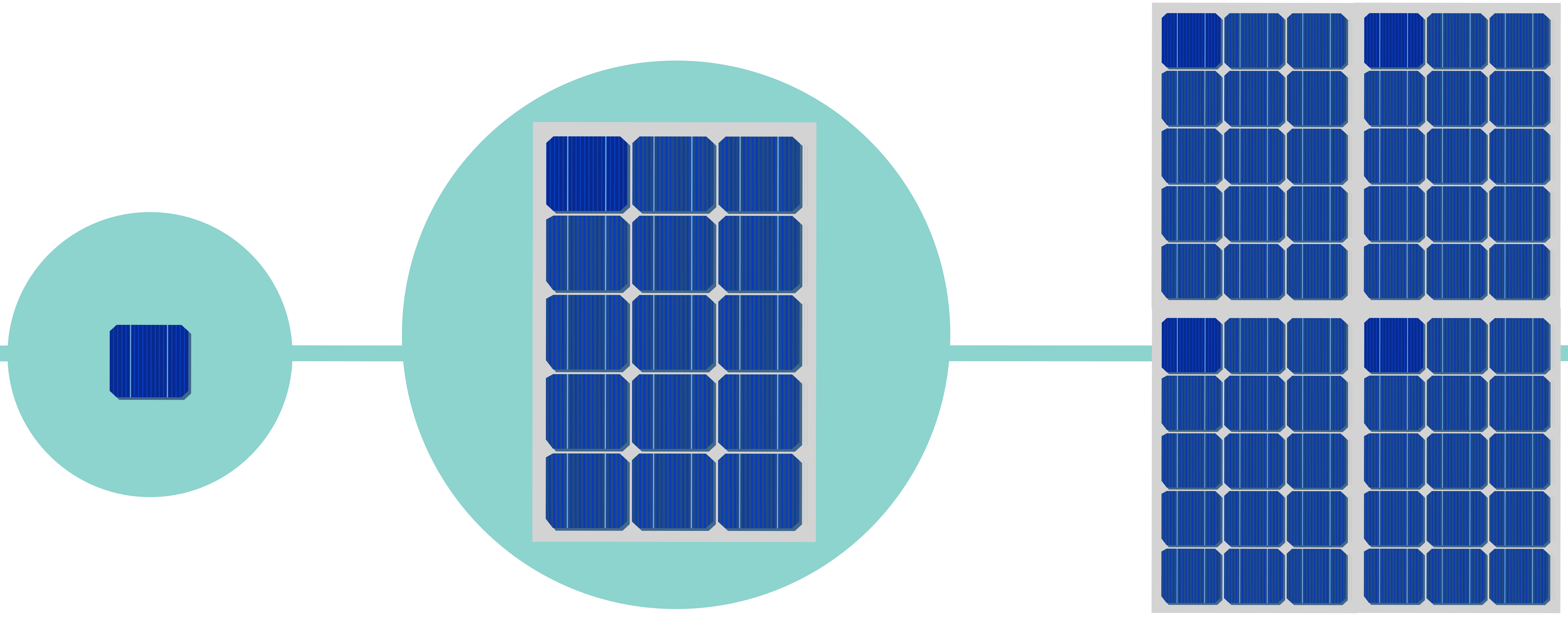


Figure 3: Definition of cell, panel and array of panels.

Although cells, panels and arrays are responsible for converting light into electricity, other electronic devices are necessary to adapt the electricity for safe energy use.

The set of PV panels and other electronic devices make up what is known as a PV system, which can have different configurations. Basically, there are two types: (i) PV systems connected to the electrical network (*on-grid*); and (b) PV systems not connected to an electrical network (*off-grid*).

See Table 1.

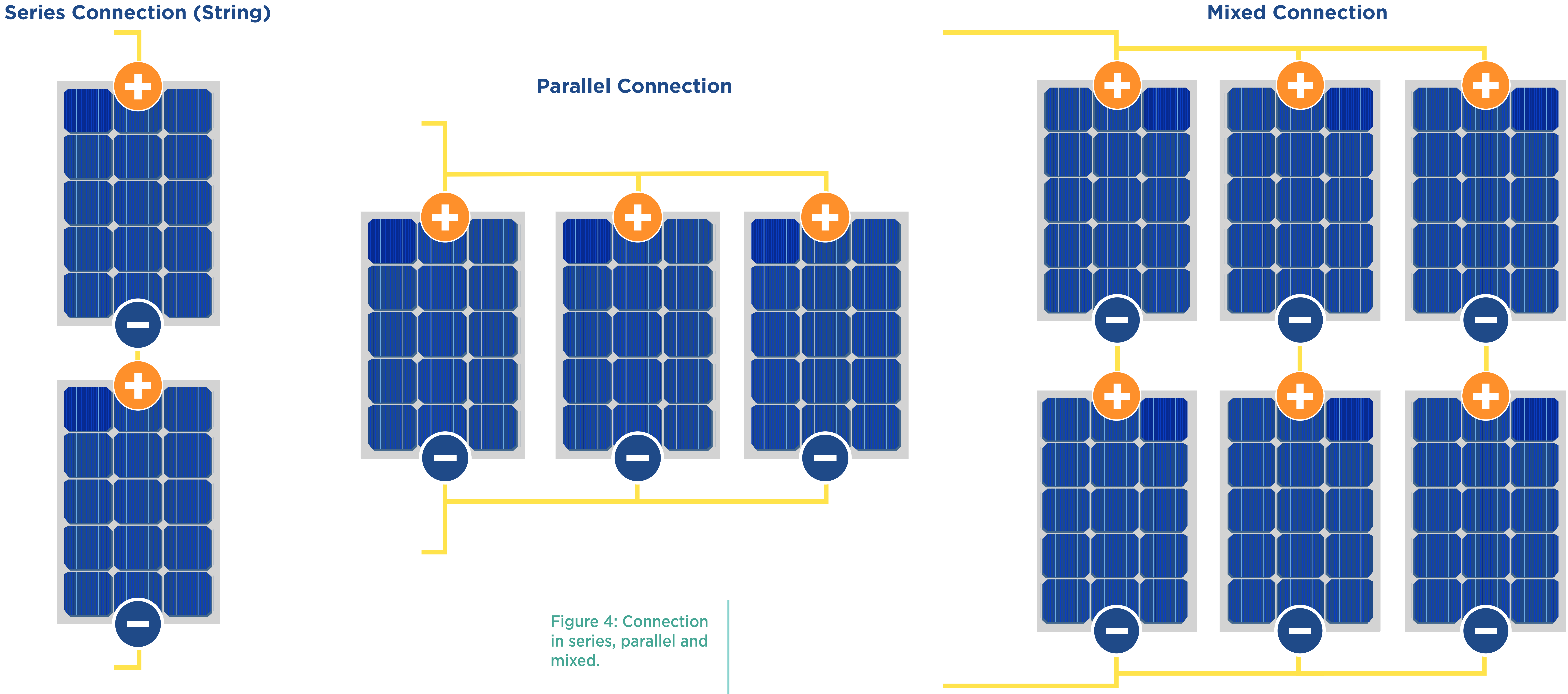


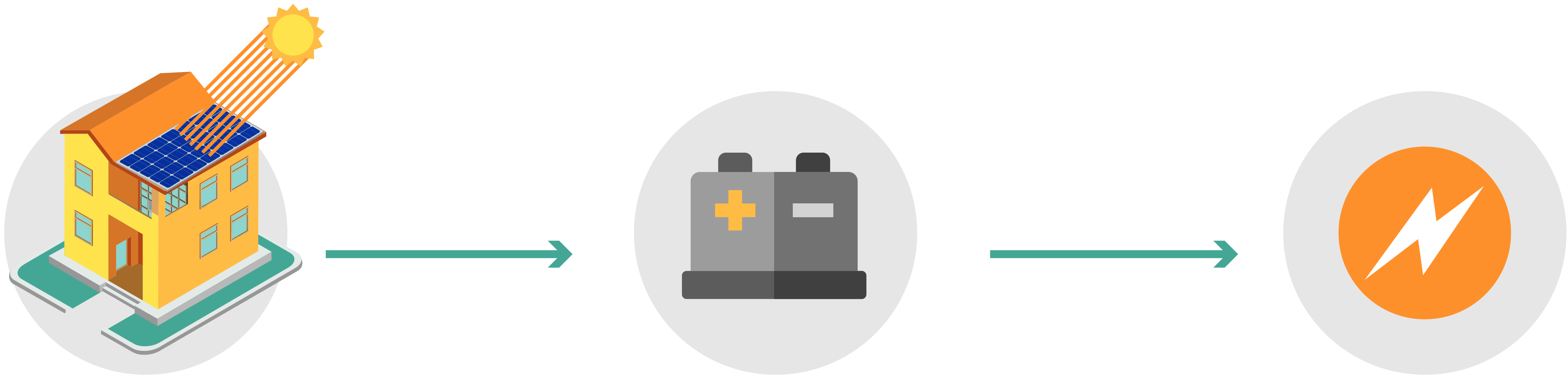
Figure 4: Connection in series, parallel and mixed.

Table 1 | Types of photovoltaic systems

Photovoltaic System connected to the electrical network

Usually, this type of system is a complementary energy source and is used to reduce electricity expenditure. In these cases, energy storage systems are not necessary.

Photovoltaic System not connected to an electrical network



Usually this type of system is used in remote areas where the public electrical network is non-existent or only provides power for a few hours.

PV systems not connected to a public electrical network are also useful, in some cases, as a compliment or substitution to the energy generated mainly by generators that use fossil fuels (for example, diesel) for their operation.

To ensure that they always have a supply of electricity they require storage systems (batteries).

M2

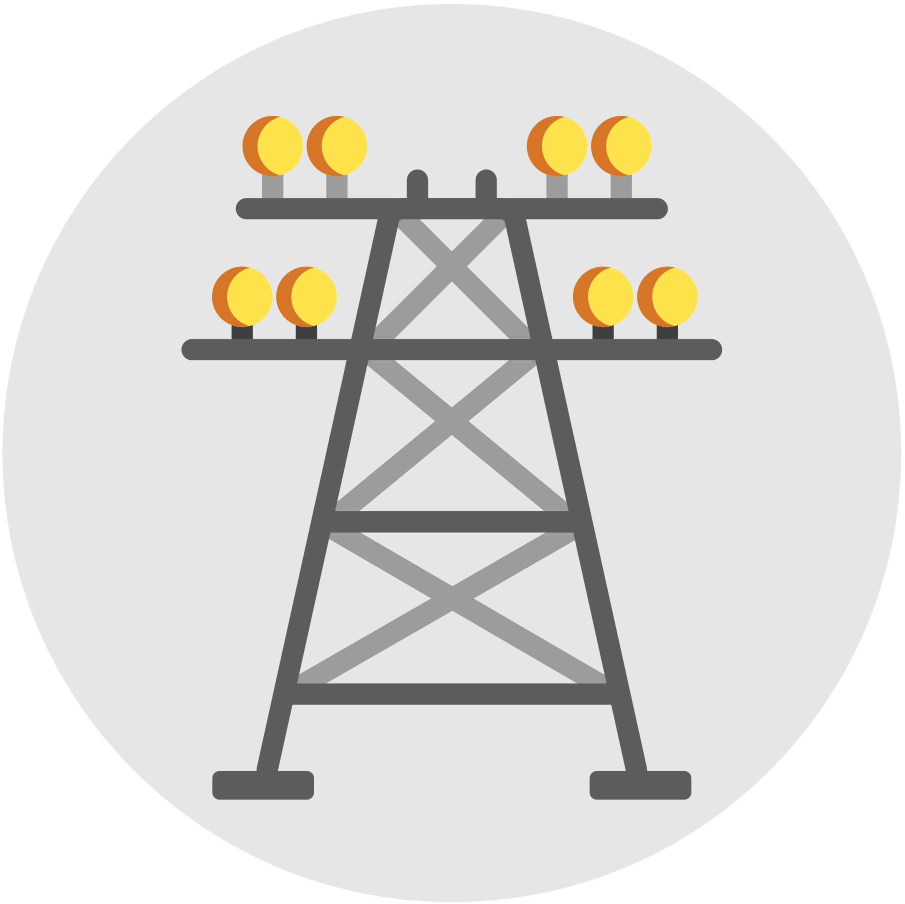
How do Photovoltaic Systems work?

Photovoltaic (PV) systems can have different types of configurations depending on the connection to an electrical network or not.

As indicated in **Table 1**, the systems can be mainly classified as:

- **A.** PV systems connected to the electrical network
- **B.** PV systems not connected to the electrical network.

Photovoltaic Systems connected to the electrical network



When connected to the electrical network, the PV system can operate as a complementary energy source. Due to the presence of the network, it is not necessary to store energy, and all the energy produced by the system is consumed directly. This reduces the use of conventional network energy and, consequently, the cost of such consumption. The excess energy produced can be exported to the electrical network.[3]

This system has two main components: the PV panels and the inverter. However, the system also requires safety devices such as fuses and circuit breakers (as well as any electrical system) to provide safety to the user and the equipment.

3 In some countries, excess energy produced above the owner's needs can be sold to the electrical network.

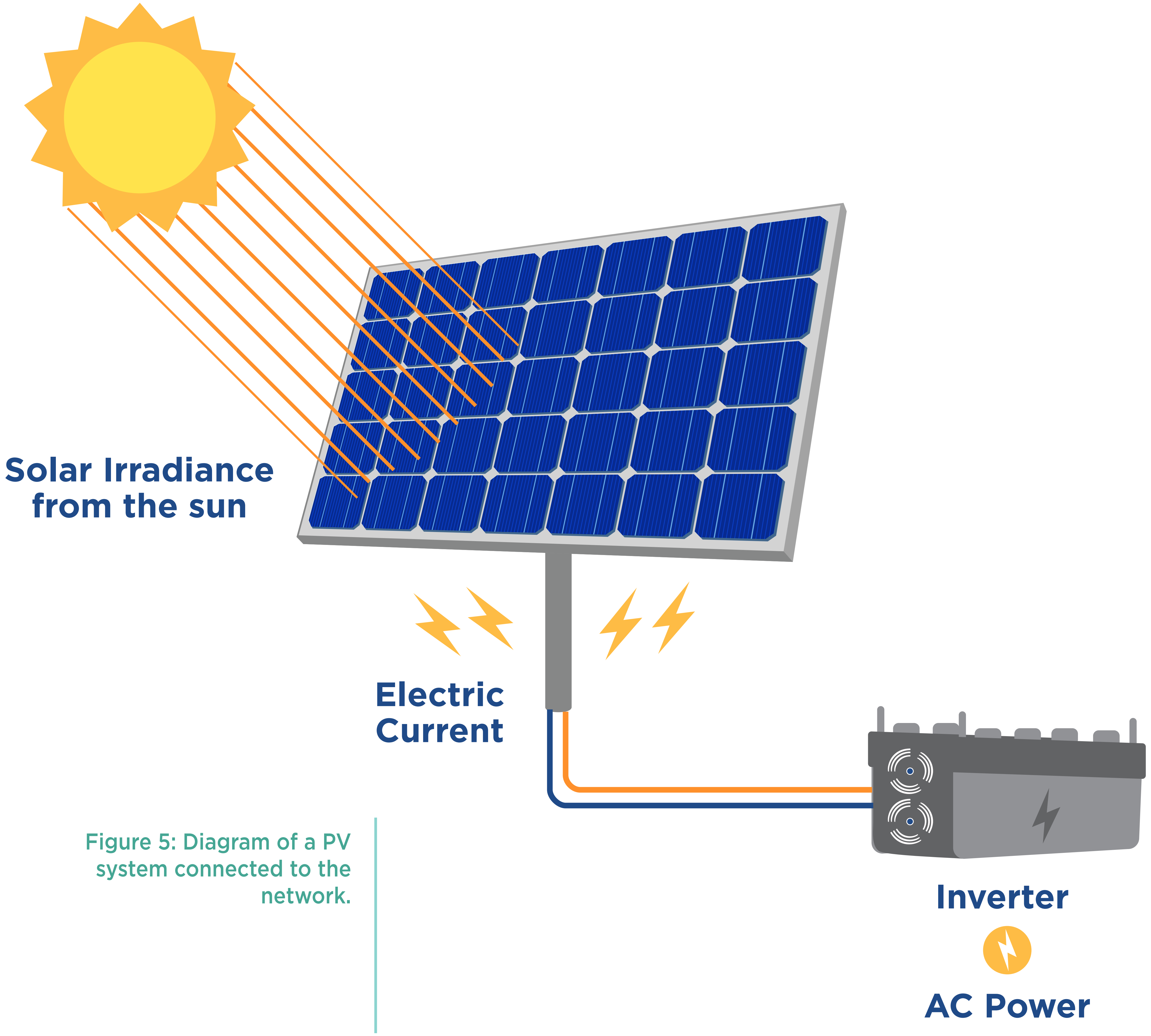


Figure 5: Diagram of a PV system connected to the network.

Main components

1 - Photovoltaic Panels:

The PV panels are flat devices in which the PV cells are mechanically assembled and electrically connected, which causes greater conversion of sunlight into electricity than with individual cells. PV panels, like individual PV cells, can be attached to each order to increase power output.

There are several types of PV panels, which can be differentiated by the type and number of cells or the kind of arrangement that can be made. Currently, silicon cell PV panels are the most widely commercialized panels due to their high efficiency. Manufacturers guarantee a life cycle of at least 25 years.

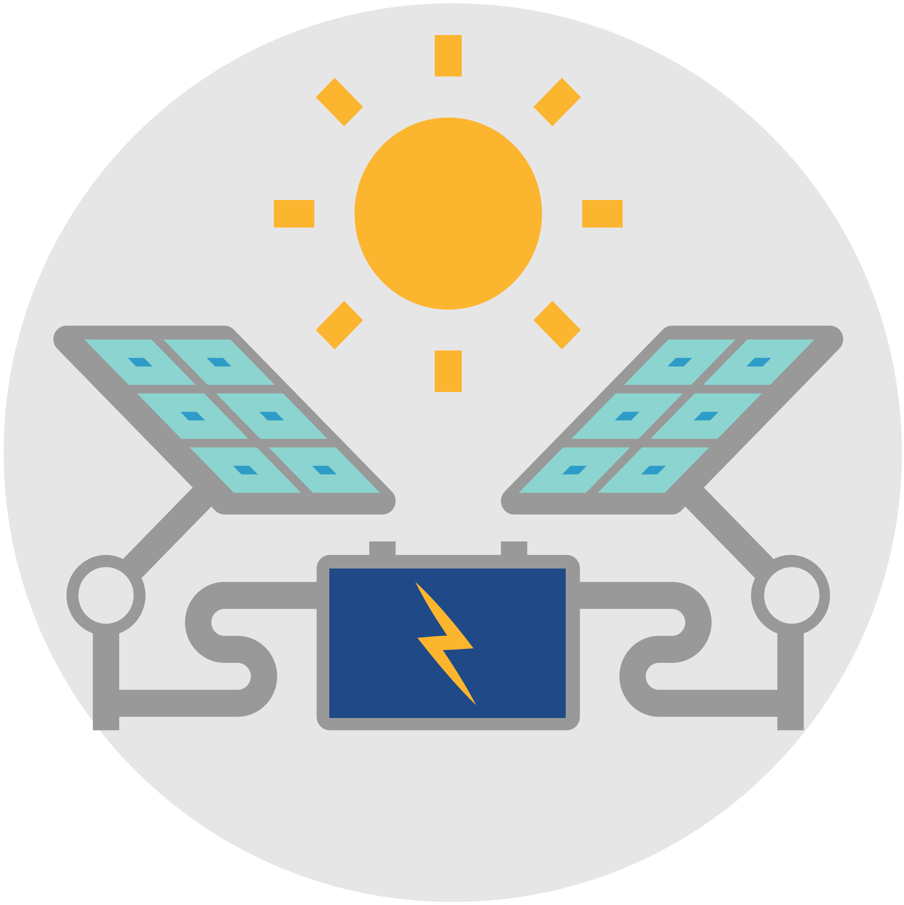
The nominal power of a PV panel is given in Wp (Watt peak) and means the maximum power output of the panel in peak conditions (estimated at a certain temperature and solar radiation). The power of the entire PV system will also be expressed in Wp, assuming that each panel is operating in peak conditions.

2 - Inverter:

The inverter is responsible for ensuring that the generated PV energy can be used in the same way as the network power, transforming direct current (DC) produced by the PV panels into alternating current (AC).

The inverters have different electrical parameters and modes of operation. Therefore, they must be correctly measured by a trained technician before being used. Its life cycle is of approximately ten years.

In addition to the panels and the inverter, the system will require the installation of protection systems (fuses, relays, etc.), which must be well sized by a trained technician.



Photovoltaic Systems not connected to an electrical network

PV systems not connected to an electrical network are called “isolated”. This makes the PV system the primary source of local energy, or a complementary source if there are generators or other sources of energy.

This system has four main components: the PV panels, the batteries, the charge controller and the inverter. They also require the installation of protection devices to provide safety to the user and to the equipment, such as fuses and circuit breakers.

When not connected to the network, PV systems use batteries to store the generated energy, which ensures electrical autonomy even in periods without sunlight.

However, in some cases, PV systems not connected to a network may not have batteries (i.e. if the building is only open during the day and there is no need to store energy) or a inverter (if the electrical devices used are low, powered by DC).

Main components

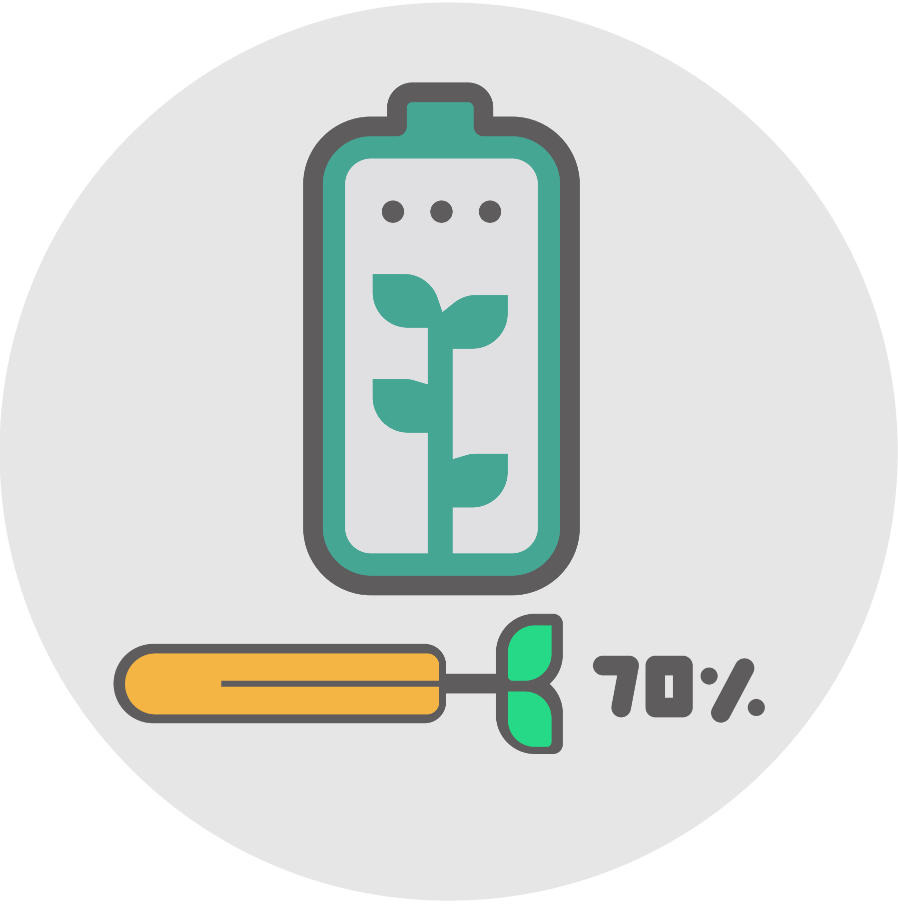
1 - Photovoltaic Panels:

The PV panels of this system have the same characteristics and fulfill the same functions as those described in the PV system connected to the network.

2 - Charge Controller:

The charge controller, as its name says, regulates the charge of the battery, ensuring that there is a charge and that no overload occurs, which avoids damaging the battery and reducing its life cycle. Since batteries are potentially dangerous, the charge controller is an essential security item, which protects users and the system itself.

The charge controllers have several different configurations, based on the electrical properties of the system and must be measured correctly. The charge controller is only necessary if the system has batteries; otherwise, the array of panels can be connected directly to the converter.



3 - Batteries:

The batteries are used to store the electricity generated. The batteries used in this type of application are deep cycle, capable of withstanding deep discharges with a considerable life cycle. Currently, in comparing with other types of batteries, the use of lithium-ion batteries is recommended because they charge fast, discharge slowly, have more storage capacity and a considerably longer life cycle.

4 - Inverter:

The inverters of systems not connected to a network have the same function as inverters of systems connected to the network, but they have other electrical characteristics. They fulfill the same function, but they are not the same type of inverters.

One of the particularities of these inverters is that they have an auxiliary input for other sources that generate energy, which allows them to work in parallel with two sources. These systems are called **hybrids.**

These inverters also have different electrical configurations and are not always necessary. If the appliances used in the system are supplied with a low DC voltage (usually 12 to 48 volts), they can be powered by batteries or by the array of panels, provided that appliances and panels are the charge controller.

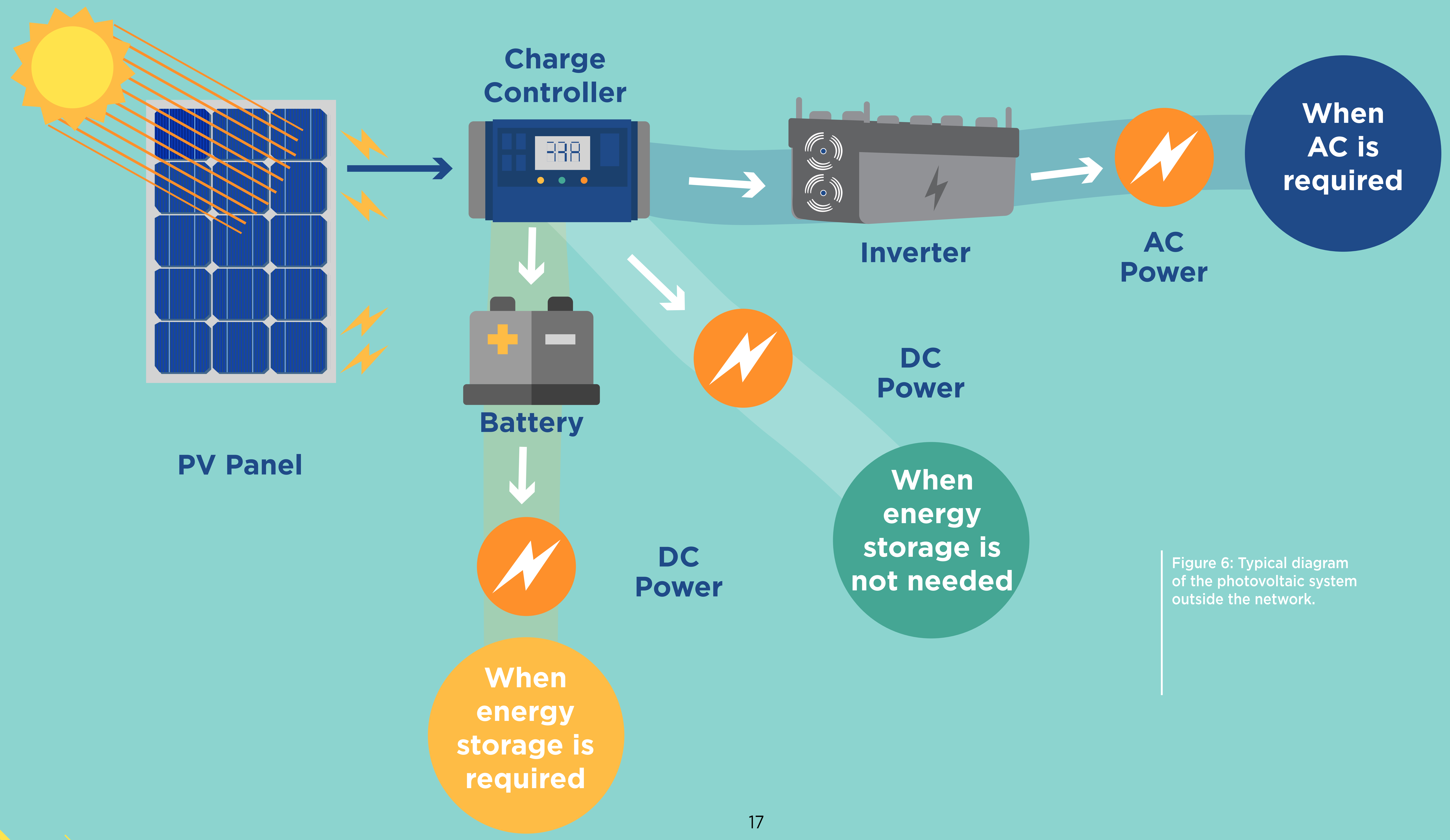


Figure 6: Typical diagram of the photovoltaic system outside the network.

M3

Why use Photovoltaic Systems?

One of the main advantages of photovoltaic (PV) systems is that they allow generating electricity in remote areas where a conventional network has no reach, or their coverage is insufficient.

Until recently, one of the most significant limitations to the installation of PV systems was the cost of the investment. Over time, this cost has been continuously reduced, reaching a point where the return of the investment can be found through rapid economic benefits.

Another aspect that makes the use of PV panels particularly attractive is the possibility of installing them in a modular way, and in the same place where energy is consumed. It is not possible with other technologies, which must be installed either centrally (such as thermoelectric generation), or at the site where the resource is located (such as hydroelectric or wind).

When there is an electrical network

In places where there are electrical network, it may be decided to install PV systems as complementary to the electricity generated. The result of this decision can lead to a reduction of the electricity consumed from the network and, consequently, the cost of such consumption.

When there is no electrical network

The issue of no electric power service in remote places or places that have no public electrical network can be solved using PV systems designed for each building, based on their specific requirements.

Given the generation of PV energy in schools, for example, students have better facilities and can access equipment and pedagogical resources that were previously inaccessible.

Although this is a solution that can be more limited than the connection to the network (regarding power and reliability), it provides a solution until the connection to the electrical network is available.

Benefits of Photovoltaic Systems

Regardless of the type of PV system used - connected to an electricity grid or not - this type of system provides multiple economic, environmental and social awareness benefits.

1 -Economic Benefits

The generation of PV energy is the segment of the electricity market that grows the fastest in the world, particularly in the last 10 years. Unlike other technologies of the conventional power generation, the cost of PV technology has been decreasing considerably. **Historically, PV system costs have decreased 100 times since 1950 and 10 times during the last 10 years, more than any other technology during the same period.**[4] Between 2010 and 2016, the total cost of the average installed system, including all hardware components and system balance (labor cost per installation, permissions, inspections, etc.), decreased by 65%.

PV panels and batteries used to be the most expensive components of a PV system, but prices have decreased significantly.

The reduction in solar panel costs is due to technological progress, mass production, the development of the local supply chain, the reduction of financial costs and the growing maturity of the sector. In the case of batteries, the technological advance has allowed improvements to the types of batteries and increases in their storage capacity, which has made the investment more profitable.

In some countries, the legislation allows surplus energy generated by the PV system to be reinjected into the electrical network and sold to the public system or used to obtain energy credits. It means that when there is no demand for the PV energy generated by the panels (for example, at noon, when everyone goes out for lunch), the energy generated by the PV system is exported to the network (for which it needs the permission of the electric company).

The energy exported is measured through a bidirectional meter that measures when energy is consumed, and when energy is exported. Depending on the legislation: (i) the energy exported can help reduce the monthly tariff (the total exported is subtracted of the total consumed); (ii) can be converted into energy “credits” (for use at night, for example, or in periods of high demand); or (iii) it can be commercialized directly.

This type of legislation for “distributed generation” is increasingly common in Latin America and the Caribbean (LAC), and effectively allows the owner of the PV system to become a generator, as well as a consumer.

The existence of this type of legislation is key to determine whether to use a system, particularly in urban areas, since it can improve the financial viability of the installation, without the need to use batteries to store the surplus.

4 Nemet, G. F. (2006). Beyond the learning curve: factors influencing cost reductions in photovoltaics. Energy Policy, 34 (17), 3218-3232.

2 - Mitigation and adaptation to climate change

PV solar energy is one of the primary measures to mitigate climate change as it is a source of renewable energy. The gradual substitution of fossil and polluting energy sources by renewable and clean energy generates a direct impact on the number of greenhouse gases emitted into the environment.

PV solar energy also provides an alternative not impacted by climate change, as would be the case of hydroelectric plants, subject to droughts and variations in hydrological regimes. In this context, the investment in photovoltaic solar energy has been an increasing socially and environmentally responsible investment.

3 - Awareness to new generations

The conversion of solar energy into PV in a school, for example, represents an excellent opportunity to share with students, parents and the entire community, the operation, components and benefits of the system. Therefore, the presence of the system can be used for more ambitious purposes than the generation of energy alone.

It is possible to make these systems installed in a school itself be used as a solid sample and integrated as part of the teaching process in various subjects. This includes PV systems to exemplify in other common topics such as the sun, clean energy, radiation, inclination, latitudes, pollution, etc. The rest of the modules in this document include more information, graphics, and tables that can be used to strengthen teaching processes.

Students can become the main promoters of the use of sustainable energy technologies, and the potential use of PV systems not only at school but also in their homes and communities. Additionally, by raising awareness about how energy is generated, people will pay more attention to the use of it, which can be helpful while promoting energy efficiency methods.

The Inter-American Development Bank (IDB) has developed interesting experiences that can be applied by teachers to strengthen the importance of renewable energies in children's lives.

An example of this may be the initiative **Rise Up**, where audiovisual content is included.

M4

How to calculate the cost of Photovoltaic Systems?

It is necessary to perform an analysis of the initial investment required to calculate the cost of photovoltaic (PV) systems, as well as the future investment that will be required for the system to function in optimal conditions, which implies a financial analysis.

Initial investment

The initial investment or the cost of PV systems varies depending on the technology, the manufacturer, the rated power, the country and the time it is calculated. Therefore, it can be complex to present a detailed cost of a PV system valid for all Latin America and the Caribbean (LAC) countries that can also be kept up to date.

To determine the cost of the system the first thing to do is to size it, as indicated in **Module 7**.

Each component of the PV system[5] (panels, inverter, batteries, support of the array of panels and the rest of the system) represent different percentages in the total cost of the PV system. These percentages have been evolving in recent years.

In Brazil, the relative costs (in %) of the components of the PV system connected to the network or not were approximately the following in 2017: **Figures 7 y 8**.[6]

PV systems not connected to a network are generally more expensive mainly due to the need of the battery storage system.

Also, when evaluating the cost of a PV system not connected to a network, it is important to consider not only the components of the PV system but also the costs of logistics, labor, and transportation, since these systems are generally used in isolated places.

5 BOS, balance of system, which includes any other complementary electrical component, power electronics, installation work, licenses, permits all what is necessary for the PV system.

6 This example corresponds to Brazil in 2017, however, the relative cost of these components may vary according to the local contexts in which the project is developed, since each country has different costs, production volumes, import regimes and taxes.

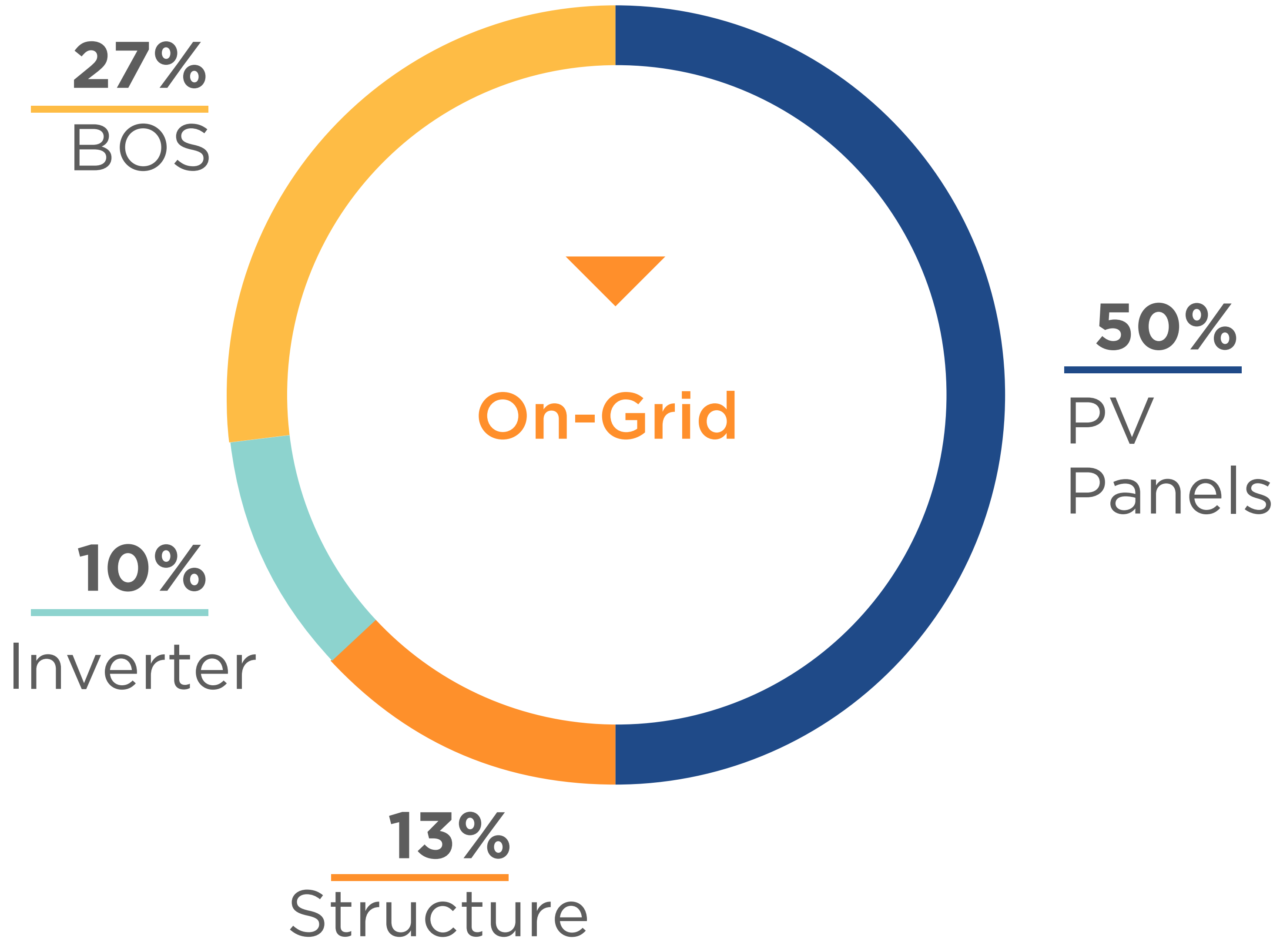


Figure 7: Relative costs of the components of a PV system connected to the Brazil network, 2017. IADB Source.

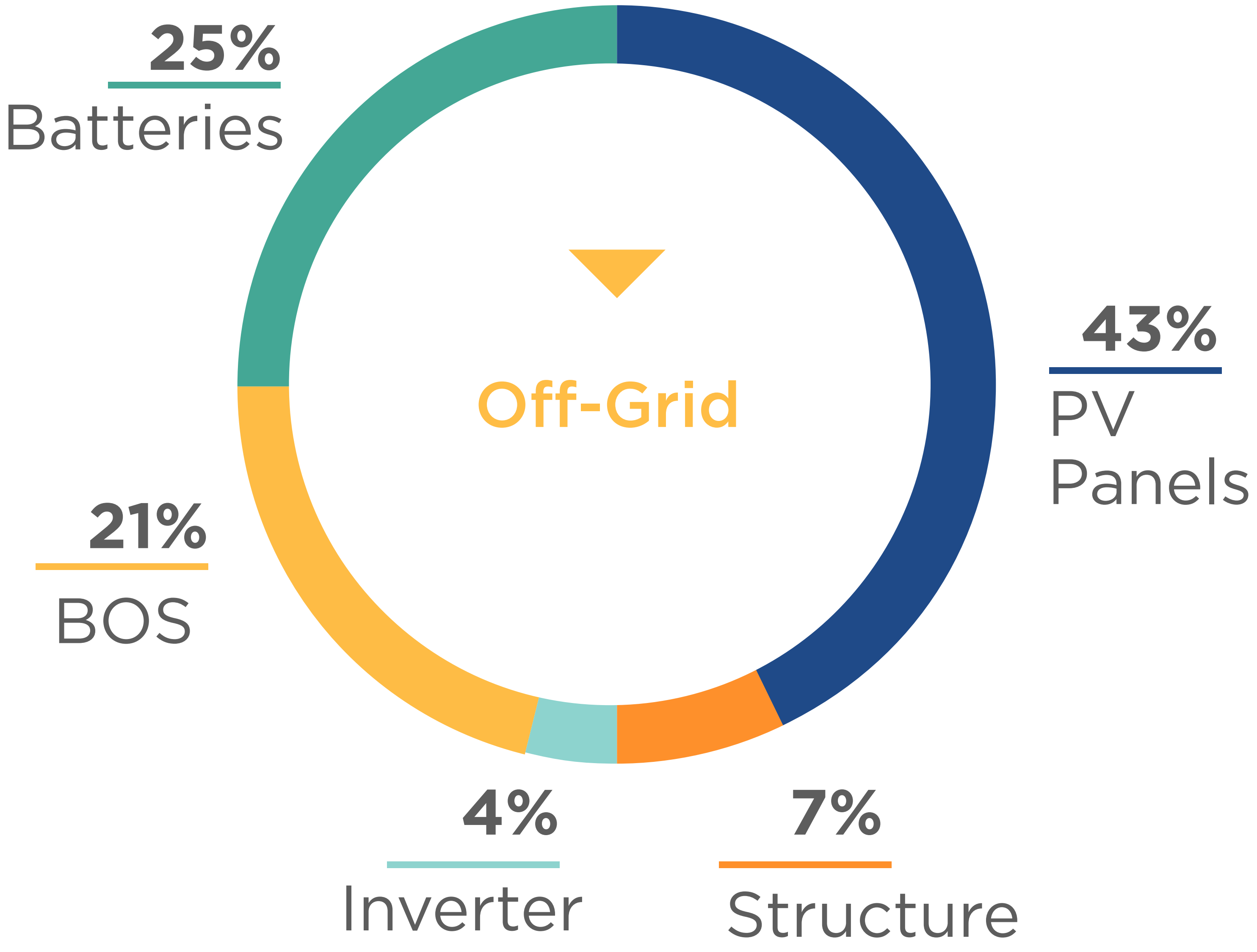


Figure 8: Relative costs of the components of a PV system not connected to a network in Brazil, 2017. IADB Source.

Financial analysis

In addition to the initial investment in the components and installation of the system, it is essential to perform a financial analysis of the same, considering the long-term investment, for which the cost of operation, maintenance, and replacement of its components should be analyzed throughout its life.

In the case of systems connected to the network, the most important financial aspects that should be considered when installing a PV system are the energy tariff and the initial costs of the PV system. The higher the energy tariff and the lower the cost of the PV system, the faster will be investment return.

For PV systems not connected to a network, the financial analysis must consider the economy that the PV system will provide when replacing the existing generators that use fossil fuels (if they exist). If there is no type of energy supply, the same analysis should be done, but comparing the possible solution alternatives.

Additionally, in order to perform a financial analysis, it is important to consider that, during the **life cycle of the PV system**, some components must be replaced (such as the inverter, the batteries, and the charge controller).

Table 2 shows the life cycle of the main components of the system.

Also, **operation and maintenance (O&M) costs** must be considered, which may be low, but still essential. For financial analysis, it can be estimated that the annual costs of O&M in systems connected to the network of a PV system are **generally in the range of 1 to 2% per year concerning the initial installation costs**.

For those systems located in remote areas, maintenance costs may be higher, mainly because they will probably use batteries, which have a shorter life than the rest of the components.

When evaluating the financial aspects of this type of investment, it is also interesting to consider that the life cycle of a PV system as a whole is 25 to 30 years. Therefore, the energy costs saved by having a PV system are a long-term investment.

The most common and straightforward[7] financial analysis that can be done is the estimate of a simple return period. The return period calculates in how many years the initial investment will be paid (considering a zero-interest rate). The investment of a PV system is considered financially viable when the return period is less than 10-15 years since most of the components of the system must be replaced within that period, as indicated in Table 2.

7 There are also other evaluation methods that can be used to calculate the financial or economic viability of a PV system. Namely: Current Net Value (CNV), Internal Rate of Return (IRR) and Time of Discarded Return (TRD). The CNV can be used to show the net difference between the benefits and costs of an energy system and is calculated by the difference between the present value of benefits and the present value of costs. The IRR is calculated by an iterative process to select the Discount Rate (DR) for which the net value of benefits and discounted costs is zero. The TRD period is the minimum time it takes to recover the investment costs considering a DR.

Table 2 Expected life cycle of the different components of the PV system.

Photovoltaic System component		Lifecycle
PV panel		25 a 30 years
Inverter		5 a 15 years
Batteries	*Lead-Acid*	3 a 5 years
	Lithium-ion	8 a 10 years
Charge controller		10 a 15 years

It is recommended to follow the following stages to calculate the return period of the investment:

STAGE 1: Calculate the initial costs of the PV system

It is necessary to know the nominal power of the system initially for establishing the cost of the system.

The costs of the PV panels are presented in nominal price/power (i.e. USD/Wp) and the prices can vary according to the place and the supplier. The cost of the other components of the PV system does not necessarily have a direct relationship with the nominal power of the system.

When calculating costs, it is essential to include all costs of installation, transportation, customs, taxes, etc.

STAGE 2: Calculate energy savings

Once the production of PV electricity per year is known, the annual savings can be calculated.

For systems connected to the network, the amount of energy a system produces during a whole year is the amount of conventional energy that did not have to be purchased from the network. In the case that there are regulations on distributed energy generation in the country, which allows one to obtain energy credits or sell the generated energy, it can be considered that all energy produced can be accredited. Therefore, the local energy tariff must be multiplied by the energy generated in place, and then the annual savings is determined. If there is no possibility of selling the surplus energy, it will be necessary to estimate the percentage that can be considered as a saving of the energy produced, since the surplus would be transferred to the network without benefit.

For systems not connected to a network, and that has a generation system based on fossil fuels, the savings are related to the reduction of fuel consumption. Once we know the amount of energy that the PV system can produce, we can know what the reduction of fuel consumption in a year is and translate it into savings. In the case of isolated systems that do not have an existing generation, the savings comparison should be made comparing the generation costs of the next viable alternative (i.e., a diesel generator).

STAGE 3: Calculate the simple return period

The last stage is simple: the initial cost of the photovoltaic system is divided by the annual savings. The resulting value will indicate the number of years that will be required to pay the initial investment. The least amount of years required, from a financial standpoint, will be more attractive to use a PV system.

It is important to remember that the simple return period is an approximate estimate of reality. However, this procedure can be very useful in obtaining a quick preliminary analysis that gives a general idea of the return period.

Table 3 Stages necessary to calculate the return period of a PV system.

Stage 1	Stage 2	Stage 3
Calculate the initial costs of the PV system	Calculate energy savings	Calculate the simple return period

M5

What is required to use the Photovoltaic Systems?

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Photovoltaic (PV) systems can be used anywhere on the planet (except the poles). However, some geographical areas have better conditions than others, either due to the intensity of solar radiation or the number of hours of sun exposure.

In Latin American and the Caribbean (LAC) there are very high radiation levels due to the geographical position of the region, which makes PV systems viable, even in winter periods or in rainy seasons.

Also, to use PV systems, you must consider other aspects such as having enough sunny surface to install the panels and give them a proper orientation and inclination.

As when installing any other system, when it is intended to install PV systems in existing buildings, it will be necessary to ensure that the internal electrical installation of the building is in excellent condition and that the structure can support the weight of the PV panels.

Solar irradiation of the area

The primary criteria that should be considered to define the installation of the PV system is the solar irradiation of the area in which the project is located. This is due to the energy production of a PV system being directly related to the amount of solar radiation that affects the arrangement of panels.

There is a lot of bibliography and tools on the internet to know what the irradiation is in certain areas, and to quantify the average amount of solar radiation that can exist on the array of panels per day in a year. Solar irradiation is the energy of the incident sun on a horizontal surface per unit area and is usually expressed using a unit of kWh/m^2.

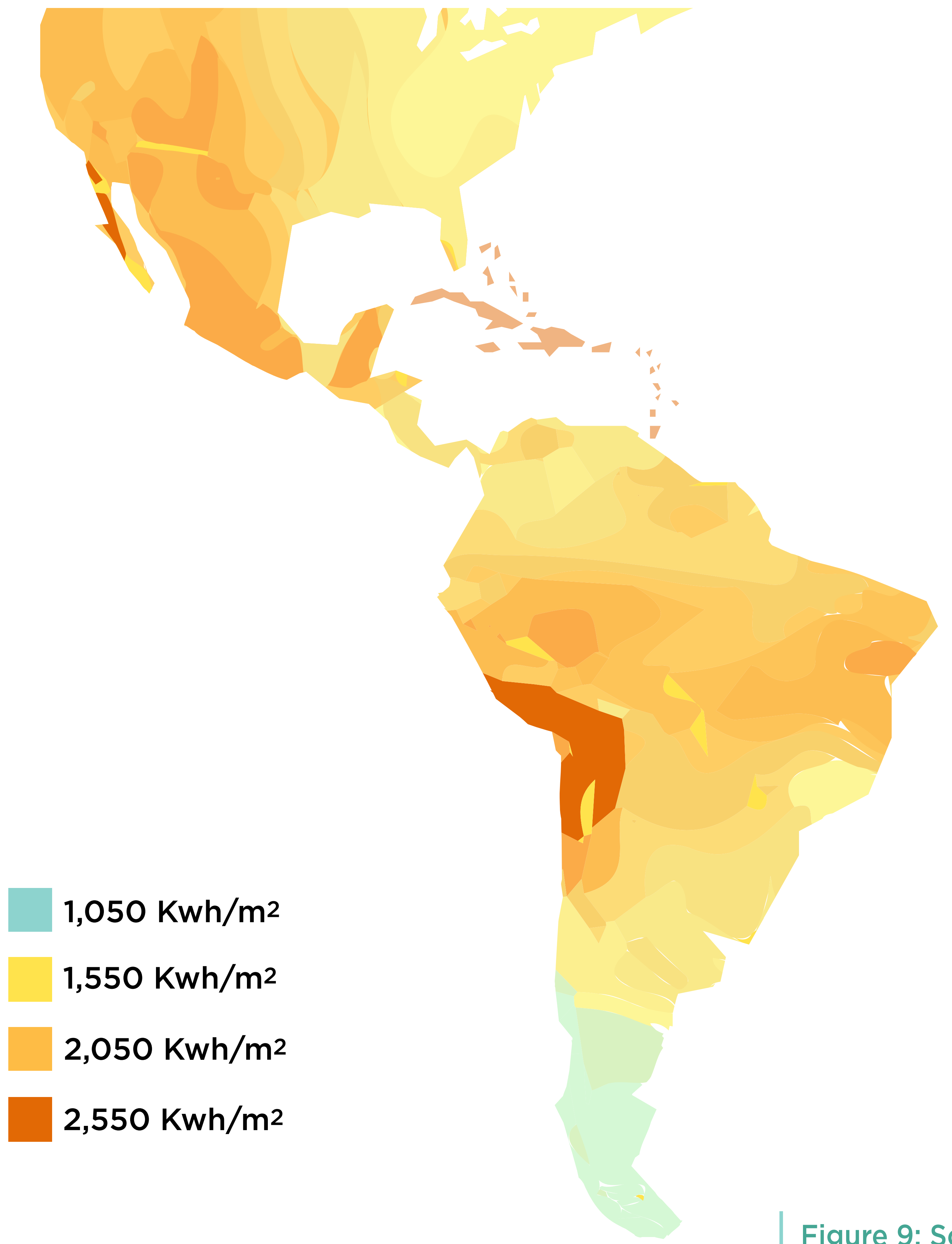


Figure 9: Solar Radiation Map of Latin America and the Caribbean. Source International Renewable Energy Agency, IRENA.

The following table shows the annual average of the horizontal solar irradiation according to the inclination by latitude in some LAC cities. These values indicate the incident solar irradiation on an array of panels mounted under optimal conditions of orientation and angle of inclination for the latitude of that city.[8]

Table 4 Annual average of solar irradiation according to the latitude inclination in some LAC cities.

Country	City	(kWh /m²/day)
Argentina	Buenos Aires	5.34
	Córdoba	5.77
	Mendoza	6.14
Belice	Belmopán	5.01
Bolivia	La Paz	5.91
	Santa Cruz de la Sierra	5.58
Brazil	Belo Horizonte	5.60
	Brasília	5.83
	Curitiba	4.72
	Florianópolis	4.95
	São Paulo	4.87
	Rio de Janeiro	5.26
Chile	Calama	7.18
	Concepción	5.46
	Santiago	6.03
	Valparaíso	5.30
Colombia	Bogotá	5.01
	Cali	4.94
	Medellín	4.96
Costa Rica	San José	5.01
Cuba	La Habana	5.30
Dominican Republic	Santo Domingo	5.24
Ecuador	Quito	5.12
El Salvador	San Salvador	6.11
Guatemala	Guatemala City	5.67
Honduras	Tegucigalpa	5.21
Jamaica	Kingston	5.51
México	Ciudad de México	5.33
	Guadalajara	5.87
	Hermosillo	6.43
Nicaragua	Managua	5.61
Panamá	Panamá City	5.59
Paraguay	Asunción	5.76
Perú	Arequipa	6.63
	Cuzco	5.76
	Lima	4.88
Puerto Rico	San Juan	5.34
Surinam	Paramaribo	4.80
Uruguay	Montevideo	5.11
Venezuela	Caracas	5.30

Source: The values of annual solar irradiation were provided by the database of moderate resolution of NREL (National Renewable Energy Laboratory) available on the **SWERA site (Evaluation of Solar and Wind Energy Resources)**

8 This information is available on the Internet. An example of an online source is the interactive map of solar irradiation and a compilation of data from the **Solar and Wind Energy Resource Assessment (SWERA).**

Sunny surface

There must be enough free surface on the roof or on the ground to install the solar panels, and these must be able to receive a total solar incidence, at least from 9:00 a.m. to 5:00 p.m.

It is necessary to bear in mind that objects that cause shade, such as neighboring buildings, trees, poles, power lines, chimneys, water tanks and even other parts of the panel array itself, can significantly reduce the power generation of a PV system.

Ideally, the array of panels should be free of any shade from 9:00 a.m. to 5:00 p.m. for a whole year, since it is the time when the solar radiation is most intense and, consequently, the maximum production of PV energy occurs.

The accumulation of dirt or snow on the surface of the PV panels also causes shade, so the surfaces should always be clean.

Surface calculation necessary

The surface required for the panel arrangement depends mainly on the energy demand of the building or the energy intended to be produced (which will be explained in more detail in **Module 7**), the characteristics of the PV panel (nominal power and size), the maximum power of the PV system in question and the separation between the PV panels.

For example, if the selected PV panel has a nominal power of 250 Wp and a surface of 1.6 m^2 (this data can be found in the specification sheet of the PV panel), the surface power for each PV panel is calculated from the following way:

$$\frac{\text{Nominal power}}{\text{panel surface}} = \text{Power per panel surface}$$

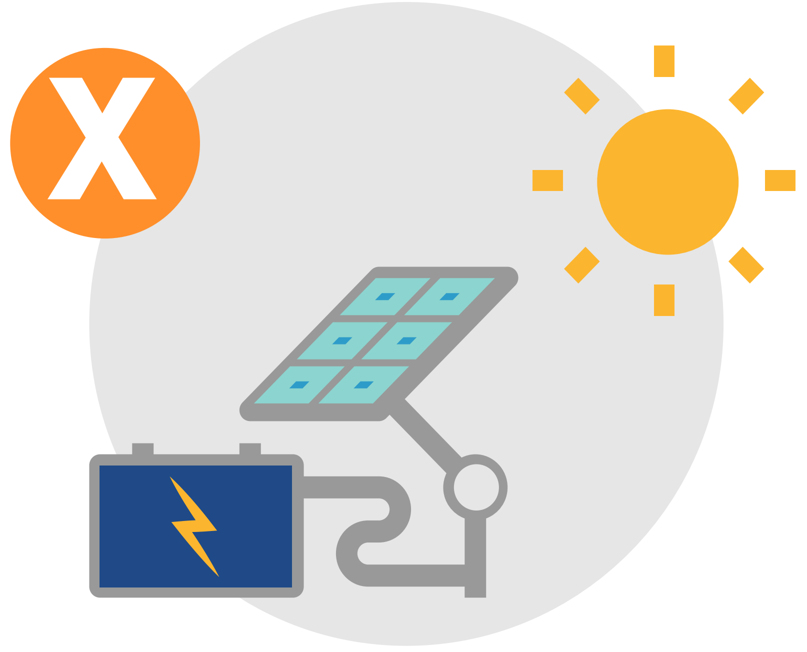
$$\frac{250\ \text{Wp}}{1.60\ \text{m}^2} = 156.25\ \text{Wp/m}^2$$

If the array of panels has a maximum power of 4,000 Wp, the total required area of the PV panels will be:

$$\frac{\text{Maximum power}}{\text{Power per panel surface}} = \text{Necessary area}$$

$$\frac{4{,}000\ \text{Wp}}{156.25\ \text{Wp/m}^2} = 25.6\ \text{m}^2$$

The space between the PV panels should also be considered and this information can be obtained from the manufacturer of the PV panel. In general, a space of 0.20m between the PV panels is used, which must be added to the total surface of the array of panels.



Adjustable orientation and tilting of the surface

The surface to host the PV panels must have the highest incidence of solar radiation throughout the year, so the panels must be oriented towards the Equator to receive the maximum amount of solar radiation available. Therefore, the optimal orientation is towards the south for facilities located in the Northern Hemisphere and towards the north for the ones in the Southern Hemisphere.

If the surface (roof or ground) does not have the proper orientation or is tilted to the opposite direction, it is possible that the panel arrangement is designed so that it has the proper orientation. In those cases, it is necessary to take care that these supports do not generate a shadow on the bordering panels.

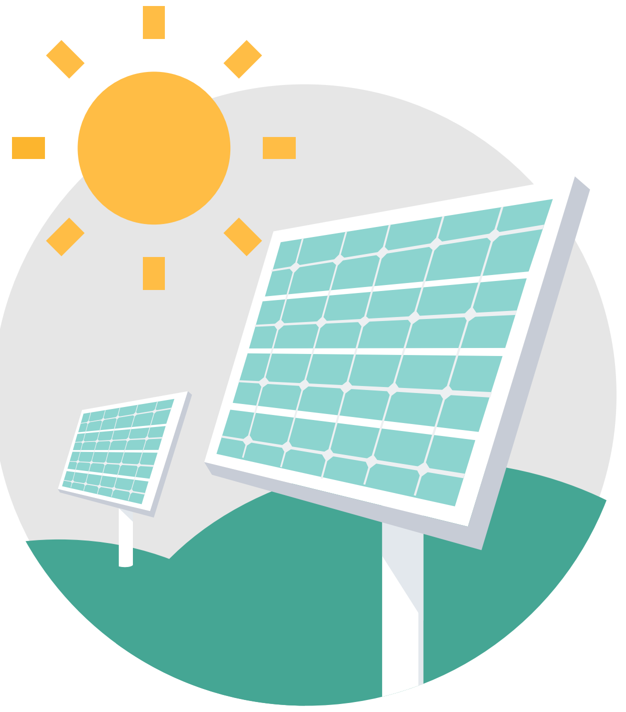
In addition to the proper orientation, panel arrangements should be installed with the proper inclination based on your geographic location, as indicated in **Module 7**.

Internal electrical installation in good condition

In the case of the installation of a PV system present in an existing construction, it must be verified that the rest of the electrical installation is in excellent condition. Otherwise, the PV panel system will not work efficiently, and its installation will not reduce possible risks due to previous installations.

In these cases, and before deciding to install a PV system, it is advisable to consult a professional to evaluate the status of the existing internal electrical installation and if there is a need to make any changes.

In cases where PV systems connected to the network are installed, it is critical to verify that the electricity meter is bidirectional (the electricity distribution company usually is in charge of this). In that way, it will allow measurement of the energy that comes from the network as well as the energy the system provides.



+sun +light

M6

Where to install the components of the Photovoltaic Systems?

The location of the different components of the photovoltaic (PV) system must be resolved at the design stage of the building in case they are new constructions. It must be ensured that there are areas where they can be located, mainly when the systems are installed in existing buildings where the location possibilities are limited.

Photovoltaic panels

PV panels or panel arrays can be mounted on the ground or roof and, in both cases, suitable supports should be selected that offer protection, support and solar access for the PV panels.

Generally, the roof is mostly chosen because their higher location and usually offer better solar exposure for the PV panels. Also, a roof is also a good option when there is no space available on the ground (this usually occurs when the building is located in an urban area).

However, sloped roofs represent a great danger for falls and, therefore, it is imperative to consider protective measures during the installation and maintenance procedures of the panel arrangements.

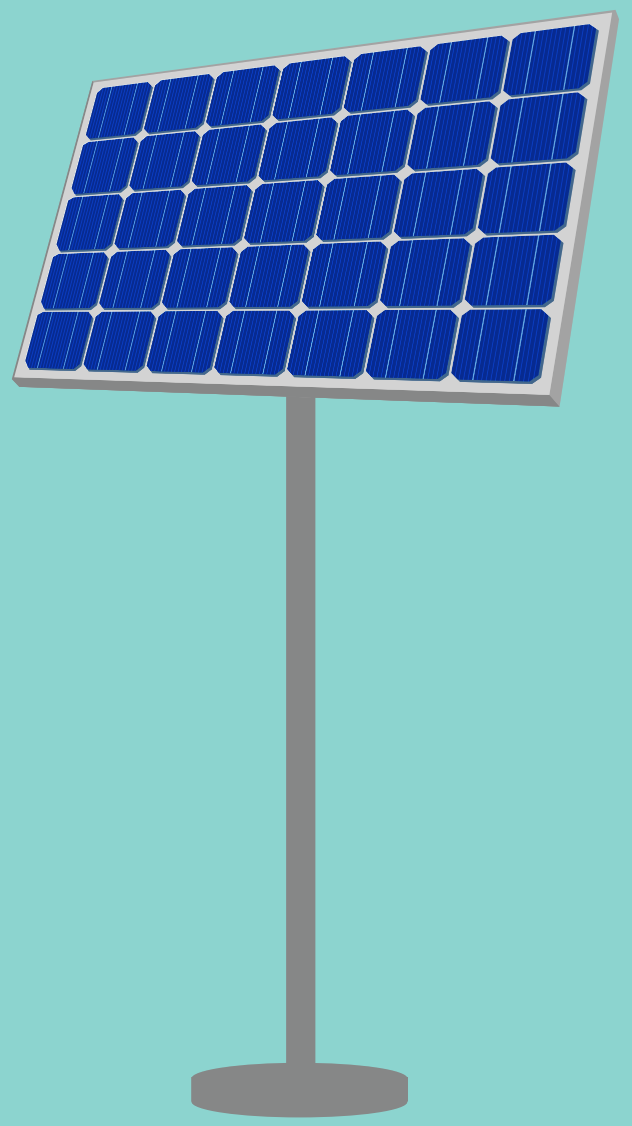
Arrangements of panels mounted on the ground are a good solution when the installation on the roof is not possible or practical, or when there is enough space available on the ground (usually in remote areas).

The main advantage of floor-mounted panel arrays is the fact that their inclination and orientation are less restricted than those mounted on roofs. Besides, there is no danger of falling from height during the installation and maintenance procedures. However, panels mounted on the ground are more susceptible to vandalism, the growth of vegetation in the surrounding areas, the accumulation of dust and new constructions or objects that can cause shade in the future.

Other details should also be considered in the arrangements of ground panels: zoning and land use restrictions and conditions, soil type and mechanical requirements for installation of supports, flood and drainage areas, fences and safety requirements, as well as cable laying that prevents energy loss.

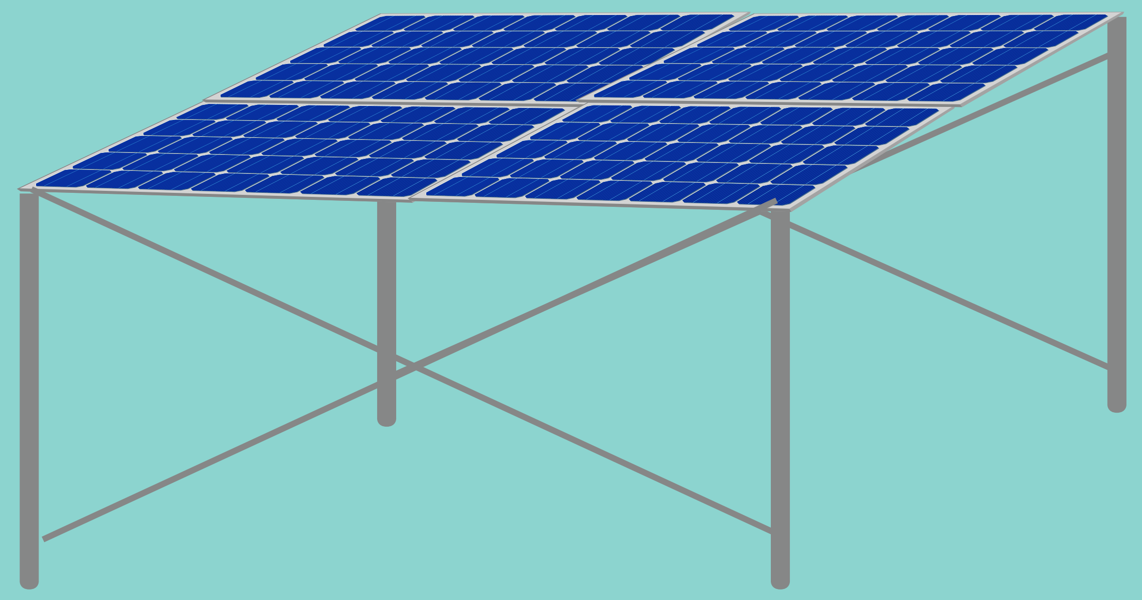
1 Roof mounting structure

Use metal or wood supports that are fixed to the roof with support bars on which the PV panels are fixed;



2 Pole mounting structure

Brackets mounted on top of a pole. These types of systems are common for "isolated" PV systems;



3 Mounting structures on the ground

Supports are typically used at ground level. The PV panels are fixed on a system of metal or wood supports.

Figure 10: Types of mounting structures for panel arrays.

M6

Supporting capacity of the roof

If the chosen place is the roof, it is important to make sure that the structure (whether new or existing) can support the weight of the panel arrangement and its metal or wooden supports, as well as the people responsible for installing it and performing maintenance.

Therefore, it is very important to evaluate the structural conditions of the roof and determine if they can support this additional load. In the cases that act on existing constructions, a qualified professional should be consulted to evaluate the structural conditions of the roof. Generally, an array of panels with its support will add approximately 20 kg/m^2 to the roof.

For areas of extreme climate conditions, i.e. with strong winds and hurricanes, some type of reinforcement for the support and the structure of the building should be considered and calculated. This requirement is also important when installing systems mounted on poles or ground structures.

Table 5 Advantages and disadvantages of each type of mounting structure.

Mounting structure	Advantage	Disadvantages
Roof	Less chance of shade; Protection against animals and vandalism.	Risk of falling during installation and maintenance. The structural conditions of the roof must withstand the permanent additional weight of the arrangement of panels and their supports and the transitory weight of the installers and those in charge of maintenance. Installation and maintenance are difficult because they are elevated.
Pole	Easy to install Less chance of shade Protection against animals and vandalism.	Suitable only for small PV systems. Installation and maintenance are difficult because they are elevated.
Ground	Easy to install Easy maintenance. Suitable for any size of PV system. Robust structural support.	More shadow possibilities. More vulnerable to situations of vandalism.

Other components

The rest of the electrical components of the PV system, including inverters, charge controllers, batteries and any other electrical equipment related to the PV system, should be installed as close as possible to the array of panels. This will minimize the length of the cables with the consequent electrical losses, installation costs and provides accessibility during the installation and maintenance procedures of the entire PV system.

Other considerations that must be considered for the location of the rest of the system:

- » Avoid installing electrical equipment in places exposed to high temperatures, sunlight, rain or humidity;
- » Provide adequate ventilation and / or artificial cooling systems to equipment that generates heat, such as inverters, batteries and charge controllers;
- » Protect all electrical components from dust, rain, moisture, chemicals and other environmental factors;
- » Some equipment has special considerations that must be verified in the manufacturer's instructions. All the sizing and installation of the PV system must be done by trained technical personnel.

Source BID

M7

How to size Photovoltaic Systems?

To adjust the size of the photovoltaic (PV) system and its components, it is necessary to perform some calculations, in addition to knowing the demand conditions, and consider the characteristics of the desired network and the components to be used.

The calculation must be done by a specialized professional. However, the following are some necessary calculations, suitable for a preliminary evaluation of the viability of a PV system.

Photovoltaic Systems connected to the electrical network

Before sizing the system, it is necessary to investigate and understand how national regulations work in each country to connect a PV system to the local network, especially in case there are specific requirements. In the same way, it is necessary to confirm the regulations about the possibility of obtaining payments or credits for the energy generated by the system that is not consumed.[9]

Also, the quality and conditions of the network should be investigated to make sure that the photovoltaic system can work well when connected to it.

9 These possibilities are normally established in the regulations on "distributed generation", and/or "self-generation" of each country.

STAGE 1: Identification of the ideal conditions for the installation of the PV system

Optimal conditions for PV installations consider the orientation (azimuth) and inclination (inclination angle) of the array of panels, to maximize the incidence of solar radiation on the panels throughout the year. The PV structures must be oriented towards the line of the Equator to receive the maximum amount of solar radiation available in that place, that is, the optimal orientation is towards the south for the installations located in the Northern Hemisphere and towards the north for the installations located in the Southern Hemisphere.

The angle of inclination of the array of panels is the angle between the surface of the panels and the horizontal plane. Generally, the optimum angle of inclination for the array of panels is equal to the local latitude. Table 7 shows the latitude and, therefore, the orientation and inclination angle recommended for the array of panels in some cities of the region.

For example, optimal conditions for an array of panels installed in Brasília, capital of Brazil, (latitude = 15.48° S) should be at an angle of approximately 15° and orientation to the north.

It is important to note that manufacturers of PV panels do not recommend installed PV structures with tilt angles less than 10°. Therefore, if the area is located at a latitude less than 10°, the recommended angle of inclination for the array of panels is 10°.

STAGE 2: Identification of the energy demand of the building

Calculating the energy consumption of the building is an essential factor to size the PV system. The PV systems connected to the network can be sized to satisfy part or all of the current energy consumption of the building. This decision will depend on the energy needs and expectations of the PV system.

Also, the timing of consumption should be verified. For example, a school may have most of its consumption during the day, and PV systems may help reduce network consumption during the day. A night school, on the other hand, will have its consumption at night, when there is no solar radiation and generation, for which the energy generated during the day is wasted. In this last case, if there were regulations on distributed generation in the country, having photovoltaic systems would allow to earn energy credits or sell the generated energy.

Table 6 Stages necessary to size a PV system connected to the network.

Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Identification of the ideal conditions for the installation of the PV system	Identification of the energy demand of the building	Evaluation of solar irradiation	Definition of the nominal power of the PV system	Definition of the number of PV panels needed	Definition of the inverter size

Table 7 | Latitude and recommended angle of inclination for the array of panels in some LAC cities

Country	City	Local latitude	Inclination and orientation recommended for the array of panels
Argentina	Buenos Aires	34°36'S	**34° north orientation**
	Córdoba	31°25'S	**31° north orientation**
	Mendoza	32°53'S	**32° north orientation**
Bahamas	Nassau	25°4'N	**25° south orientation**
Barbados	Bridgetown	13°06'N	**13° south orientation**
Belice	Belmopán	17°12'N	**17° south orientation**
Bolivia	La Paz	16°30'S	**16° north orientation**
	Santa Cruz de la Sierra	17°48'S	**17° north orientation**
Brazil	Belo Horizonte	19°55'S	**19° north orientation**
	Brasília	15°48'S	**15° north orientation**
	Curitiba	25°25'S	**25° north orientation**
	Florianópolis	27°50'S	**27° north orientation**
	São Paulo	23°33'S	**23° north orientation**
	Rio de Janeiro	22°55'S	**22° north orientation**
Chile	Calama	22°28'S	**22° north orientation**
	Concepción	36°50'S	**36° north orientation**
	Santiago	33°27'S	**33° north orientation**
	Valparaíso	33°03'S	**33° north orientation**
Colômbia	Bogotá	4°36'N	**10° south orientation**
	Cali	3°25'N	**10° south orientation**
	Medellín	6°14'N	**10° south orientation**
Costa Rica	San José	9°56'N	**10° south orientation**
Ecuador	Quito	0°15'S	**10° south orientation**
El Salvador	San Salvador	13°41'N	**13° south orientation**
Guatemala	Ciudad de Guatemala	14°37'N	**14° south orientation**
Haití	Port-au-Prince	8°32'N	**10° south orientation**
Honduras	Tegucigalpa	14°06'N	**14° south orientation**
Jamaica	Kingston	17°59'N	**17° south orientation**
México	Cidade do México	19°26'N	**19° south orientation**
	Guadalajara	20°40'N	**20° south orientation**
	Hermosillo	29°06'N	**29° south orientation**
Nicaragua	Manágua	12°08'N	**12° south orientation**
Panamá	Ciudad de Panamá	8°59'N	**10° south orientation**
Paraguay	Asunción	25°17'S	**25° north orientation**
Perú	Arequipa	16°24'S	**16° north orientation**
	Cuzco	13°32'S	**13° north orientation**
	Lima	12°03'S	**12° north orientation**
	Trujillo	8°6'S	**10° north orientation**
Dominican Republic	Santo Domingo	18°28'N	**18° south orientation**
	Santiago de los Caballeros	19°28'N	**19° south orientation**
Surinam	Paramaribo	5°52'N	**10° south orientation**
Trinidad y Tobago	Port of Spain	10°40'N	**10° south orientation**
Uruguay	Montevideo	34°53'S	**34° north orientation**
Venezuela	Caracas	10°30'N	**10° north orientation**

Table 8 Energy consumption of common household appliances.

Device	Power (W)	Time of operation (h/day)	Energy (kWh/day)
Air conditioner	600	8	4.8
Ceiling fan	73	8	0.584
Desktop computer	62.5	8	0.5
Electric shower	5,500	0.5	2.75
Fluorescent lamp	23	5	0.115
Freezer	75	24	1.8
Electric heater	1,600	8	12.80
Internet modem	8	8	0.064
Microwave	1,200	0.5	0.6
Display Unit	55	8	0.440
Laptop	20	8	0.160
Printer	15	1	0.015
Projector	24	1	0.024
Radio	5	10	0.05
Refrigerator	55	24	1.32
Router	6	8	0.048
Scanner	9	1	0.009
Music equipment	110	3	0.33
TV 32”	95	5	0.457
Wireless phone	3	24	0.072

For existing constructions

This stage can be carried out by reviewing the electricity bills of the last year (or earlier, if available). Reading the building’s electricity bill can show the monthly energy consumption profile of this facility and help calculate the total amount of energy that can be consumed throughout the year.

The size of the PV system will be based on the total energy consumption of a whole year.

For example, a building consumes an average of 1,000 kWh per year. If the expectation is that the PV system will supply half of its demand, its nominal power rating will be sized to generate 500kWh per year.

In any case, when determining the necessary energy, it is also essential to consider future forecasts and the higher load that may be required, especially considering the impact of the incorporation of technology and electrical appliances in buildings.

For new constructions

For new constructions, the use of energy can be calculated from the classifications of the equipment and the expected load (power) usage profiles x annual hours of use.

For that, you will need the verification of all the electrical devices that will be used, its power, and its operating time per day in hours. Multiplying the power of the device (expressed in Watts) by its operating time, the daily energy consumption is obtained (in Watts-hour).

If this procedure is carried out with all the electrical appliances and its consumption is added, an estimated calculation of the daily demand can be obtained. It is not necessary that the values obtained be exact, but significant differences can cause distortions in the calculations of the size of the system; therefore, it is recommended to be conservative. Table 8 shows some reference values for this stage.

STAGE 3: Evaluation of solar irradiation

Solar irradiation is the energy of the sun incident on a surface per unit area in a given period and is usually expressed in a unit of kWh/m²/day.

The amount of solar irradiation that shines on the array of panels is directly related to the energy production of a PV system. Therefore, it is vital to consider the installation of the array of panels without any object that may cause shade and to achieve, whenever possible, the optimal conditions of orientation and inclination, as explained in **STAGE 1**.

At this point, in the process of defining the size of the PV system, the objective is to quantify the average amount of solar radiation that shines on the array of panels per day in a year.

Table 4 shows the annual average of solar irradiation according to the latitude inclination in some LAC cities.[10] These values indicate the incident solar irradiation on an array of panels mounted under optimal conditions of orientation and angle of inclination for the latitude of that city.

10 Similar information from several cities can be found on the Internet. An example of an online source is the interactive map of solar irradiation and a compilation of data from the **Solar and Wind Energy Resource Assessment (SWERA)**.

Table 9 Nominal power (in Wp) necessary to supply a particular energy demand under similar solar irradiation conditions

Annual Energy Demand (kWh / year)	Annual average of solar irradiation according to latitude (Wp/m²/day)								
	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
1,000	1.83	1.46	1.22	1.04	0.91	0.81	0.73	0.66	0.61
1,500	2.74	2.19	1.83	1.57	1.37	1.22	1.10	1.00	0.91
2,000	3.65	2.92	2.44	2.09	1.83	1.62	1.46	1.33	1.22
2,500	4.57	3,65	3.04	2.61	2.28	2.03	1.83	1.66	1.52
3,000	5.48	4.38	3.65	3.13	2.74	2.44	2.19	1.99	1.83
3,500	6.39	5.11	4.26	3.65	3.20	2.84	2.56	2.32	2.13
4,000	7.31	5.84	4.87	4.17	3.65	3.25	2.92	2.66	2.44
4,500	8.22	6.58	5.48	4.70	4.11	3.65	3.29	2.99	2.74
5,000	9.13	7.31	6.09	5.22	4.57	4.06	3.65	3.32	3.04
5,500	10.05	8.04	6.70	5.74	5.02	4.46	4.02	3.65	3.35
6,000	10.96	8.77	7.31	6.26	5.48	4.87	4.38	3.99	3.65
6,500	11.87	9.50	7.91	6.78	5.94	5.28	4.75	4.32	3.96
7,000	13.70	10.23	8.52	7.31	6.39	5.68	5.11	4.65	4.26
7,500	12.79	10.23	8.52	7.31	6.39	5.68	5.11	4.65	4.26
8,000	14.61	11.69	9.74	8.35	7.31	6.49	5.84	5.31	4.87
8,500	15.53	12.42	10.35	8.87	7.76	6.90	6.21	5.65	5.18
9,000	16.44	13.15	10.96	9.39	8.22	7.31	6.58	5.98	5.48
9,500	17.35	13.88	11.57	9.92	8.68	7.71	6.94	6.31	5.78
10,000	18.26	14.61	12.18	10.44	9.13	8.12	7.31	6.64	6.09

Source: Strategic Research Group on Solar Energy of the Federal University of Santa Catarina (UFSC), Brazil - **FOTOVOLTAICA-UFSC**.

STAGE 4: Definition of the nominal power of the PV system

At this stage, the annual energy demand of a school must be known, as well as the annual solar irradiation incident on the array of panels **Table 9** shows an approximation of the nominal power that a PV system must have to supply the energy needs of a school[11] under the similar solar irradiation conditions.

The value of the school's annual energy demand is shown in the second column of **Table 9** When comparing energy demand with the irradiation level of the place, shown in the upper part of the Table, an approximate calculation of the nominal power is needed for the PV system in kWp to be obtained.

It is a very approximate calculation, but it will give a good perception of the size of the PV system required to supply the annual energy needs of a school.

11 For systems with connection to the network, the annual energy demand is generally used, since the sum of the monthly invoices is made. Some professionals perform the calculation based on an "average" day but using another table.

STAGE 5: Definition of the number of PV panels needed

To know how many PV panels will be needed to supply that nominal power, it will be necessary to know the nominal power of each available PV panel. The number of PV panels required is the result of the division of the total nominal power of the PV system by the nominal power of each panel.

$$\frac{\text{Nominal power required}}{\text{Nominal power of a panel}} = \text{Number of panels needed}$$

In most cases, the result will be a decimal number, which means that it must be rounded up or down. Generally, round up is the safest option, as this ensures the supply of all the necessary power.

For a PV system of 1,975 Wp that uses PV panels with a rating of 275 Wp per panel, the result is equal to 7.18. Since the result is very close to 7, it can be rounded down.

For a system with the same 1,975 Wp that uses PV panels rated at 110 Wp per panel, the result is 17.95, which is very close to 18. In this case, it would be recommended to round up excessively since it would be a risk to choose anything below that number.

When the result is not clear, normally roundup is the best option.

Source BID

STAGE 6: Definition of the inverter size

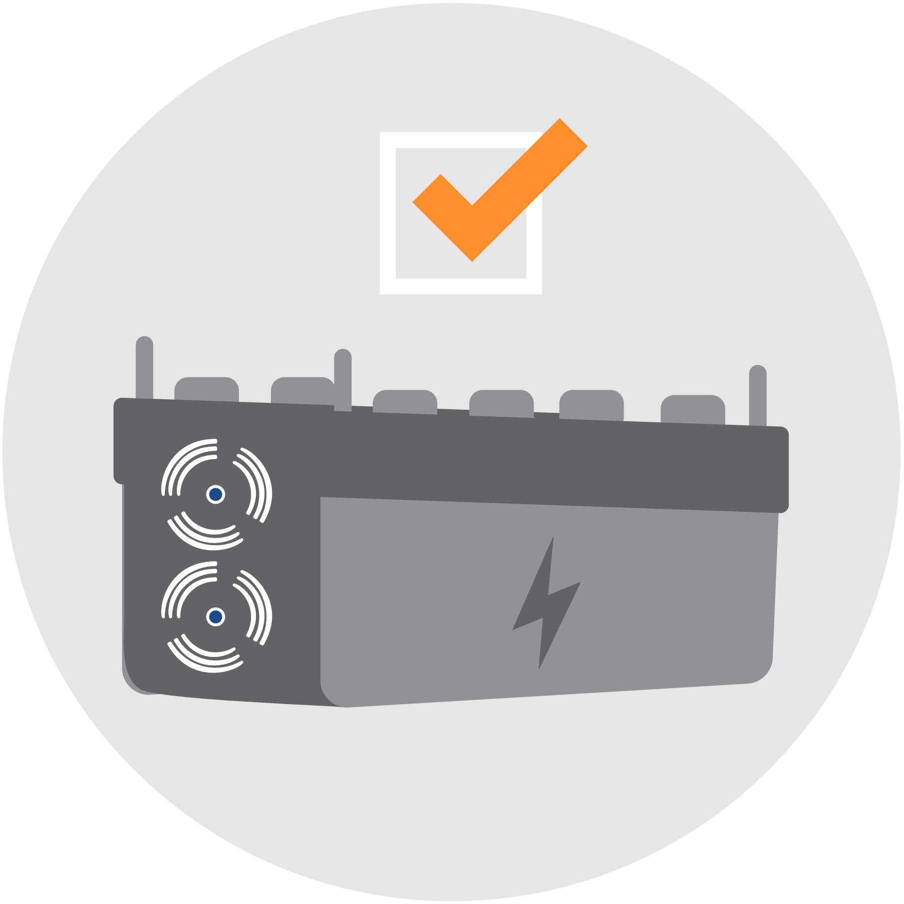
The size of the inverter will depend on the nominal power of the PV system and the electrical characteristics of the PV panels adopted.

Generally, to size the inverter, the power of this must supply the total of the nominal power of the PV system. Sometimes more than one inverter will be necessary, and this decision will depend on the commercially available conversion technologies in place.

The definition of the size of the inverter will also depend on other electrical characteristics, such as the input/output voltage and the voltage variation of the chosen inverter. It is essential to consider that the AC side of the inverter must have the same electrical characteristics as the local network, such as voltage and frequency.

As the inverter is directly responsible for determining the maximum power output of the system, it is also important to consider what happens with the excess energy in situations of zero demand. If the power of the system is much higher than the energy demand, the excess energy is injected into the network.

There are other additional aspects that must be considered to define the appropriate size of the inverter. Therefore, the definition of the size and selection of the inverter must be made by a professional.



Example 1: Photovoltaic Systems connected to the electrical network

This example considers an existing school located in Florianópolis, in the southern region of Brazil. The school wants to have a PV system that supplies 100% of the school's energy demand. To perform the calculations, follow the steps in Table 6.

STAGE 1: Identification of the ideal conditions for the installation of the PV system

According to Table 7, Florianópolis is located in the southern hemisphere at a latitude of 27°. Therefore, the optimum conditions to install a PV system that maximizes the incidence of solar radiation in the array of panels should be an inclination of approximately 27° oriented to the north.

STAGE 2: Identification of the energy demand of the building

The following figure shows the monthly energy consumption of the school shown in the energy account. By adding the monthly consumption presented, it is possible to calculate the annual energy consumption of the school. Therefore, this school consumes approximately 5,010 kWh/year.

The school wants to have a PV system that supplies 100% of its energy consumption; Also, it is intended that the system foresees an increase in consumption of 20% for the future. Therefore, its energy demand to size the PV system is 6,012 kWh/year.

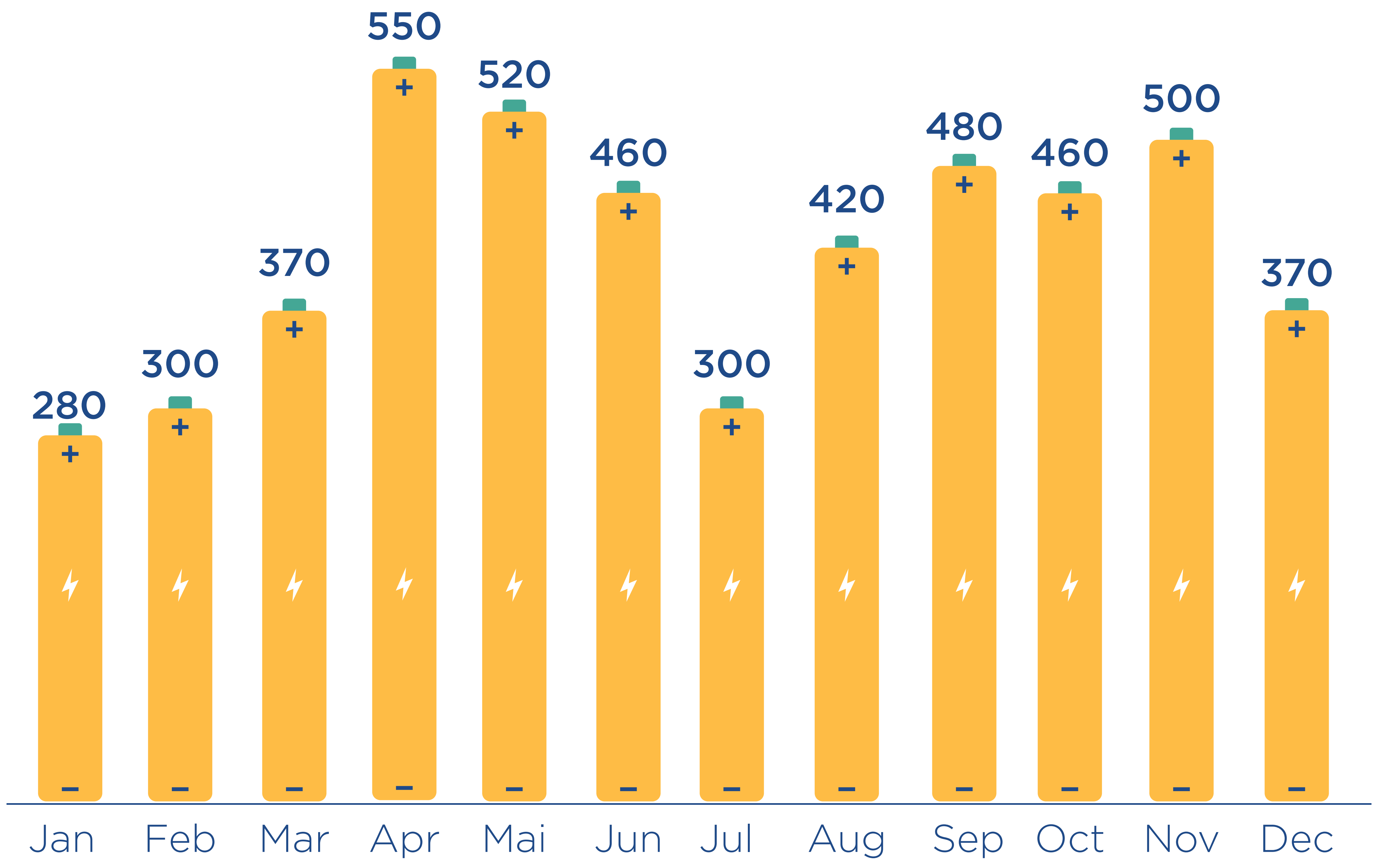
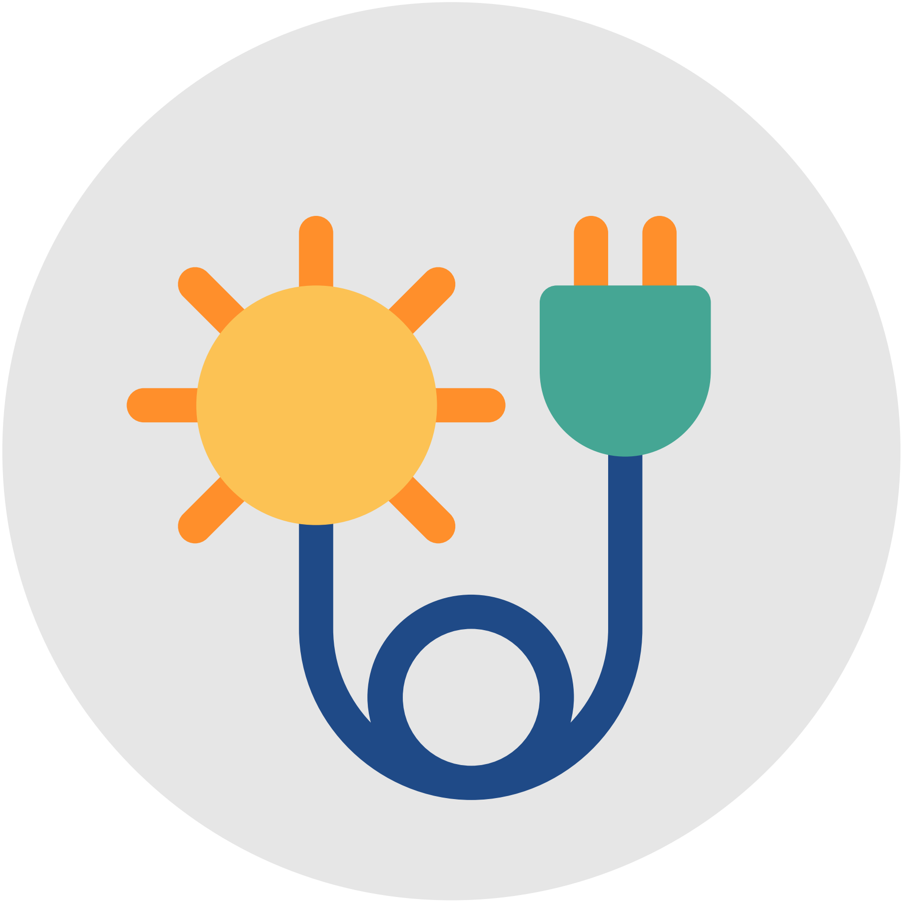


Figure 11: Monthly energy consumption of the school given by the electric power account.



STAGE 3: Evaluation of solar irradiation

According to **Table 4**, the annual average solar irradiation according to the latitude tilt for Florianópolis is 4.95 kWh/m^2 per day. It means that an annual average of 4.95 kWh/m^2 per day is the amount of solar radiation that will receive an inclined surface at 27° and oriented to the north.

STAGE 4: Definition of the nominal power of the PV system

At this time, it is known that the annual energy demand of the school is 6,012 kWh/year and the annual average of solar irradiation according to the latitude tilt for Florianópolis is 4.95 kWh/m^2 per day.

As **Table 9** does not include the exact values of 6,012 kWh / year for energy demand and 4.95 kWh/m^2 per day for solar irradiation, it is advisable to use the approximate numbers. Therefore, it is estimated that a PV system should have approximately 4.38 kWp of nominal installed power to supply a school with an annual energy demand of 6,000 kWh/year, with 5.00 kWh/m^2 per day of annual average solar irradiation according to the latitude and inclination

STAGE 5: Definition of the number of PV panels needed

The installation of the nominal power is defined by the nominal power of the selected PV panels and the number of PV panels needed. This information can be found in the datasheet of the PV panel.

Assuming that the available panels have a nominal power of 265 Wp to supply 4.38 kWp (4,380 Wp), the system must have at least 17 panels.

STAGE 6: Definition of the inverter size

The size of the inverter depends on the electrical characteristics of the PV panels adopted and on the electrical characteristics of the inverters available in the market.

Generally, to size the inverter, the power of this must supply the nominal power of the PV system. Therefore, in this case, the inverter (or inverters) must reach approximately between 4 and 5 kW.

Photovoltaic Systems not connected to an electrical network

The process to define the size of PV systems not connected to a network is more complicated than in the PV systems connected to a network. This complexity arises due to the intermittency of the solar resource, a factor that must be considered to ensure the autonomy of the system.

Therefore, the appropriate energy storage infrastructure must be well sized and specified.

Frequently, fuel generators are used as a source of complementary energy to the network. The use of PV energy allows users to stop using generators for power supply; however, there will be cases in which the PV energy is not enough, and the generator must be used together with the PV energy.

STAGE 1: Identification of ideal conditions for the PV system installation

The identification of optimal conditions of the array of panels must be carried out in the same way as indicated in **STAGE 1** of the system with connection to the network.

STAGE 2: Identification of energy demand of a building

The identification of the energy consumption of the building must be carried out as indicated in **STAGE 2** of the system with connection to the network. For the case of new constructions, the data in **Table 7** can also be used.

If you work with a system that uses any other source of energy as a complement to PV, you must subtract the daily energy produced by this additional source of the required energy demand. For example, if there is a system with a daily energy demand of 10 kWh, with a diesel generator that produces 3 kWh/day, and users decide to stop using the generator, they should use the value of 10 kWh to estimate of the PV energy required.

Table 10 Stages necessary to size a PV system not connected to a network.

Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	Stage 9
Identification of ideal conditions for the PV system installation	Identification of energy demand of a building	Evaluation of solar irradiation	Definition of the PV system nominal power	Definition of the number of PV panels needed	Definition of the battery storage size	Definition of the electrical system configuration	Definition of the charge controller size	Definition of the inverter size

However, if you wish to continue using the generator, you should use the value of 7 kWh/day for the next stages (10 - 3 = 7). It is recommended to consult the original distributor to determine the generator's power output.

In any case, when determining the necessary energy, it is also essential to consider future forecasts and the higher load that may be required, especially considering the impact of adding the technology and electrical appliances in buildings.

STAGE 3: Evaluation of solar irradiation

The solar irradiation evaluation must be carried out in the same way as indicated in **STAGE 3** of the system with connection to the network.

STAGE 4: Definition of the PV system nominal power

With the data of solar irradiation and energy demand, it is possible to know the necessary nominal power.

Table 11

Nominal power (in Wp) necessary to supply a particular energy demand in the similar solar irradiation conditions

Daily energy demand (kWh/day)	Annual average of solar irradiation according to latitude (kWh/m²/day)								
	2,0	2.5	3.0	3.5	4.0	4,5	5.0	5.5	6.0
0.25	250	200	167	143	125	111	100	91	83
0.5	500	400	333	286	250	222	200	182	167
0.75	750	600	500	429	375	333	300	273	250
1	1,000	800	667	571	500	444	400	364	333
5	5,000	4,000	3,333	2,857	2,500	2,222	2,000	1,818	1,667
10	10,000	8,000	6,667	5,714	5,000	4,444	4,000	3,636	3,333
15	15,000	12,000	10,000	8,571	7,500	6,667	6,000	5,455	5,000
20	20,000	16,000	13,333	11,429	10,000	8,889	8,000	7,273	6,667
25	25,000	20,000	16,667	14,286	12,500	11,111	10,000	9,091	8,333
30	30,000	24,000	20,000	17,143	15,000	13,333	12,000	10,909	10,000
35	35,000	28,000	23,333	20,000	17,500	15,556	14,000	12,727	11,667
40	40,000	32,000	26,667	22,857	20,000	17,778	16,000	14,545	13,333
45	45,000	36,000	30,000	25,714	22,500	20,000	18,000	16,364	15,000
50	50,000	40,000	33,333	28,571	25,000	22,222	20,000	18,182	16,667
55	55,000	44,000	36,667	31,429	27,500	24,444	22,000	20,000	18,333
60	60,000	48,000	40,000	34,286	30,000	26,667	24,000	21,818	20,000
65	65,000	52,000	43,333	37,143	32,500	28,889	26,000	23,636	21,667
70	70,000	56,000	46,667	40,000	35,000	31,111	28,000	25,455	23,333
75	75,000	60,000	50,000	42,857	37,500	33,333	30,000	27,273	25,000
80	80,000	64,000	53,333	45,714	40,000	35,556	32,000	29,091	26,667
85	85,000	68,000	56,667	48,571	42,500	37,778	34,000	30,909	28,333
90	90,000	72,000	60,000	51,429	45,000	40,000	36,000	32,727	30,000
95	95,000	76,000	63,333	54,286	47,500	42,222	38,000	34,545	31,667
100	100,000	80,000	66,667	57,143	50,000	44,444	40,000	36,364	33,333

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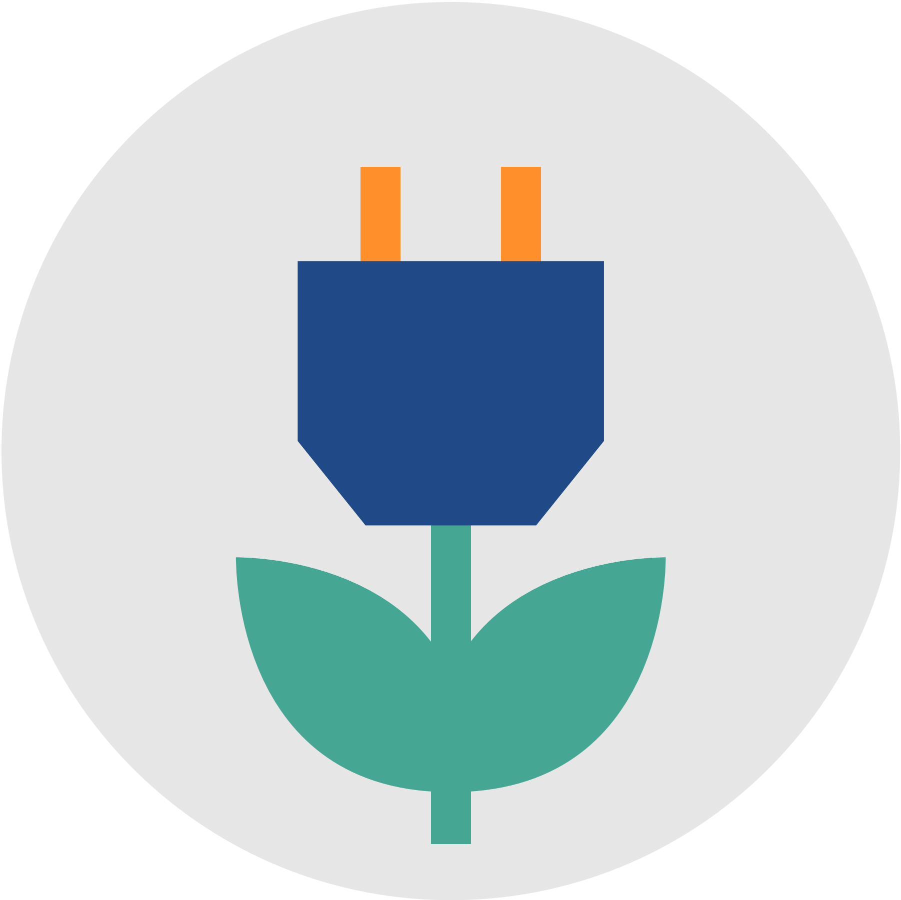


Table 11 shows the daily energy demand with the irradiation levels, leading to the PV power needed for the system.[12] These values are approximate. If the value of the energy demand is not in the Table, an approximate value can be obtained by using the next highest value or an average between the two closest values.

In most cases, the result is not a whole number, which means that the result must be rounded up or down. Usually, the safest option is to round up, especially in off-grid PV systems. For example, if a school with a demand of 25 kWh/day is located somewhere with an irradiation level of 4 kWh/m^2/day, the recommended PV power should be at least 12,500 Wp (or 12.5 kWp).

STAGE 5: Definition of the number of PV panels needed

The photovoltaic power shown in Table 11 is the total power of the system in Wp. It is necessary to divide the PV power obtained by the power of a single PV panel to obtain the necessary number of panels.

$$\frac{\text{Nominal power required}}{\text{Nominal power of a panel}} = \text{Number of panels needed}$$

For a PV panel with a nominal power of 320 Wp, the number of panels required is 40 (12.500 ÷ 320 = 39.06).

Even if the result is very close to 39, in PV systems not connected to the network, it is better to round up, that is, use more panels to ensure that the necessary energy is delivered.

12 Table 11, for systems not connected to a network, uses the daily energy demand, while Tabla 9, for systems with connection to the network uses the annual energy demand. It happens because, in isolated systems, there are no monthly energy bills, which is why it is more common to work on a "day" basis. In systems connected to the network, it is done based on the year, adding the monthly invoices, although it could also be done based on an "average" day.

STAGE 6: Definition of the battery storage size[13]

To size the battery storage, the main factor to consider is the autonomy of the system defining the number of days the battery can supply power in the absence of sun.

Apparently, the higher the autonomy and the battery storage, the higher the recharge time and the cost. Table 12 shows the energy demand with different levels of autonomy, which leads to the minimum load required for the battery storage.[14] If the value of the energy demand is not in Table 12, an approximate value can be obtained by using the next highest value or an average of the two closest values.

The battery storage shown in Table 12 is the total storage in Ah (Ampere-hour). To obtain the necessary amount of batteries, you must divide the value obtained by the value of the charge of a single battery and round the result.

$$\frac{\text{Nominal charging of batteries required}}{\text{Nominal power of a battery}} = \text{Amount of batteries needed}$$

For example, for a school with a demand of 10 kWh/day, it must have an energy autonomy of 5 days. The school needs a battery system of 5,787 Ah to ensure this condition. If the chosen battery is 165 Ah, the system will need at least 36 batteries (5,787 ÷ 165 = 35.07).

13 If for any reason the user does not want to have an energy storage system, this stage may not be applicable. It can happen, for example, when the energy consumption coincides with the moment of generation of it. For example, if the school is open during the day and bot at night, storing energy is not necessary. Alternatively, if the photovoltaic system is used for pumping a water tank, it can work when there is the sun without the need to storage energy.

14 This table is only referential and valid for conventional 12 V lead-acid batteries. For other technologies or other voltages, it is suggested to consult a specialized technician. In the case of lithium batteries, the values of the calculation are one-fourth that of the values indicated in Table 12.

Table 12

Approximate value of the nominal charge of the lead-acid batteries (in Ah) necessary to supply a specific energy demand under similar autonomy conditions.

Daily energy demand (kWh/day)	System autonomy (days)		
	3	4	5
0.25	98	116	145
0.5	196	231	289
0.75	294	347	434
1	392	463	579
5	1,961	2,315	2,894
10	3,922	4,630	5,787
15	5,882	6,944	8,681
20	7,843	9,259	11,574
25	9,804	11,574	14,468
30	11,765	13,889	17,361
35	13,725	16,204	20,255
40	15,686	18,519	23,148
45	17,647	20,833	26,042
50	19,608	23,148	28,935
55	21,569	25,463	31,829
60	23,529	27,778	34,722
65	25,490	30,093	37,616
70	27,451	32,407	40,509
75	29,412	34,722	43,403
80	31,373	37,037	46,296
85	33,333	39,352	49,190
90	35,294	41,667	52,083
95	37,255	43,981	54,977
100	39,216	46,296	57,870

STAGE 7: Definition of the electrical system configuration[15]

After sizing the PV system and the battery storage, the next step is to specify its electrical configuration. The batteries for this type of application usually have a nominal voltage of 12 V, but you can form chains of batteries and obtain banks of batteries of 24, 36 or 48 V.

These values are the operating voltages, but the battery charge occurs with higher voltages (approximately 20% higher than the operating voltage).

Although this voltage may vary depending on the manufacturer and the power of the panel, panels with the same number of cells usually have very similar voltages. The following table suggests the best way to connect the PV panels with 36, 60 and 72 cells for each battery voltage.

It is important to note that the voltage of the PV system is defined by the technician who sizes it, while the cells per panel depend on the manufacturer. The technician must define how many panels to use depending on the voltage of the system and the cells per panel available in the market.

Table 13 shows the sizes of the recommended chain. It means that all other PV panels chains must be connected in parallel. If there are not enough panels to complete the chains, it is recommended to increase the number of PV panels in the system.

If any configuration cannot be used, the battery storage voltage should be increased or a smaller PV panel used. Table 13 also shows that most of the time the array of panels has chains with an even number of photovoltaic panels. Consequently, it is assumed that most of the time it is better to round up the number of photovoltaic panels of the system, until the next even number.

If the system appliances use direct current (DC) voltage of 12 to 48 V and there is no battery system, the array of panels will supply the loads directly through the charge controller.[16] Table 13, should also be used to define the electrical configuration of the array of panels, but it should be read as if the battery voltage

15 If the system does not include batteries and the devices do not use DC voltage of 12 to 48 V, this step is not applicable. In this case, the electrical configuration of the system will depend on the electrical characteristics of the inverter.

16 Devices can never be connected directly to the PV panels. There should always be a charge controller.

was the desired voltage. For example, if the devices of an installation use 48 V, the recommended configurations are chains of 4 panels of 36 cells, 2 panels of 60 cells or 2 panels of 72 cells.

STAGE 8: Definition of the charge controller size

The charge controllers limit the voltage with which the array of panels supplies power. This stage is used to determine which charge controller is necessary.

There is a wide variety of charge controllers for different electrical configurations available in the market. Charge controllers are classified according to the values of voltage, current, and power. In general, voltage and power are the most important factors, since other properties generally have higher limits than the values observed in the system. The charge controllers available in the market are typically 10A, 20A, 40A, etc.

Therefore, the charge controller must have the nominal voltage equal to the battery storage or the devices nominal voltage, if they use DC voltage. It is recommended to have the assistance of a professional to evaluate it correctly.

STAGE 9: Definition of the inverter size[17]

Like the charge controller, the inverter is also classified by the values of voltage, current, and power, but in this case, its power is as essential as its voltage (again, the current usually has higher limits than the values that will be observed in the system).

The power of the inverter corresponds to the power that is delivered to electrical appliances. Ideally, it is equal to or greater than the maximum demand (that means that the inverter is responsible for defining the actual power output of the system). Concerning the voltage, two values must be observed: the input voltage (DC) and the output voltage (AC).

The inverter input corresponds to the DC, to the side that has the energy of the PV system, while the output corresponds to the AC, which has the energy that must be distributed for its use. The input voltage must be equal to the nominal voltage of the battery storage and the charge controller, while the output voltage must be equal to the supply voltage of the electrical devices connected to the system.

17 If the devices use DC voltage, the converter is not necessary, and this step not applicable.

Table 13 Recommended configurations based on battery voltage and the number of PV cells per panel.

		Quantity of cells in the elevated pv panel		
		36 cells	60 cells	72 cells
Battery storage voltage (V)	12	1 panel by chain	Cannot be used	Cannot be used
	24	2 panels by chain	1 panel by chain	1 panel by chain
	36	3 panels by chain	Cannot be used	Cannot be used
	48	4 panels by chain	2 panels by chain	2 panels by chain

In LAC, this value is 110 or 220V (see a table of network specifications by country, if needed). Attention: if the devices used are 12, 24, 36 or 48V DC, an inverter is not necessary, and the equipment can be connected directly to the charge controller.

Example 2: Photovoltaic System out of the electrical network battery storage

This example considers a school on an island located in Florianópolis, in the southern region of Brazil. There the network has a value of 220 V and all the devices of the school use this same voltage, therefore, a inverter is necessary. Users want to replace their diesel generators for PV energy and use batteries to store energy. The stages of Table 10, are to be followed.

STAGE 1: Identification of ideal conditions for the installation of the PV system

The first step in sizing a PV system outside the network is to ensure that the place where the system is installed receives sufficient sunlight. The school is high enough so that the trees do not produce shade on the roof, which makes the roof an ideal place for the arrangement of panels. As indicated in Table 7, the local latitude is 27° 50'S, so the array of panels should be oriented to the north with an inclination of 27°.

STAGE 2: Identification of energy demand of a building

All electrical appliances must be specified in a list with its power and daily use to identify the energy consumption of the school. In this example, the school has only the following devices: 1 ceiling fan, 1 fluorescent lamp, 1 Internet modem, 1 laptop, 1 projector, 1 radio, and 1 wireless phone.

After verifying the power of each device and evaluating the usage, the daily consumption of each one can be obtained, multiplying the power and the time of operation, as shown in the following Table, with data from Table 8.

A total of 1.069 kWh/day is obtained adding up all the energy consumption, but the load is estimated at 1.283 kWh/day if there is a future load increase of 20%.

Table 14 | Energy consumption of school equipment.

Device	Power (W)	Time of operation (h/day)	Energy (kWh/day)
Ceiling fan	73	8	0.584
Fluorescent lamp	23	5	0.115
Internet modem	8	8	0.064
Laptop	20	8	0.160
Projector	24	1	0.024
Radio	5	10	0.05
Wireless phone	3	24	0.072
TOTAL			1,069

STAGE 3: Evaluation of solar irradiation

Next, you must determine the minimum daily irradiation level for Florianópolis, which, according to Table 4, is 4.95 kWh/ m²/day.

STAGE 4: Definition of the PV system nominal power

With the data of solar irradiation (STAGE 3) and energy demand (STAGE 2), it is possible to know the necessary nominal power.

According to Table 11, there are two possibilities: use the size definition for 1 kWh/day or 5 kWh/day. The second option is safer, but more expensive and, for this reason, 1 kWh/day will be used since it is very close to our calculated value.

As for the irradiation, we can use 4.5 or 5 kWh/m²/day. The value of 4.5 kWh/ m²/day is safer, as it increases the size of the system to meet a low irradiance. Therefore, this value will be used, which will lead to an array of panels with a rated power of 444 Wp.

STAGE 5: Definition of the number of PV panels needed

The available panels have a nominal power of 265 Wp to replace the 444 Wp; the system must have at least two panels.

STAGE 6: Definition of the battery storage size

To size the battery storage, you must define the autonomy of the system. In Florianópolis, it is rare for more than three days to pass without clear skies. Therefore, it is considered that a 3-day autonomy is enough. A 392 Ah battery storage should be installed using the information in Table 12.

The available batteries have 120 Ah, therefore, to cover the required 392 Ah, at least 4 batteries are needed.

STAGE 7: Definition of the electrical system configuration

The electrical configuration must be defined based on the sizes of the array of panels and the battery set. According to Table 13, since there are four batteries, we can use 12, 24 or 48 V. If the panels used have 60 cells, we could use 24 or 48 V.

For this system, 48 V will be chosen, which means that the four batteries will be connected in parallel while the panels will be combined in 2 chains of 2 panels.

STAGE 8: Definition of the charge controller size

The size of the charge controller depends on the current and voltage of the array of panels and its availability on the market. In general, the charge controller must have a nominal voltage equal to the batteries and they come generally as 10A, 20A, 40A, etc.

STAGE 9: Definition of the inverter size

The size of the inverter also depends on the current and voltage of the array of panels, but mainly on the power. There are several different configurations available, but it is recommended to use an inverter with nominal power close to the power of the array of panels. For this example, an inverter with 1 kW should be enough, as long as its output voltage is 220 V.

Example 3: Photovoltaic System out of the electrical network without battery storage

This example considers a small school in Quito, the capital of Ecuador. The school opens only during the day so it is not necessary to store energy in batteries. In Ecuador, generally all school devices use a voltage of 120 and an inverter for that voltage is necessary. The stages of Table 10 are to be followed.

STAGE 1: Identification of ideal conditions for the PV System installation

The first step in sizing a PV system not connected to the network is to make sure that the place receives enough sunlight. The school observed is located in an open field, without trees or other elements that can produce shade, so the roof is the ideal place for the array of panels. According to Table 7, the local latitude is 0° 15’S, and the recommended minimum angle of inclination is 10°, the array of panels should be oriented to the north with an inclination of 10°.

STAGE 2: Identification of energy demand of a building

All electrical appliances must be specified in a list with its power and daily use to identify the energy consumption of the school. In this example, the school has only the following devices: 1 ceiling fan, 2 fluorescent lamps, and 1 radio.

After verifying the power of each device and evaluating their usage, the daily consumption of each one can be obtained by multiplying the power and the time of operation, as shown in the following Table, with data from Table 8.

If all the energy consumption is added up, a total of 0.864 kWh/day is obtained and when there is an extension of 20%, a total of 1.037 kWh/day can be obtained.

Table 15 | Energy consumption of the school equipment

Advice	Quantity	Power (W)	Time of operation (h/day)	Energy (kWh/day)
Ceiling fan	1	73	8	0.584
Fluorescent lamp	2	23	5	0.230
Radio	1	5	10	0.05
TOTAL				0.864

STAGE 3: Evaluation of solar irradiation

According to **Table 4**, the minimum daily irradiation level for Quito is 5.12 kWh/m^2/day.

STAGE 4: Definition of the PV system nominal power

It is possible to know the necessary nominal power with the data of solar irradiation (STAGE 3) and energy demand (STAGE 2).

According to **Table 11**, there are two possibilities: use the size definition for 1 kWh/day or 5 kWh/day. The second option is safer, but more expensive. Since no battery storage is required, more panels will ensure that even on days of low sunlight the system can generate enough power to supply the devices. However, considering that the demand, even with a growth of 20%, is very close to 1kWh/day (1.037 kWh/day), the chosen value is 1 kWh/day, to avoid oversizing the system.

Regarding the irradiation, according to **Table 11**, it is possible to use 5 kWh/m^2/day, which leads to an array of panels with a nominal power of 400 Wp.

STAGE 5: Definition of the number of PV panels needed

The available panels have a nominal power of 265 Wp. Therefore, the system must have at least 2 panels to replace the 400 Wp.

STAGE 6: Defining the battery storage size

Since the system does not have batteries, this stage is not applicable.

STAGE 7: Definition of the electrical system configuration

Once the size of the array of panels is defined, its electrical configuration must also be defined. As there are no batteries, the 2 panels can be used in series or parallel, depending on the operating voltage of the inverter selected.

STAGE 8: Definition of the charge controller size

As the system does not have batteries but has an inverter, a charge controller is not necessary, since the inverter itself will limit the output voltage. This stage is not applicable.

STAGE 9: Definition of the inverter size

The size of the inverter will depend on the current and the voltage of the array of panels, but mainly on the power. There are several different configurations available, but it is recommended to use an inverter with nominal power close to the power of the array of panels. For this example, a 0.5 or 1kW inverter should be enough, as long as its output voltage is 120 V.

Example 4: Photovoltaic System not connected to the electrical network without inverter

This example considers a small school in Buenos Aires, capital of Argentina. The school needs to have storage in batteries, and all devices have 24 V DC operating voltage, so n inverter is not necessary. The devices can be connected directly to the charge controller. The stages of Table 10 are to be followed.

STAGE 1: Identification of ideal conditions for the PV system installatio

The first step in sizing a PV system outside the network is to ensure that the place where the system is installed receives sufficient sunlight. The school is located in an open field, without trees or other elements that can produce shade, the roof is the ideal place for the arrangement of panels. According to Table 7, the local latitude is 34° 36'S, so the array of panels should be oriented to the north, with an inclination of 34°.

STAGE 2: Identification of energy demand of a building

To identify the energy consumption of the school, all electrical appliances must be specified in a list with its power and daily use. In this example, the school has only the following devices: 1 ceiling fan, 3 fluorescent lamps, 1 radio and 1 refrigerator.

After verifying the power of each device and evaluating their usage daily, the daily consumption of each one can be obtained by multiplying the power and the time of operation, as shown in the following Table, with data from Table 8.

If all the energy consumption is added up, a total of 2.299 kWh/day is obtained and when there is an extension of 20%, a total of 2.759 kWh/day can be obtained.

Table 16 | Energy consumption of the school equipment

Device	Quantity	Power (W)	Time of operation (h / day)	Energy (kWh/day)
Ceiling fan	1	73	8	0.584
Fluorescent lamp	3	23	5	0.345
Radio	1	5	10	0.05
Refrigerator	1	55	24	1.32
TOTAL				2.299

STAGE 3: Evaluation of solar irradiation

Next, the minimum level of daily irradiation must be determined, which according to Table 4, it is 5.34 kWh/m²/day in Buenos Aires.

STAGE 4: Definition of the PV system nominal power

With the data of solar irradiation (STAGE 3) and energy demand (STAGE 2), it is possible to know the necessary nominal power.

According to Table 11, there are two possibilities: use the size definition for 1 kWh/day or 5 kWh/day. The ideal option would be something between those values by using their average value. As for irradiation, the value of 5 kWh/m²/day should be used.

To obtain the necessary average, we must choose the recommended power values for demands of 1 and 5 kWh/day in the desired irradiation. Add both values and divide by two: 400 + 2,000 = 2,400, then 2,400 ÷ 2 = 1,200. The desired array of panels has a nominal power of 1,200 Wp.

STAGE 5: Definition of the number of PV panels needed

If the available panels have a nominal power of 320 Wp, to replace the 1,200 Wp, the system must have at least 4 panels.

STAGE 6: Defining the battery storage size

To size the battery storage, you must define the autonomy of the system. In Buenos Aires, it is not uncommon for more than three days to pass without clear skies. Therefore, it is preferable to have a 5-day autonomy. As for STAGE 4, the same process of obtaining an average value is necessary. Taking the recommended values for 1 and 5 kWh in Table 12, another average can be obtained: 579 + 2,874 = 3,453, the result is 1,726.5. The desired battery storage has a load of 1,726.5 Ah.

The available batteries have 150 Ah, so at least 12 of them are needed.

STAGE 7: Definition of the electrical system configuration

The electrical configuration must be defined when the sizes of the array of panels and the battery set is obtained. Since the system uses 24 V appliances, the batteries must also produce that voltage. Each of the 12 batteries has a voltage of 12 V and in order to have a 24 V output, it is necessary to connect the batteries in chains of 2. This results in 6 parallel chains and a 24 V battery system. As a 72 cell panel is used, the array of panels must have all the panels in parallel. Table 13 can be used for this process.

STAGE 8: Definition of the charge controller size

The size of the charge controller depends on the current and voltage of the array of panels and also its availability on local market. In general, the charge controller must have a nominal voltage equal to the batteries and come generally as 10A, 20A, 40A, etc.

STAGE 9: Definition of the inverter size

Since the system does not have an inverter, this stage is not applicable.

Important: points to consider during the calculation of the number of panels

As explained in Module 7, Ithe array of panels nominal power arises from the combination of energy demand and solar irradiation in the area in which it is installed. Therefore, the nominal power does not arise from the sum of the power of the equipment that will be connected to the PV system (demand).

The power of the array of panels depends on how much energy is required during the day, not on the maximum power to be delivered. It is the charge controller (or inverter) that determines the power supplied to the equipment.

EXAMPLE A

If a school had a constant load of an appliance at 1kW for 8 hours, it would be 8kWh of demand. In order to supply this value, a panel larger than 1kW is required, whereas 2kW to 3kW (depending on the radiation) would probably be enough.

In the morning, if the system is connected to the network, the school consumes 1,000W. Part of which comes from the electrical network, and part from the PV panel (which generates with low radiation, less than 1,000W). At midday, the appliance consumes all its power from the PV panel (1,000W), and even a part of the energy of the panel is exported to the electrical network (because it is higher than 1,000W and will be generating about 3,000W). In the afternoon, the school consumes part of the panel and another part of the electrical network. On average, during the day, the energy generated by the PV panel would be equal to the 8,000kWh consumed by the school. However, one part would have to come from the electrical network and another part from the PV panel.

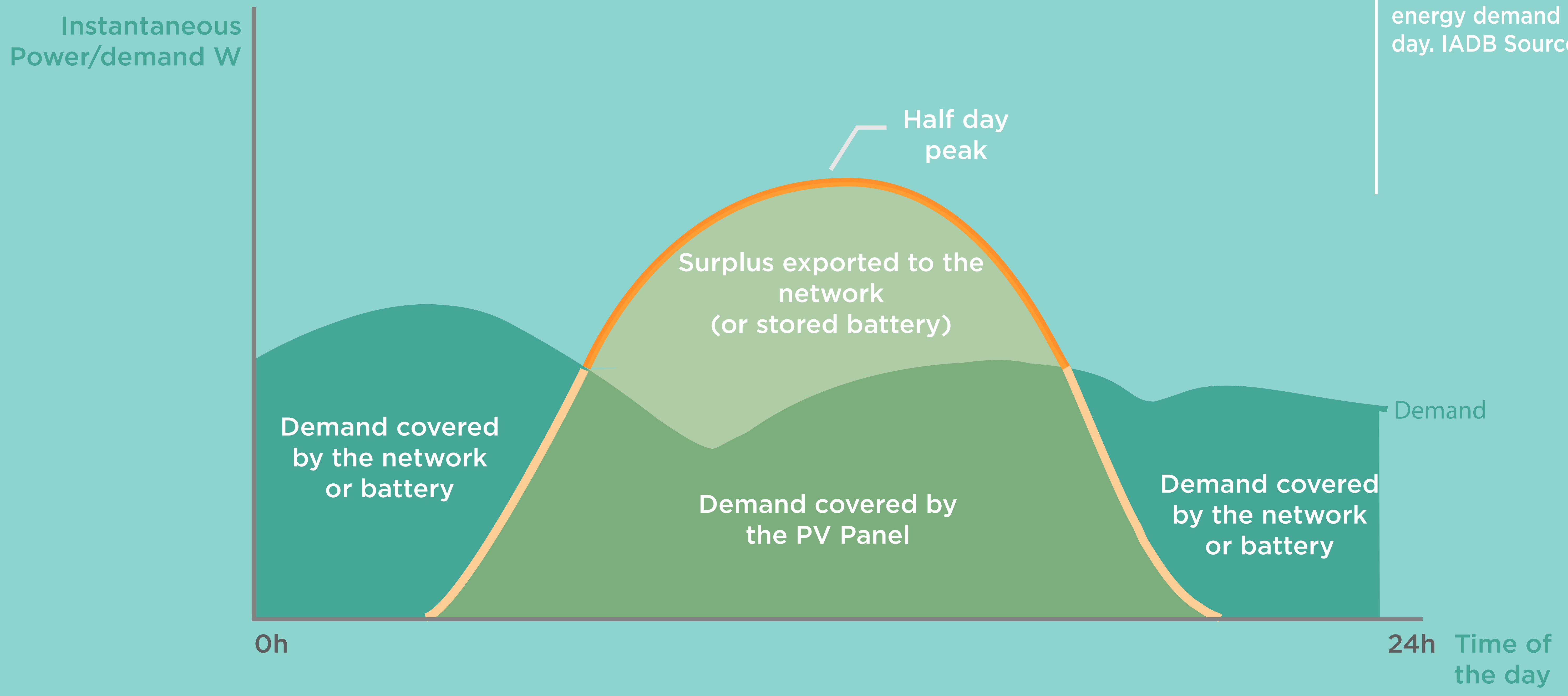


Figure 12: Relationship of energy demand during the day. IADB Source.

It is essential to verify whether there are laws of distributed energy generation in a country, in other words, if they allow the surplus of PV energy to be sold or returned to the electrical network. If there are no laws of distributed generation, the power of the panel should be limited to the maximum demand, in order never to export energy to the network, since it will not be compensated.

In that case, the power of the PV system should be equal to the maximum instantaneous demand. It means that the panel should be 1kWp, but only deliver that power at noon. The rest of the day, a piece would come from the network. Also, the PV system could not provide 100% of the energy, because it will be sized for the maximum demand.

If the system is not connected to the electrical network and stores energy in batteries, the operation is the same. The power of the panels usually is more significant than the sum of the demand loads because the temporary consumption must be considered.

EXAMPLE B

In a PV system connected to the network and, if possible, exports energy to the grid, it was determined that the annual demand is 6,000 kWh/year and estimated that the daily demand would be 16 kWh/day.

These 16kWh/day are not necessarily the sum of different devices since the devices are not all used at the same time. At that 16kWh/day could be reached, for example, with 1,000 W for 16 h, 2,000 W for 8 h, 4,000 W for 4 h, etc., or with any possible combination.

The consumption curve varies every minute, depending on what is turned on or off at a specific moment. The area under the demand curve represents the energy demanded.

Therefore, the size of the array of panels does not depend on the maximum power (instantaneous), but on the total energy demand (area under the curve).

When the PV system cannot export to the electrical network, it is recommended that the size of the panel be limited to the maximum demand of the system, which will depend on the charge controller.

The inverter must be able to deliver the necessary power in case all the devices are used simultaneously, so if the inverter is less than the sum of all the devices, the PV system will not work with the power or voltage for which it was designed.

M8

How to install Photovoltaic Systems?

+sun +light

After a professional determines the correct size, the installation stage of the photovoltaic (PV) system will begin. Although this process must always be done by an experienced professional, the user can observe, making sure it is done correctly.

This section will offer tests and verifications that the user can perform without security risks both for systems connected or not to the electrical network.

Photovoltaic Systems connected to the electrical network

The components of the PV systems connected to the network are: the PV panels and the inverter, as well as the cables and protection devices.

Photovoltaic Panels

PV panels are delicate pieces of hardware that must be handled and stored with care. Due to their glass surface, they should always be stored in suitable boxes and dry environments. If there are no suitable boxes available, they should be stacked vertically (and slightly inclined). During the installation process, the array of panels connection should be made in low sunlight or with the PV panels covered. After installation, ensure that the connectors are correctly connected, and the cables are sufficiently fixed to prevent excessive wear.

Inverter

The inverter is an electronic device that must also be stored with care. Any serious impact can damage the electronic components, which will prevent the inverter from functioning correctly. It must be stored in its original box in a dry and well-ventilated space until installed. You can also install the equipment directly on the wall, preferably, near the array of panels and the battery storage to avoid possible electricity leakage into the cables.

Protection Devices

The primary protection devices in PV systems are fuses, switches, circuit breakers, and surge protection devices (SPD). A professional must decide the proper size of all these devices, according to the electrical parameters of the system, such as current and voltage. All these devices must be installed in sealed and secure boxes. Another part of the protection system is the ground connection of electrical components and metal parts. All of the equipment must have a valid ground connection so that

the user has the highest safety. Since PV systems generally operate with DC voltages more significant than 50 VDC, arcs must be avoided, and batteries must not be short-circuited.

Cables

All parts of the PV system must be connected with cables of suitable caliber. A technician must determine the correct size/diameter of the cables based on the current and voltage of the system, as well as the environmental conditions. Since most cables will be in outside areas, they must be cautiously insulated. Appropriate pipes should be used depending on the conditions to which the cable will be subjected. Also, any contact between the cables with metal must be adequately insulated to avoid short circuits or accidents. Avoid bent cables during installation and avoid insulation damage.

Table 17 Equipment used in PV systems connected to the network.

Equipment	Description
Photovoltaic panels	PV panels are a fragile equipment that convert sunlight into DC (direct current) electricity. The panels can be connected and form arrays of panels to supply more energy.
Inverter	The inverter transfers the DC power of the panels into AC (alternating current) energy. This allows the PV system to power the AC appliances and at the same time inject power into the network.
Protection devices	Protection devices are security items used to protect both the user and the equipment. For PV systems, the most commonly used components are fuses and circuit breakers.
Cables	Cables are very important in PV systems because they are used to connect all the equipment. Different parts of the system require different types of cables due to their electrical properties.

Photovoltaic Systems not connected to the electrical network

As mentioned, the electrical components of the PV systems not connected to the electrical network are the PV panels, the battery storage, the charge controller and the inverter, as well as the protection devices and the cables.

Photovoltaic Panels

The PV panels are the same as those used for **Systems connected to the electrical network**.

Battery Storage

Batteries are especially dangerous devices due to their DC voltage and current levels. A short circuit in a battery can cause an explosion or fire. The most commonly used batteries in systems without a network connection contain chemicals that can leak if there is no cautious taken in the external part. All batteries should be treated as delicate parts and should be stored and handled correctly.

Batteries should be stored with their contacts covered and in ventilated and dry places to avoid dangerous short-circuit events. Once installed, the connections should be covered with insulating materials to prevent accidental touches. The battery storage should be connected somewhere near the array of panels to prevent voltage drops, but in a closed environment with controlled access exclusively to trained personnel. The batteries should also not be exposed to other components. In the case of smaller battery storages, the batteries can be installed in safety cabinets or compartments, provided they have adequate ventilation and access control.

Charge controller and inverter

The charge controller is a delicate part of the electronic equipment, just like the inverter, so it must be handled with caution. Any serious impact can damage electronic components preventing them from working correctly. Therefore, this equipment must be stored in its original box in a dry and well-ventilated space until installation. You can also install the material directly on the wall, preferably, close to the array of panels and the battery storage to avoid possible electricity leakage in the cables.

Protection devices

The protection devices are the same as those used for **Systems connected to the electrical network.**

Cables

The cables are the same as those used for **Systems connected to the electrical network.**

Table 18 | Equipment used in PV systems outside the network.

Equipment	Description
Photovoltaic panels	PV panels are fragile equipment that convert sunlight into DC (direct current) electricity. The panels can be connected and form arrays of panels to supply more energy.
Battery storage	The batteries are used to store the energy generated by the array of panels. The batteries can be connected to form a battery storage.
Charge controller	The charge controller controls the charging voltage of the battery storage.
Inverter	The inverter transfers the DC power of the panels into AC (alternating current) energy, allowing the PV system to control the AC appliances and at the same time injecting power into the network.
Protection devices	Protection devices are security items used to protect both the user and the equipment. For PV systems, the most commonly used components are fuses and circuit breakers.
Cables	Cables are very important in PV systems since they are used to connect all the equipment. Different parts of the system require different types of cables due to their electrical properties.

Security measures

The installation of PV systems is an activity that, if not carried out correctly, can cause a low performance of the system and damage or event death to people in charge of the installation or to users.[18]

The installation of a PV system must always be carried out by a trained professional or under a personal supervision. People who do not have the proper training should refrain from working directly on the installation but can at least observe and see if the system is being installed correctly.

The installers must know the corresponding rules and procedures, as well as comply with the following safety recommendations:

» Use suitable equipment for personal protection such as gloves, helmets, goggles and protective clothing.

» Use the appropriate equipment, making sure that the tools are dry, isolated and the devices well calibrated..

» Always work in teams of two or more for greater safety at work.

» Appropriately isolate the work area, so the outside area is not at risk of receiving an electric shock.

Storage and handling of photovoltaic panels

Although PV panels were created to withstand extreme environmental conditions for many years, they can be damaged if stored, handled or improperly installed. The following are recommendations for storing, handling and installing PV panels:

» Keep the PV panels in their packaging until the moment of installation.

» PV panels must be supported with both hands.

» Do not place PV panels on hard floors or supported by their edges or borders.

» Keep electrical contacts clean and dry.

» Do not step on the PV panels.

When installing the PV panels and their mounting systems, the manufacturer's instructions must be followed so that the product warranties are valid.

Most PV panels are glass sheets wrapped in an aluminum frame, which provides the mechanical support for the sheet and is a means of fixing the PV panel. Usually, clamps are used to fix the frames of the PV panels in their supports.

18 In the case of projects financed with funds from the Inter-American Development Bank, these security measures must be incorporated into the corresponding bidding documents to be carried out by the contractor.

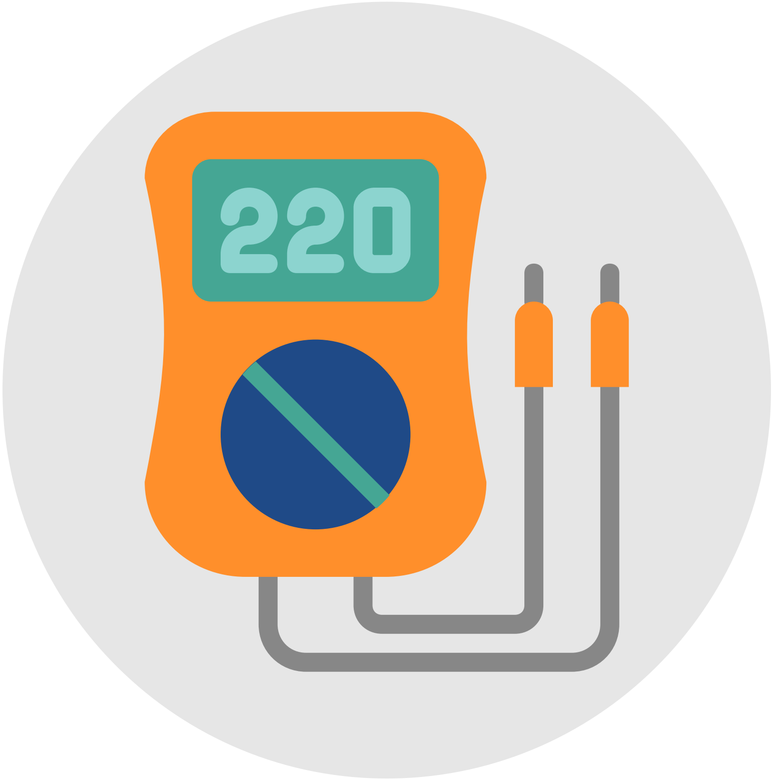
It is imperative to install the appropriate clamps for the PV panels used and apply the proper torque. Thus, the clamps will remain firmly in place without improperly compressing the PV panel, which may cause damage to it.

Installation standards[19]

The PV installations connected to the network generally require specific authorizations for the installation and operation of the corresponding public local electrical network, which must be consulted in all cases before installing the system.

The rules apply not only to guarantee the safety of the installer but also of the future users of the system. It also applies in cases where there is no electrical network, and PV systems are installed without connection to the electrical network.

Table 19 shows a summary list of international standards and procedures that installers must follow to ensure system[20] performance and safety.



19 In the case of projects financed with funds from the Inter-American Development Bank, the installation regulations must be incorporated into the corresponding bidding documents so that they can be carried out by the contractor.

20 As of April 2018, there are no international standards for lithium batteries.

Table 19 | Important international standards for PV systems applications

Standard	Title	Short description
IEEE Std 937-2007	Practices recommended by the Institute of Electrical and Electronics Engineers (IEEE) for the installation and maintenance of lead acid batteries for PV systems.	This standard offers design considerations and procedures for storage, installation, assembly, ventilation and maintenance of secondary lead-acid batteries for PV energy systems. It also includes safety precautions and instrumentation considerations. Although it covers general recommended practices, battery manufacturers can offer specific instructions for installing and maintaining batteries.
IEEE Std 450-2010	Practices recommended by the IEEE for the maintenance, testing and replacement of lead acid batteries with ventilation for fixed applications.	This standard provides maintenance considerations, testing schedules and testing procedures that can be used to optimize the life and performance of permanently installed lead-acid batteries used for emergency service. These best practices also provide guidelines for determining when batteries should be replaced. These recommended practices are used in fixed emergency service applications in which a charger keeps the battery fully charged and supplies the DC loads.
IEC TS 62257-1:2015	Recommendations for renewable energy and hybrid systems for rural electrification - Part 1: General introduction to the IEC 62257 series and rural access to electricity.	IEC TS 62257-1: 2015 (E) shows a methodology to implement rural electrification using autonomous hybrid systems of renewable energy. It also provides a guide that helps facilitate the reading and use of the IEC 62257 series to configure decentralized rural electrification in developed or developing countries. The IEC 62257 series includes: - Parts 2 to 6 of the standard: methodological procedures for the administration and implementation of projects. - Parts 7 to 12 of the standard: technical specifications for individual or collective systems and the associated components.
IEC TS 62257-2:2015	Recommendations for renewable energy and hybrid systems for rural electrification - Part 2: From requirements to a series of electrification systems.	IEC TS 62257-2: 2015(E) proposes a methodology for configuring and carrying out socio-economic studies as part of the framework of decentralized rural energy projects. Standard dedicated to groups of projects and specifically to specialists in charge of socio-economic studies in international projects. This specification also offers some technical solutions that can be recommended, depending on the qualitative and quantitative demands of energy, depending on the needs and the economic situation of the clients.

Standard	Title	Short description
IEC TS 62257-3:2015	Recommendations for renewable energy and hybrid systems for rural electrification - Part 3: Project development and administration.	IEC TS 62257-3: 2015 (E) provides information on the responsibilities related to the implementation of rural electrification systems. More specifically it deals with: - Contractual relationships to be built between the different counterparts of a project. - Important tests to be applied to the hybrid electrification and renewable energy systems. - Principles of quality control to be implemented. - Requirements for recycling and environmental protection.
IEC TS 62257-4:2015	Recommendations for renewable energy and hybrid systems for rural electrification - Part 4: Selection and design of the system.	IEC TS 62257-4: 2015 (E) offers a method to describe the results expected with the electrification system regardless of the technical solutions that can be implemented. The purpose is to offer a method to help contractors and project authors to select and design the electrification system for remote locations observing identified needs, such as those described in IEC TS 62257-2.
IEC TS 62257-5:2015	Recommendations for renewable energy and hybrid systems for rural electrification - Part 5: Protection against electrical hazards.	IEC TS 62257-5: 2015 (E) specifies the general requirements for the protection of people and machines against electrical hazards for application in decentralized rural energy systems. The requirements for protection against electric shock are based on the basic rules of the IEC 61140 and IEC 60364 standards. The decentralized rural energy systems are designed to supply electric power in places that are not connected to an interconnected system or a national network, in response to basic needs. Among these places, we can mention remote homes and rural houses, as well as services for communities and economic activities.
IEC TS 62257-6:2015	Recommendations for renewable energy and hybrid systems for rural electrification - Part 6: Approval, operation, maintenance and replacement.	IEC TS 62257-6: 2015 (E) describes the various norms that must be applied for the approval, operation, maintenance and replacement of decentralized rural energy systems designed to supply electrical power in places that are not connected to a significant interconnected system or a national network, in response to basic needs. This technical specification proposes a methodology to achieve the best technical and economic conditions for approval, operation, maintenance and replacement of equipment and the life cycle of the complete system.
IEC TS 62257-7-1:2010	Recommendations for small hybrid and renewable energy systems for rural electrification - Part 7-1: Generators - Photovoltaic generators.	IEC TS 62257-7-1: 2010 (E) specifies the general requirements for the design and safety of generators used in decentralized rural electrification systems. Defines the requirements for low voltage and extra-low voltage PV structures. It is important to use caution with the voltage level for safety reasons and for the fact that it influences the protection measures and the operator level of skills.

Standard	Title	Short description
IEC TS 62257-7-3:2008	Recommendations for small hybrid and renewable energy systems for rural electrification - Part 7-3: Generator set - Selection of generator sets for rural electrification systems.	IEC TS 62257-7-3: 2008 (E) specifies the general requirements for selecting, sizing, constructing and operating generator sets in decentralized rural electrification systems. It applies to all low-voltage electricity generating sets, with combustion engines, with a rated power of up to 100 kVA and designed to supply electrical power in remote locations, used in systems in accordance with IEC / TS 62257-2.
IEC TS 62257-1:2007	Recommendations for small hybrid and renewable energy systems for rural electrification - Part 8-1: Selection of batteries and battery monitoring systems for autonomous electrification systems - Specific case of wet lead acid batteries for automobiles, available in developing countries.	It proposes simple and economical comparative tests for a panel of wet lead acid batteries for automobiles, the most satisfactory model for individual PV electrification systems.
IEC TS 62257-9-1:2016	Recommendations for hybrid and renewable energy systems for rural electrification - Part 9-1: Integrated systems - Micro = energy systems.	IEC TS 62257-9-1: 2016 (E) defines the general requirements to design, build and operate micro-energy plants and the general conditions to provide security for people and goods. The micro-energy plants covered by this specification are low-voltage, three-phase or single-phase alternating current (AC), with a nominal capacity less than or equal to 100 kVA.
IEC TS 62257-9-2:2016	Recommendations for hybrid and renewable energy systems for rural electrification - Part 9-2: Integrated systems - Distributed generation.	IEC TS 62257-9-2: 2016 (E) specifies the distributed generation composed of high lines for technical and economic reasons in the context of decentralized rural electrification. The distributed generation covered by this part of IEC 62257 is a low-voltage, three-phase or single-phase alternating current (AC) with a nominal capacity less than or equal to 100 kVA. It is fed by a single power plant of distributed generation.
IEC TS 62257-9-3:2016	Recommendations for hybrid and renewable energy systems for rural electrification - Part 9-3: Integrated systems - User interface.	IEC TS 62257-9-3: 2016 (E) specifies the general requirements to design and implement the interface equipment in the user's installation that connects to the distributed generation network or the generating part of an autonomous system. It is applied to simplified user interfaces (distribution board) in electrical installations with a maximum power of 500 VA in decentralized rural electrification systems.
IEC TS 62257-9-4:2016	Recommendations for hybrid and renewable energy systems for rural electrification - Part 9-4: Integrated systems - User installation.	IEC TS 62257-9-4: 2016 (E) specifies the general requirements for the design and implementation of a user installation. It is applied to single-phase electrical installations of the user with a maximum power of 500 VA in decentralized systems of rural electrification. It refers to facilities powered by a distributed AC generation network and to installations that comprise its power plant with a single distributed generation unit of AC or DC.

Standard	Title	Short description
IEC TS 62257-9-6:2008	Recommendations for small hybrid and renewable energy systems for rural electrification - Part 9-6: Integrated system - Selection of individual photovoltaic electrification systems (FV-IES).	IEC 62257-9-6: 2008 (E) proposes a simple selection procedure and comparative economic tests that can be carried out in developing countries laboratories to identify the most suitable model of small individual PV electrification systems (FV-IES) of up to 500 Wp for a specific rural electrification project of a series of products sent for testing. The tests specified in IEC 62257-9-6 allow an evaluation of the FV-IES performance according to the requirements of the general project specification (refer to IEC / TS 62257-2) and verification of its capacity to supply the necessary service.
IEC 62109-1:2010	Power inverters safety for use in photovoltaic energy systems - Part 1: General Requirements.	IEC 62109-1: 2010 (E) is applied to the power conversion equipment (PCE) for use in PV systems where a consistent technical level concerning safety is required. It defines the minimum requirements to design and manufacture power conversion equipment (PCE) for protection against electric shock, energy, fire, mechanical risks, and others. It also defines the general requirements applicable to all types of PCV FV.
IEC 62109-2:2011	Power inverters safety for use in photovoltaic systems - Part 2: Specific requirements for converters.	IEC 62109-2: 2011 covers the specific safety requirements applicable to DC and AC converters and products that, among others, perform converter functions, in which the converter is intended for use in PV energy systems. The inverters included in this standard can be interactive converters with the network, autonomous or multiple, powered by one or several PV panels grouped in various configurations of the arrangement of panels and they can be intended for use in conjunction with batteries or other forms of energy storage. This standard should be used in conjunction with IEC 62109-1.
IEC 61000-6-1:2016 RLV Versión límite	Electromagnetic Compatibility (EMC) - Part 6-1: Generic Standards - Immunity standard for residential, commercial and light industry environments.	The IEC 61000-6-1: 2016 standard for EMC immunity requirements applies to electrical and electronic equipment intended for use in public, residential, commercial and light industry environments. The immunity requirements are defined in the frequency range from 0 Hz to 400 GHz. It is not necessary to carry out tests with frequencies in which the conditions were not specified.

Standard	Title	Short description
IEC 62485-2:2010	Safety requirements for the installation of the main battery and secondary batteries - Part 2: Fixed batteries.	IEC 62485-2: 2010 standard applies to the installations of the main battery and the fixed secondary batteries with a maximum voltage of DC 1500 V (nominal) and describes the primary measures of protection against the risks caused by: » electricity. » gas emissions. » electrolytes. This international standard defines the requirements on safety aspects related to construction, use, inspection, maintenance, and disposal. It refers to the batteries of lead-acid and NiCd / NiMH.
IEC 61724-1:2017	Performance of the photovoltaic system - Part 1: Supervision.	IEC 61724-1: 2017 (E) defines the equipment, methods, and terminology to analyze and monitor the performance of PV systems. It refers to sensors, facilities, and the precision to control the machine, in addition to the acquisition of data of the measured parameters and quality checks, calculated parameters and performance measurements. Also, it serves as a basis for other standards regarding the data collected.
IEC TS 61724-2:2016	Performance of the photovoltaic system - Part 2: Capacity assessment method.	The standard IEC TS 61724-2: 2016 (E) defines a procedure to measure and analyze the energy production of a specific PV system, with the objective of evaluating the quality of the performance of the photovoltaic system. This test should be applied for a relatively short period (some days with too much sun). The objective of this document is to specify a systematic procedure to compare the energy produced measured with the energy expected in a PV system on days with enough sun.
IEC TS 61724-3:2016	Performance of the photovoltaic system - Part 3: Energy evaluation method.	IEC TS 61724-3: 2016 (E) defines a procedure to measure and analyze the energy production of a specific PV system compared to the expected energy production for the same system under real-time conditions as determined by those interested in the test. The production of energy is characterized specifically for the periods in which the system is working (available). The periods in which the system is not working (unavailable) are quantified as part of an availability measurement. The objective of this technical specification is to define a procedure to compare the measured electrical energy with the electric power expected from the PV system.

Source: All standards are found on the IEC and IEEE.

M9

How to operate and maintain Photovoltaic Systems?

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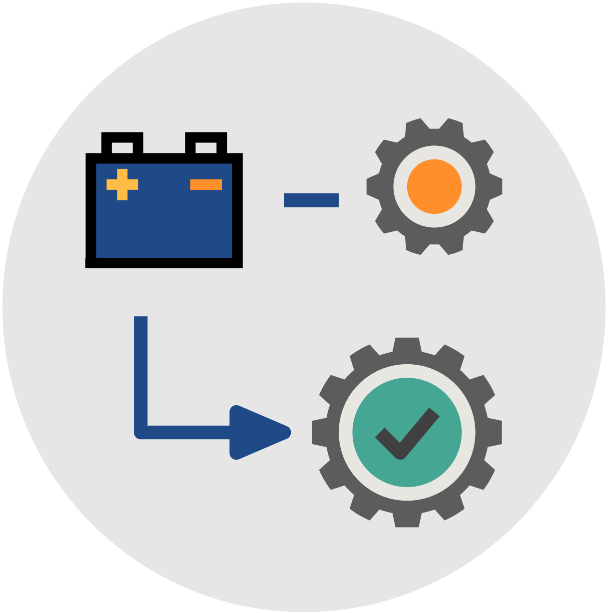
The operation and maintenance of the photovoltaic (PV) systems is a fundamental element in guaranteeing the durability and performance throughout the useful life for which the system was designed.

Although some tasks must be carried out by trained personnel, some significant actions can be carried out by any everyday user of the system.



Operation

The operation of PV systems is mostly automatic, which means that user interference is not necessary when the system is operating correctly. Usually, the inverter has a digital screen that allows the user access to essential data about the results of the system.

A good habit is to regularly check the inverter data to see if the information matches with what was expected. Users should verify with the installers the expected levels of voltage, current, power, and energy.

It is possible to check weekly the output values of the system, making sure that it works correctly.

If any anomaly is found, it must be reported to the technical service or trained maintenance personnel.

Maintenance

The adequately designed and installed PV installations work without problems with minimal maintenance, which can even be done by people in the community with some minimum training. However, more specific activities such as replacement or solution of breakages must be carried out by qualified personnel.

A complete failure does not commonly occur in PV systems connected to the electrical network. When appropriately sized and installed, PV systems connected to the network work well for many years and possible failures are usually solved with simple repairs. Periodic maintenance is required to ensure that the PV system works as expected in the long term. Maintenance helps identify and avoid potential problems that may affect performance.

Before carrying out any maintenance procedure, the system must be disconnected from any load or network using a switch or circuit breaker.

The maintenance activities carried out correctly are also essential to ensure that, once installed, the components of the system maintain the manufacturer's guarantees, which are generally from 25 to 30 years for PV panels and from 5 to 10 years for inverters.

The main maintenance activities are:

Cleaning

Cleaning is the primary maintenance activity.

In the case of PV panels, it is necessary to periodically check and clean the glass surface of the panels, dust, leaves, branches, bird droppings, insects or soil, etc. The cleaning of the panels must be done with water, and in case any adhering element must be removed, soap can be used.

It is advisable to carry out this activity when the sun is not at its maximum irradiation so as not to affect the functioning of the system.

In the case of batteries, cleaning should be done at least once a month, with special care not to carry metallic elements in the hands, such as rings or bracelets, which may come into accidental contact with the poles of the batteries.

Visual inspection

The visual inspection can be carried out by any user and, when finding any anomaly, the specialized personnel should be contacted.

Table 20 summarizes some visual inspection activities that must be performed on the components of the PV system.

Table 20 | **Visual inspection procedures for PV systems.**

Photovoltaic system component	Visual inspection
Photovoltaic panels	Verification of physical damage: » Curved frames or with corrosion. » Broken glass or cracks or other physical defects.
	Check for cleaniness.
Inverter and charge controller	Verify if there is an error message.
Batteries	Check for rusty parts in the battery, swollen cabinets and leakage of chemical liquids.
Cables and connectors	Check the conditions of the cables and connectors, verifying if there is physical damage that may be caused by weather or insects and rodents.

Electrical tests

It is imperative to request the help of experienced professionals to carry out maintenance activities that involve electrical tests.

Repairs

Repairs must also be carried out by experienced professionals, and under no circumstances it is advisable to regular users to open boxes or covers of system components.

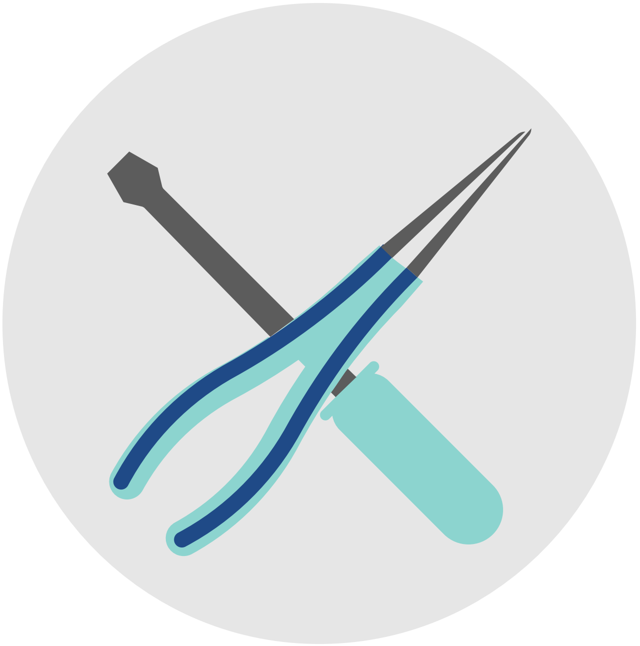


Table 21 | **Visual inspection procedures and recommended measures for PV systems.**

Photovoltaic system component	Visual inspection	Action
Photovoltaic panels	Verify physical damage: - Curved frames or with corrosion. - Broken glass or cracks or other physical defects.	Replace the damaged PV panel.
	Check for cleaniness.	Clean the PV panels with damp cotton cloth (using only water).
Inverter and charge controller	Verify if there is an error message.	Check the manufacturer's instructions for the meaning of this error message and request assistance from a specialized professional if necessary.
Batteries	Check for rusty parts in the battery, swollen cabinets and leakage of chemical liquids.	Replace the damaged battery storage.
Cables and connectors	Check the conditions of the cables and connectors, verifying if there is physical damage that may be caused by weather or insects and rodents.	Replace damaged components and perform corrective actions on connectors that are not properly connected.

Replacement

Replacement in the case of failure

Table 21 incorporates into Table 20 some suggestions for reparation measures, which must be evaluated by a professional before being carried out.

Programmed replacement

PV systems are composed of many elements with different life cycles. Therefore, it is essential to consider the replacement of some components during the life cycle of the entire system. Table 2 summarizes the life cycle of the main components of the PV system.

Final disposal of the components

Generally, PV cells can be reused and exchanged when they are damaged in a PV panel. Also, in some countries, some companies recycle PV panels once they reach their useful life, since their main components are glass and metal. However, recycling technology is not yet widespread or easily accessible.

If it is not possible to recycle the panels, once a PV panel has reached its useful life, it is necessary to dispose of it carefully since its elements can cause damage (mainly glass) and some of its components are classified as hazardous waste. Some countries classify as industrial, hazardous or electronic material waste[21].

Regarding batteries, the other main component of PV systems must be removed by a company with a corresponding environmental license once they have reached their useful life. Meanwhile, they should not be out in the open, but in a covered space, and in a container that avoids the possible leakage of liquids. They should not be disposed in the household trash or have their contents emptied out.

The most recommended option is that if there is a company that carries out the periodic maintenance of the system components, the service contract establishes that it must withdraw and take over the components of the system once they have reached their useful life.

21 IRENA. (2016). End-of-life management: Solar photovoltaic panels.

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Practical guide for the implementation of photovoltaic systems in social infrastructure projects

Mauro Passos – Arturo Alarcon – Wilhelm Dalaison

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