SOLAR PV APPLICATION AND DESIGN

Trainer

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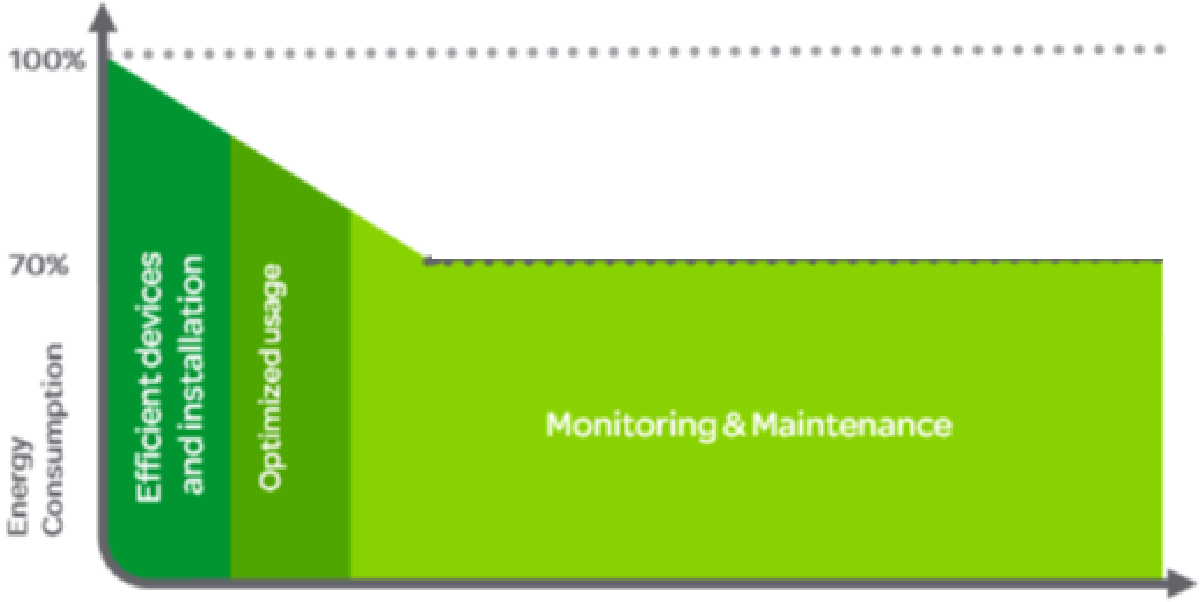
About the Training

- **Overall objective** is to equip participant with the knowledge required to
  - size and design basic solar PV system
  - stand-out in recruitment processes when seeking employment from solar energy companies, and
  - a step further into establishing your own solar energy business

- The **feedback** of the participants will be considered and the training material can be modified or new slides may be added. At the end of the training, participants will get the modified material.

- Please don't be formal and cooperate actively. Your feedback is highly welcome.

Concept of Sustainable Energy



Less energy via energy efficiency gains, and

Greener energy via promotion of renewables

Energy

- The word energy has its origins in the Greek word ENERGIA
  - ✓ activity, drive, vigor, force, power strength

- It is the capacity to perform work or heating or cooling

- Energy is one of the most important concepts of natural sciences. Nevertheless it is very difficult to define it in few words

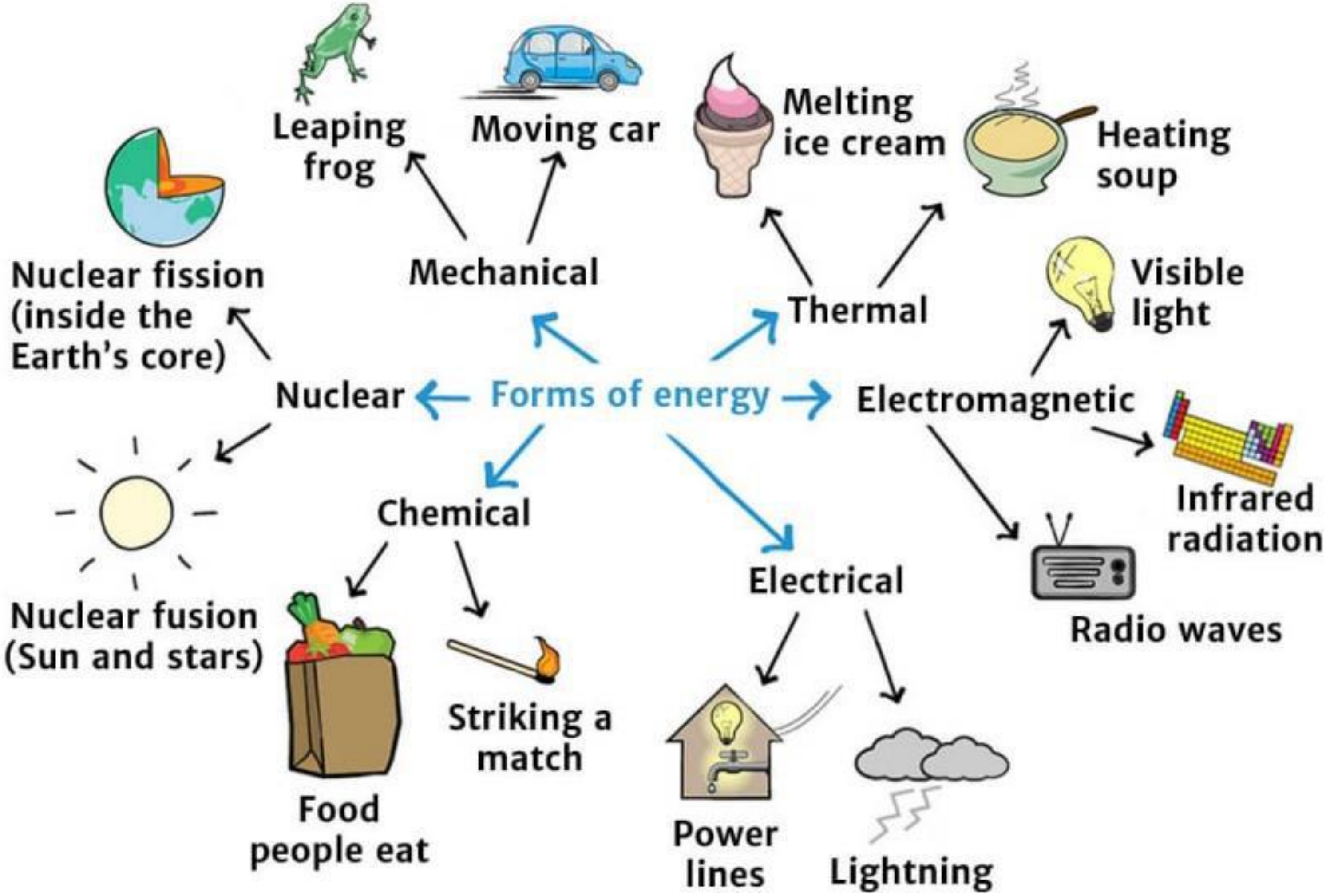
Needs for Energy

Basic needs

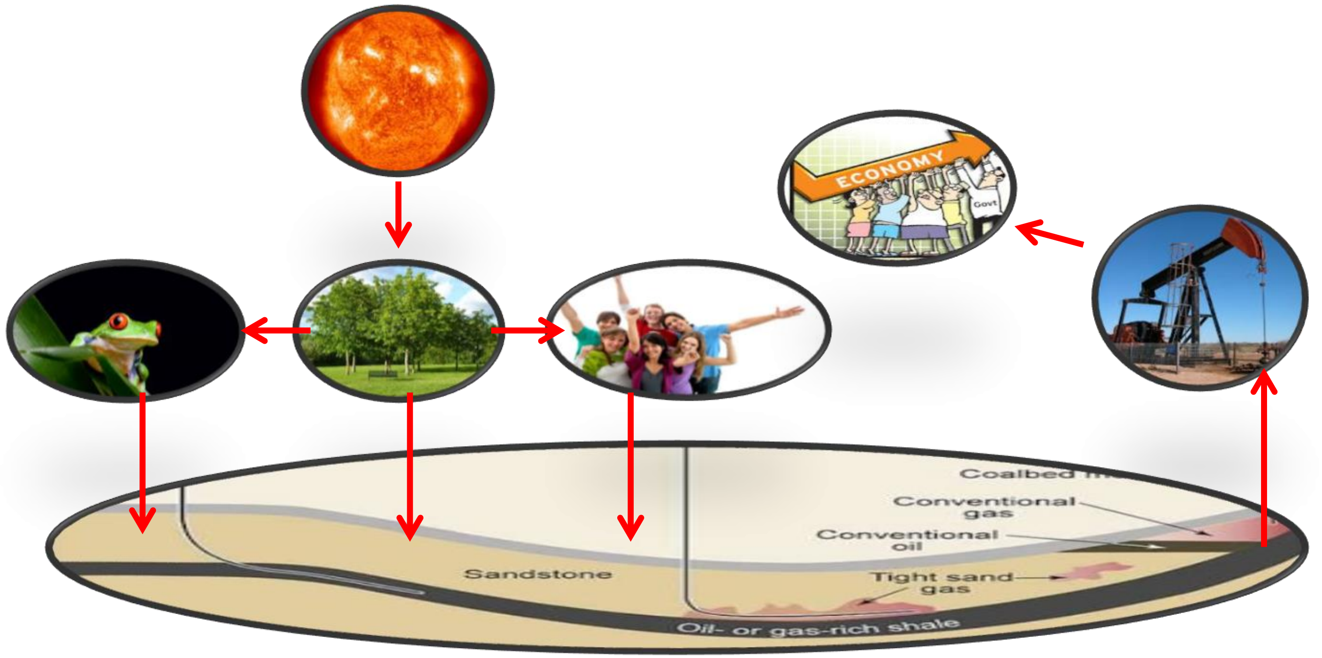
- Preparation of food
- Heating and cooling
- Personal hygiene
- Light
- Work

- Needs in the industrial society
  - Production
  - Transportation
  - Goods
  - Commodities

Forms of Energy



Energy Sources and Law of Energy Conservation



- Energy does not remain in the same form always. To cause change, energy itself changes from one form to another. During changes, energy is always conserved, i.e., it is not created anew nor destroyed; this is known as the law of energy conservation
- In other words, the law of energy conservation states that “energy cannot be created or destroyed but can be converted from one form to another.

Energy and Power

Energy is capacity to do work

Energy = Force x Distance

J (Joule) = N (Newton) x m (meter)

Power = Energy / Time

W (Watt) = J (Joule) / s (second)

Energy = Power x Time

J (Joule) = W (Watt) x s (second)

Energy and Power Units

- **Energy**
  - **Joule:** One Newton over a distance of 1 m. 1J = 1Nm
    - Joule is the unit of thermal energy
  - Amount of watts in one hour **(kWh)**
  - Power x Time
- **Power**
  - **Rate of energy** (when one ampere is pushed by one volt)
  - Power (W) = Voltage (V) x Current (I)
  - How fast energy is used
  - **Watt:**1 J/s
  - 1 kWh = 3,600 kJ = 3.6 MJ = 0.0036 GJ

Exercise

- What is the cost of 5 kW continuous operation in a year?

  365 days * 24 h = 8760 h/year

  Cost of electricity: 0.1 USD/kWh

  → 5 kW * 8760 h = 43,800 kWh/y

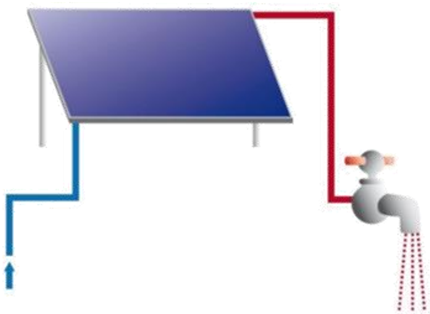
  → 43,800 kWh/y * 0,1 USD = 4,380 USD

SOLAR PV APPLICATION AND DESIGN

Introduction to the course

- **Photovoltaics (PV)** is the technology which generates **electricity** directly from sunlight via the photoelectric effect.
- The photovoltaic module, which is made up of photovoltaic cells, transforms solar energy into DC electricity. Another solar energy technology is solar thermal. **Solar thermal** uses solar energy to generate **heat** rather than electricity.

Photovoltaics



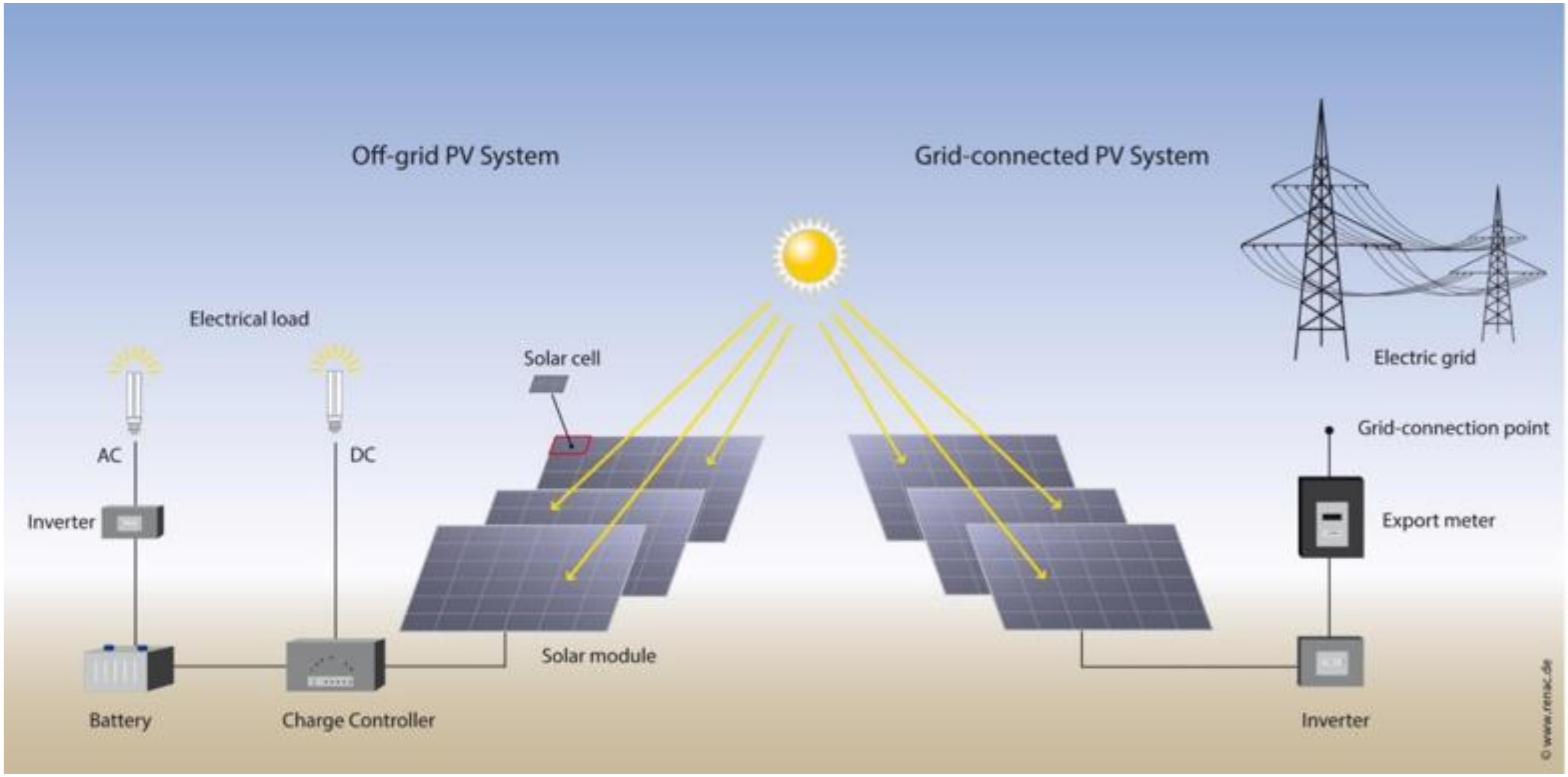
Solar Thermal

- It is important to make a clear distinction between these two very different technologies which are often confused since they use the same energy source (solar radiation).
- The electricity generated using PV can be fed into the electricity grid, stored in batteries for later use, or used directly. As of 2018, the **total global installed PV capacity** was approximately 390 GW.

Introduction to the course

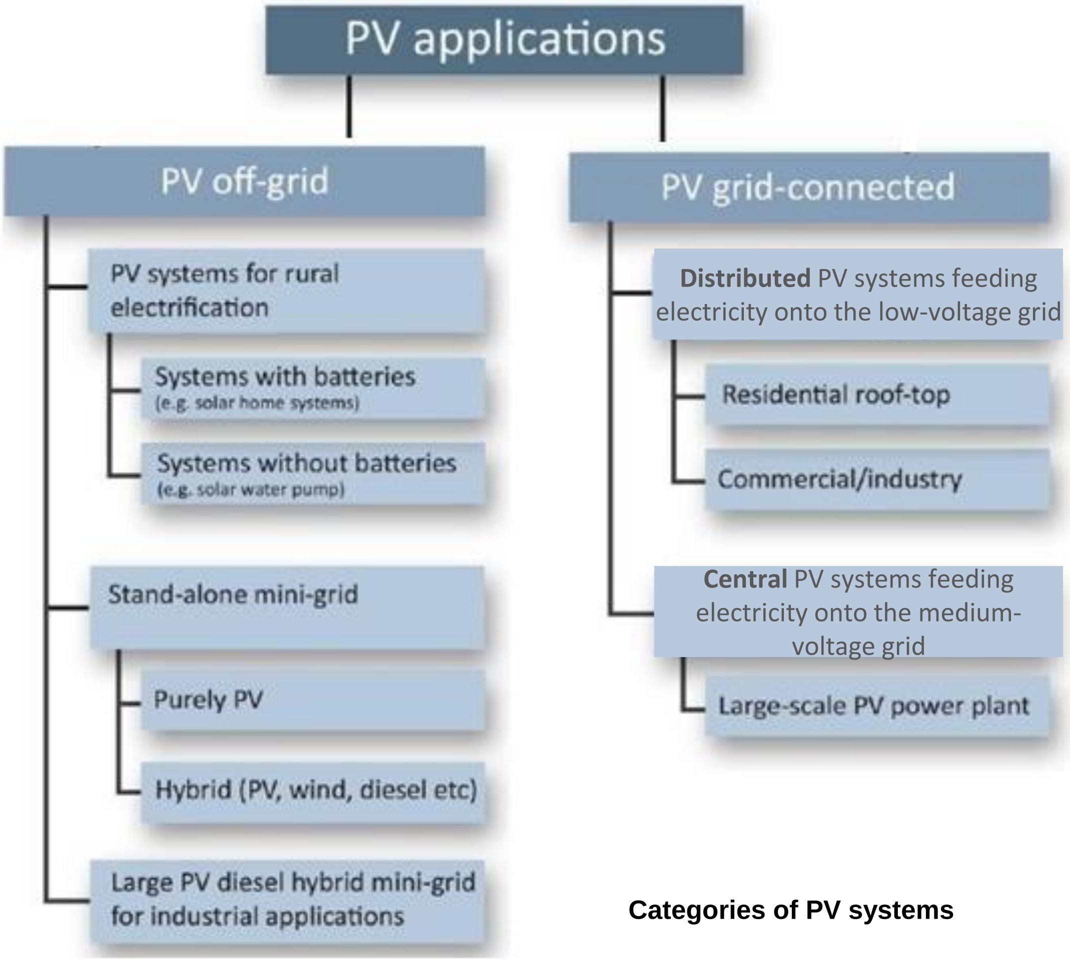
Residential grid-connected PV system (large array) and single solar thermal collector below PV array on a roof in Germany

Off-Grid PV System and Grid-Connected PV System



Overview of off-grid (left) and grid-connected (right) PV systems.

PV System Applications



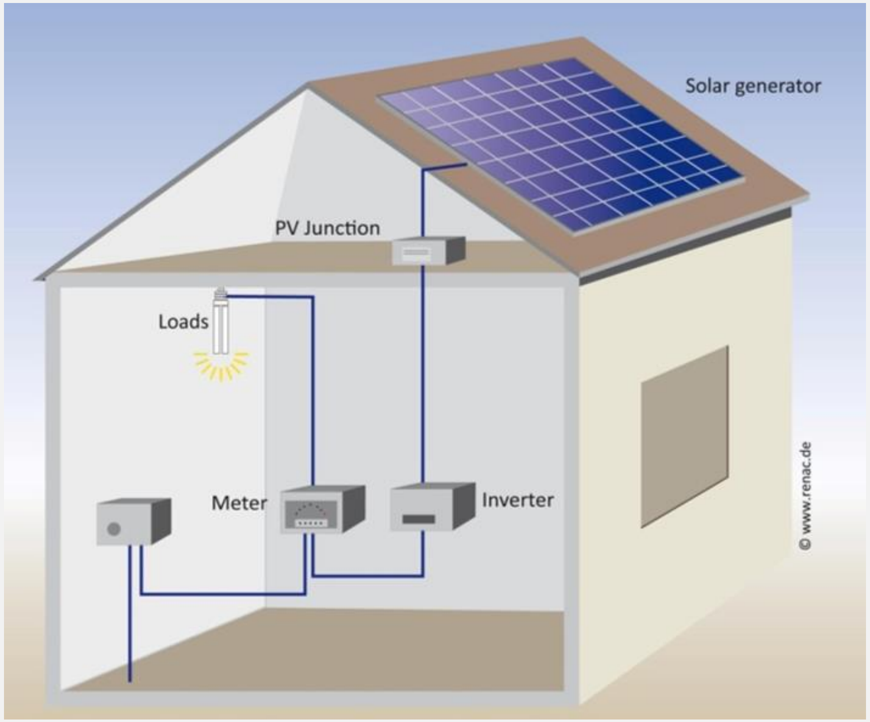
Categories of PV systems

Source: RENAC

Grid-connected configuration

1. Distributed PV systems

- Can have various sizes and will be located at different points in a central electricity grid. Distributed systems are typically constructed on residential, commercial or industrial buildings. Systems on residential buildings are usually small roof-top systems generating electricity for private consumption or for sale to the electricity utility.
- Systems on commercial or industrial roofs are also used to either offset on-site electricity consumption or to sell electricity to the utility. However, commercial/ industrial systems are often much larger than residential systems. Distributed systems are usually connected to the low voltage distribution grid.
- In all grid-connected systems, the PV array (sometimes referred to as solar generator, see figure “Typical residential PV system”) generates DC electricity and is connected via junction boxes to an inverter, which converts the direct current (DC) into alternating current (AC). The inverter output is connected to a meter which records the amount of energy being fed into the grid.



Typical residential PV system

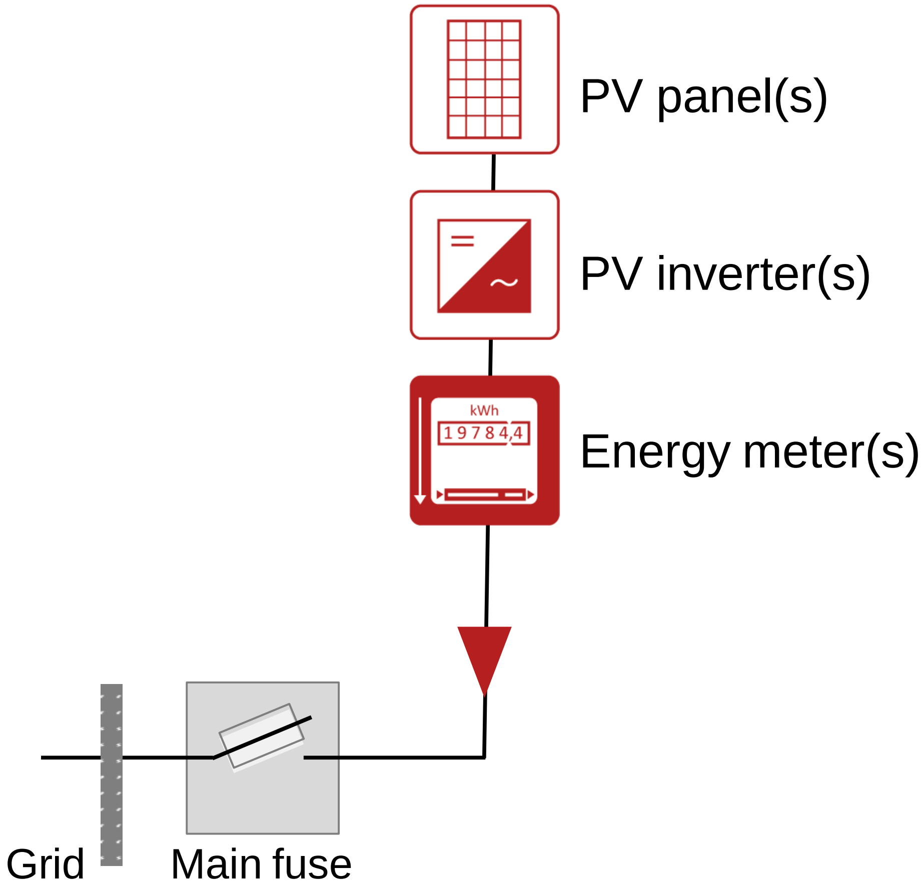
Grid-connected configuration

2. Central PV systems

Are also known as solar farms, solar parks or utility-scale PV systems. Large-scale PV power generation is concentrated at one specific location. Such plants can take up large areas of land and feed directly into the electricity grid. The configuration of such plants is more comparable to conventional power plants, producing 3-phase power. They are connected to medium or high voltage transmission networks.

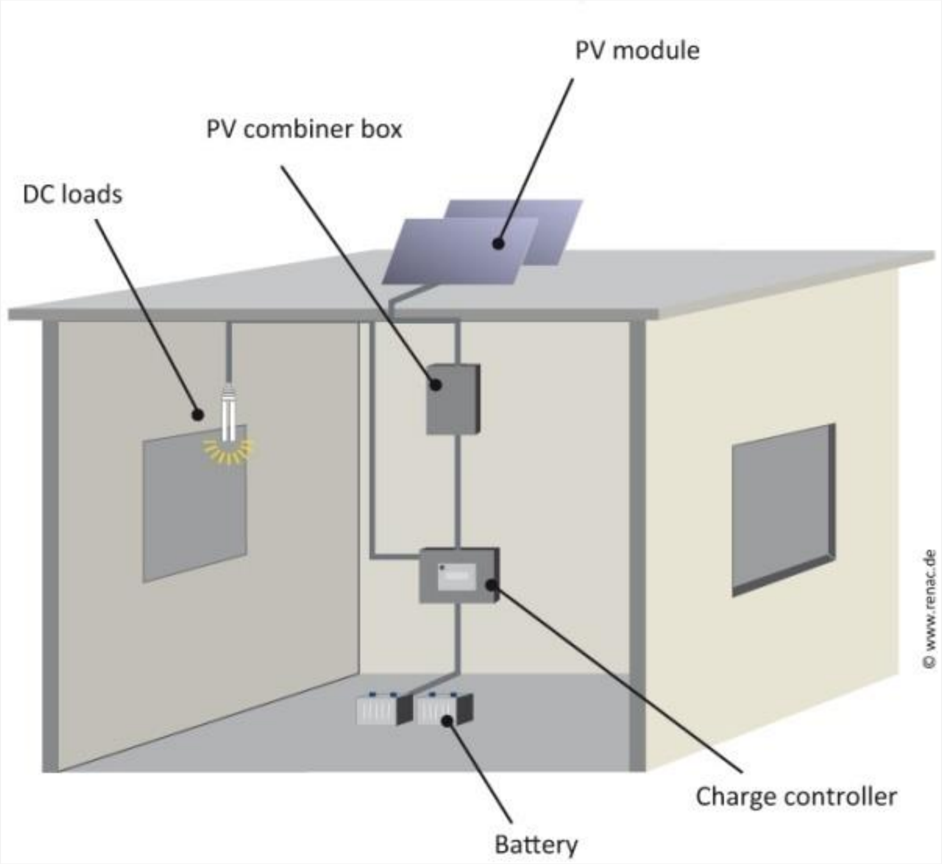
Solar farm in Germany (PV tracking system)

Schematic of a grid-connected PV-system



Off-grid configuration

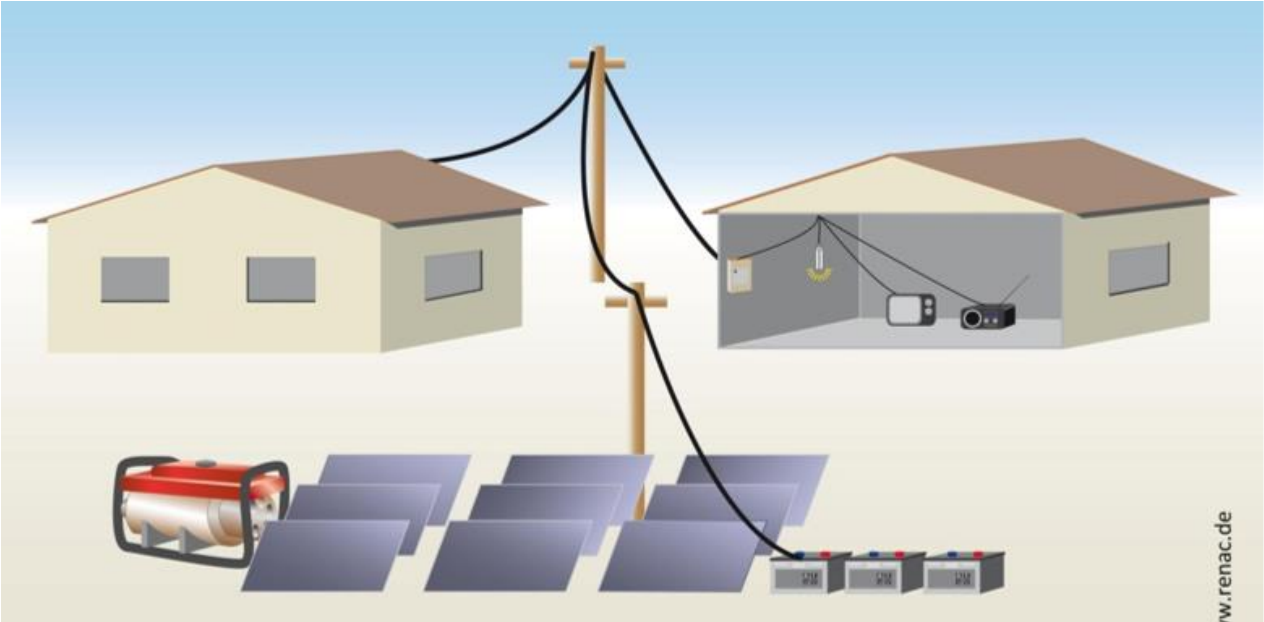
- **Off-grid PV systems** are not connected to the electricity grid. They are also called **stand-alone PV systems**. The electricity produced is consumed very close to the location where it is generated. Off-grid systems usually incorporate battery storage so that electricity can be supplied even when the sun is not shining. **Solar water pumping systems** are a major exception to this.
- Off-grid systems are usually found at locations where there is no electricity grid available.
- The system components differ from grid-connected systems and the array size is typically much smaller, especially for small off-grid applications like **solar home systems**.
- The PV modules are connected to a **charge controller** which regulates the charging and discharging of the batteries. Only DC power is supplied.
- Many of these systems also have inverters (connected directly to the batteries) which supply AC power.



Typical off-grid PV system (solar home system)

Off-grid configuration

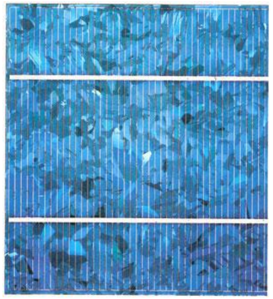
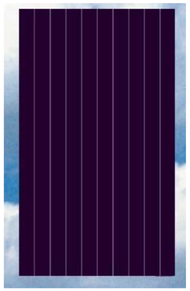
- **Micro- and mini-grids** are basically small electricity grids providing electricity to, for example, a small island or a remote building complex or village.
- Here we are classifying them as off-grid systems. They usually have back-up power sources, most commonly a diesel generator. Some larger micro- and mini-grid systems do not have battery storage.
- Electricity is typically produced and stored at a central point from which it is distributed (at AC grid voltages). A range of types and configurations are possible.



Micro/mini-grid set-up

COMPONENTS OF A PV SYSTEM

Overview of PV Cell type

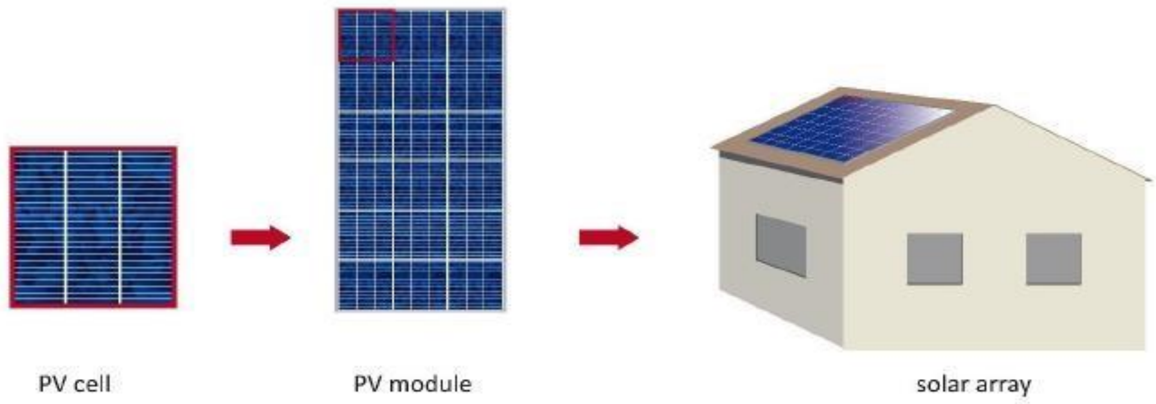
  

Characteristic	Si-wafer based (poly)	Si-wafer based (mono)	Thin film (CdTe)
Panel efficiency	up to 18%	up to 22%	up to 17%
Power temperature coefficient (%/°C)	-0.40 to -0.50	-0.35 to -0.45	-0.25 to -0.35
Market share	**62%**	33%	5%

Sources: RENAC Research

- The PV cell is the core component of a PV system since it generates the electricity. There are many different types of PV technologies, but the market is dominated by crystalline silicon (c-Si) based PV cells.
- Nearly 80% of the cells on the market are c-Si based cells, either monocrystalline or polycrystalline. The remainder of the market is taken by thin-film (amorphous silicon, CdTe and CIGS) modules.
- Selected technical characteristics of silicon wafer based and thin-film solar panels:

PV Modules

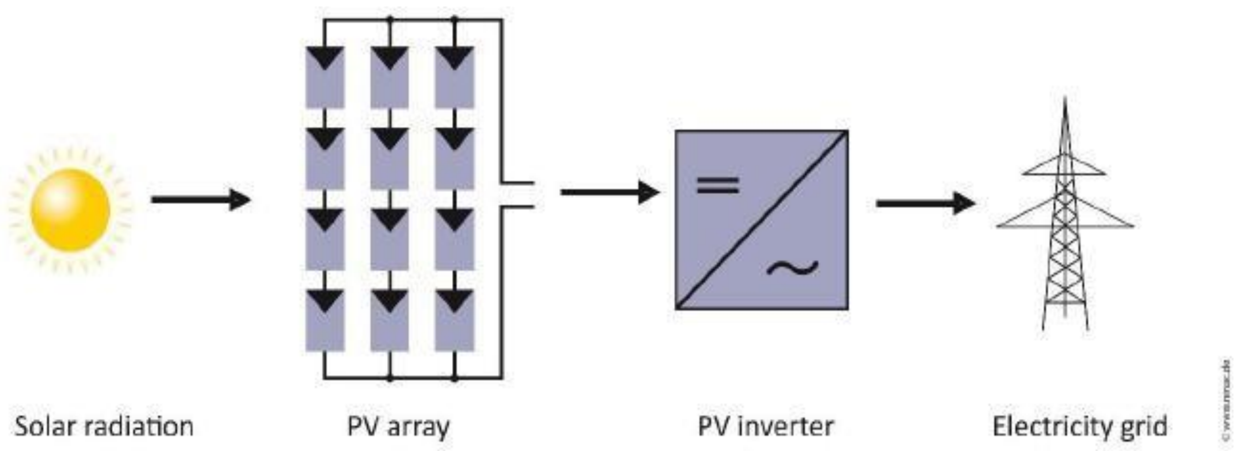


Source: RENAC

- **PV modules** are formed by connecting **PV cells** in series and/or in parallel and encasing them in a protective material,
- PV modules can also be connected in series and/or in parallel in order to form a **PV array**,
- The number of modules determines the maximum power generation capacity of a PV plant.

Inverters

- An inverter converts direct current (DC) input from the PV array or battery into alternating current (AC) output



- PV modules produce only DC. However, electrical energy is usually transmitted and distributed in AC form and most appliances consume AC power.

Types of Inverters

There are **three different sizes of inverters** :

Micro Inverters	String Inverters	Central Inverters
		
Micro inverters which are directly connected to a PV module (e.g. up to 300 W)	**String inverters** which are connected to one or a few strings of PV modules. Each string can have e.g. up to 20 modules.	**Central inverters** which are used in large PV parks of several megawatts, because many strings can be connected to the inverter.

Introduction to mounting structures

- The **fundamental requirements** of mounting structures are that they must support the weight of the PV modules, they must distribute the load evenly onto the roof/ground below, and they must withstand expected extra loading, e.g. from wind or snow.
- Since large array structures (including modules) are heavy, it is necessary to seek the advice of a structural engineer prior to roof mounting.
- The structure should have **optimum orientation and tilt angles** to maximise power output and all shading should be avoided. The structure will typically be made from aluminium or galvanised steel. Painted steel and wood are also options though such structures will probably require more maintenance over the 20+ year lifetime of the system.

Mounting Structures

- Solar panels can be installed on fixed supports or on trackers,
- Fixed supports are most often directed towards the south in the northern hemisphere and vice versa,
- Trackers are motorized structures that follow the path of the sun,

Ground fixed support

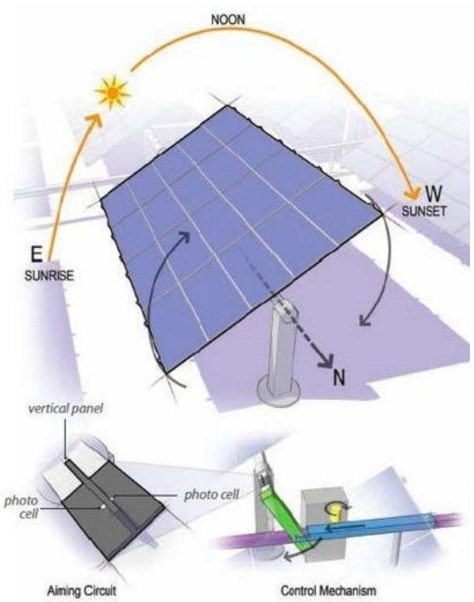
House roof top fixation system

Commercial roof top fixation system

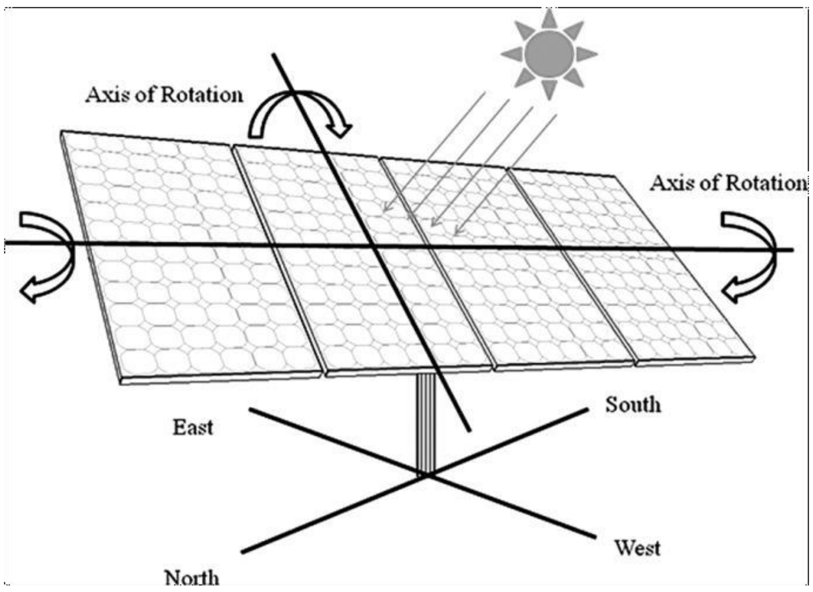
Mounting Structures

- Trckers are motorized structures that follow the path of the sun:
  - **Single-axis trackers** (one single axis of rotation) track the sun east to west, rotating on a single point, moving either in unison, by panel row or by section.
  - **Two-axis trackers** rotate on both the X and Y axes, making panels track the sun directly.

Mono axis concept



Dual axis concept



Source: Solar Powerworld

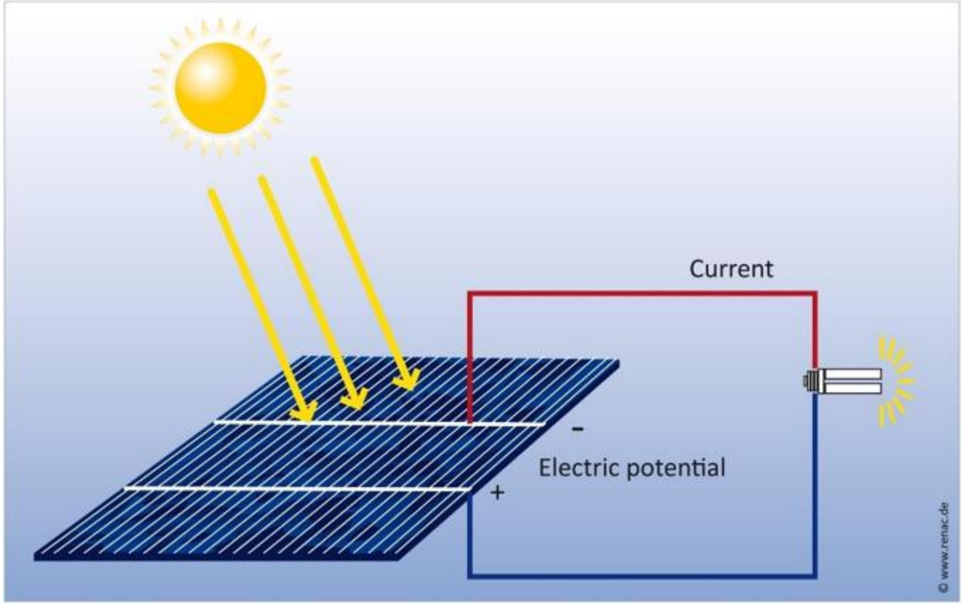
PHYSICAL ASPECTS OF PV SYSTEM

PV cell power output

- The electrical power P for DC systems, measured in Watts [W], is the product of voltage V measured in Volts [V] and current I measured in Amperes [A]:

$$P = V \times I$$

- Under normal sunlight conditions the PV cell's voltage remains fairly constant. However, the cell's **current** is very sensitive to **sunlight intensity**. High solar irradiance will produce a high electrical current; low solar irradiance will produce a low electrical current.



PV cell exposed to sunlight

- The **surface area** of the PV cell also affects the electric current output. A cell with a large surface area will produce more electric current than a cell with a small surface area.
- Thus, the **two main factors** that affect the output of a PV cell are the **intensity of the sunlight** falling on it and the **size of the cell**. Other factors are also important and will be discussed in the following sections.

Electrical characteristics and the I-V curve

The I-V curve

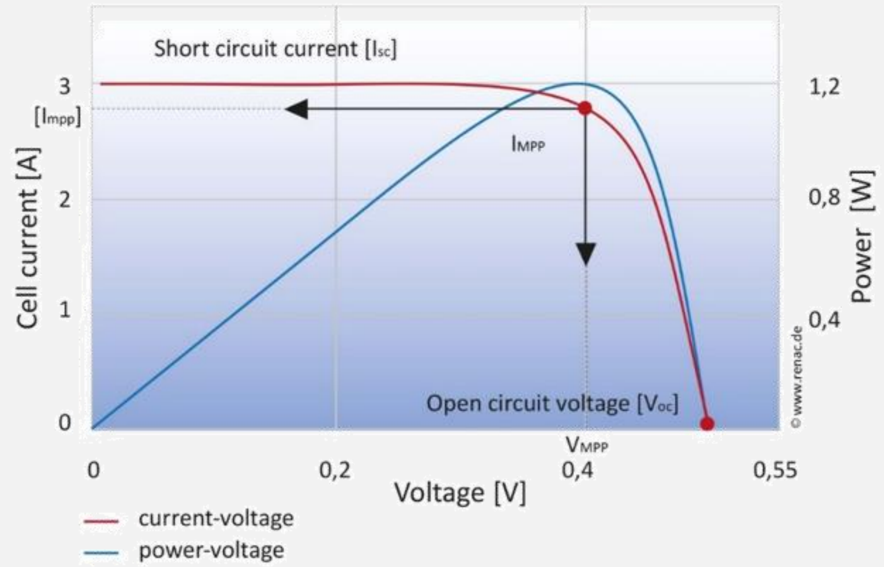
- Describes an important electrical characteristic of a PV cell. At any given time, a PV cell is operating with a specific current and voltage which lies along its I-V curve (red curve in the figure).
- This line shows the current I which is produced over a range of voltages. Isc represents the short circuit (SC) current, i.e. the value at which the current is at a maximum and the voltage is equal to zero.
- Voc represents the open circuit (OC) voltage, i.e. the value at which the voltage is at its maximum and the current is equal to zero.

The power curve

- The power curve of the PV cell is shown by the blue line. This line shows the electric power produced over a range of voltages. Under normal operating conditions, the curves grow and contract along both the current and voltage axis.
- The **maximum power point (MPP)**, the point at which the cell produces the maximum power, occurs at the 'knee' of the power curve where the product of voltage and current are greatest. The maximum power is thus:

$$P_{MPP} = V_{MPP} \times I_{MPP}$$

$$P = V \times I$$



I-V curve and power curve of a PV cell

FACTORS AFFECTING POWER OUTPUT

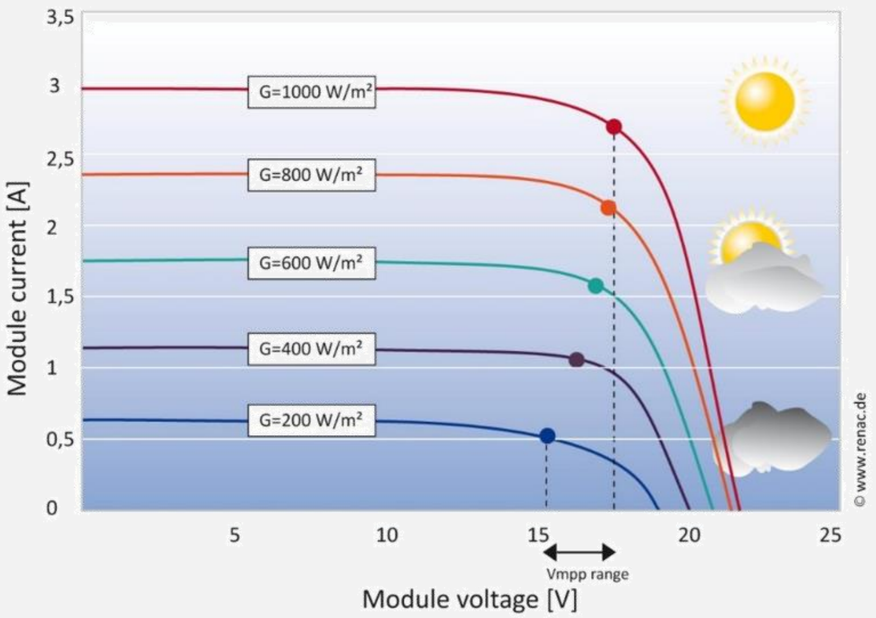
Electrical characteristics and the I-V curve

There are **three critical** factors which affect the instantaneous output of a PV cell or module.

1. **solar irradiance** incident on the surface,
2. the **temperature** of the PV cells, and
3. the **electrical load resistance** connected to the PV cell or module.

Impact of irradiance

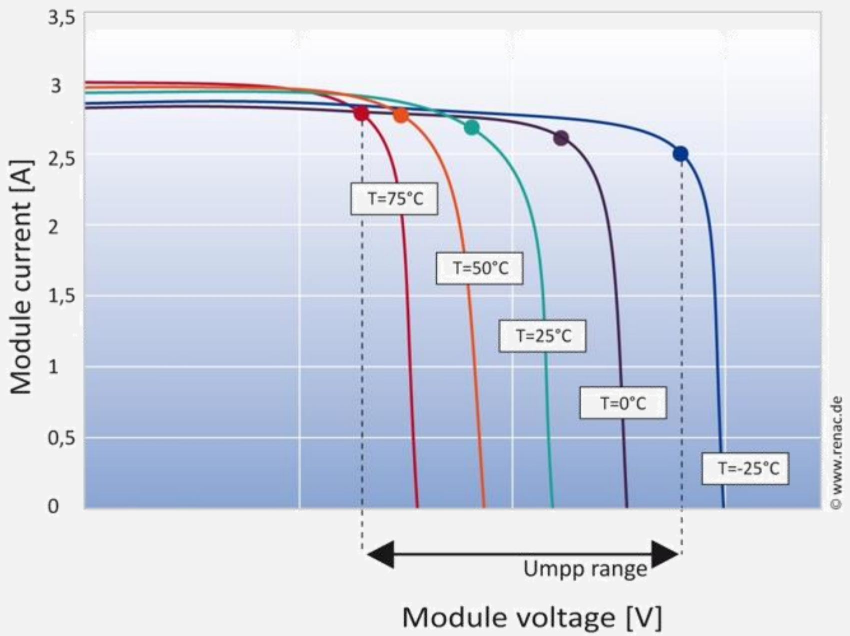
- The output power of a PV cell or PV module directly depends on the solar irradiance incident on its surface. As irradiance G increases, the current I increases due to an increase in the level of the photoelectric effect.
- Voltage output V, on the other hand, varies only slightly with changing irradiance (see figure). This means that as soon as the sun illuminates the surface of the cell/module, the voltage rises to a value that is close to VOC. Regardless of a change in solar irradiance, such as shading from passing clouds, the voltage will fluctuate only slightly below that VOC range.
- The current, however, will increase in direct proportion to the irradiance, only reaching the module's full current under strong irradiance conditions, such as 1 kW/m2. For this reason, current produced by the photoelectric effect in a PV cell is referred to as **photocurrent**.
- Passing clouds or people, which cast shadows on the PV modules, will cause a drop in current output. Since current is directly proportional to power, shading has a significant effect on power output.



Solar irradiance dependent I-V curve

Impact of temperature

- The performance of PV cells also varies with temperature. Since PV cells and modules cannot convert 100% of the absorbed light into usable electricity, some of this energy is lost in the form of heat, which causes the temperature of the cell to increase. This is a normal part of the operation of a PV cell and cannot be avoided.
- **As the cell gets hot, its power output drops**. This is because the open circuit voltage VOC decreases significantly when the internal cell temperature rises (see figure). The short circuit current ISC increases slightly with increasing temperature but not enough to compensate for the large drop in V_{OC}.
- Under normal conditions, the PV cell will always operate at a temperature higher than the ambient temperature. The ideal operating state for maximising power output is high irradiance with low temperatures. Such conditions are rare, e.g. high up in the mountains in winter on a clear day.



Temperature dependent I-V curve

Impact of load resistance

- An electrical load connected to a PV module will determine the point on the PV module's I-V curve where the module will operate. An electrical load could be a light bulb, a pump, the grid or a battery. If there is less sunlight available, then the load will pull less current.
- The voltage across the load and the amount of current that the load pulls from the module is determined, for a given irradiance and therefore for a given I-V curve, by the equation:

$$I = V / R$$

where I is current in Ampere, V is voltage in Volts and R is load resistance in Ohms.

Note about batteries:

- if batteries are connected to the PV modules, as in an off-grid system, the batteries will determine the voltage at which the PV modules operate. The module output current will then correspond to the module's I-V curve at that voltage.

STANDARD TEST CONDITIONS

Standard test conditions

- Due to the variability of power output of the PV cells depending on parameters such as irradiation and temperature, the performance of different cells operating under different conditions cannot be compared easily.
- In order to enable meaningful comparisons between PV cells (or PV modules), the rated output of a cell or module is always measured under specific conditions. These conditions are standardised across all testing facilities worldwide and are called Standard Test Conditions (STC).

STC parameters are:

- Light spectrum: AM 1.5
- Irradiance: 1,000 W/m^2
- Cell temperature: 25 °C
- Each finished PV cell (or PV module) leaving the production line undergoes a flash test: it is exposed to a flash of light under careful control of the STC parameters, lasting only milliseconds, and the output performance is recorded.
- Subsequently, the cells or modules are sorted and sold according to their rated power. The rated power is measured in units of Watt-peak [W_p] or kilowatt-peak [kW_p] and refers to the rated power under STC.

TEMPERATURE COEFFICIENT

Temperature coefficient

- The temperature coefficient shows how voltage, current or power output of a PV cell or module change with changing temperature.
- Module datasheets give temperature coefficients (T_C) for open circuit voltage V_{OC} under STC, short circuit current I_{SC} under STC, and power at the maximum power point P_{MPP} under STC.
- The voltage temperature coefficient is the most common one used. Inverters (and other devices, such as charge controllers) can be damaged by module/string voltages that exceed the specified input voltages of these inverters (and other devices). Conversely, if the voltage is too low, this can cause system underperformance.

Voltage temperature coefficients

- Voltage temperature coefficients are given in the form of e.g. -0.156 V / °C or -156 mV / °C or as % / °C (e.g. -0.36% / °C).

Current temperature coefficients

- Current temperature coefficients are given in the form of 0.0029 A / °C or 2.9 mA / °C or as % / °C (e.g. + 0.45% / °C).

Power temperature coefficients

- Power temperature coefficients are given in the form of -0.42 W/ °C or as %/ °C (e.g -0.42% / °C).

Calculation exercise

- Assume the following data: The yearly daytime temperature at a location ranges from -10ºC to +45ºC. A PV module is being installed which has:
  - a V_{OC} of 43.24 V at STC,
  - a V_{MPP} of 35.35 V at STC, and
  - a temperature coefficient T_C (V_{OC}) of -0.168636 V / °C.
- *Note: temperature coefficient Tc (V_{MPP}) is slightly different than T_C (V_{OC}). In this case, for the calculations, the difference will be neglected.*
- This means that for every °C temperature drop below 25°C, the module voltage will rise by 0.168636 V. Similarly for every °C temperature rise above 25°C, the module voltage will drop by 0.168636 V.

Calculation exercise

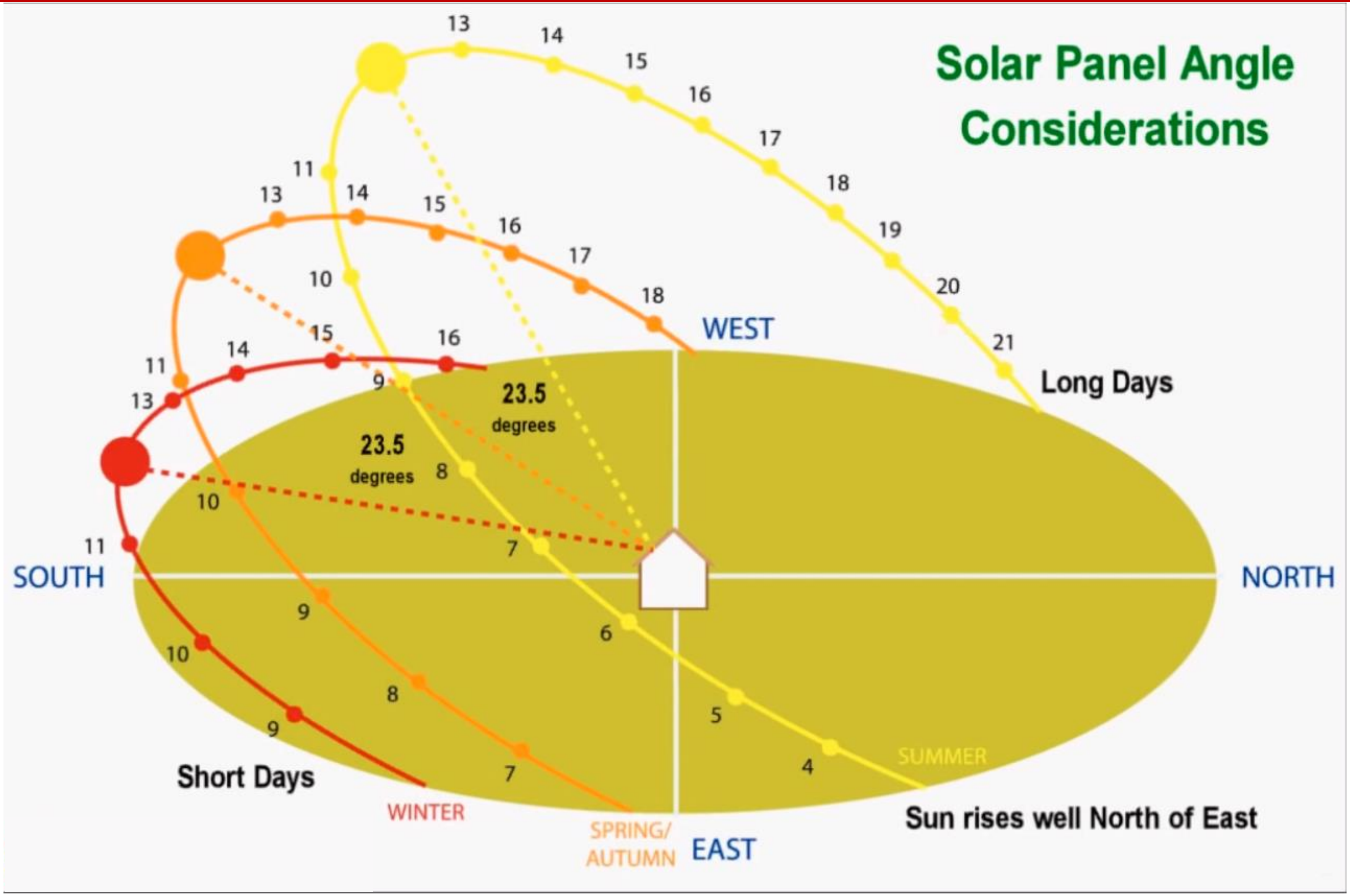
- What will be the maximum V_{OC} produced by the module?
  - The maximum VOC will be produced at the lowest ambient temperature, -10°C. So the lowest cell temperature will be - 10°C.
  - V_{OC} (-10°C) = 43.24 V + [(25°C - (-10°C)) × 0.1686 V / °C] = 49.14 V
- What will be the maximum V_{MPP} (voltage when the module is operating at its maximum power point, i.e. in full sun) produced by the module?
  - V_{MPP} (-10°C) = 35.35 V + [(25°C - (-10°C)) × 0.1686 V / °C] = 41.25 V
- What will be the minimum V_{OC} produced by the module?
  - The minimum V_{OC} will be produced at the highest ambient temperature, 45°C. But the cell temperature of roof-top or open field PV systems can be 25°C higher than the ambient temperature, so this will be 70°C
  - V_{OC} (+70°C) = 43.24 V + [(25°C - 70°C) × 0.1686 V / °C] = 35.65 V
- What will be the minimum V_{MPP} (voltage when the module is operating at its maximum power point, i.e. in full sun) produced by the module?
  - The minimum V_{MPP} will be produced at the highest ambient temperature, 45°C. But the cell temperature of roof-top or open field PV systems can as a rule of thumb be 25°C higher than the ambient temperature, so this will be 70°C.
  - V_{MPP} (+70°C) = 35.35 V + [(25°C - 70°C) × 0.1686 V/°C] = 27.76 V

ORIENTATION AND INCLINATION (TILT) OF PV MODULES

Orientation and inclination (tilt) of PV modules

- The PV module's orientation and inclination (tilt) significantly affect the amount of irradiation that the surface receives, and hence the amount of energy that the module produces.
- In the **northern hemisphere**, the PV module should be facing **south**; in the southern hemisphere it should be facing north. This guarantees the maximum irradiation level on the PV module throughout the year. In regions close to the equator, the orientation is less important.
- The optimum tilt angle of the PV module depends strongly on the location. As a rule of thumb, the module should be tilted to an angle equal to the latitude of the installation site. **(Nigeria is situated in the northern latitude between 4° and 14°)**
- Roof mounted modules are usually simply installed at the same angle as the roof since the extra cost of adjusting the tilt angle exceeds the benefit of the extra energy that would be generated.
- In regions close to the equator, the most solar irradiation is captured if the PV module is flat. However, in practice a minimum tilt angle of 10-15° is recommended to allow for self-cleaning.

Tilt Angle and Orientation Considerations

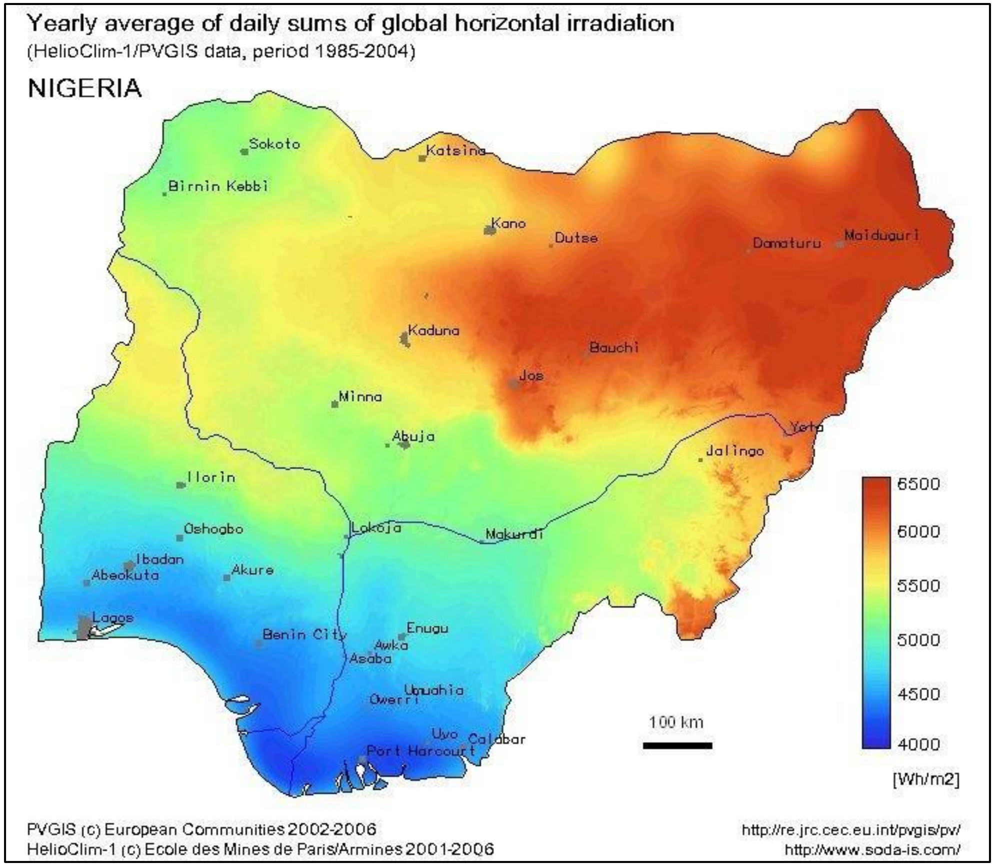


SOLAR YIELD ESTIMATION

Picture: www.fotolia.com

Resource Assessment

- In order to assess the energy yield of a PV system, one has to know about the available resource (input) to the PV system, meaning the solar irradiation,
- Colour-coded solar resource maps provide a first indication of the available solar energy production (AEP) potential in a certain region.
- The input data are usually provided as an average annual sum in kWh/m² (the darker the colour, the better the resource potential).



Source: Helioclim/PVGis

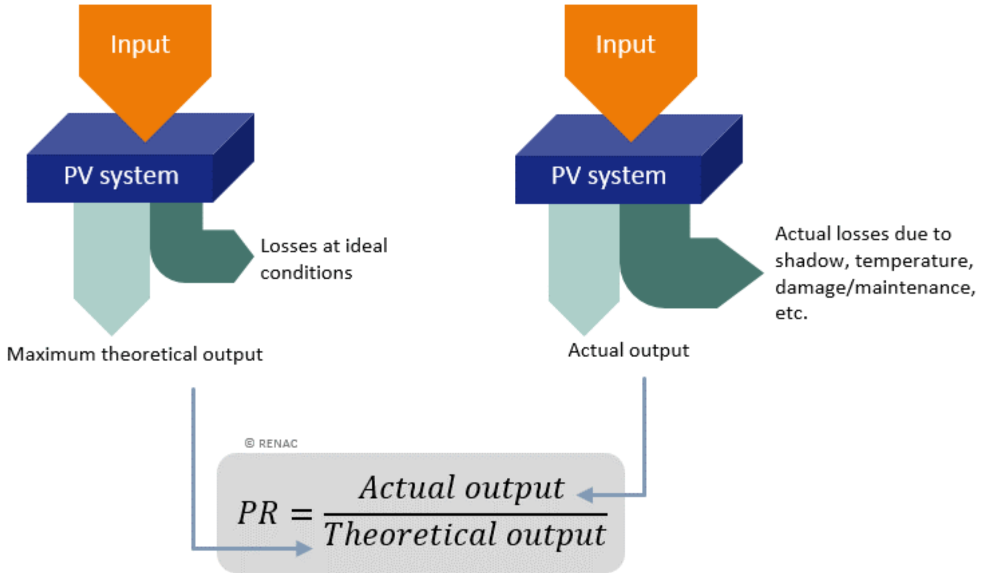
Resource Assessment

- The economic feasibility of a PV plant critically depends on its electricity yield, which in turn depends on both the meteorological conditions at the location and the performance of the plant itself.
- As the electricity yield is heavily dependent on solar irradiation levels, it is essential that accurate and long-term climate data are available for the given location. Solar irradiation at a site is often stated in terms of the **Peak Sun Hours (PSH)** over a certain period.
- Furthermore, component quality, plant design and layout as well as the maintenance plan will affect the performance and consequently the energy yield of the plant.

PERFORMANCE RATIO

Performance Ratio

- The **Performance Ratio (PR)** is one of the most important parameters for assessing the performance of a PV plant. It is the ratio of actual plant output to nominal plant output (at STC).



$$PR = \frac{Actual\ output}{Theoretical\ output}$$

- It is determined by monitoring the actual plant output over a defined period (e.g. one year) and dividing this by the nominal plant output in that same period.
- The PR will change from period to period depending on environmental and technical conditions at the plant.

Performance Ratio

- A low PR is indicative of high system losses, for example due to high module temperature, reflection of solar irradiation from the module, soiling of the front glass, shading, component failure, mismatched module outputs, etc. Therefore, higher PR values are desirable.
- In contrast, PR is also used with common reference values in the planning stage of a PV system. For example, a PR of 0.75-0.80 is used for grid-connected PV plants and 0.65 for off-grid plants. This means that the expected gross energy production potential would have to be multiplied by the performance ratio value or reduced by (1-PR) to reflect the expected production after system losses.
- Once the energy yield of a PV system has been estimated, the revenue from electricity sales can be calculated in order to evaluate the profitability of a project.

ENERGY YIELD CALCULATION AND EXAMPLE

Energy yield calculation and example

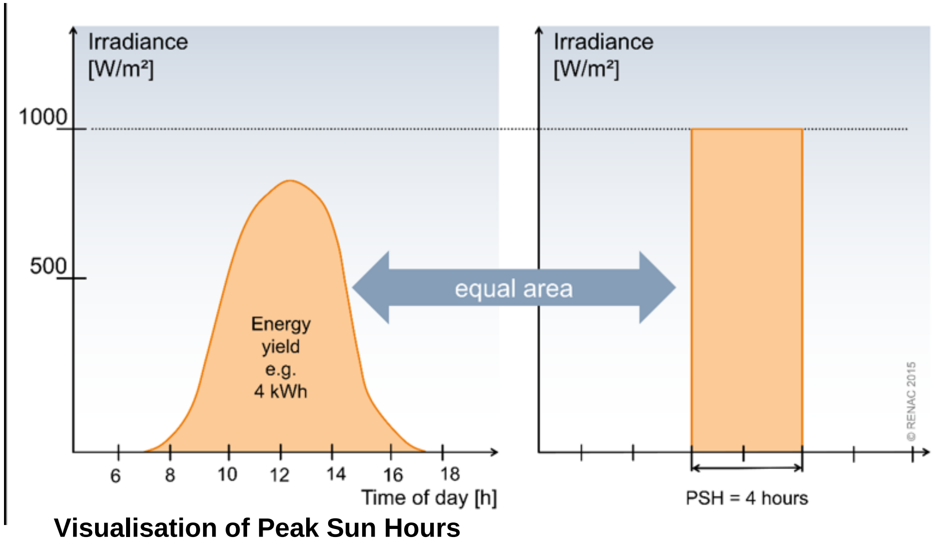
- The following equation provides a quick and simple way to estimate the energy yield of a PV plant over a particular period of time:

$$E = PSH \times P_{Peak} \times PR$$

- Where,
  - ***E:*** Energy yield of the PV plant over a period of time (e.g. over one year) [kWh/year]
  - ***PSH:*** Peak Sun Hours at the location of the PV plant over the same period of time [h/year]
  - P_{Peak}: Peak nominal power of the PV plant [kWp]
  - ***PR:*** Performance Ratio of the PV plant, normally between 0.65 and 0.85
- The Peak Sun Hour (PSH) is an imaginary case, where the sun shines at a constant irradiance of 1000 W/m² for one hour.

Energy yield calculation and example

- We can visualise the PSH by looking at the area below the solar irradiance curve. This area must be similar to the area of a rectangle with a "height" of 1000 W/m². The width of the rectangle determines the PSH.



Visualisation of Peak Sun Hours

Example: If Irradiance is 1KW/m², How many sun hour is required to produce 4KWh?

$$E = PSH \times P_{Peak} \times PR,$$

$$PSH = \frac{4KWh/m^2}{1KW/m^2} = 4 Hours$$ **(assuming losses are neglected)**

Examples

- A PV plant developer is planning two PV plants, one in Northern Europe and the other in the Southern USA, and wants to estimate the energy yield of each to gauge their economic feasibility.
- **SYSTEM IN NORTHERN EUROPE:**

  Rated power = 1,000 Wp;

  PSH = 1,200;

  PR = 0.8

  $E_{Europe} = PSH \times P_{Peak} \times PR = 1{,}200\ h \times 1{,}000\ W_p \times 0.8 = 960{,}000\ Wh/a = \mathbf{960\ kWh/a}$

- **SYSTEM IN THE SOUTHERN USA:**

  Rated power = 1,000 Wp;

  PSH = 1,900 ;

  PR = 0.7:

  $E_{USA} = PSH \times P_{Peak} \times PR = 1{,}900\ h \times 1{,}000\ W_p \times 0.7 = 1{,}330{,}000\ Wh/a = \mathbf{1{,}330\ kWh/a}$

- Although the system in the Southern USA has a lower estimated PR due to higher ambient temperatures, the output is higher because more solar irradiation is available. Once the PV plants are operational, the actual plant outputs can be monitored and thus the actual PRs calculated.

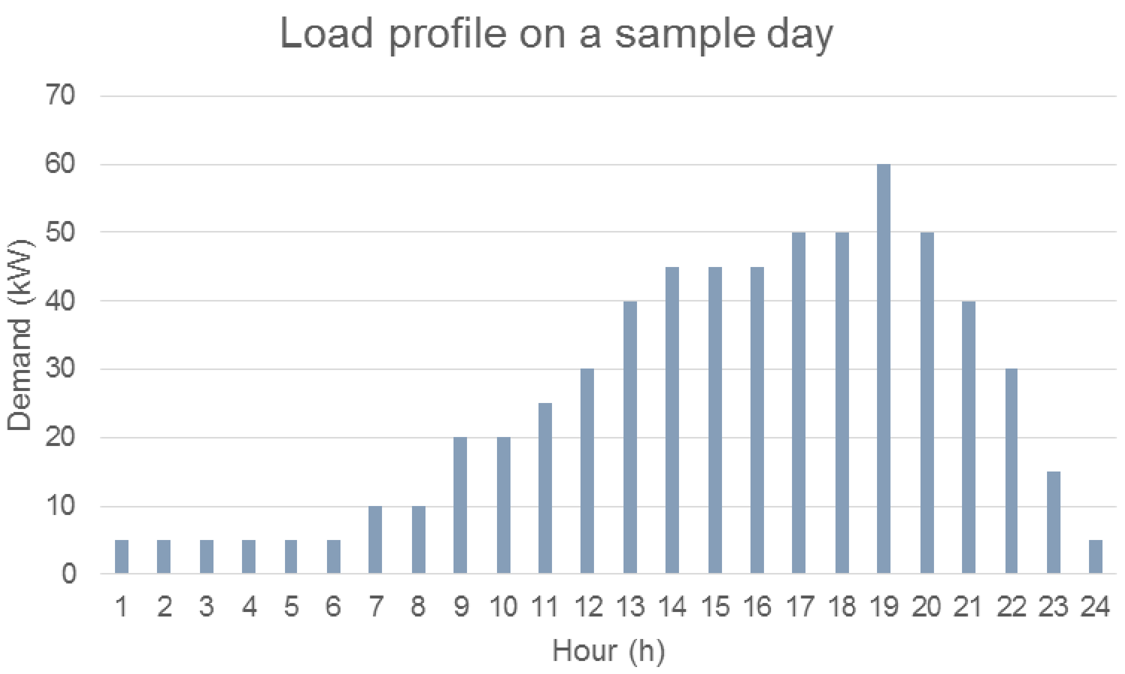
LOAD PROFILE

Load profile

- For a successful electrification project, it is necessary to conduct a precise analysis of expected electricity demand, as it has significant impact on the design and costs within the project.
- The system should neither be unnecessarily oversized nor undersized. System oversizing leads to high costs. System under sizing could lead to dissatisfaction of electricity consumers due to unreliable electricity supply.
- Therefore, electricity generation and electricity demand should be in balance with each other. For this reason, demand analysis is required leading to the creation of a load profile.
- A load profile is a graph showing variations of electrical consumption over time. The time span can be a day, a month or a year. A forecasted load profile with a minute-by-minute resolution on the time scale would be desirable, but usually it is not possible to predict demand with such accuracy. A load profile with an hourly resolution is a good estimate to start with.

Load profile

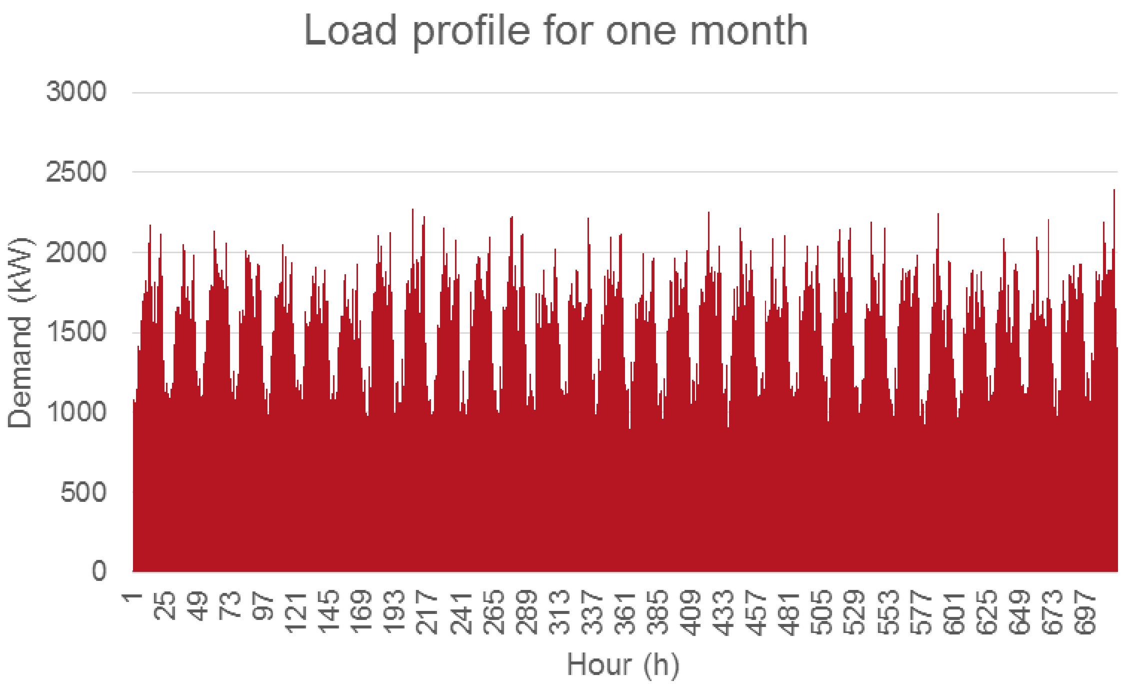
The figure 'Load profile on a sample day' shows an example of hourly demand forming a load profile for one day.



Load profile on a sample day

Load profile

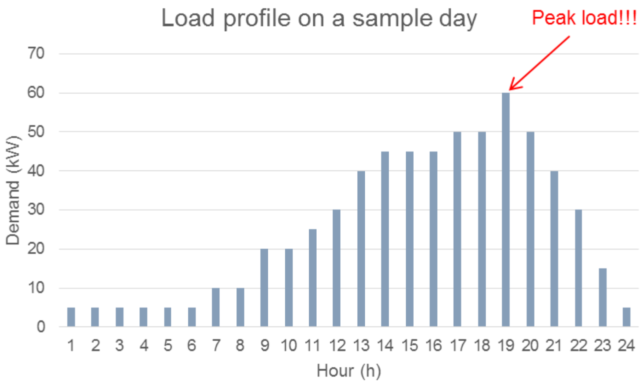
The figure 'Load profile for one month' shows that a load profile may change on a daily basis. Load profiles may change more significantly between seasons, e.g. due to changing daylight hours and climate conditions.



Load profile for one month

Peak load

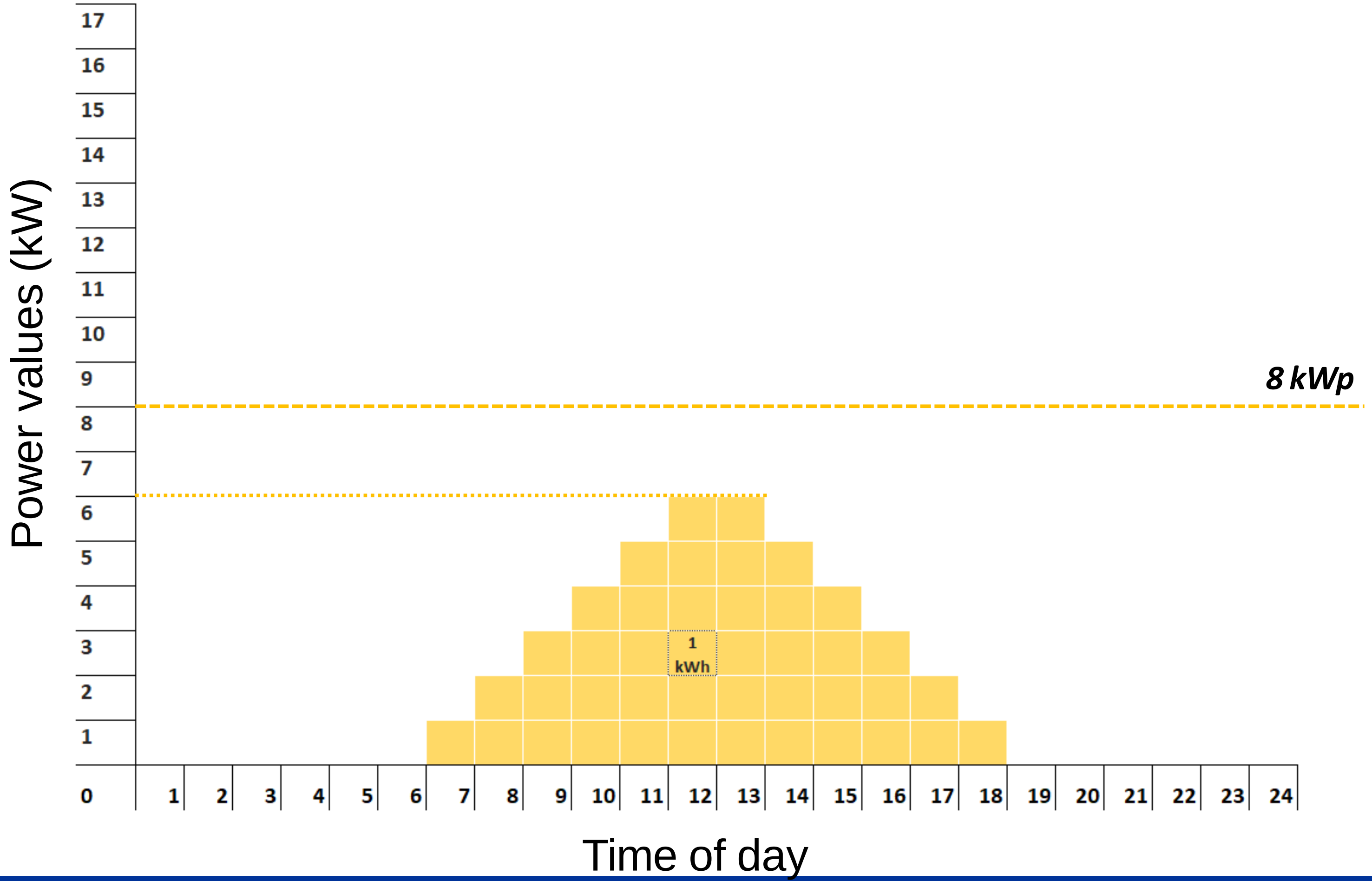
- An important point in load profiles is the peak load. The generator(s) in the system must be able to deliver the peak load and an adequate additional reserve power. The figure shows a peak load in a sample day occurring at 7pm in the evening. “Peak load” describes the maximum load (electric power consumption) within a certain period, e.g. a day or a year.



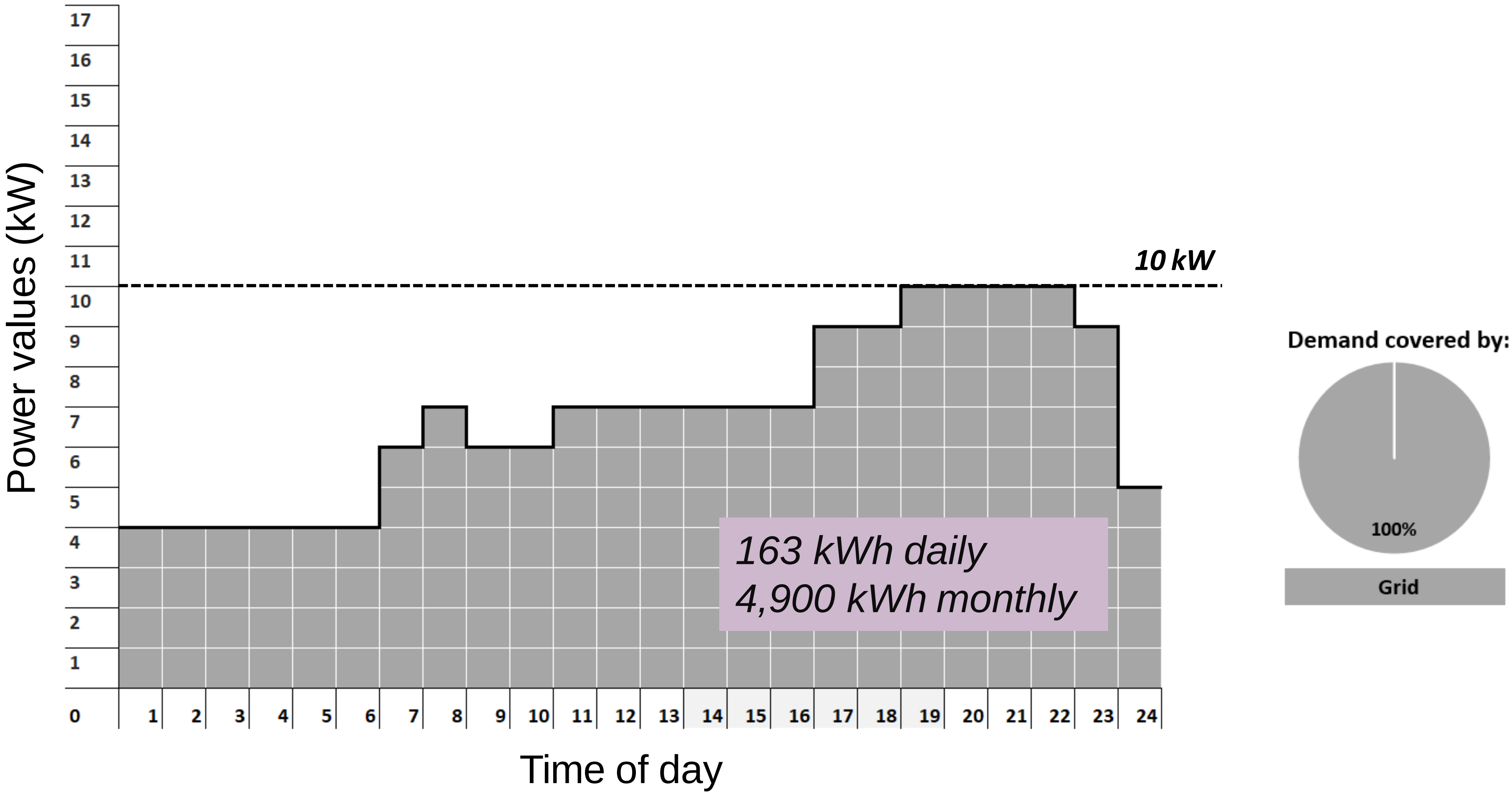
- This load is significantly higher than the average supply level. Its occurrence during a day or a year depends on consumption patterns, type of consumers (households, industry, etc.) and climatic conditions.
- For an optimal analysis the load profile should be generated for the complete year. The unit for the values of a load profile must be given in Watts (W) or Kilowatts (kW). If seasonal variations of energy demand are likely, all seasons should be evaluated regarding their individual load profile. Differing values for weekdays and weekend days must be considered, too.
- In “greenfield” projects where an entire electrification system is built from scratch, energy demand can be estimated by listing all major appliances and multiplying each by the foreseen running hours.

INTEGRATION OF SOLAR GENERATION PROFILE INTO ELECTRICITY DEMAND PROFILE

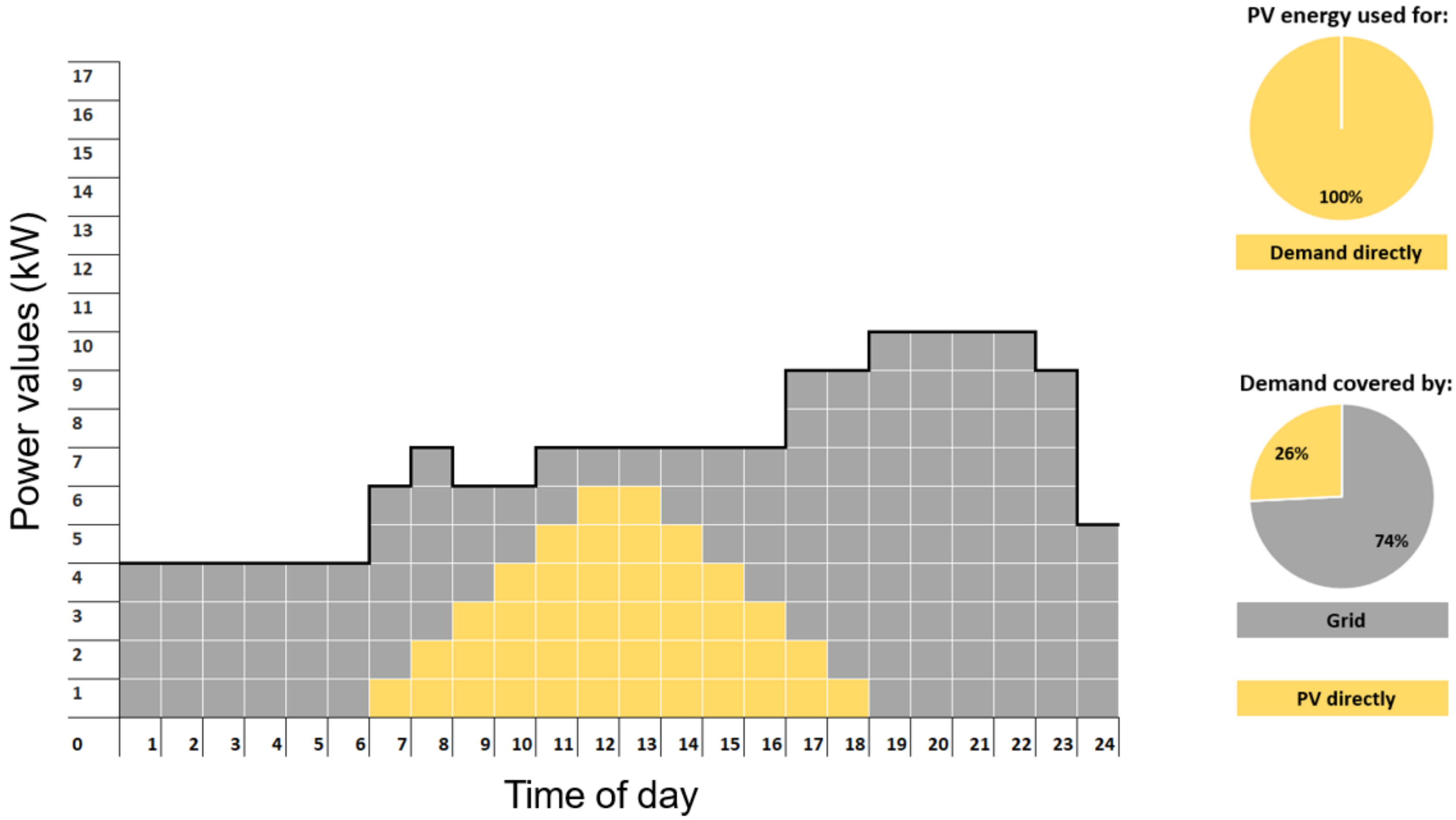
Simplified daily generation profile of an 8 kWp PV system



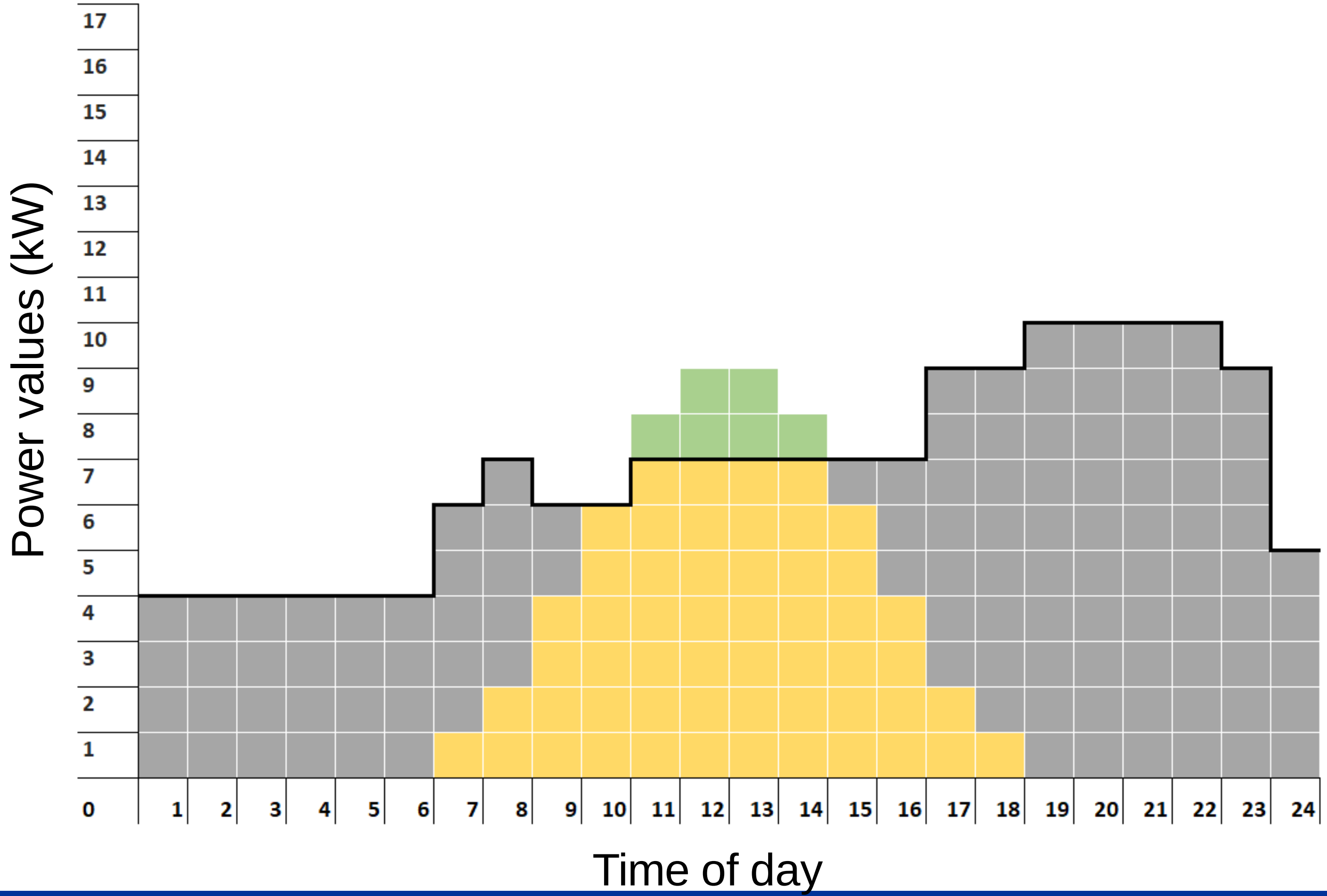
Simplified daily demand profile with 10 kW peak load*no PV system installed*

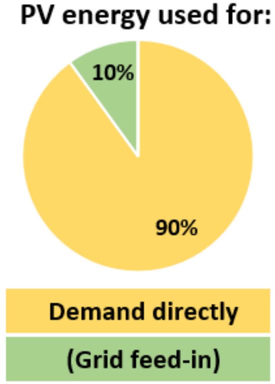


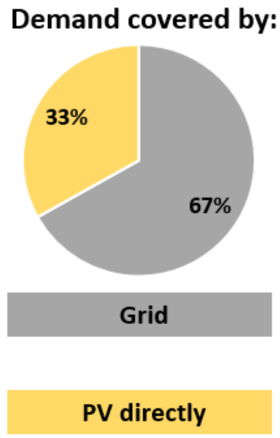
Simplified daily demand profile with 10 kW peak load and 8 kWp PV system installed



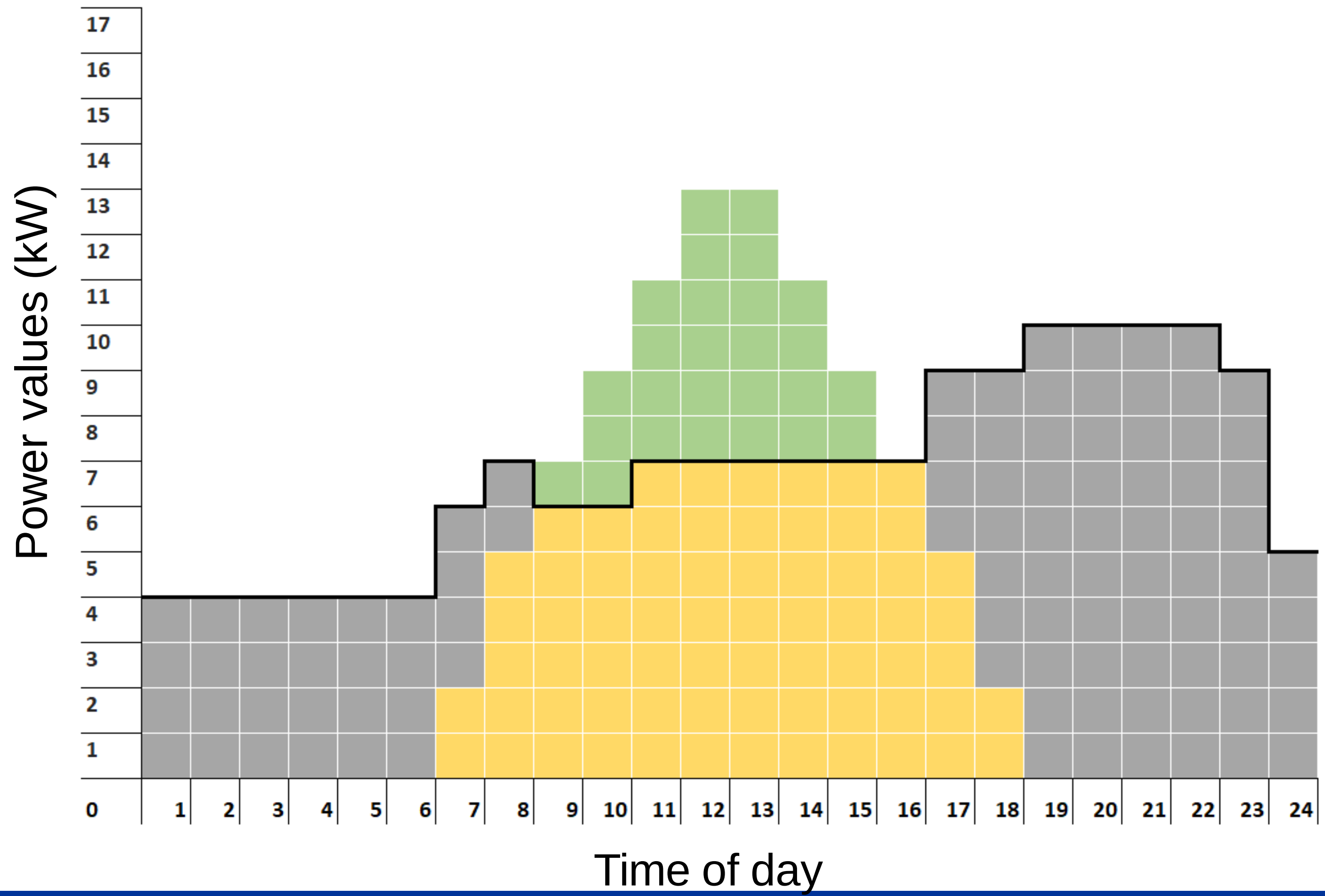
Simplified daily demand profile with 10 kW peak load
11 kWp PV system installed

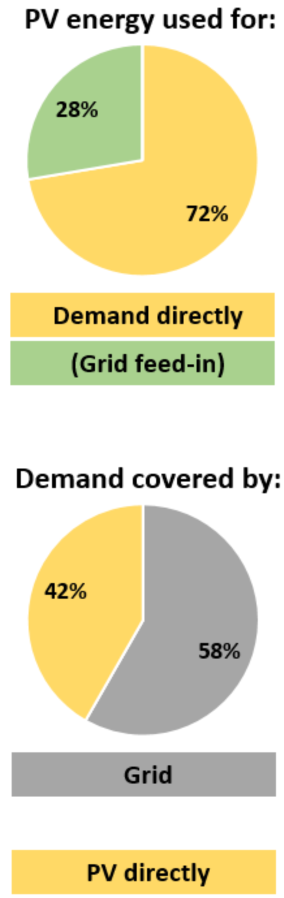




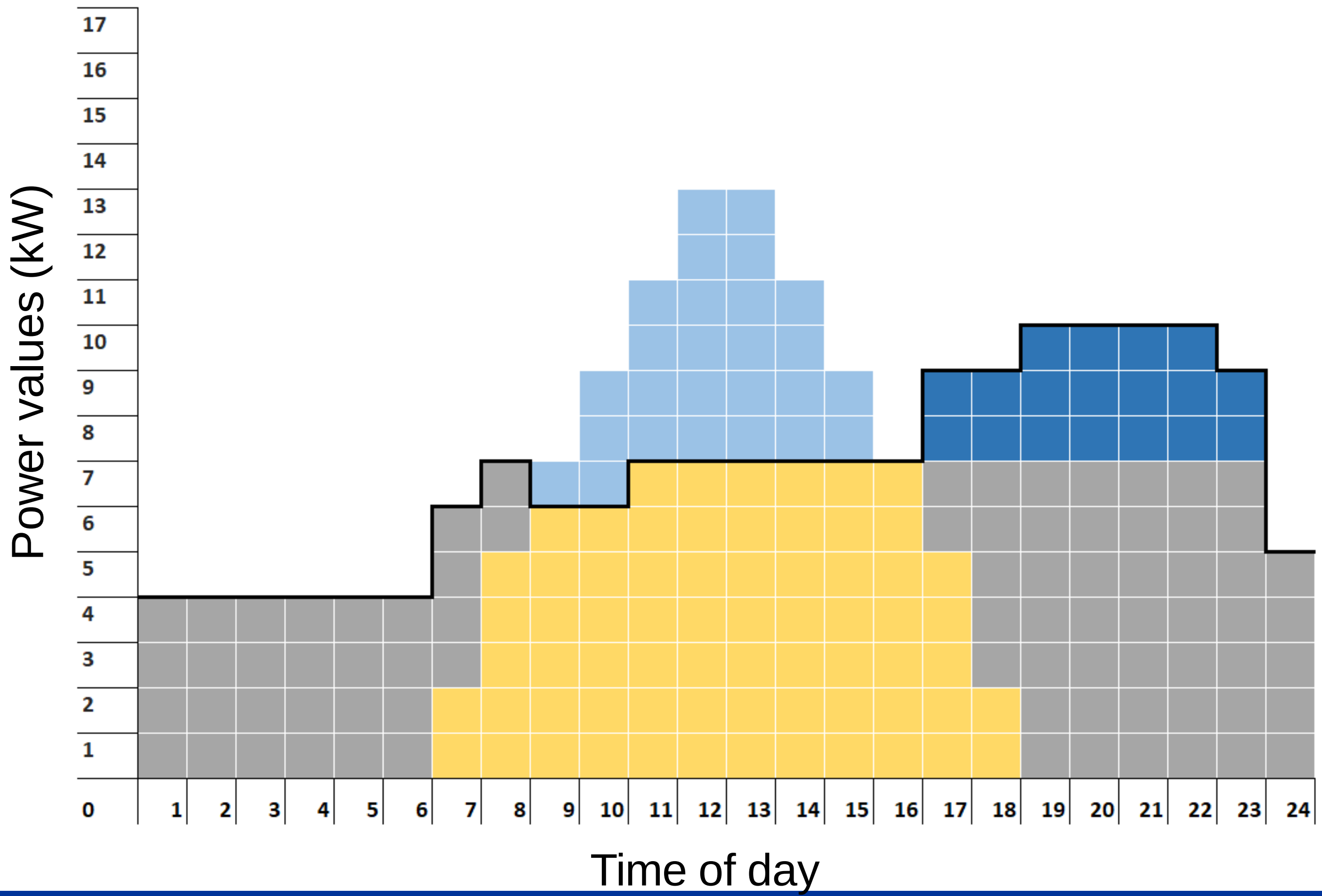


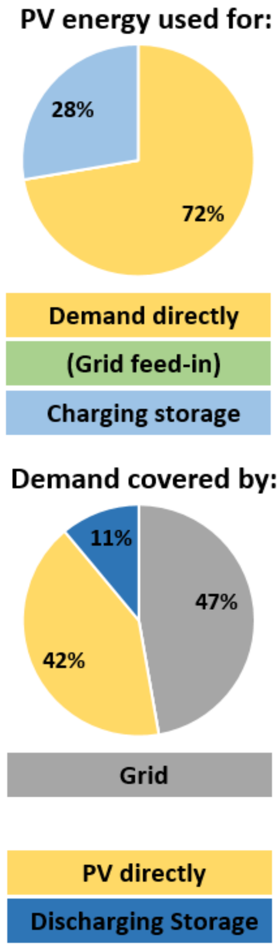
Simplified daily demand profile with 10 kW peak load
17 kWp PV system installed



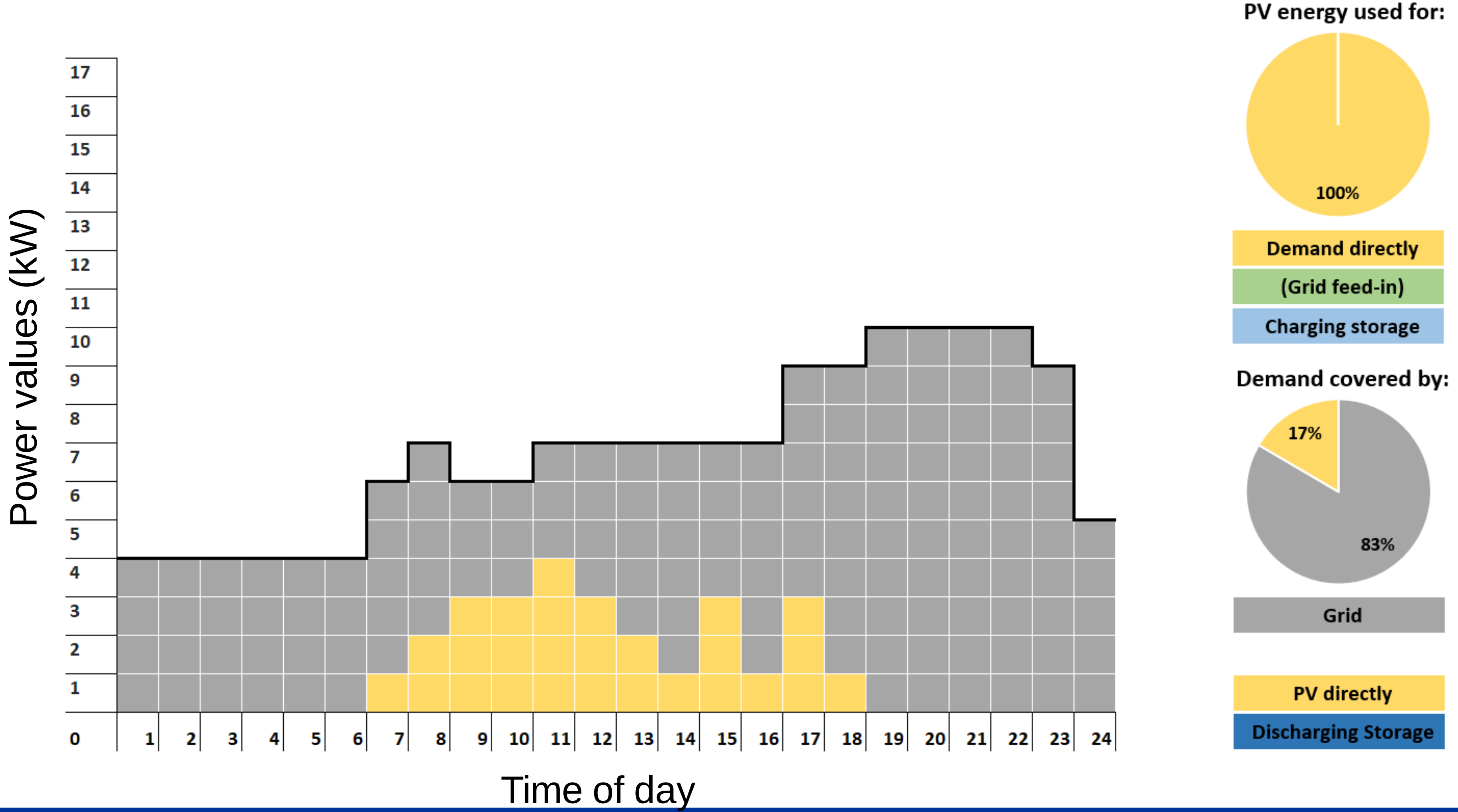


Simplified daily demand profile with 10 kW peak load 17 kWp PV system installed – plus storage





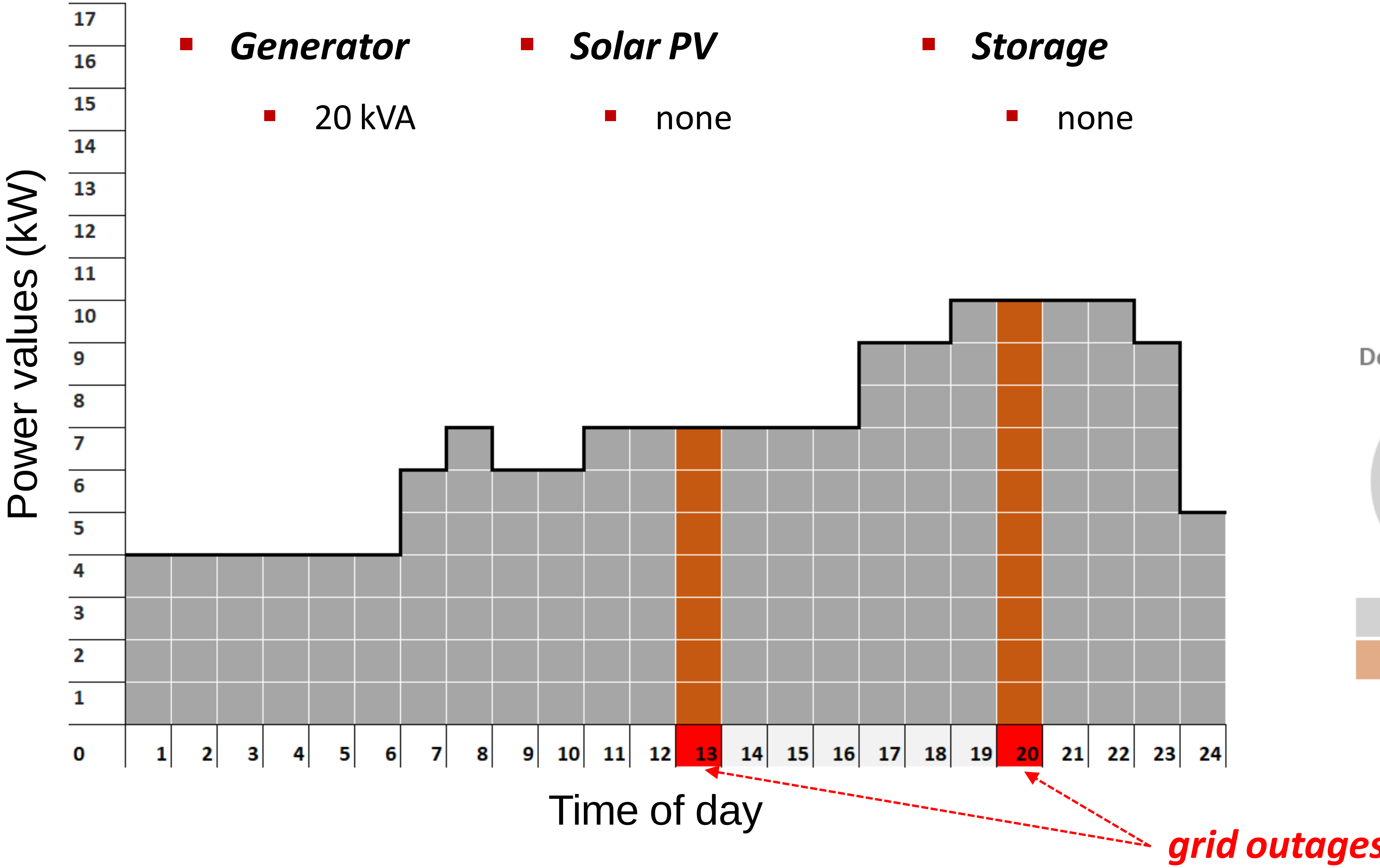
17 kWp will produce less on a cloudy day…

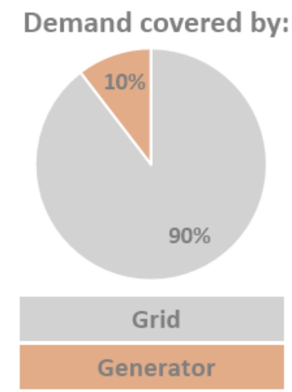


HOW TO GET RID OF MY BACKUP GENERATOR!

0) Regular generator backup

- ***Generator***
  - 20 kVA
- ***Solar PV***
  - none
- ***Storage***
  - none

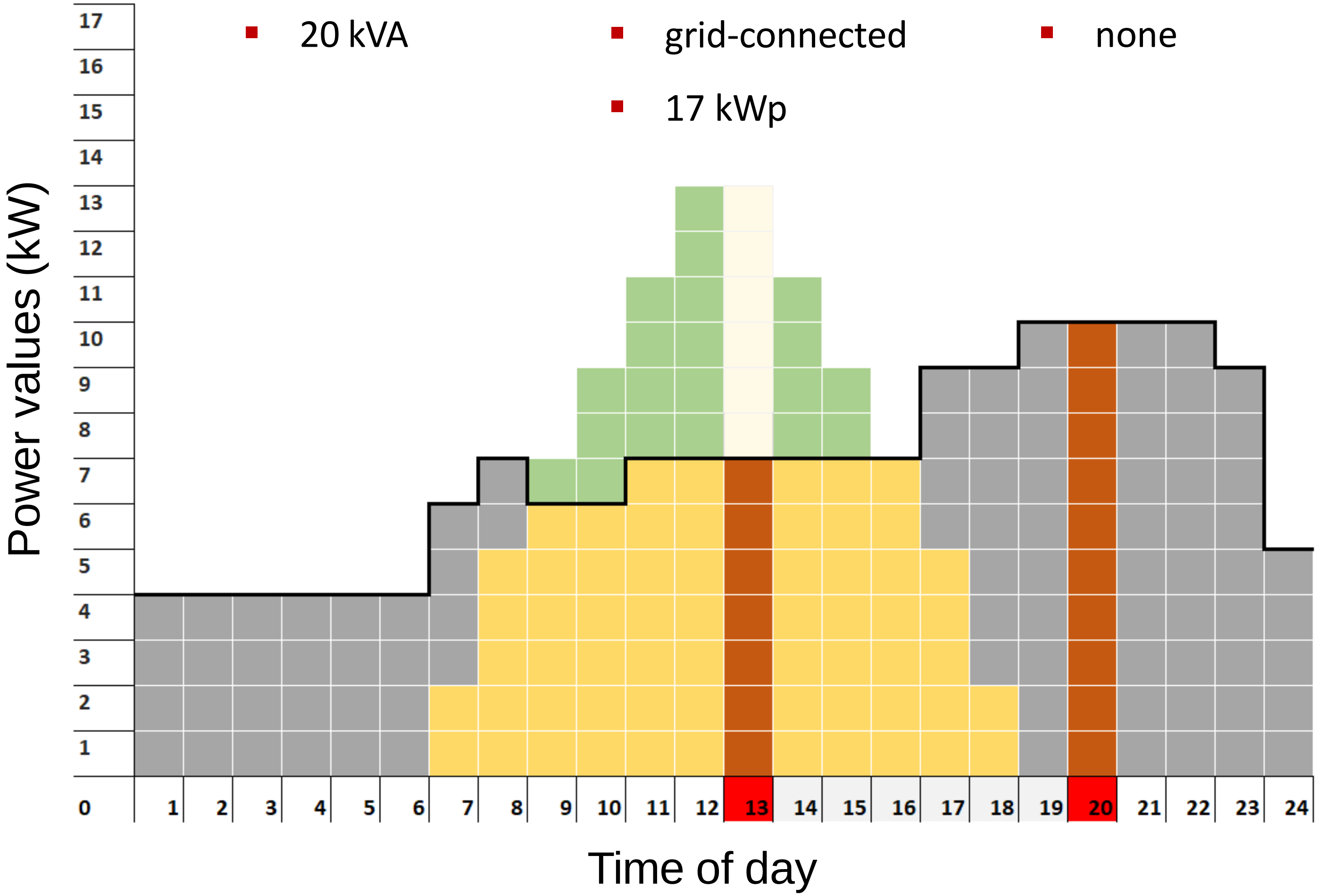


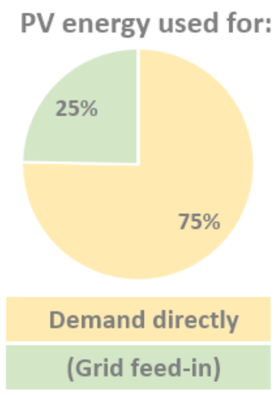


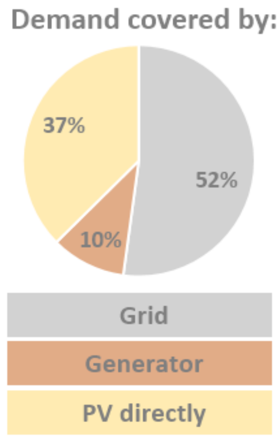
1a) Add grid-connected PV*

disconnects during generator operation

- ***Generator***
  - 20 kVA
- ***Solar PV***
  - grid-connected
  - 17 kWp
- ***Storage***
  - none



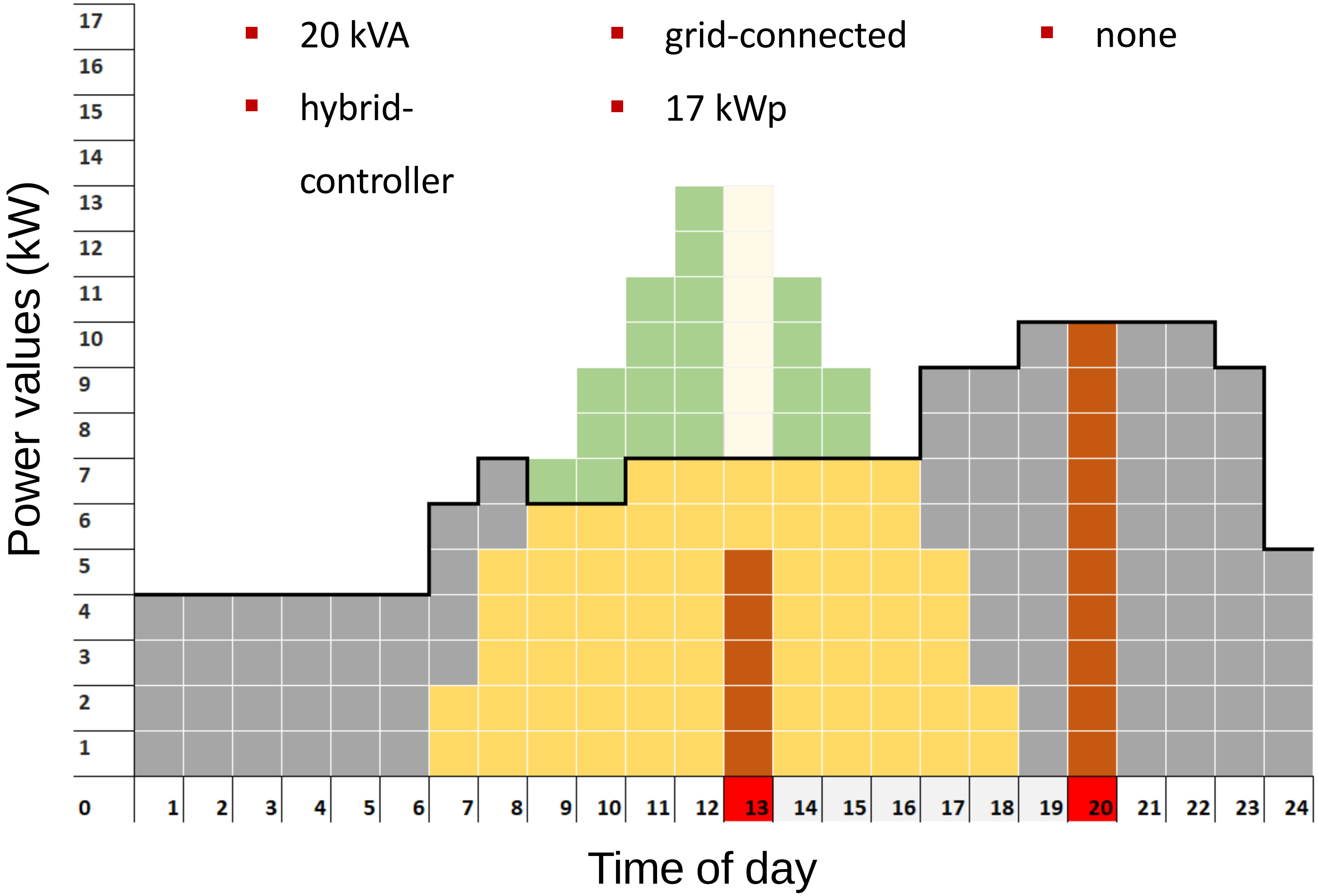


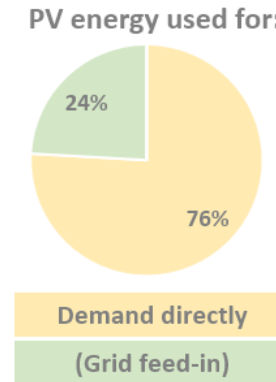


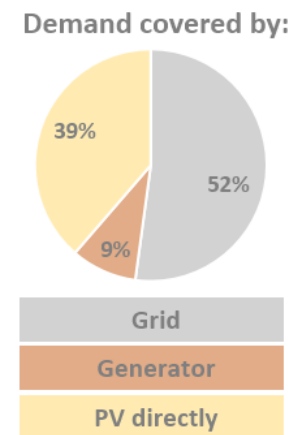
1b) Add grid-connected PV*

stays connected during generator operation

- ***Generator***
  - 20 kVA
  - hybrid-controller
- ***Solar PV***
  - grid-connected
  - 17 kWp
- ***Storage***
  - none



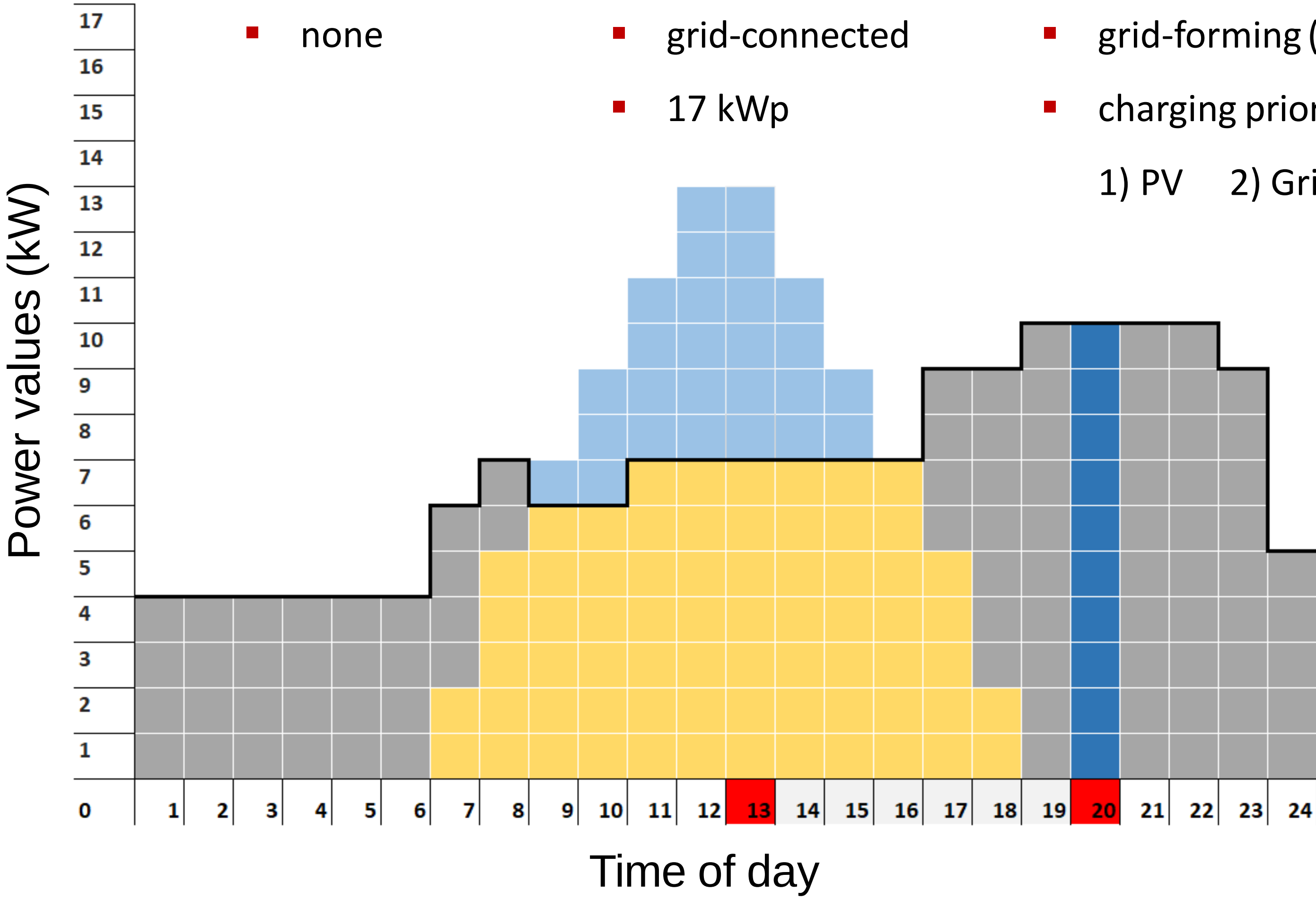


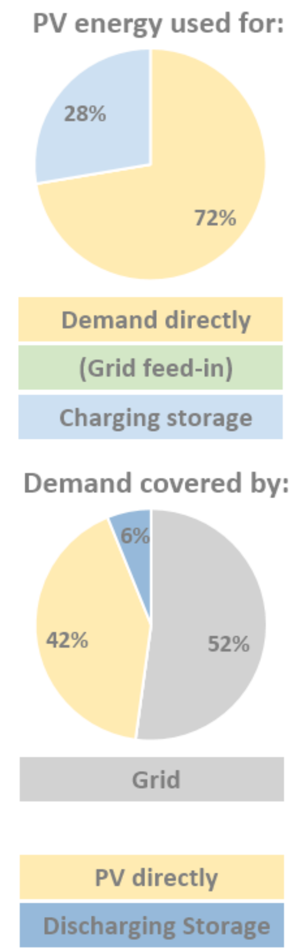


2) Add storage, get rid of generator

- ***Generator***
  - none
- ***Solar PV***
  - grid-connected
  - 17 kWp
- ***Storage***
  - grid-forming (UPS)
  - charging priority:

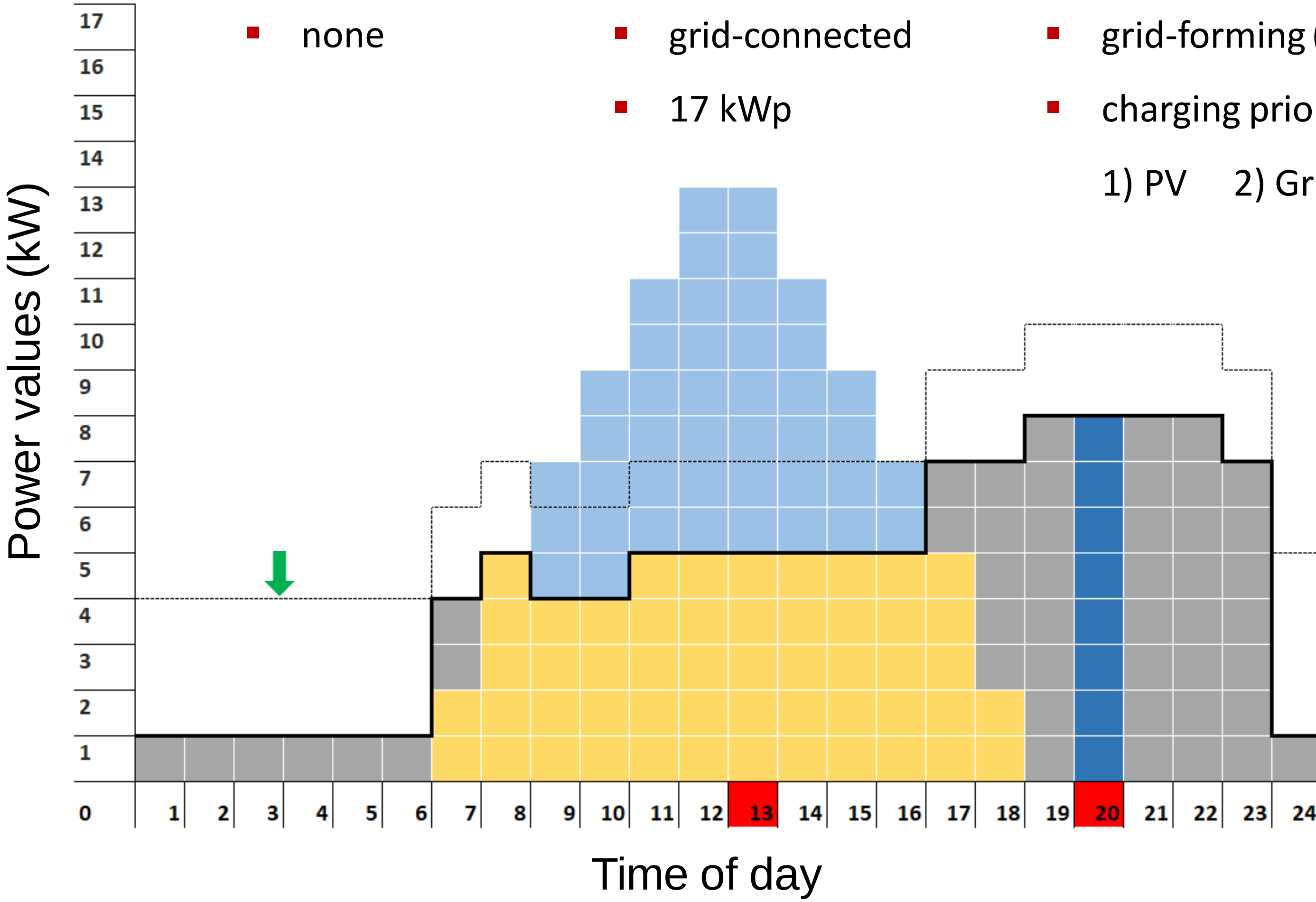
    1) PV   2) Grid

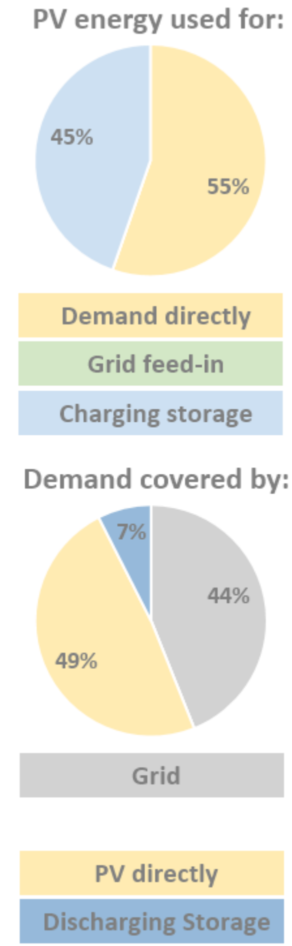




3) Lifting energy efficiency potential

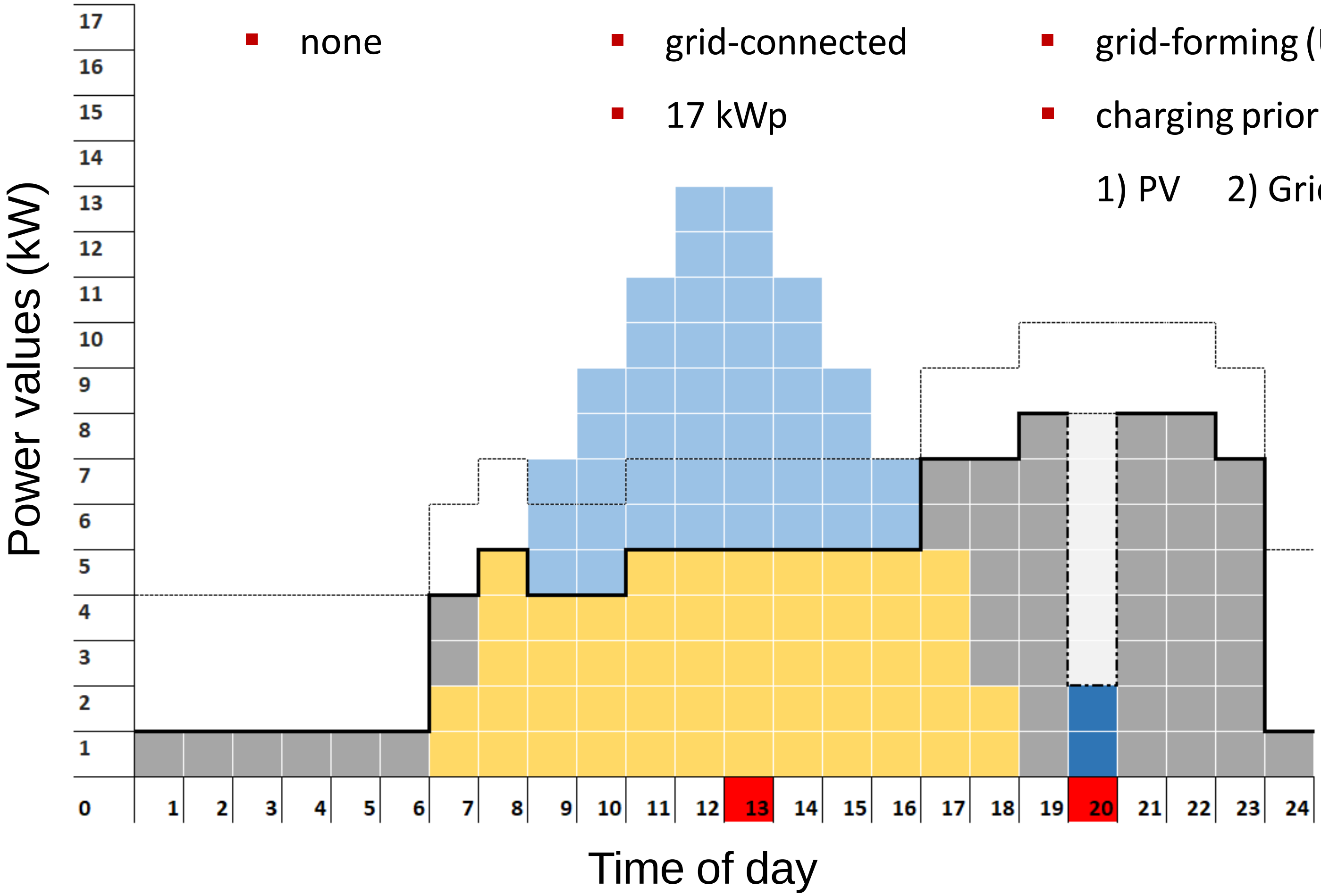
- ***Generator***
  - none
- ***Solar PV***
  - grid-connected
  - 17 kWp
- ***Storage***
  - grid-forming (UPS)
  - charging priority:
    1) PV 2) Grid

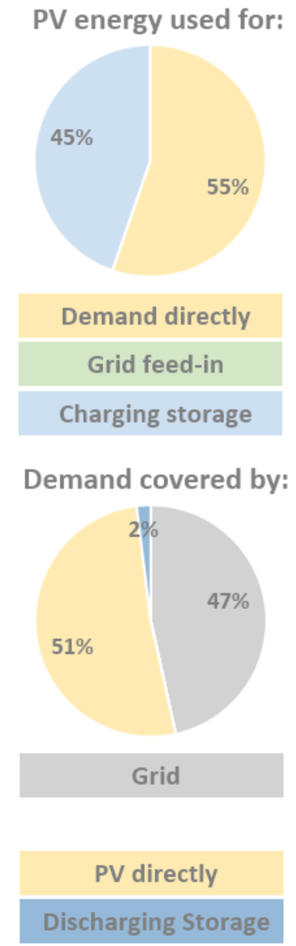




4a) Prioritizing loads

- ***Generator***
  - none
- ***Solar PV***
  - grid-connected
  - 17 kWp
- ***Storage***
  - grid-forming (UPS)
  - charging priority:
    1) PV 2) Grid

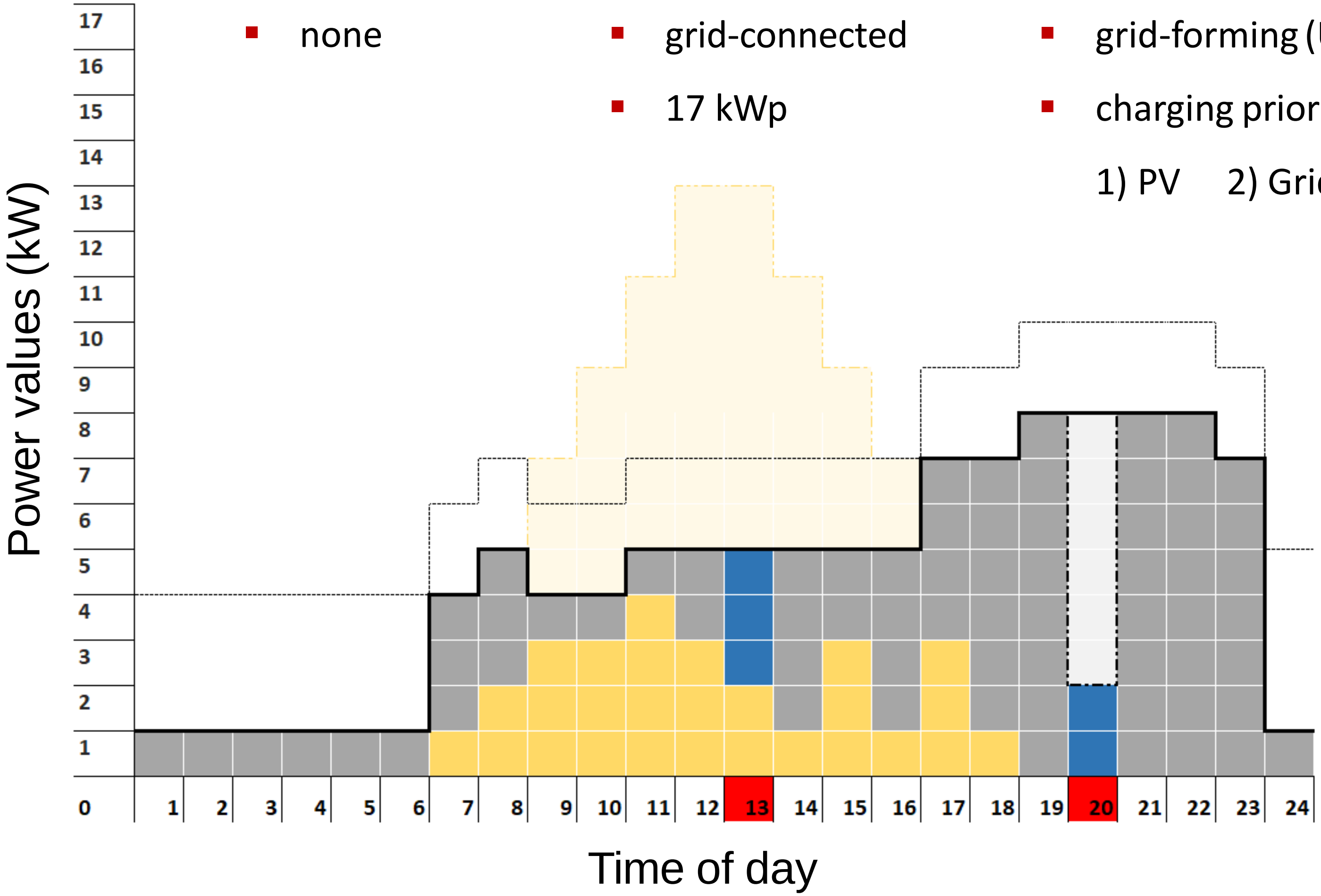


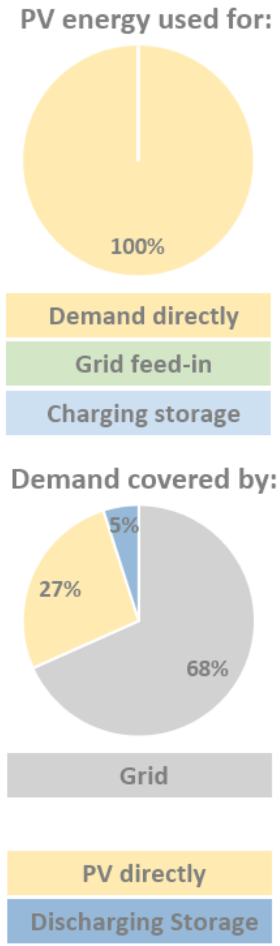


4b) Prioritizing loads (worst cloudy day in NG)

- ***Generator***
  - none
- ***Solar PV***
  - grid-connected
  - 17 kWp
- ***Storage***
  - grid-forming (UPS)
  - charging priority:

    1) PV 2) Grid





Thank you for your attention

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