

## Solar project

# Teaching content Photovoltaics

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Change history

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## **Solar project**

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### **1 Introduction**

With this document, we want to contribute to a better understanding of the use of solar energy through photovoltaics. It is intended to provide a comprehensive overview of the wide range of topics relating to photovoltaics.

The target group is school teachers. The aim is to impart knowledge on the various subject areas to subject teachers and provide impetus for integrating content into the school curriculum.

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## 2 The power of the sun and how we can harness it

### 2.1 The basics of solar radiation<sup>1</sup>

#### 2.1.1 Global radiation

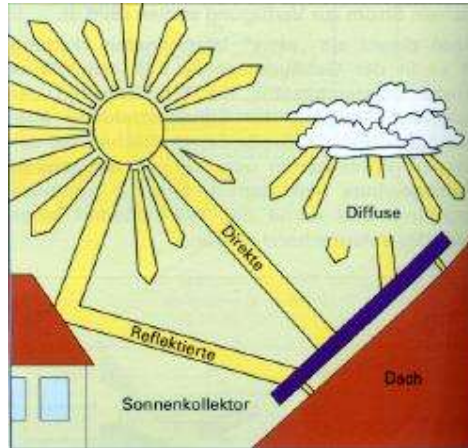


Figure1 : Global radiation<sup>2</sup>

Global radiation is the total amount of solar radiation that reaches the earth's surface. It is made up of two main components: direct radiation and diffuse radiation.

$$E_G = E_{Direkt} + E_{Diffus}$$

#### 2.1.2 Solar constant

The solar constant is the average amount of energy that the earth receives from space per second and per square meter. It is approximately 1367 watts per square meter. This constant is important as it characterizes the flow of energy from the sun to the earth and is fundamental for many calculations in astronomy, climatology and energy production.

$$E_G = \frac{\text{Strahlungsleistung}}{\text{Kugeloberfläche}} = \frac{P_{\text{Sonne}}}{4 * \pi * r_{se}^2} = \frac{3,845 * 10^{26} W}{4 * \pi * (1,496 * 10^{11} m)^2} = 1367 W/m^2$$

#### 2.1.3 Direct radiation

Direct radiation comes directly from the sun to the earth without being scattered or reflected by the atmosphere. It is more intense and concentrated, especially when the sky is clear.

<sup>1</sup> Konrad Mertens, *Photovoltaik - Lehrbuch zu Grundlagen, Technologie und Praxis*. Munich: Hanser Verlag 2020, pp. 41-61

<sup>2</sup> Training center Taunusstein, [Online]. Available: <http://www.schulungsstelle-traunstein.de/Energieberatung/background/5304029665089601f/530402966806ae302/530402966806f4b2a/index.html>. [Accessed on 28 02 24].

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### 2.1.4 Diffuse radiation

Diffuse radiation occurs when the sun's rays are scattered by air molecules, clouds, dust and other particles in the atmosphere. This scattered radiation reaches the earth's surface from different directions and ensures more uniform illumination, especially when the sky is overcast.

Diffuse radiation in Germany is often underestimated, although over the whole year it makes a larger contribution to total global radiation than direct radiation.

When planning a photovoltaic system, it is important to determine the local global radiation in order to be able to calculate the possible yield.

## 2.2 Global energy demand

World energy demand is the total amount of energy required by all countries in the world to meet their economic, industrial, transportation and personal needs.

To quantify global energy demand, the unit kilowatt hour (kWh) is usually used. A kilowatt hour corresponds to the amount of energy that is generated or consumed when a device with an output of one kilowatt (kW) is operated for one hour.

Global energy demand is measured in terawatt hours (TWh), not kilowatt hours (kWh), as these are very large quantities. One terawatt hour corresponds to one billion kilowatt hours.

The exact figure for global energy demand can vary depending on the source and year, but to give a rough idea: Annual global energy demand is typically in the tens of thousands of terawatt hours (TWh).

The breakdown of global energy demand into different categories can vary depending on the source and year. In general, the main categories of world energy demand include:

1. **Power generation:** Around 40-45% of total energy demand is accounted for by the generation of electrical energy. This is generated from various sources such as coal, natural gas, renewable energies (such as solar energy and wind energy) and nuclear energy.
2. **Transport sector:** The transport sector accounts for around 25-30% of global energy demand. This sector includes the energy requirements for cars, trucks, trains, ships and airplanes, which are largely covered by fossil fuels such as petrol, diesel and kerosene.
3. **Industrial sector:** The industrial sector accounts for around 20-25% of global energy demand. Industry requires energy to manufacture goods, process raw materials and carry out industrial processes. The energy comes from various sources, including fossil fuels and electrical energy.
4. **Heating and cooling:** Approximately 10-15% of total energy demand is accounted for by heating and cooling. This includes the energy required for heating, air conditioning and hot water in residential and commercial buildings. The energy sources can vary depending on the region and consumer preferences.

These percentages may vary depending on the region, economic structure and energy policy, but provide an overview of the distribution of global energy demand across the various sectors.

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### 2.3 Forms of solar energy use

#### 2.3.1 Solar thermal energy

Solar thermal is a technology that uses solar energy to generate heat. This heat can be used for various purposes, including water heating, space heating and industrial process heat. Solar thermal is a sustainable and environmentally friendly alternative to fossil fuels as it produces no harmful emissions and the use of solar energy is virtually unlimited.

##### 2.3.1.1 Functional principle of solar thermal energy

The basic operating principle of solar thermal energy is to collect solar radiation and convert it into usable heat. This is mainly achieved by solar collectors. There are two main types of solar collectors: Flat plate collectors and evacuated tube collectors.

##### 2.3.1.2 Solar collectors

**Flat-plate collectors** consist of an absorber surface that absorbs solar radiation and converts it into heat. This heat is transported by a heat transfer medium (usually water or a water-glycol mixture). The absorber surface is embedded in an insulated housing, which is fitted with a transparent cover to minimize heat loss.

**Vacuum tube collectors** work on a similar principle, but the absorber surfaces are enclosed in glass tubes from which the air has been removed to create a vacuum. This vacuum acts as excellent insulation and significantly reduces heat loss, making these collectors particularly efficient.

##### 2.3.1.3 Heat transport and storage

The heat collected by the collectors is transported to a heat storage tank via the heat transfer medium. This heat storage tank can consist of a simple water tank or a more complex system for storing large quantities of heat. The stored heat can then be called up as required and used for various applications.

##### 2.3.1.4 Thermodynamic principles

The efficiency of solar collectors can be described by the thermodynamic principles of heat transfer. The basic equation for calculating the heat output of a solar collector is:

$$Q = A \cdot I \cdot \eta$$

where:

- $Q$  is the heat output generated (watts),
- $A$  is the area of the collector (square meters),
- $I$  is the solar irradiation (watts per square meter),
- $\eta$  is the efficiency of the collector.

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The efficiency  $\eta$  of a solar collector depends on several factors, including the quality of the absorber surface, the type of insulation and the temperature difference between the absorber and the environment. The efficiency can be expressed by the following formula:

$$\eta = \eta_0 - a_1 \cdot (T_m - T_a) - a_2 \cdot (T_m - T_a)^2$$

where:

- $\eta_0$  is the optical efficiency of the collector (i.e. the efficiency under ideal conditions),
- $a_1$  and  $a_2$  are empirically determined loss coefficients,
- $T_m$  is the average temperature of the heat transfer medium,
- $T_a$  is the ambient temperature.

### 2.3.1.5 Advantages and challenges

Solar thermal energy offers numerous advantages:

- **Environmentally friendly:** No CO<sub>2</sub> emissions during operation.
- **Sustainability:** Use of inexhaustible solar energy.
- **Cost efficiency:** Reduced operating costs after installation.

However, there are also challenges:

- **Initial costs:** High acquisition costs for solar collectors and storage systems.
- **Space requirement:** Need for sufficient space to install the collectors.
- **Weather dependency:** Efficiency dependent on solar radiation.

### 2.3.1.6 Conclusion

Solar thermal energy is a promising technology for the sustainable generation of thermal energy. By using solar collectors and efficient storage systems, it can make a significant contribution to reducing dependence on fossil fuels and lowering CO<sub>2</sub> emissions. Through continuous research and development, the efficiency and cost-effectiveness of this technology can be further improved to promote its widespread use.

## 2.3.2 Photovoltaics

### 2.3.2.1 Functional principle of photovoltaics

The basic component of a photovoltaic system is the photovoltaic cell, often simply referred to as a solar cell. Solar cells consist of semiconductor materials, usually silicon, which are able to convert light into electricity. The functionality of a solar cell is based on the photovoltaic effect.

### 2.3.2.2 The photovoltaic effect

The photovoltaic effect describes the generation of electrical voltage and current in a material when it is exposed to light. This happens in several steps:

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### 1. Absorption of light:

- When photons (light particles) hit the solar cell, electrons in the semiconductor material are excited and raised to a higher energy level.

### 2. Generation of electron-hole pairs:

- These excited electrons leave holes (missing electrons) in the atoms of the semiconductor material. So-called electron-hole pairs are created.

### 3. Separation of the charge carriers:

- In a p-n junction structure, which consists of a p-doped (positive) and an n-doped (negative) semiconductor, the electrons and holes are separated. The built-in electric field in the p-n junction ensures that electrons migrate towards the n-doped region and holes towards the p-doped region.

### 4. Generation of electricity:

- When the solar cell is connected to an external load, the electrons flow through the circuit, resulting in an electric current.

### 2.3.2.3 Mathematical description

The output of a solar cell can be described by the current-voltage curve (I-V curve). The generated current  $I$  of a solar cell depends on the applied voltage  $U$  and the light intensity  $E_G$ . The basic equation that describes the relationship is the Shockley equation for the diode:

$$I = IL - I_0 \left( e^{\frac{qU}{nkT}} - 1 \right)$$

where:

- $I$  is the current generated (in amperes),
- $IL$  the luminous flux (in amperes) is proportional to the light intensity  $G$ ,
- $I_0$  is the reverse current of the diode (in amperes),
- $q$  is the elementary charge ( $1.602 \times 10^{-19}$  Coulomb),
- $U$  is the voltage (in volts),
- $n$  is the diode ideality factor,
- $k$  is the Boltzmann constant ( $1.381 \times 10^{-23}$  J/K),
- $T$  is the absolute temperature (in Kelvin).

### 2.3.2.4 Efficiency and power calculation

The efficiency  $\eta$  of a solar cell indicates how much of the irradiated light energy is converted into electrical energy. It is calculated by:

$$\eta = \frac{P_{max}}{P_{in}}$$

where:

- $P_{max}$  is the maximum power (in watts) that the solar cell can deliver,
- $P_{in}$  is the irradiated light output (in watts), which is given by  $P_{in} = E_G \cdot A$ ,
- $E_G$  is the solar irradiation (in watts per square meter),
- $A$  is the area of the solar cell (in square meters).

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### 2.3.2.5 Maximum power point (MPP)

The point on the I-V curve at which the power is at its maximum is referred to as the maximum power point (MPP). The maximum power  $P_{max}$  is reached when the product of the current  $I$  and the voltage  $U$  is at its maximum:

$$P_{max} = I_{mp} \cdot U_{mp}$$

where:

- $I_{mp}$  is the current at maximum power,
- $U_{mp}$  is the voltage at maximum power.

### 2.3.2.6 Conclusion

Photovoltaics is an effective technology for converting sunlight into electrical energy. By utilizing the photovoltaic effect in semiconductor materials, solar cells can generate clean and renewable energy. The continuous development of this technology is helping to increase efficiency and reduce costs, making it an increasingly important component in the global energy mix.

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### 3 Electrotechnical basics

#### 3.1 Task for converting energy and cycling

**Given:**

A photovoltaic system generates 5 kWh of energy on a sunny day. An average person generates 100 watts of power when cycling.

**Task definition:**

1. Convert the energy of 5 kWh into kilojoules (kJ).
2. Calculate how long you would have to cycle to generate the same amount of energy (5 kWh).

**Solutions:**

##### 1. conversion from kWh to kJ:

Energy in kilowatt hours (kWh) can be converted into kilojoules (kJ) by multiplying it by 3600 (the number of seconds in an hour), since 1 kWh = 3600 kJ.

$$5 \text{ kWh} \times 3600 \frac{\text{kJ}}{\text{kWh}} = 18000 \text{ kJ}$$

The energy of 5 kWh therefore corresponds to 18000 kJ.

##### 2. calculation of the cycling time:

An average person generates 100 watts of power when cycling. This corresponds to 100 joules per second (J/s).

To generate the same amount of energy of 18000 kJ, the time must be calculated:

$$\text{Leistung} = \frac{\text{Energie}}{\text{Zeit}}$$

The power is 100 J/s (or 100 W) and the energy is 18000 kJ (or 18000000 J).

$$\text{Zeit} = \frac{18000000 \text{ J}}{100 \frac{\text{J}}{\text{s}}} = 180000 \text{ Sekunden}$$

To convert the time into hours:

$$180000 \text{ Sekunden} \div 3600 \frac{\text{Sekunden}}{\text{Stunde}} = 50 \text{ Stunden}$$

**Answer:** To generate the same amount of energy of 5 kWh (18000 kJ), you would have to cycle for 50 hours.

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### 4 Forms of application for photovoltaics

Photovoltaic systems are available in various designs and sizes. Very small solar cells are used, for example, to power pocket calculators - eliminating the need for batteries, rechargeable batteries or an external power supply.

Small systems and large systems (also known as ground-mounted photovoltaic systems on agricultural land) are used to supply electricity and feed it into the grid. The most important differences, advantages and disadvantages of both systems are explained below.

#### 4.1 Small photovoltaic systems

There is no clear definition of the difference between large and small systems in the literature. As a rule, a distinction is made between small systems,

- individual systems for private use with an output of 1 kWp to 10 kWp and
- 10 to 100 kWp systems, which are frequently used in commercial applications.

The photovoltaic modules are installed on house roofs or building façades and electrically connected to each other. The direct current generated by the photovoltaic modules is converted into alternating current via an inverter and fed into the electricity grid in return for remuneration or consumed on site, e.g. to operate electrical appliances or to charge a power storage unit (battery).

##### Advantages of small systems

- Generally not subject to approval
- Self-sufficient power supply possible (independence from the power grid)

##### Disadvantages of small systems

- Limited available space on building roofs restricts the number of photovoltaic modules
- Shading on building roofs and the inclination of pitched roofs reduce energy generation

Examples of small photovoltaic systems can also be found in the Colombian capital Bogotá, where they are used to supply administrative buildings with electricity.

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Image1 Photovoltaic system on the roof of a building in the city of Bogotá<sup>3</sup>

### 4.2 Large-scale photovoltaic systems

Large-scale photovoltaic systems are systems with an output of 100 kWp to several MWp. The photovoltaic modules are installed on large roof surfaces (e.g. industrial buildings) or on open spaces. Increasingly, ground-mounted systems are being installed on agricultural land.

#### Advantages of large systems

- Achieving high electricity yields
- Cost-effective procurement of individual components (e.g. inverters, photovoltaic modules, cables) by purchasing larger quantities
- Contribution to biodiversity through the conversion of intensively used agricultural land

#### Disadvantages of large systems

- Large area required for the photovoltaic modules

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<sup>3</sup> Meyer Iris, 2015, A self-consumption system high above the rooftops of Bogotá, <https://www.ibc-blog.de/2015/10/eigenverbrauchssystem-hoch-ueber-den-daechern-von-bogota/>)

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- Higher (investment) costs for the installation and maintenance of modules and infrastructure

Very large photovoltaic systems (VLS-PV) are systems with an output of 10 MWp to several GWp. These large solar parks are built in regions with high annual solar irradiation, e.g. in desert regions.<sup>45</sup>

Guayepo PV Solar Park (Parque Solar Fotovoltaico Guayepo) I & II is a photovoltaic solar park under construction in Ponedera, Atlantico, Colombia. The solar park with an output of 487 MWp is scheduled to go into operation in 2024. The project, with an investment of over 290 million US dollars, covers an area of 1,110 hectares (equivalent to around 1,585 soccer pitches). It comprises more than 820,600 solar modules, enabling the park to generate an estimated 1,030 GWh per year. This capacity is enough to supply over 1.46 million people with electricity, which is roughly equivalent to the population of Barranquilla.



**Image2** Guayepo I & II Solar Park. Credit: Enel Green Power<sup>6</sup>

### 4.3 The photovoltaic strategy in Germany

The German government has decided to double the share of renewable energies in electricity consumption in Germany from just over 40% today to 80% by 2030. The target is set out in the

<sup>4</sup> Gabler, Hansjörg, 2002, Photovoltaische Großanlagen - Technologie und Realisierung, [https://www.fvee.de/wp-content/uploads/2022/02/th2002\\_04\\_01.pdf](https://www.fvee.de/wp-content/uploads/2022/02/th2002_04_01.pdf)

<sup>5</sup> Federal Ministry of Economics and Climate Protection (BMWK), 2023, Photovoltaic strategy - fields of action and measures for an accelerated expansion of photovoltaics, [https://www.bmwk.de/Redaktion/DE/Publikationen/Energie/photovoltaik-strategie-2023.pdf?\\_\\_blob=publicationFile&v=8](https://www.bmwk.de/Redaktion/DE/Publikationen/Energie/photovoltaik-strategie-2023.pdf?__blob=publicationFile&v=8)

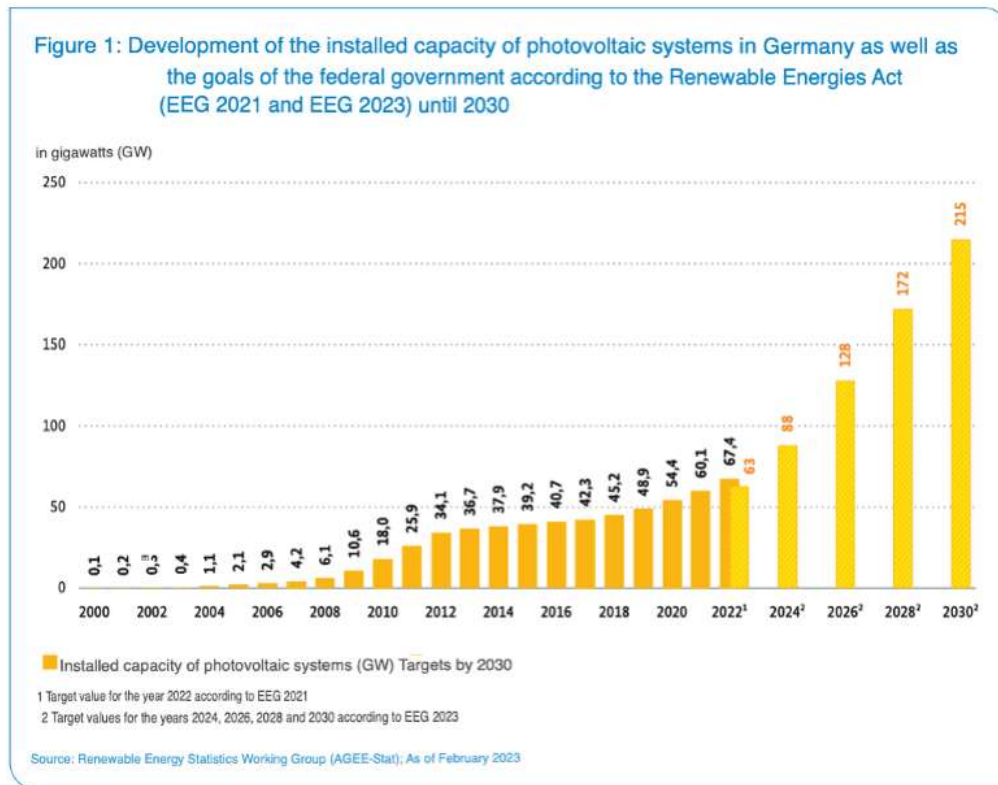
<sup>6</sup> A Giatsidakis, 2023, Largest Solar Park in Colombia Begins Powering the Nation, <https://www.colombiaone.com/2023/12/27/colombia-largest-solar-park/>

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Renewable Energy Sources Act (EEG 2023). In addition to the expansion of wind power and biomass plants, the expansion of photovoltaics is a key component.

The EEG 2023 provides for the expansion of photovoltaics to up to 215 gigawatts of installed photovoltaic capacity in 2030, which corresponds to an annual expansion of more than 22 gigawatts.



**Figure3** Installed capacity of photovoltaic systems (GW) and targets by 2030 in Germany<sup>7</sup>

In order to achieve this goal, the German government's photovoltaic strategy describes three main fields of action:

- **Expansion of ground-mounted systems**

The German government is pursuing the goal of constructing ground-mounted PV systems with a total output of around 11 GW per year from 2026. The systems are to be installed on agricultural land (so-called agrivoltaics) as well as on sealed and contaminated areas. Floating PV systems are also to be built. In order to achieve the goal of expanding ground-mounted systems, building permit procedures are to be simplified and the financial participation of local authorities expanded, among other things.

- **Promotion of rooftop photovoltaic systems**

The German government's strategic goal also provides for the expansion of rooftop

<sup>7</sup> Anu Bhambhani, 2023, Germany Invites Public Consultation For PV Strategy <https://taiyangnews.info/germany-invites-public-consultation-for-pv-strategy>

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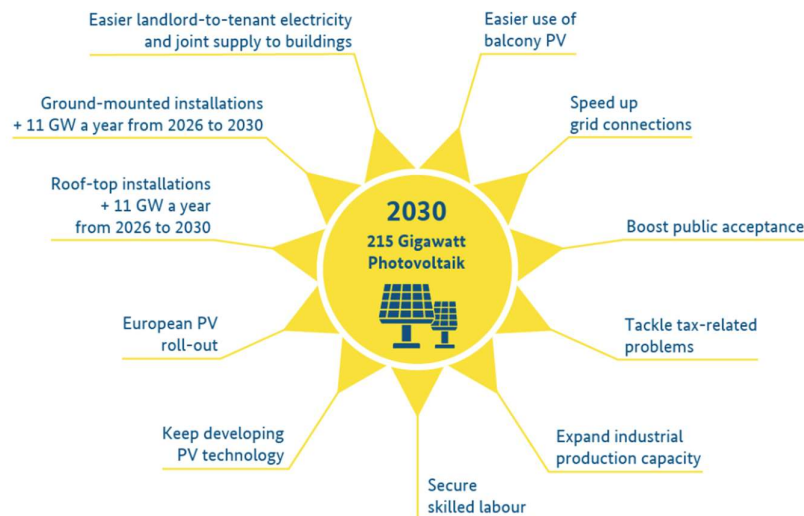
photovoltaic systems by around 11 GW per year from 2026. Two solar packages are to be launched to promote the expansion of rooftop photovoltaic systems. The measures adopted include simplifying the direct marketing of electricity fed into the grid by photovoltaics, reducing bureaucracy and optimizing construction and technical requirements.

- **Securing the necessary skilled workers**

According to a study by the Competence Center for Securing Skilled Workers (KOFA, "Energie aus Wind und Sonne" 3/2022), there is already an annual average shortage of more than 200,000 skilled workers in the professions relevant to wind and solar energy in 2021/2022<sup>8</sup>

### PV Strategy for a faster solar roll-out

Comprehensive package of measures to add 215 GW of installed PV capacity by 2030



Picture4 Measures of the German PV Strategy<sup>9</sup>

## 4.4 Colombia's energy transition policy

Colombia's geographical location and natural conditions make the country very attractive for the use of renewable energies. The Andean country already covers the majority of its electricity needs from green sources, particularly hydropower. Climate change and the El Niño weather phenomenon could mean that there is no longer enough water available to generate electricity. In contrast, non-conventional renewable energy sources such as wind, solar energy and biomass only accounted for

<sup>8</sup> Federal Ministry of Economics and Climate Protection (BMWK), 2023, Photovoltaic strategy - fields of action and measures for an accelerated expansion of photovoltaics, [https://www.bmwk.de/Redaktion/DE/Publikationen/Energie/photovoltaik-strategie-2023.pdf?\\_\\_blob=publicationFile&v=8](https://www.bmwk.de/Redaktion/DE/Publikationen/Energie/photovoltaik-strategie-2023.pdf?__blob=publicationFile&v=8)

<sup>9</sup> Federal Ministry for Economic Affairs and Climate Protection, 2023, PV strategy for a faster solar roll-out, <https://www.bmwk.energiewende.de/EWD/Redaktion/EN/Newsletter/2023/05/Meldung/direkt-answers.html>

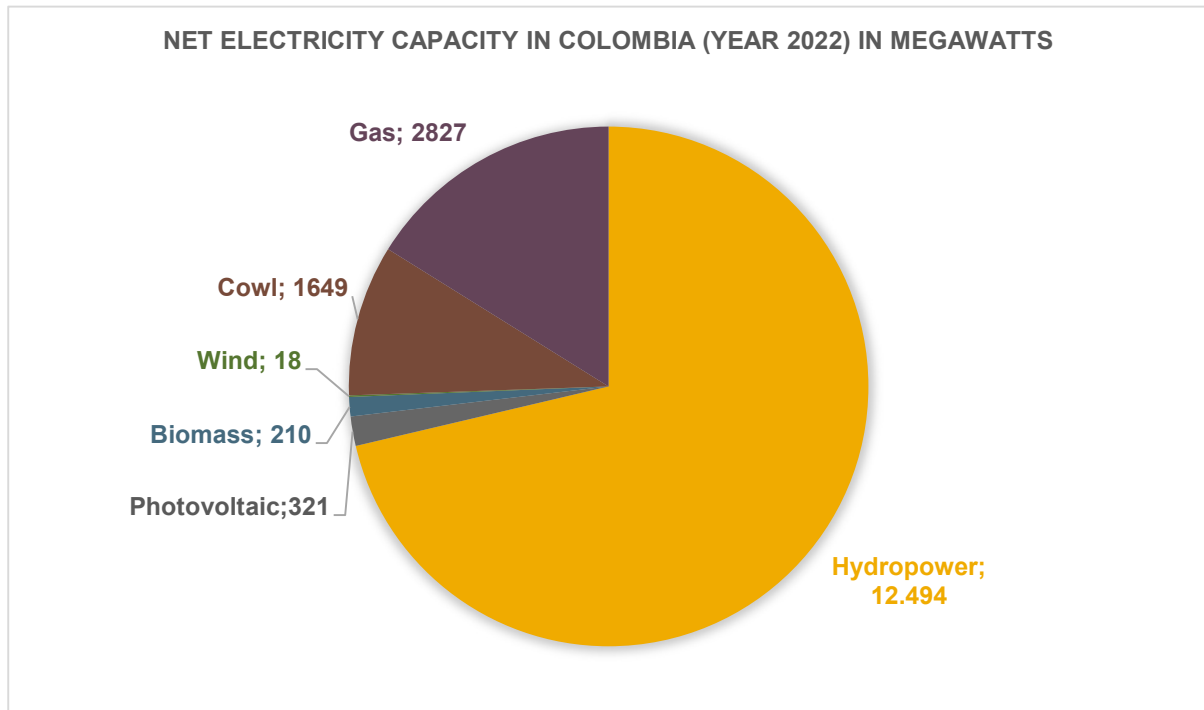
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just under 3 percent of installed capacity at the end of 2022. This is set to change, even if the expansion has recently been delayed.

### PEN 2020-2050 and PEN 2022-2052

According to the draft National Energy Plan (PEN 2022-2052)<sup>1</sup>, the share of renewable energies (excluding hydropower) in the electricity supply could rise to around 70 percent by 2052 in the best-case scenario. Instruments such as tax incentives and public auctions for strategic energy sources are intended to achieve these targets. The government under Gustavo Petro wants to make the country less dependent on fossil fuels. In addition to higher taxes, a halt to new exploration licenses is also planned



**Picture5** Net electricity capacity in Colombia 2022 <sup>10</sup>

In the current National Energy Plan (PEN 2020-2050), the share of hydropower in electricity generation in Colombia could fall to 36% by 2050. In the same year, non-conventional renewable energies such as wind and solar energy could then account for around 44%.

### Ley 1715 de 2014 (tax benefits for photovoltaics) and Ley 2099 de 2021

The country's climate strategy is considered ambitious. The solar energy sector is benefiting from this. Tax benefits for photovoltaics have been in place since the introduction of Law 1715 of 2014.

<sup>10</sup> Upme, 2023, Actualización Plan Energético Nacional (PEN) 2022 - 2052  
[https://www1.upme.gov.co/DemandayEficiencia/Documents/PEN\\_2020\\_2050/Actualizacion\\_PEN\\_2022-2052\\_VF.pdf](https://www1.upme.gov.co/DemandayEficiencia/Documents/PEN_2020_2050/Actualizacion_PEN_2022-2052_VF.pdf)

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The energy transition law Ley 2099 de 2021 clarified the ambitions for the expansion of photovoltaics. Among other things, the Colombian government has declared its willingness to promote photovoltaic systems on public buildings, particularly in educational and healthcare facilities.<sup>11</sup>

### 4.5 Examples of photovoltaic projects

#### Transformation of LEAG (Jänschwalde, Germany)

The power plant company LEAG, one of Germany's largest electricity producers, is undergoing a transformation process from the use of fossil fuels to climate-friendly renewable energy. The gigawatt factory - Germany's largest wind and solar park to date - is being built at the former Jänschwalde open-cast mine in Lusatia, where lignite was mined for decades. The energy park is set to generate up to 7 GW of renewable electricity capacity by 2030. In addition to wind turbines, several solar parks are planned, built and commissioned at regular intervals.

One of the largest open-space photovoltaic plants planned to date is the Bohrau Energy Park. Covering an area of around 400 hectares, it will be built in several sections on agricultural recultivation land of the Jänschwalde open-cast mine. The solar park is expected to have a total output of 400 MW.



**Picture6** LEAG Gigawatt Factory in Lusatia<sup>12</sup>

<sup>11</sup> upme, 2023, Actualización Plan Energético Nacional (PEN) 2022 - 2052  
[https://www1.upme.gov.co/DemandayEficiencia/Documents/PEN\\_2020\\_2050/Actualizacion\\_PEN\\_2022-2052\\_VF.pdf](https://www1.upme.gov.co/DemandayEficiencia/Documents/PEN_2020_2050/Actualizacion_PEN_2022-2052_VF.pdf)

<sup>12</sup> LEAG, 2024, Press release, <https://www.leag.de/de/news/details/leag-und-projektentwickler-epne-treiben-energiewende-voran-und-bringen-gruenstrom-grossprojekte-auf-di/>

## **Solar project**

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### **Floating solar system (Córdoba, Colombia)**

In 2023, a large floating solar plant was put into operation on the reservoir of the Colombian Urrá dam. The "Aguasol" floating solar project was installed at the 340 MW Urrá hydropower plant in the Sinú river basin in Córdoba in north-western Colombia. With a retention capacity of 1.6 billion cubic meters of water, the Urrá dam is one of the largest in Colombia. The solar plant consists of more than 2800 solar modules with a total area of 1.7 hectares and achieves an output of 1.5 MWp. This makes it the largest floating solar plant in South America. The aim of the "Aguasol" project is to show that dams can be combined with floating solar plants to cope with fluctuating water levels, increase electricity production and thus improve the security of energy supply. In the first year, the solar plant is expected to produce around 2400 MWh of electricity, which is sufficient to operate the hydropower plant. In addition, it is predicted that the solar plant can avoid more than 1540 tons of carbon dioxide emissions annually.

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**Picture7** floating solar power system "Aguasol" in Córdoba, Colombia<sup>13</sup>

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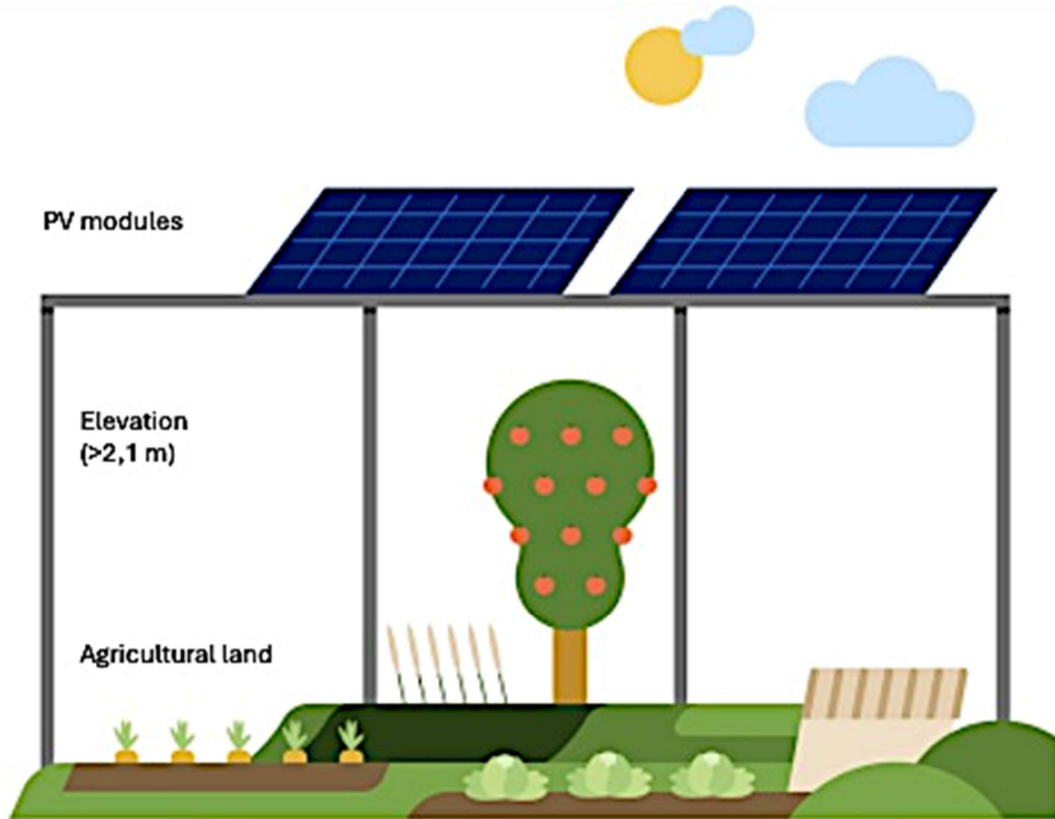
<sup>13</sup> Noria, Projects, <https://noriaenergy.com/portfolio/>

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### 4.6 Agri Photovoltaik

A major disadvantage of photovoltaic systems is their high land requirement. In order to avoid ecological, political, economic or social conflicts, technologies can be used that allow land to be used simultaneously, e.g. for agriculture and electricity generation. So-called agri-photovoltaic systems are used both as closed systems and as open systems (as photovoltaic greenhouses).



Quelle: Fraunhofer-Institut für Solare Energiesysteme

Picture8 Agri-PV system - how it works<sup>14</sup>

Open Agri-PV systems can be used in various forms.

#### 4.6.1 Elevated photovoltaic systems

Elevated PV systems are often used, where the solar modules are mounted several meters above the ground - often over 2 meters - to allow the use of agricultural machinery and the cultivation of crops below.

<sup>14</sup> EnBW, 2024, Apple or electricity? Both are possible with Agri-PV! <https://www.enbw.com/unternehmen/eco-journal/agri-photovoltaik-loest-gleich-zwei-probleme.html>

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### 4.6.2 Vertical PV systems

Vertical PV systems are an alternative to this. In contrast to elevated PV systems, the solar modules are mounted vertically, often in rows. Plants are grown between the modules.

PV systems on greenhouses and integrated PV systems, e.g. in fences or stables, also enable electricity to be generated without impacting on agriculture.

### 4.6.3 Advantages of agri-photovoltaic systems

1. **Dual use of land**

Agri-PV systems maximize the efficiency of land use by making it possible to produce both food and energy on the same area of land.

2. **Yield increase**

In some cases, partial shading by the PV modules can have a positive impact on crop production by mitigating temperature extremes and direct sunlight, which can lead to better growing conditions.

3. **Climate protection:**

By generating renewable energy, Agri-PV systems help to reduce greenhouse gas emissions and support the energy transition towards more sustainable energy sources.

4. **Economic advantages:**

Farmers can benefit economically from the additional source of income from electricity generation. This can be particularly advantageous in regions with fluctuating agricultural yields.

5. **Wide range of applications:**

Agri-PV systems can be used in various forms, e.g. as high-altitude PV modules above farmland, as vertical PV modules in rows or as flexible PV films on greenhouses.

6. **Saving water:**

Shading the PV modules can reduce the plants' water requirements, which is particularly beneficial in dry regions.

Overall, agricultural photovoltaic systems offer an innovative way to combine food production and sustainable energy generation, which can contribute to a more efficient use of resources and climate protection.

### 4.6.4 Examples of agrivoltaic systems

Unergy is a start-up company based in Medellín that specializes in financing renewable energy projects. One of Unergy's key projects is the construction and financing of solar mini-farms in regions with a solar radiation of more than 1,800 kWh/kWp and an inclination of less than 10 degrees.

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Target areas include areas near the Atlantic coast, the Caribbean, the northern territories and the low valleys of the Andes region.

In agri-photovoltaic projects, photovoltaic panels not only generate electricity, but also support agricultural activities that require moderate solar radiation, such as the cultivation of highly productive pumpkin crops and the keeping of small livestock. In addition, the amount of water required for irrigation is reduced, which further improves the environmental aspects and reduces the cost of agricultural resources.



Picture9 Agri PV system by Unergy<sup>15</sup>

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<sup>15</sup> 2024, Unergy implements first small-scale Agri-PV projects in Latin America, <https://www.erneuerbareenergien.de/technologie/solar/unergy-setzt-erste-kleine-agri-pv-projekte-lateinamerika-um>

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## 5 Excursus on storage technologies

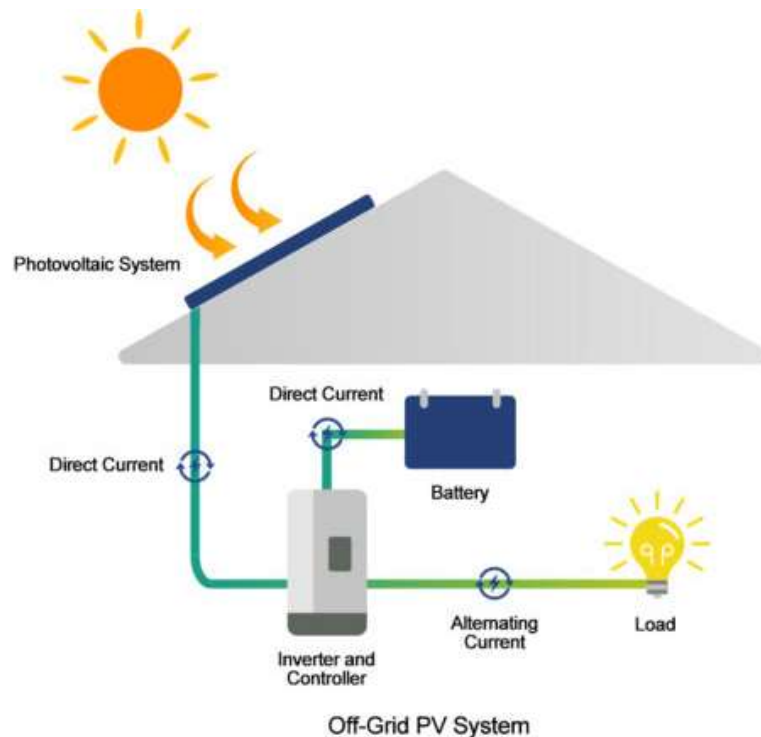
### 5.1 Introduction

Photovoltaic systems only produce electricity when the sun is shining. To ensure that the electricity generated can also be used during dark hours when the sun is not shining, it must be stored. The integration of an energy storage system for electricity from photovoltaic systems is described below and storage systems currently available on the market are presented.

### 5.2 Network-independent systems

The electricity generated by a photovoltaic system can be consumed directly by the household or fed into the public grid (grid-connected system). In Germany, the operator of the photovoltaic system receives remuneration for feeding electricity into the grid under the Renewable Energy Sources Act (EEG).

If you want to use the electricity yourself and not feed it into the public grid, you need a so-called stand-alone system. Stand-alone systems are energy supply systems that function independently of the public power grid. They generate, store and manage electricity locally without being dependent on a central power supply. Stand-alone systems are often used in remote areas where connection to the electricity grid is difficult or expensive, or in emergency situations to ensure a self-sufficient energy supply.



Picture10 the components of an off-grid PV system<sup>16</sup>

<sup>16</sup> Maysun solar, 2022, <https://www.maysunsolar.de/blog/inselfanlage-netzgekoppelt-pvanlage>

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An off-grid energy system for using electricity from a photovoltaic system consists of:

- **energy generator**, the solar modules of the photovoltaic system
- **Storage systems** that store surplus energy and can be used at times when the sun is not shining
- **Inverters** that convert the direct current generated by the solar modules into alternating current, which is required for most household appliances
- **Charge controllers** that regulate the current flow between the solar cells and the storage systems to prevent overcharging or deep discharging of the storage system

There are various ways to integrate the storage system into the energy system. As solar energy storage systems are charged and discharged with direct current, the storage system can be installed together with the PV system, which also generates direct current, as a DC coupling upstream of the inverter. A major advantage of DC systems is the lower conversion losses.

Alternatively, solar energy storage systems can be installed as AC coupling with their own inverter in the AC circuit. This makes it easier to retrofit existing energy systems.

### 5.3 Storage solutions - in comparison

There are a variety of technologies for storing electricity from photovoltaic systems, which offer different advantages depending on the application, scalability, efficiency and costs. The most important storage technologies for PV electricity are

#### Lithium Ion Battery

Lithium-ion batteries are most commonly used for storage. These offer a high energy density and a long service life. In lithium-ion batteries, the positive electrode contains either transition metal oxides such as lithium cobalt oxide (LCO), lithium nickel cobalt aluminum oxide (LNCA), lithium nickel manganese cobalt oxide (LNMC) or lithium manganese oxide (LMO) as active materials or transition metal phosphates such as lithium iron phosphate (LFP).

A major disadvantage of lithium-ion batteries is the risk of overheating and therefore the risk of fire.

#### Lead-acid batteries

In lead-acid batteries, both the negative and positive electrodes are made of lead or a lead alloy. The electrolyte is sulphuric acid, which is involved in the cell reaction. When charged, the positive electrode consists of lead dioxide (PbO<sub>2</sub>) and the negative electrode of lead (Pb). Together with the sulphuric acid, lead sulphate (PbSO<sub>4</sub>) is formed on both electrodes during discharge, which is converted back into lead dioxide or lead during charging.

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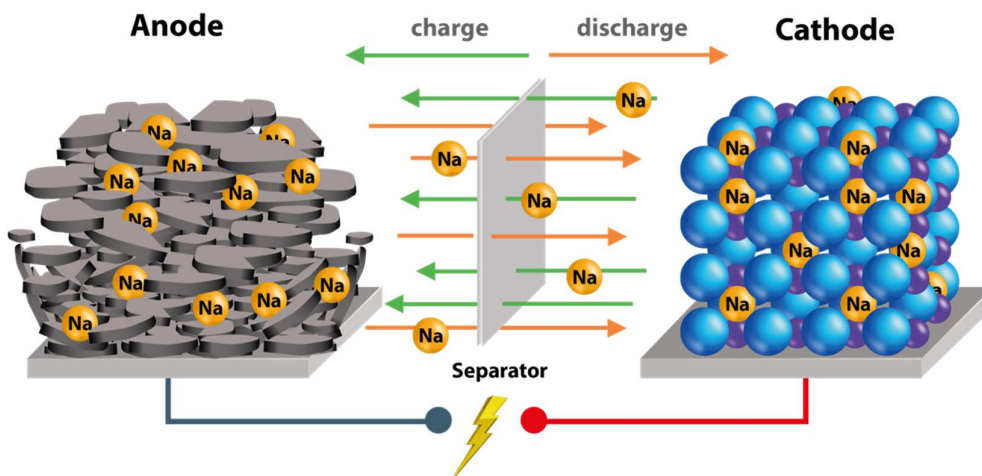
Lead-acid batteries are inexpensive, but have a shorter service life and lower energy density than lithium-ion batteries.

### Saltwater batteries

The use of saltwater batteries to store electricity is not yet widespread. One advantage over other storage systems is the use of environmentally friendly materials. The electrolyte used in saltwater batteries is generally a sodium ion solution, usually an aqueous sodium chloride (NaCl) solution. NaCl is known as common salt and is readily available. The disadvantage, however, is its low energy density and performance, which requires a larger storage system than lithium-ion batteries.

### Sodium-ion batteries

Sodium-ion batteries work in a similar way to lithium-ion batteries, but use sodium ions ( $\text{Na}^+$ ) instead of lithium ions ( $\text{Li}^+$ ) as charge carriers. These ions move between an anode and a cathode during the charging and discharging process. Like saltwater batteries, sodium-ion batteries are more environmentally friendly than lithium-ion batteries, for example. However, at the current stage of development, the energy density and performance of this technology are also lower.



Picture11 How a sodium-ion battery works<sup>17</sup>

### Redox flow storage

This type of storage system uses a liquid that stores electrons. A redox flow storage system consists of two separate tanks filled with electrolyte liquid, the stack and the pumps. The stack consists of

<sup>17</sup> Daniel, C.; Besenhard, J.O. Handbook of Battery Materials; John Wiley & Sons: Weinheim, Germany, 2012

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several galvanic cells. When electricity is stored, the liquids flow and a chemical reaction takes place. If necessary, the reaction is reversed to release current. The advantage Vanadium solutions are most commonly used in redox flow storage systems. The construction of a redox flow storage system with tank systems, pumps and pipes is very complex and is therefore used more in companies and less in the private sector.

## Hydrogen

Hydrogen can also be used to store electricity. Surplus electricity is used to split water into hydrogen and oxygen by electrolysis. The hydrogen can then be stored and later used in a fuel cell to generate electricity. Due to its low overall efficiency (electrolysis, storage and reconversion), hydrogen is currently more suitable for long-term and large-scale storage solutions.

## Costs of storage technologies

- **Lithium-ion batteries:** This technology is currently the most widespread and has become significantly more cost-effective in recent years. Depending on the system and manufacturer, the costs are around EUR 800 to 1,200 per kWh of storage capacity.
- **Lead-acid batteries:** They are the cheapest solution in terms of purchase costs, with prices ranging from around EUR 200 to EUR 500 per kWh. However, they are more expensive in the long term due to their shorter service life and lower efficiency.
- **Redox flow batteries:** These storage systems are currently still more expensive, ranging from around EUR 1,500 to EUR 3,000 per kWh of storage capacity, as they are mainly used in large-scale projects. However, they can be economical for stationary and long-term applications.
- **Saltwater batteries:** These batteries are priced between lead-acid and lithium-ion batteries, costing between around €500 and €1,500 per kWh. However, their environmental friendliness and longevity offer advantages that can pay off in the long term.
- **Sodium-ion batteries:** This technology is still under development, but it is expected that it could be more cost-effective than lithium-ion batteries once it becomes commercially available.

In addition, there are costs for the installation and maintenance of the storage and energy systems, which vary depending on the energy system and the storage technology used.<sup>18</sup>

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<sup>18</sup> Graulich, Hilbert, Heinemann, 2018, Use and economic efficiency of photovoltaic battery storage systems in combination with saving electricity, <https://www.oeko.de/fileadmin/oekodoc/PV-Batteriespeicher-ETT-Information.pdf>

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### 6 Brief process from planning to commissioning of a PV system

This chapter provides a brief and clear overview of the steps that need to be taken to take a photovoltaic system from planning to commissioning. The list is intended to provide an overview and can be used as a checklist. In the actual implementation, the topics must be further detailed depending on the current situation on site. As part of the photovoltaic project at the Colegio Fervan school, this is a crucial part of the certification process - the pupils should have gone through the process once in practice.

#### 6.1 Planning and approval

- **Demand assessment:** Determine how much electricity the house needs in order to determine the size of the PV system.
- **Roof inspection:** Checking the statics of the roof to ensure that it can support the weight of the solar modules.
- **Alignment and inclination:** The orientation and pitch of the roof is checked to ensure that the solar modules receive optimum sunlight.
- **Permits:** Obtaining the necessary permits from local authorities, energy suppliers or grid operators.

#### 6.2 Selection of components

- **Solar modules:** Selection of solar modules based on output, efficiency and roof size.
- **Inverter:** The inverter is selected based on the module output and the feed-in requirement. It converts the direct current (DC) generated by the solar modules into alternating current (AC), which can be used in the household grid.
- **Mounting system:** Selection of a mounting system that matches the roof structure and the modules.

#### 6.3 Installing the substructure

- **Mounting the brackets:** A special substructure is installed on the roof to hold the solar modules. The brackets are attached directly to the roof, either on roof tiles, metal rails or hooks.
- **Roof penetrations:** If necessary, small openings are created in the roof to feed cables through the roof. These are carefully sealed to prevent leaks.

#### 6.4 Mounting the solar modules

- **Mounting the modules:** The solar modules are securely mounted on the substructure and fixed in the intended positions.

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- **Electrical connection:** The modules are wired together so that the current flows through the cabling and reaches the inverter.

### 6.5 Installing the inverter

- **Inverter location:** The inverter is installed near the solar modules or in the basement/technical room where it is easily accessible.
- **Wiring:** The cables that carry the electricity from the modules are connected to the inverter. This converts the direct current generated into usable alternating current.

### 6.6 Connection to the power grid

- **Meter connection:** A bidirectional meter is installed to measure the electricity fed into the grid and the electricity drawn from the grid. This documents self-consumption and the feed-in of surplus electricity into the grid.
- **Grid connection:** The system is connected to the domestic grid and the public electricity grid.

### 6.7 System testing and commissioning

- **Test run:** The entire system is tested to ensure that all components function correctly and that the current flows as desired.
- **Commissioning:** After successful testing, the system is officially put into operation.

### 6.8 Maintenance and monitoring

- **Regular inspections:** To maintain efficiency, the solar modules and inverter should be checked regularly. The use of drones is worthwhile for larger systems.
- **Monitoring systems:** A monitoring system is often installed to check the performance of the PV system and to become aware of any faults at an early stage.

These steps ensure the safe and efficient installation of a photovoltaic system that will produce environmentally friendly electricity for many years and will not send you another bill for energy consumption.

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# 7 Planning a photovoltaic system

## 7.1 Location analysis

The site analysis is an important first step in the planning of photovoltaic systems in order to ensure the long-term profitability and efficiency of the system. It is used to determine the best possible conditions for producing electricity from solar energy by evaluating various site factors. A careful analysis helps to minimize risks and maximize energy production.

Important points in the site analysis for photovoltaics:

### **Solar radiation:**

- Average sunshine duration and hours of sunshine.
- Inclination and orientation of the surface for maximum solar radiation.

### **Shading:**

- Possible shading by buildings, trees or other obstacles.
- Seasonal changes in shading.

### **Availability of space:**

- Size and type of available area (roof, open space).
- Load-bearing capacity of the roof structure (for roof systems).

### **Network connection:**

- Distance and capacity of the connection to the power grid.
- Availability and capacity of storage facilities (optional).

### **Climatic conditions:**

- Influence of temperature, wind and rain on the efficiency of the modules.
- Risk of extreme weather events such as storms or hail.

### **Legal framework:**

- Zoning and building regulations.
- Approval procedure and possible subsidies.

### **Economic factors:**

- Feed-in tariffs and electricity prices.
- Costs for installation, maintenance and connection to the grid.

### **Accessibility and infrastructure:**

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- Accessibility for the transportation of modules and maintenance.
- Local infrastructure for power supply and maintenance.

### 7.2 Take measurements

Once the location of the system has been selected, the available area must be determined. Knowing the exact dimensions of the area to be covered is crucial for efficient planning of a photovoltaic system (PV system). It influences the number of solar modules that can be installed and therefore the maximum power generation. It can also be used to determine the number of modules that need to be purchased.

There are various methods for determining the area, the most relevant of which are listed and briefly described below.

#### Manual measurement

- **Tools:** tape measure, laser range finder, spirit level.
- **Implementation:** Manually measure the length and width of the roof or open area to determine the available square meters.
- **Area of application:** Often for smaller installations (roof systems). Simple and cost-effective, but time-consuming.

#### Photogrammetry

- **Method:** Aerial images of the roof or area are taken using drones or special cameras. These images are then converted into a digital 3D model that provides precise area information.
- **Area of application:** Particularly useful for larger areas or complex roof structures.
- **Advantages:** Fast and accurate results. Ideal for hard-to-reach areas.

#### Satellite and GIS data

- **Method:** Use of satellite images and geographical information systems (GIS) to calculate the dimensions of the area to be occupied. A precise mapping of the site can be created.
- **Area of application:** For large projects or ground-mounted PV systems that require a large-scale analysis.

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- **Advantages:** Cost-efficient and precise over long distances. Enables topographical data to be taken into account.

### Architectural plans

- **Method:** Use existing building plans or CAD data to calculate the dimensions of the roof or area.
- **Application:** If precise plans of the building or area are available, this is a simple and accurate method.
- **Advantages:** No additional surveying tool required if the plans are up-to-date.

## 7.3 Determination of the energy requirement

It is important to know the energy requirements when planning a photovoltaic system (PV system), as this forms the basis for an efficient and economically viable system design. The points of interest are listed below:

- **Analysis of current electricity consumption:** Determine electricity consumption data (kWh) from the last 12 months (e.g. via electricity bills).
- **Future demand:** Consideration of potential changes in electricity consumption, such as the introduction of e-mobility or new household appliances.
- **Create a load profile:** How is electricity consumption distributed throughout the day? High self-consumption during the day makes the PV system more efficient.

**Objective:** The system should be designed in such a way that it either completely covers the electricity demand or at least covers a large part of the electricity through self-consumption.

## 7.4 Dimensioning of the photovoltaic system

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The dimensioning of a PV system is the next step after the potential yield and energy requirements have been determined. The parameters determined in the previous steps are used to determine how large the system should be. In Colombia, a PV system can generate around 1400 - 1800kWh per kWp of installed capacity per year. The dimensioning should be done in such a way that the energy demand and the area requirements are optimally covered.

### 7.5 Selection of technical components

Once the system has been dimensioned, the corresponding components can be selected. The most important components that can be selected after dimensioning are listed below. The aim here is to select components that meet the requirements of the system and at the same time minimize losses.

- **PV modules:** The PV modules are the basis for the design of the other components required. Modules are available in different sizes and performance classes.
- **Inverter:** The inverter converts the direct current (DC) from the solar modules into usable alternating current (AC). It must be suitable for the size of the system and the modules. The maximum inverter output should be around 90-100 % of the PV system. An inverter with several MPP trackers optimizes energy generation, especially for systems with differently aligned module arrays.
- **Cable dimensioning:** The cables should be correctly dimensioned to minimize power losses. The cross-section and length of the cables are important factors. Larger cross-sections reduce losses.
- **Substructure:** The substructure of a photovoltaic system (PV system) is a crucial component that supports the solar modules and ensures their stability. It influences the longevity, efficiency and safety of the system. The size of the substructure should be matched to the number of PV modules.
- **Protective devices:** The protective devices are there to protect the electrical components. When selecting these, the size of the system should also be taken into account.
- **Storage system (optional):** If a battery storage system is planned, its capacity must be matched to the self-consumption. Typical battery capacities are 5-15 kWh.

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A materials list should be drawn up with all the materials required. In addition to providing a clear overview for complete planning, this is also important for carrying out a meaningful profitability analysis.

### 7.6 Profitability analysis

The profitability analysis is used to assess the profitability of the PV system by determining the investment costs, the expected yields and the amortization period. It helps to decide whether and when the system is financially worthwhile. The most important aspects of a profitability analysis are listed below.

- **Investment costs:** Costs for modules, inverters, substructure, components, installation and any electricity storage.
- **Yield:** Annual kWh generated based on location and system output.
- **Feed-in tariff and electricity price:** Remuneration for electricity fed into the grid vs. savings through self-consumption.
- **Amortization period:** Period in which the investment is covered by income and savings.
- **Maintenance and operating costs:** Long-term costs that influence earnings.
- **Financing and subsidies:** Available loans and government subsidy programs that can reduce costs.

This analysis can be used to assess whether the investment in a PV system makes sense from an economic point of view.

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## 8 Construction of a PV system

### Installation instructions for a photovoltaic system on a roof

#### 8.1 Planning and preparation

##### Parts list

- **Solar panels:** Number according to the desired capacity (e.g. 10 panels of 300 W each)
- **Mounting rails:** Sufficient for mounting all solar panels
- **Roof hooks or brackets:** Matching the number of mounting rails and rafters
- **Fixing clamps:** For securely fastening the solar panels to the mounting rails (end and middle clamps)
- **Inverter:** Suitable for the total output of the solar panels
- **DC cable:** Sufficient length for wiring the solar panels and connecting them to the inverter
- **AC cable:** Sufficient length for connecting the inverter to the low-voltage main distribution board (LVMD)
- **Cable ducts and cable ties:** for neat cable management
- **Screws and plugs:** Suitable for fastening the mounting rails and brackets
- **Tools:** Drill, wrench, tape measure, screwdriver
- **Safety equipment:** gloves, safety goggles, helmet

#### 8.2 Erect scaffolding

- **Assembly:** Erect stable scaffolding that allows safe access to the roof. Ensure that the scaffolding is firmly anchored and complies with all safety regulations.
- **Safety check:** Check the scaffolding for stability and correct assembly before stepping onto it.

#### 8.3 Attach mounting rails

- **Positioning:** Measure the surface of the roof and mark the position of the mounting rails. Make sure that the rails are parallel and evenly distributed.
- **Fastening:** Attach the mounting rails to the roof using roof hooks or special brackets. Screw the brackets firmly to the rafters. Make sure that the rails are stable and secure.

#### 8.4 Installing solar panels

- **Prepare the clamps:** Mount the end and middle clamps on the mounting rails.
- **Fasten the first end clamp:** Initially, only the first end clamp is firmly attached.
- **Position the first module:** Align the first solar panel and fix it in place with the end clamp. A module is always mounted on two mounting rails.
- **Attach center clamps and modules:** Attach a solar panel and a center clamp one after the other. Slide the next module onto the mounting rail, connect it to the previous modules and

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secure it with a center clamp. Repeat this process until all modules have been installed. Two clamps are used to attach each module.

- **Termination with end clamp:** The last end clamp is fitted at the end of the rail to fix the last module in place.
- **Establish the connection:** Connect the solar panels to each other using the MC4 connectors.

### 8.5 Cabling

- **Stringing:** Connect the solar panels in strings. A string consists of several solar panels connected in series. Make sure you observe the correct polarity (plus to minus).
- **Cable management:** The cables must be tied up to ensure that no dirt accumulates. Use cable ties and cable ducts to securely fasten the cables. Edge protection must be fitted where there are sharp edges.
- **Connection to the inverter:** Run the DC cables (direct current) from the solar panels to the inverter. Make sure that the bending radius of the cables is not too tight to avoid damage.

### 8.6 Installing the inverter

- **Positioning:** Install the inverter in a well-ventilated location, ideally close to the low-voltage main distribution board (LVMD). The inverter should be protected from direct sunlight and moisture.
- **Mounting distances:** Observe the mounting distances recommended by the manufacturer to ensure adequate ventilation. A typical distance to walls is at least 30 cm, to other devices at least 50 cm.
- **Connections:** Connect the DC cables from the solar panels and the AC cables (alternating current) to the NSHV according to the manufacturer's instructions.

### 8.7 Connection to the power grid

- **Commission an electrician:** Have a qualified electrician carry out the connection to the power grid. This step is crucial for the safety and proper functioning of the system.
- **Install a meter:** If necessary, install a new electricity meter or have the existing meter adjusted by your energy supplier.

### 8.8 Commissioning and inspection

- **Check the system:** Check all connections and the entire system for any faults or loose connections.
- **Commissioning:** Switch on the system and check the function of the inverter and the solar panels. Ensure that the system is working correctly and producing electricity.
- **Monitoring portal:** Set up the monitoring portal if your inverter supports this. You can use the monitoring portal to monitor the performance and status of your photovoltaic system. This enables early detection of problems and optimal use of the system.

#### Important notes:

- **Permits:** Check whether you need a permit for the installation.

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- **Subsidy programs:** Find out about possible subsidy programs and financial support for photovoltaic systems.
- **Insurance:** Take out insurance for your photovoltaic system in order to be protected against possible damage.

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### 9 Operation of a PV system

There are a few points to consider when operating a PV system. As operation is designed for 20-25 years, it should be ensured that the system delivers the expected performance over this period. The following points should be taken into account.

#### 9.1 Regular monitoring

##### Monitoring systems

- **Install a monitoring system:** A monitoring system helps to monitor the performance of the PV system in real time and collect data. Popular systems include SolarEdge, Enphase or SMA.
- **Check the yield data regularly:** Daily or weekly checks of the data can quickly reveal deviations. Signs of problems could be unexpected drops in performance or failures.

##### Advantages of monitoring

- **Early fault detection:** fast response time in the event of problems.
- **Optimization potential:** Detection and elimination of inefficient operating states.

#### 9.2 Cleaning the PV modules

##### Cleaning frequency

- **Standard interval:** Once a year, ideally in spring, to remove soiling from the winter. The frequency of cleaning depends on how dirty the modules are and should be determined by visual inspection.
- **Special circumstances:** In areas with high levels of air pollution, pollen contamination, near farms or close to the coast, more frequent cleaning (every six months or quarterly) may be advisable.

##### When is cleaning advisable?

- **Visible soiling:** If modules are clearly soiled, such as by bird droppings, leaves, dust or other soiling.
- **Drop in output:** If the yield drops by more than 5-10% for no apparent reason.

##### Cleaning methods

- **Manual cleaning:** Soft water and a soft brush or cloth. Do not use aggressive cleaning agents as they can damage the surface of the modules.

##### Advantages of cleaning

- **Maximizing yield:** Clean modules ensure optimum absorption of sunlight.
- **Longer service life:** Regular cleaning can extend the service life of the modules.

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### 9.3 Maintenance and inspection

#### Maintenance intervals

- **Annual inspection:** Check all system components to ensure that they are working properly and have no visible damage.
- **Five-yearly inspection:** Comprehensive inspection of the entire electrical installation by a specialist.

#### Maintenance tasks

- **Mechanical inspection:** Check the mounting systems for strength and stability. Checking the frames and fastenings for corrosion and other damage.
- **Electrical inspection:** Checking the inverters, fuses, cabling and earthing systems. Measurement of electrical values to ensure performance.
- **Inspection of the modules:** Visual inspection for cracks, delamination and other physical damage. Check for hotspots with infrared cameras, if available.
- **Shade management:** Regularly check that no new shading has been created by trees or similar. Prune trees if necessary.

#### Advantages of maintenance

- **Safety:** avoidance of electrical hazards and fire protection.
- **Long-term efficiency:** Ensuring optimum performance and extending the service life of the system.

### 9.4 Annual earnings and financial analysis

#### Yield evaluation

- **Comparison with previous years:** Analysis of yield data compared to previous years to identify trends and deviations.
- **Power loss:** Calculation of the degradation rate of the modules and analysis of power losses.
- **Monitoring data:** Detailed analysis of data from the monitoring system to identify faults and performance problems.

#### Financial evaluation

- **Income from feed-in tariffs:** Determination of the annual income from the feed-in tariff or direct marketing of the electricity generated.
- **Savings from self-consumption:** Calculation of savings from self-consumed solar power, based on current electricity tariffs.
- **Maintenance and operating costs:** List of all costs incurred for maintenance, cleaning and operation of the system.
- **Amortization calculation:** Update of the amortization plan based on current income and costs. Calculation of the amortization of investment costs achieved to date.

#### Advantages of financial analysis

- **Transparency:** Clear overview of the financial performance of the investment.
- **Planning security:** basis for future financial decisions and investments.

### 9.5 Documentation and reporting

#### Documentation obligation

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- **Regular records:** All maintenance and inspection measures as well as yield data should be documented in a maintenance logbook or digital platform.
- **Reports for authorities:** Preparation of reports for authorities or funding bodies, if required. This may be necessary in the context of funding programs, for example.

### Annual report

- **Yield report:** Compilation and analysis of the annual yields and performance data of the PV system.
- **Financial report:** Summary of the financial performance of the investment, including income, costs and amortization.

### Advantages of documentation

- **Traceability:** Overview of all implemented measures and their results.
- **Legal and funding compliance:** fulfillment of legal and funding requirements.

## 9.6 Interference measures

### Fault management

- **Troubleshooting:** Immediate identification and rectification of faults in the monitoring system. This could be done by restarting the system, replacing defective components or contacting the service provider.
- **Spare parts:** Keep a stock of important spare parts (such as fuses, replacement modules) and contact information for service providers to hand.

### Advantages of fault management

- **Minimization of downtimes:** Quick response and rectification of problems prevent longer yield losses.
- **Safety:** Avoidance of hazards due to defective components or installations.

This detailed guide will help you to operate a PV system efficiently and safely to ensure maximum yields and a long service life.

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### 10 Financing models for a PV system

Various financing models can be used to finance photovoltaic systems. The choice of financing model depends on various factors.

#### 10.1 Financing factors

Typical factors to consider when financing are:

1. **Available equity capital**

The amount of equity available influences the decision for a financing model. System operators who have sufficient equity may be able to finance the system themselves, while others are dependent on external financing.

2. **Financing costs**

The interest rates and conditions for loans and leasing agreements vary depending on the financial institution and the credit rating of the system operator. The financing costs have a significant influence on the financing model. Equity is a key factor in reducing financing costs - typically, the higher the equity ratio, the lower the financing costs.

3. **Willingness to take risks**

Some financing models, such as leasing or contracting, transfer part of the risk to the provider. System operators who want to minimize the risk could opt for such models.

4. **Tax aspects**

The tax implications of the various financing models can also play a role. Depending on the country and tax system, there may be different tax advantages that influence the choice of financing model.

5. **Personal preferences**

The individual financial situation and preferences of the system operator can also influence the choice of financing model. Ultimately, the decision for a financing model should be carefully examined and all relevant factors taken into account.

#### 10.2 Financing models

The following typical financing models can be found on the market:

1. **Self-financing**

The system operator finances the photovoltaic system entirely from his own funds. Own funds

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can be divided into equity and own work in the form of labor.

### 2. Loan financing

The system operator takes out a loan from a bank or other financial institution to finance the system. The interest on the loan and the repayment of the loan are paid from the income from the photovoltaic system.

### 3. Leasing

The system operator leases the photovoltaic system from a provider and pays regular leasing installments. At the end of the leasing term, the operator can usually purchase the system at a previously agreed residual value.

### 4. Contracting

With contracting, a specialized provider takes over the financing, installation and operation of the photovoltaic system. The operator pays an agreed fee for the use of the system without being the owner.

### 5. Crowdfunding

System operators can use online platforms to publicly finance their photovoltaic project by collecting small amounts from a large number of investors. These financing models differ in terms of the financial and legal framework conditions as well as the risks and opportunities for the system operator.

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# 11 Social Entrepreneurship

## 11.1 Introduction

Let's start with a quote from Leo Birnbaum (CEO of E.ON SE). When asked during his 25 years in the energy industry what his greatest success has been so far, he replied: "The greatest success is that renewable energies are economical - this makes the transition to a more sustainable energy system self-sustaining."

This chapter is intended to encourage the development of a suitable financing model for a PV system for schools and the surrounding residents. We hope to be able to confirm Leo Birnbaum's statement *We take the Colegio Fervan Campestre as a case study.*

**Our goal is to develop a business model that enables the Colegio Fervan Campestre to install and operate a PV system to reduce annual electricity costs while using green, environmentally friendly energy.**

## 11.2 What business models are available on the photovoltaic market today?

Nowadays, we can essentially distinguish between two business models for the use of PV systems:

### 11.2.1 Investment-oriented models

These business models are driven by investors who want to invest in renewable energy production plants that generate a return on investment within 3 to 15 years. At the beginning of the photovoltaic era, these models were driven by political incentives such as a fixed price per kWh over e.g. 20 years. With such an offer, Germany advanced the industrialization and installation rate of renewable energy generation with wind, solar or biogas. Today, incentives are no longer necessary. It is up to the creativity of investors to decide what the business model looks like and how they earn money with the production of renewable energies. Nevertheless, it is advisable to check the local subsidies for the countries in which a system is to be built. There are a variety of options for individual or joint investment packages.

### 11.2.2 Consumption-oriented models

Other business models aim to cover their own consumption through their own production facilities. The focus here is on optimizing the company's own energy cost structure - and as a side effect, the impact on the environment can also be reduced. In Europe, companies that invest in sustainable energy generation can also benefit from their sustainability reporting.

In 2023/24, the growth rates of German companies in the construction of photovoltaic systems will show significant growth - partly due to the advantages in terms of sustainability reporting and, above all, the positive effect on their own energy costs. Increasingly, communities are joining together in

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which several parties share the investment in their own PV power generation. The energy yield is then also shared within the community. Additional synergies can be exploited by combining different consumption patterns.

### 11.3 What is social entrepreneurship?

Having looked at the two basic types of business model, we will now turn our attention to social entrepreneurship. The idea of supplying the Colegio Fervan Campestre with sustainable energy and earning money in the process comes very close to social entrepreneurship.

What could a model that we call a social entrepreneurship business model look like?

Before we look at social entrepreneurship, let's take a brief look at what entrepreneurship actually is.

In its most basic form, entrepreneurship refers to an individual or a small group of partners setting out to start a new business. An entrepreneur actively seeks out a specific business venture. The entrepreneur takes risks to develop the business venture and profits if the venture is successful.

Source: <https://online.stanford.edu/what-is-entrepreneurship>

In view of climate change and human resilience, the way in which traditional entrepreneurship is practiced seems to be increasingly outdated. The economy needs to rethink and adapt to nature. In his book "The Age of Resilience", Jeremy Rifkin even argues that capitalism in its current form has no chance of survival ([Interview with Jeremy Rifkin, sociologist and economist](#)). He is convinced that at least one additional component must be added to future-proof business models: the impact on the environment. We call companies that try to positively shape the impact of their business activities on the environment social entrepreneurs.

Adding a social component to entrepreneurship changes the approach, but fundamentally the rules of entrepreneurship still apply. Broadly speaking, social entrepreneurship is a new, innovative business venture that brings about change. A social entrepreneur has a specific cause that is close to their heart and develops a business model that aims to make a positive impact.

Social entrepreneurs are the "change makers" who develop innovative initiatives and organizations that solve social, environmental, economic or political problems. Crucially, these people have an entrepreneurial mindset, recognize opportunities for change that others don't see and use existing resources to make a difference - with social impact at the heart of their business model.

Example: [What is social entrepreneurship?](#)

Source: <https://krocstories.sandiego.edu/peace/the-innovating-peace-blog/what-is-social-entrepreneurship-and-social-innovation-definition-ideas-and-examples>

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### 11.4 Methods for the development of business models

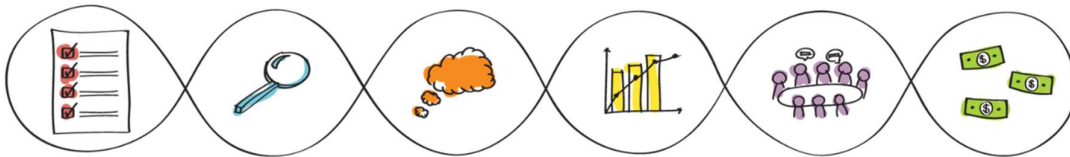
There are two methods we want to look at that help to develop business models in a structured way

- a. The design thinking method
- b. The business canvas method

Both methods complement each other. While design thinking promotes the development of an idea, the business canvas model supports the concrete development of the implementation model.

#### 11.4.1 Design Thinking

By definition, design thinking is an approach to working on complex problems. It is simultaneously "a method, a set of principles, a particular way of thinking and a process with a variety of supporting tools" (Poguntke, 2021). The special thing about the design thinking process is that it is based on a specific process. It follows a specific system and must always be designed in such a way that it fits the problem to be solved.



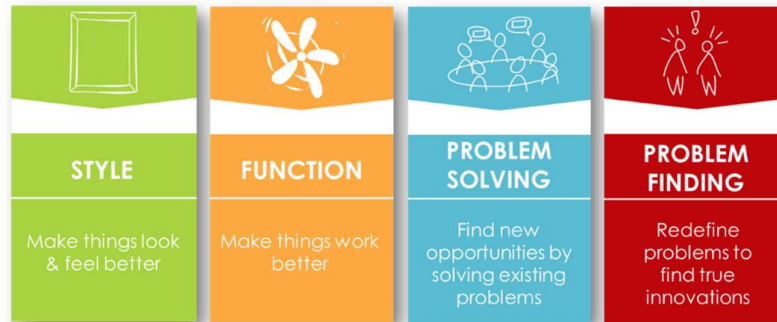
The six phases of design thinking are

- I. **Empathy**  
Understanding the needs and feelings of the users or stakeholders affected by the problem or opportunity being addressed.
- II. **Definition**  
Definition of the problem or opportunity based on the findings from the empathy phase.
- III. **Ideate**  
Develop creative and innovative ideas to solve the defined problem or exploit the defined opportunity.
- IV. **Prototype**  
Creating a rough or preliminary version of the solution to test it and gather feedback.
- V. **Test**  
Testing the prototype with actual users to gather feedback and identify possible improvements.
- VI. **Implement**  
Implementation of the final solution based on the feedback received during the test phase.

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The focus throughout the process is on finding the right mix of usability, attractiveness and feasibility. One of the most important aspects of the method is to understand the problem. The biggest change in the way design thinking works is not to think in terms of solutions as before. Only when the problem has been correctly understood and localized can a meaningful and profitable solution be developed.



Typical problems for which people and companies apply the design thinking method.

In our case, we are focusing on the area of problem solving. In the first phase, we need to understand the problems we want to solve with our project. Typical problems could be high energy costs, frequent interruptions to the power supply and/or too high a proportion of fossil fuels in the current energy mix.

Let's start directly with exercises to find out what we want to solve with our photovoltaic problem and later develop ideas on how we can solve the problems.

### 11.4.2 Design Thinking exercises

Below we have put together some examples to help you design and apply design thinking in your workshops.

#### Exercise 1 - Empathize

- Describe the current energy supply situation.
- Which interest groups are involved/affected? Please describe all directly and indirectly involved interest groups and what problems they have in connection with energy.
- What positive aspects of the current situation do you not want to lose?

#### Exercise 2 - Define

- Please describe the problem that you observed in exercise 1. Formulate the description as specifically as possible - and include the different perspectives of the interest groups involved.

#### Exercise 3 - Ideate

- Please think about scenarios that could solve the identified problems. Describe these potential scenarios as precisely as possible. You can think of a scenario for a perfect world and then ask yourself what is hindering the achievement of this perfect situation. Perhaps this will help you to develop better ideas ...

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### Exercise 4 - Prototype

- Please design a solution model (prototype) - make it as tangible as possible.

### Exercise 5 - Test

- Please go out and test your defined prototype to collect feedback and identify possible improvements. Describe the improvements to the prototype.

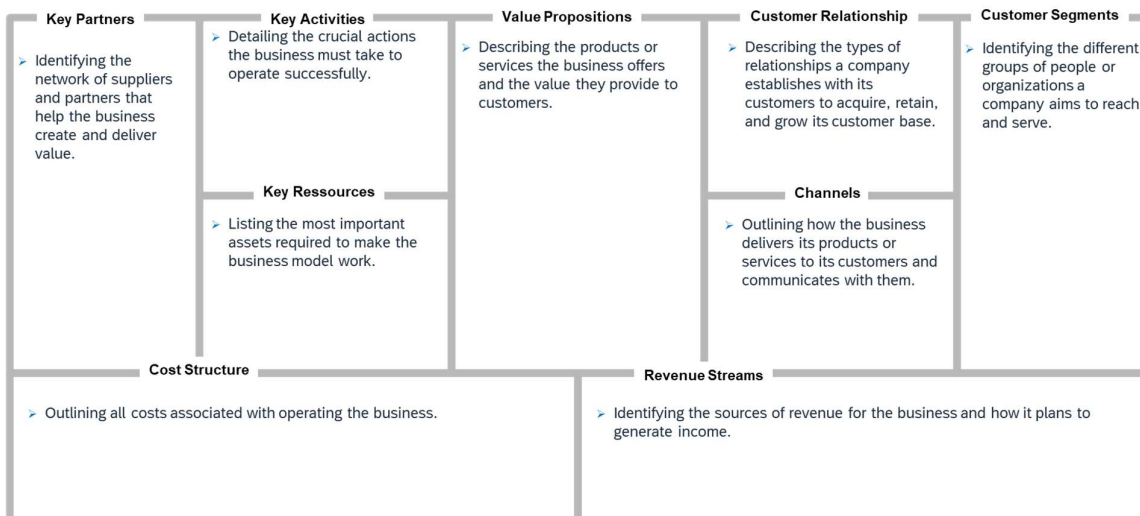
### Exercise 6 - Implement

- Describe your final solution and develop a plan for implementation. Use the business canvas model

## 11.4.3 The Business Canvas Methodology

The business canvas method popularized by Alexander Osterwalder is a strategic management tool that can be used to develop, document and analyze business models. The method is based on a one-page document that covers nine key areas.

By examining and completing each section of the canvas, people can gain a better understanding of the business model, identify potential areas for improvement and develop strategies for growth and sustainability. The business canvas method is often used as a starting point for business planning, innovation and entrepreneurship.



Business Canvas Model One pager

### Exercise 7 - Use the Business Canvas Model (BCM)

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In order to apply BCM, several steps are usually required to effectively implement this strategic management tool. Some guidelines for adopting the business canvas model are described below:

### **1. familiarize yourself with the Business Model Canvas**

Start by studying the key components of the business canvas model, understanding the purpose and importance of each section and how they work together.

### **2 Identify your business model**

Evaluate your current business model and use the template to define the most important aspects of your business

### **3. collect feedback**

Involve your team, stakeholders and relevant experts in discussions about your business model. Use their input to refine and validate the concept and gain different perspectives

### **4. use it as a tool**

The canvas can be used as a planning tool for the photovoltaic system at Colegio Fervan Campestre. Use the canvas to visualize and communicate potential changes to your business model.

### **5 Continuous review and update**

The business environment is changing, so it is important to regularly review and update your business model to adapt to these changes and ensure its relevance to your project.

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## **12 Professions**

### **12.1 Introduction**

As described in Chapter 3, the use of solar energy in Germany and Colombia is to be expanded in the coming years. In order to achieve the targets set, the deployment of skilled workers in this sector must be significantly increased. A study from Germany from 2022 shows which skilled workers are needed and what their availability currently looks like.

(Source: Energy from wind and sun What skilled workers do we need? KOFA)

### **12.2 Skilled workers required**

#### **Which specialists are needed?**

The production of solar modules currently takes place mainly in China, but there are plans to invest in production in Germany again, which would require skilled workers (e.g. engineers).

Specialists are required for the installation of photovoltaic systems on roofs (small systems). This work is usually carried out by trained roofers, less often by plumbing, heating and air conditioning technicians. There are further training opportunities for craftsmen and engineers, for example to become a specialist in solar technology, also known as a "solar installer" (not a state-recognized training course). The courses, which are often offered by chambers of trade, teach the basics of planning, installing and maintaining photovoltaic systems.

In Germany, the connection and acceptance of a PV system may only be carried out by qualified electricians and master craftsmen, as the activities involve safety risks.

Engineers from the fields of electrical and mechanical engineering are also in demand when planning ground-mounted systems and large solar parks. Electrical engineers take care of feeding the electricity into the grid and the associated stability of the energy network.

**Table1 important activities and typical occupations for the expansion of solar energy**

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Tasks	Typical job profiles or qualifications
Distribution and sale of PV systems/consulting	Both technical and commercial background, e.g. business administration
Installation and maintenance of PV systems on the roof	Generally roofers, but also plumbing, heating and air conditioning technicians, semi-skilled workers
Connection to the power grid	Electricians (skilled workers and foremen)
Planning and design of solar parks	Electrical engineers, industrial engineers, mechanical engineers
Maintenance and repair of solar parks	Electrical engineers (skilled workers and specialists)
Research, development and planning of the electricity grid and efficient use of electricity	Academics/engineers from the fields of electronics, computer science, electrical engineering, sector coupling

### 12.3 Skills shortage in the solar industry

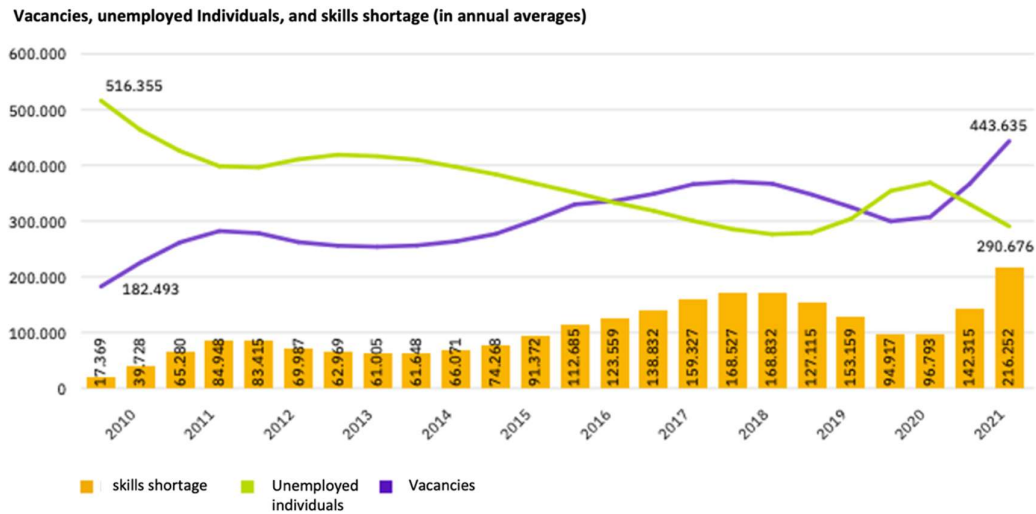
The study "Energy from wind and sun" by the Competence Center for Securing Skilled Workers (KOFA) deals with the shortage of skilled workers caused by the expansion of renewable energies, wind and solar energy.

#### How big is the skills shortage?

According to this study, there are currently almost 444,000 vacancies in professions relevant to solar and wind energy. The bottleneck in the energy transition, with a gap of almost 17,000, is electricians. Due to the legal regulations, the required safety standards and occupational health and safety for working with high voltage current, they play a key role in the energy transition.

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**Image12** KOFA calculations are based on special evaluations by the Federal Employment Agency and the IAB Job Vacancy Survey 2022<sup>19</sup>

Women are also underrepresented in the solar and wind energy professions (the proportion of women in heating and air conditioning technology is only 0.4-1.5%). It is therefore the declared aim of the German government to increase the proportion of women in the relevant STEM and skilled trades professions.<sup>20</sup>

<sup>19</sup> Roland Ernst, 2022, There is a shortage of 216,000 skilled workers for the energy transition, <https://www.pv-magazine.de/2022/11/28/fuer-die-energiewende-fehlen-216-000-fachkraefte>)

<sup>20</sup> KOFA, 2022, Energy from wind and sun <https://www.kofa.de/media/Publikationen/Studien/Solar-und-Windenergie.pdf>