SELINUS UNIVERSITY
OF SCIENCES AND LITERATURE

THE PHOTOVOLTAIC, A DRIVING FORCE FOR THE NEW GREEN DEAL

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"I hereby declare that I am the only author of this thesis and that his content is only the result of the readings made and the research carried out ".

Antonio Cagnazzi

“The starting point of all achievement is desire.
Keep this constantly in mind.
Weak desire brings weak results, just as a small fire makes a small amount of heat. “

Napoleon Hill

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0 INTRODUCTION

In the current global energy and environmental context has become relevant and a priority (also following the Kyoto Protocol) the goal of reducing emissions of greenhouse gases and pollutants, including by means of exploitation of alternative and renewable energy sources, that support and reduce the use of fuels fossils, which are moreover destined to run out for the considerable consumption by different countries.

The sun is certainly a source of renewable energy from great potential, which can be drawn in respect environment. Just think that instant by instant the surface of the earth's hemisphere exposed to the Sun receives a power greater than 50 thousand TW; the amount of energy solar that arrives on earth is therefore enormous, about ten thousand times greater than all the energy used from humanity as a whole.

Among the different systems that use renewable energy sources, PV is promising for its intrinsic qualities of the system itself, since it has very low costs operating conditions (fuel is free) and limited needs maintenance, is reliable, quiet and relatively simple to install. In addition, photovoltaics, in some isolated applications, it is certainly convenient in comparison to other energy sources, especially in places where it is difficult and uneconomical to reach with traditional electric lines.

In this thesis we intend to analyze the problems and the basic concepts encountered in construction of a photovoltaic system; starting from a general description of the methods of exploitation of solar energy through photovoltaic systems, they come the system components, the appropriate sizing, the possible optimization in the PV systems are mainly described, the standards to refer and there is a description of what the photovoltaic market is today.

1 ENERGY

1.1 ENERGY SOURCES

Energy is indisputably a resource on which humanity has become dependent. Without energy, our society will not function. Without energy, we cannot find or administer medicine to cure disease, prepare food, purify water, drive our cars, operate computers, study at night, etc. The current energy need is roughly 15 TW ($15 \cdot 10^{12}$ W) and this number is projected to increase. Historically fossil fuel (coal, petroleum, and natural gas) have enabled our energy consumption for the past century, and continues to dominate our energy production. Today roughly 81% of our energy is supplied by fossil fuel, 2.7% is being supplied by nuclear energy, and the remaining share is renewable sources, with biomass being the largest source of energy at roughly 12%. You can see a breakdown of our energy consumption in figure 1.

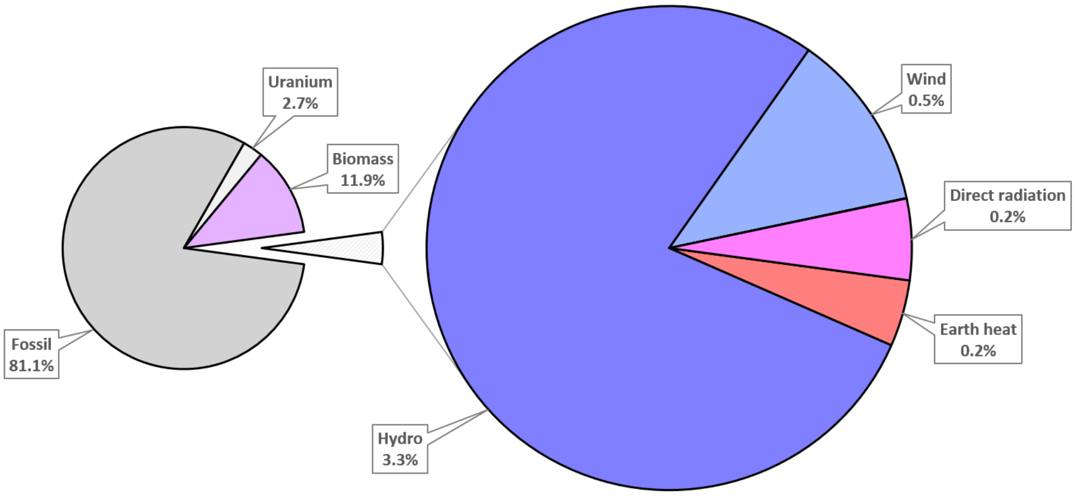


Figure 1: Current energy mix. The total energy consumption is roughly 15 TW. Source: Wikipedia.

Fossil fuels are continually being formed via natural processes such as anaerobic decomposition of buried dead organisms fueled by photosynthesis. They are, however, generally considered non-renewable resources because fossil fuels take millions of years to form and the known viable reserves are being depleted faster than new ones are being made. Even if fossil fuels can cover the energy consumption for many years to come, there are many other reasons to look for alternatives. CO_2 pollution is probably the strongest arguments against fossil fuels, but combustion of fossil fuels also produces other **air** pollutants**,** such as nitrogen oxides, sulfur dioxide, volatile organic compounds, and heavy metals. Harvesting, processing, and distributing fossil fuels create their own environmental concerns. Coal mining methods, particularly mountaintop removal and strip mining, have negative environmental impacts, and offshore oil drilling pose a hazard to aquatic organisms. Hydraulic fracturing used to extract natural gas entail its own suit of local environmental concerns.

When we are looking for energy sources available that can replace fossil fuels, it is useful to consider how much energy each process can deliver. Below you can see estimates of the available power from each energy process:

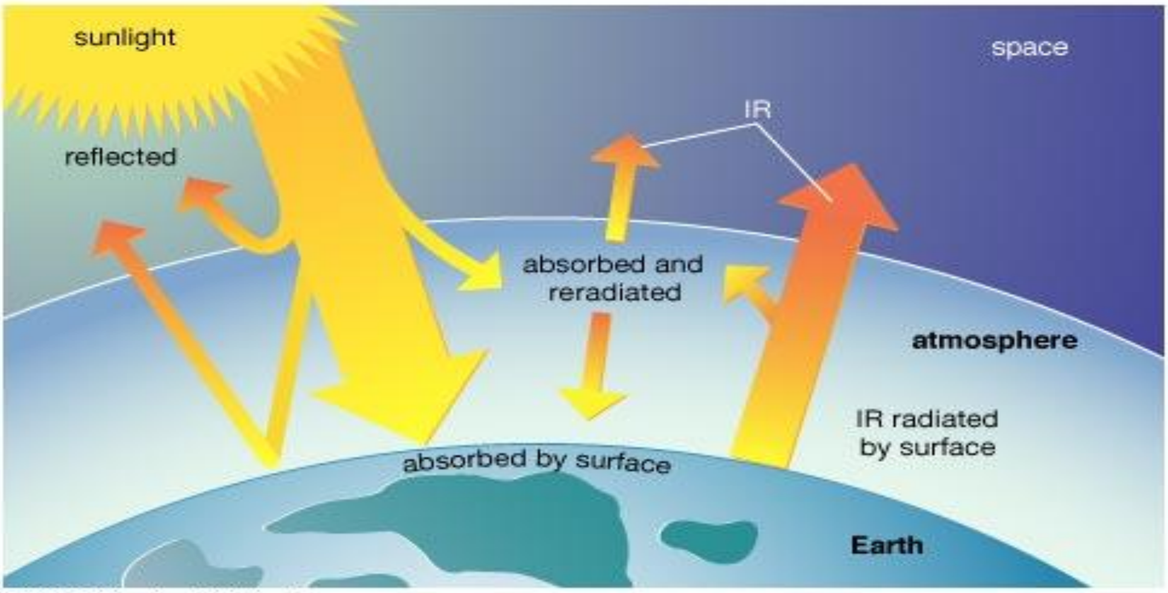
- Tide: 0.3 TW
- Earth heat: 2 TW
- Hydro power: 4 TW
- Wind: 75 TW
- Biomass: 6 TW
- Direct radiation: 26,000 TW
- Coal: 900 TWy
- Petroleum: 240 TWy

- Natural gas: 215 TWy
- Uranium: 300 TWy

Notice that numbers for fossil fuel and uranium are in total energy, the remaining numbers are given as resources available per year (the resources could be given as TWy/y to emphasize that they are a yearly resource, however they are shown in TW for simplicity). While the specific numbers may vary from source to source, the magnitude of the numbers are reasonably accurate.

1.2 SOLAR ENERGY

The solar energy is radiation from the sun capable of producing heat, causing chemical reactions, or generating electricity. The total amount of solar energy incident on Earth is vastly in excess of the world’s current and anticipated energy requirements. If suitably harnessed, this highly diffused source has the potential to satisfy all future energy needs. In the 21st century solar energy is expected to become increasingly attractive as a renewable energy source because of its inexhaustible supply and its nonpolluting character, in stark contrast to the finite fossil fuels coal, petroleum, and natural gas. In the nucleus of the sun reactions occur unceasingly of thermonuclear fusion at millions of degrees that free huge amounts of energy in the form of radiation electromagnetic. Part of this received energy the exterior of the Earth's atmosphere with radiation average (solar constant) of about 1367 W / m2 ± 3% which varies as a function of the Earth-Sun distance 1 and the solar activity 2 (sunspots). By solar radiation we mean the intensity of the radiation solar electromagnetic incident on a surface of unit area [kW / m2]. This intensity is equal to the integral of the power associated with each frequency value of the spectrum of solar radiation. In passing through the atmosphere, solar radiation is attenuated, because in part it is reflected and absorbed (above all from water vapor and other atmospheric gases). The radiation that continues is partially diffused from the air and solid particles suspended in the air.



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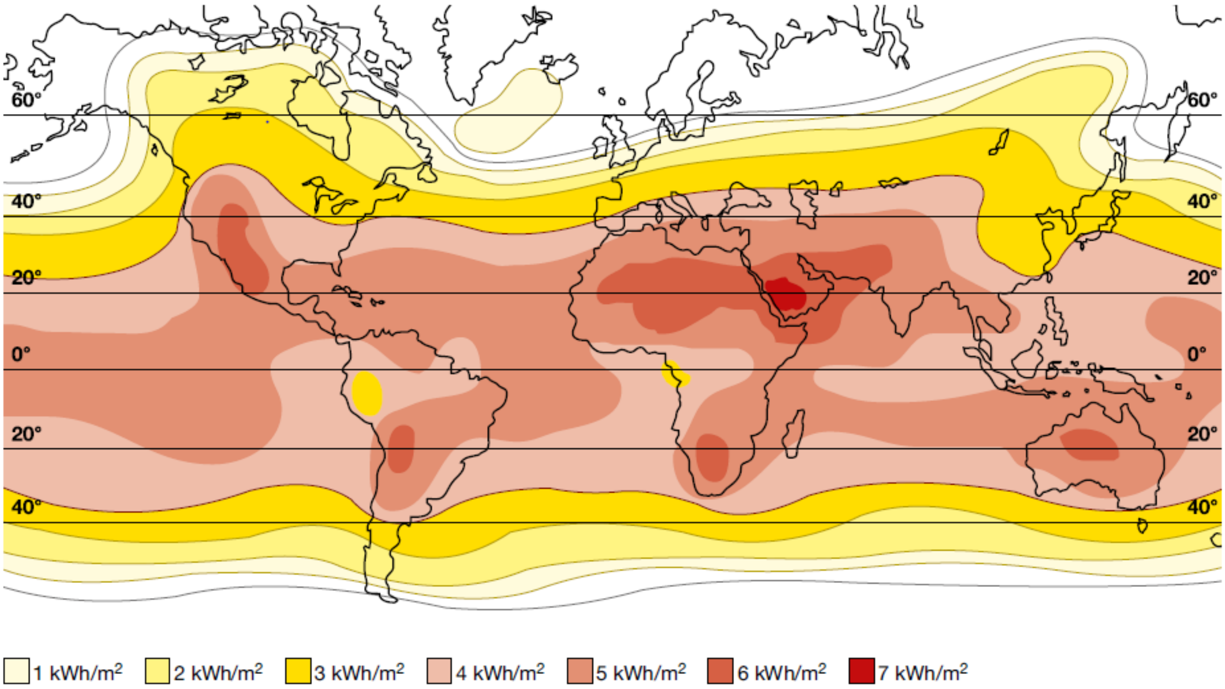


Figure shows the world solar atlas of the average solar radiation on the inclined plane 30 ° South [KWh / m2 / day].

2 SOLAR CELL

2.1 HISTORY

The first photovoltaic cell in the world and therefore the photovoltaic effect was discovered by Alexandre Edmond Becquerel**.** In his experiment, carried out in 1839, Becquerel placed two platinum electrodes in a container with silver chloride in an acidic solution. When illuminated voltage and current were generated over the electrodes and Becquerel found that the strength of the current changed with illumination. Because of this work, the photovoltaic effect has also been known as the "Becquerel effect".

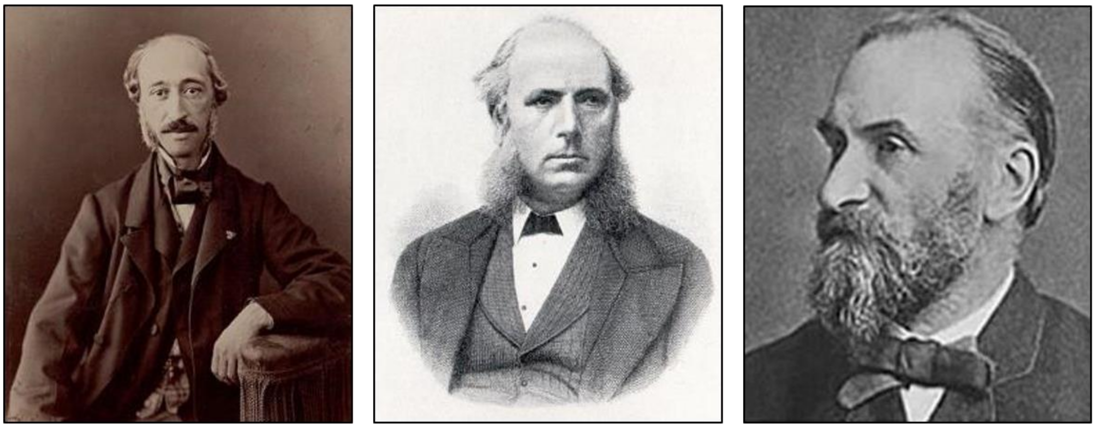


Figure 1. From left to right: Alexandre Edmond Becquerel, Willoughby Smith, and *William Grylls Adams*.

The next significant photovoltaic development arose from the interest in the photoconductive effect in selenium after Willoughby Smith found that selenium shows photoconductivity in 1873. In 1877 William Grylls Adams and his student Richard Evans Day observed the photovoltaic effect in solidified selenium by illuminating a junction between selenium and platinum. This was the first demonstration of the photovoltaic effect in an all solid-state system, proving that electricity could be produced from light without moving parts. In 1884 the first rooftop solar array was installed in New York, demonstrating an efficiency of almost 1%. The solar array used selenium solar cells invented the year before by an American inventor Charles Fritts, demonstrating that meaningful power could be extracted from solar cells. The invention impressed Werner von Siemens who stated: “The direct conversion of light into electricity has been shown for the first time”. At this early stage of solar cell history optimism gripped the inventors. Fritts optimistically predicted that “we may ere long see the photoelectric plate competing with [coal-fired electrical-generating plants]”. The first fossil-fueled power plants had only been built three years before Fritts announced his intentions by Thomas Edison. At the time the technology seemed poised to gain importance in a world discovering the wonders of electricity. James Clerk Maxwell praised the study of photoelectricity as “a very valuable contribution to science.” But neither Maxwell nor Siemens had a clue as to how the phenomenon of photoelectricity worked. Maxwell wondered, “Is the radiation the immediate cause or does it act by producing some change in the chemical state?” Siemens urged a “thorough investigation to determine upon what the electromotive light-action of [the] selenium depends.”

In subsequent years, the physical understanding of the phenomenon was improved with contributions from the likes of Heinrich Hertz who investigated ultraviolet light photoconductivity and discovered the photoelectric effect. In 1905 Albert Einstein publishes a paper explaining the photoelectric effect on a quantum basis later earning him a Nobel prize in physics.

The progress towards practical solar cells proved slow despite the breakthroughs in understanding. Bruno Lange, a German scientist whose 1931 solar panel resembled Fritts's design, predicted that, "in the not distant future, huge plants will employ thousands of these plates to transform sunlight into electric power...that can compete with hydroelectric and steam-driven generators in running factories and lighting homes." But Lange's solar cell worked no better than Fritts's.

2.2 POWER FROM EARLY SOLAR CELLS

To put into perspective the power produced by these early solar cells, we can make a simple calculation of the power produced by a 1 m^2 solar panel. With 1000 W/m^2 ($\sigma_{AM1.5G}$) and a known area, we can calculate that a 1% efficient solar cell can produce 10 W. $\sigma_{AM1.5G}$ is the incoming energy density (1000 W/m^2), A is the area (1 m^2), and η is the efficiency (1%).

$$P=\sigma AM1.5G\cdot A\cdot \eta=1000Wm2\cdot 1m2\cdot 0.01=10W$$

If you check the units, you will see that the square meter terms (m^2) cancels out, and since the efficiency is unit less, we are left with a result in watts (W).

Where a 10 W power source was impressive at the time of Charles Fritts, it seemed less impressive as time went along. With no breakthroughs on the horizon and the contemporary rapid development of electric generators leading to large scale electricity produced by coal-fired steam or hydro power, the head of Westinghouse’s photoelectricity division could only conclude: “The photovoltaic cells will not prove interesting to the practical engineer until the efficiency has increased at least fifty times.” The pessimistic prognosis was elaborated by the authors of Photoelectricity and Its Applications, writing in 1949: “It must be left to the future whether the discovery of materially more efficient cells will reopen the possibility of harnessing solar energy for useful purposes.”

2.3 POWER FROM A SOLAR CELL

To understand and measure how much power is produced from a solar cell, the characteristic curve of a solar cell is an important concept to understand. The characteristic curve show the current and voltage (IV) characteristics of a solar cell or module giving a detailed description of its solar energy conversion ability and efficiency, see figure 1. This characteristics curve is most often called an IV-curve and is basically a graphical representation of the operation of the solar cell or module summarizing the relationship between the current and voltage at the existing conditions of irradiance and temperature. IV curves provide the information required to configure a solar system so that it can operate as close to its optimal peak power point as possible.

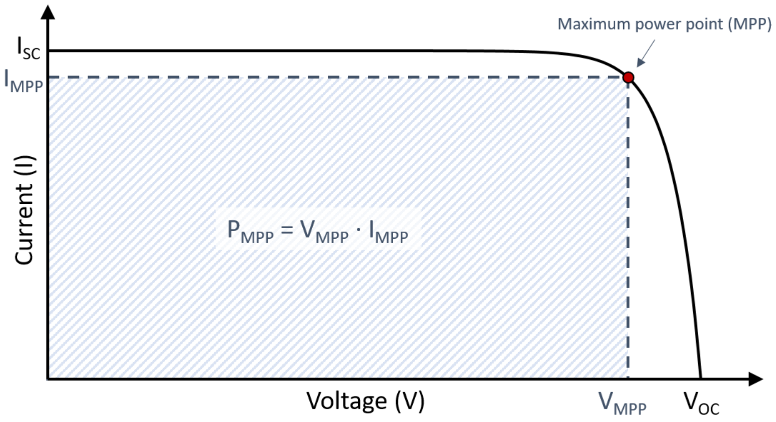


Figure 1. Characteristic IV curve of a solar cell. The short circuit current (I_{SC}), and open circuit voltage (V_{OC}) is marked along with the maximum power point current (I_{MPP}) and voltage (V_{MPP}).

It is easy to measure two of the characteristic values of the IV curve, namely the open circuit voltage (V_{OC}) and the short circuit current (I_{SC}) with a simple multimeter. The open circuit voltage of the solar cell is the maximum voltage that the solar cell will supply, while the short circuit current of a solar cell is the maximum current the solar cell will produce. The issue with the two states, I_{SC} and V_{OC}, is that the most interesting aspect of a solar cell is not the current flow with no potential drop, nor the potential drop with no current flow, but the product of these two; the power. When either the potential drop or the current flow is zero, the power, being the product of the two, will be zero. Therefore, a more interesting aspect is the maximum power the solar cell can produce.

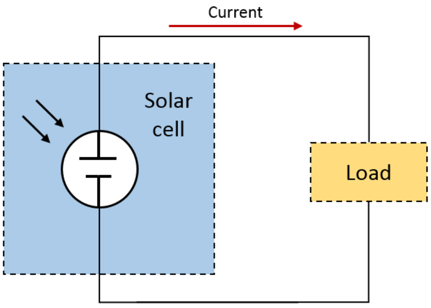


Figure 2. Schematic of solar cell with a load. An IV curve is obtained when the load is varied and the voltage and amperage is recorded.

By increasing the resistive load on a solar cell continuously from zero (short circuit) to a very high value (equivalent to open circuit) one can determine the maximum power point, see figure 2. Plotting the power as a function of the voltage results in the blue curve, see figure 3, where the maximum power point (P_{MPP}) is the peak point of the power curve.

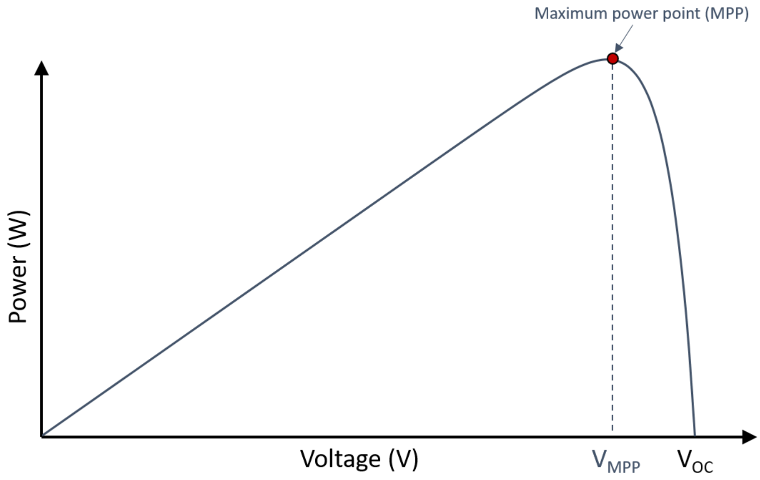


Figure 3. Power curve for a solar cell. The power is the product of the voltage and the current.

A high quality monocrystalline silicon solar cell may produce 0.55 V open-circuit (V_{OC}) , at 45 °C cell temperature (and a slightly higher voltage at lower temperatures), however, the maximum power is typically produced with 75% to 80% of the open-circuit voltage and 90% of the short-circuit current. If a solar cell vendors only rates their solar cell "power" as $V_{OC} \cdot I_{SC}$, without giving load curves, the actual performance can be seriously distorted.

The value linking the product of V_{OC} and I_{SC} to P_{mpp} (maximum power point) is the fill factor (FF)

FF=PMPPVOC·IISCFF =\frac{P_{MPP}}{V_{OC}\cdot I_{ISC}}FF=

VOC·IISC PMPP

The fill factor is used as a quality parameter for solar cells and has a value around 80% for a normal silicon PV cell. The primary parameter extracted from the IV curve is the power conversion efficiency (PCE), which describes the general efficiency of the solar cell; that is the ratio of generated electricity to incoming light energy. It can also be expressed in terms of the open circuit voltage, the short circuit current, and the fill factor

η=PoutPin=VOC·ISC·FFPin

This formula builds upon last week, in that we now focus on the power output of the solar cell. As you may remember we can express the input power in terms of the area of the solar cell and the solar constant as $P_{in}=\sigma \cdot A$.

2.3.1 IMPORTANT TERMS

Open Circuit Voltage (VOC) The open circuit voltage of the solar cell is the maximum voltage that the solar cell will supply; that is the voltage when an infinite load is applied.

- **Short Circuit Current (ISC)** The short circuit current of a solar cell is the maximum current of the solar cell under conditions of a zero resistance load; a free flow or zero volt potential drop across the cell.
- **Maximum power output (PMPP)** The maximum power point is the maximum product of voltage and current along the IV curve.

- **Fill factor (FF)** The fill factor is the ratio between the maximum power produced by the solar cell and the product of VOC and ISC.
- **Power conversion efficiency (η or PCE)** The power conversion efficiency is the ratio of output power to input power.

2.4 MODELLING A SOLAR CELL

To understand the electronic behavior of a solar cell, it can be useful to create an electrically equivalent model**.** In figure 1 left, you can see a schematic representation of a solar cell, and to the right is a simplified electrical equivalent. We call this the simplified equivalent circuit.

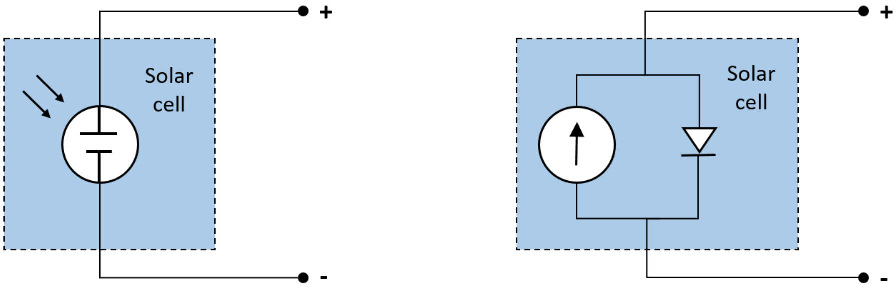


Figure 1. Schematic representation of a solar cell (left) and a simplified electrical equivalent circuit with one diode (right).

The electrical behavior of the equivalent circuit can be expressed mathematically by considering Kirchhoff's circuit law

$I=IPh-ID$

I_{Ph} is the photo current and I_D is the current running through the diode**.** By substituting in the formula for the Shockley diode equation, we get the following

$I=IPh–ISeVDnVT−1$

I_S the reverse bias saturation current**,** V_D is the voltage across the diode**,** V_T is the thermal voltage (kT/q, Boltzmann constant times temperature divided by electron charge), and n is the diode ideality factor. The ideality factor n typically varies from 1 to 2 (though can in some cases be higher), depending on the fabrication process and semiconductor material. The ideality factor accounts for imperfect junctions as observed in real transistors and mainly accounts for carrier recombination. When n is 1, the equation is called the Shockley ideal diode equation.

If we draw an IV curve using this formula we can see, we get the same characteristic solar cell curve that we saw in the last module, see figure 2. Let us now look at the short circuit current and the open circuit voltage as expressed by the formula above.

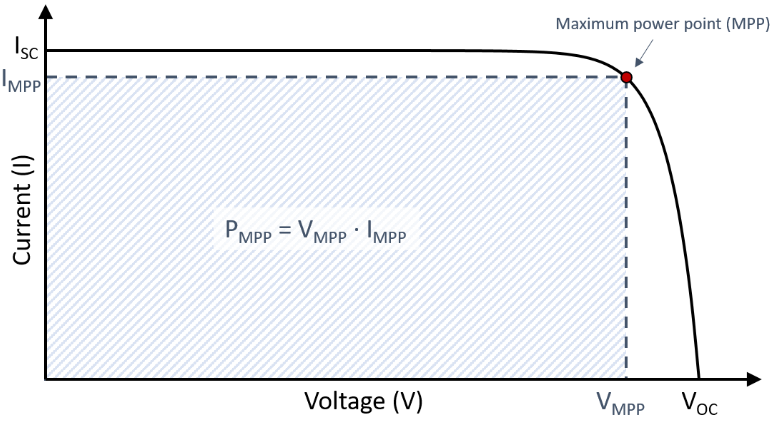


Figure 2. Characteristic IV curve of a solar cell. The short circuit current (I_{SC}), and open circuit voltage (V_{OC}) is marked.

2.5 SHORT CIRCUIT CURRENT

As we know from the last module, a short circuited solar cells (the contacts are directly connected) delivers the short circuit current (I_{SC}) and the voltage is 0. With the simplified equivalent circuit equation, this results in

ISC=IV=0=IPh–ISe0–1=IPh

Thus, we know that the short circuit current (I_{SC}) is equal to the photocurrent (I_{Ph})**.** We can in fact see this result directly from looking at the equivalent circuit (figure 1), since an external short circuit also short circuits the internal diode (meaning I_D=0).

The photo current is directly proportional to the number of photons hitting the solar cell (*learn more in week 3*) and thus the short circuit current is proportional to the irradiance. In figure 3, you can see the characteristic solar cell curve as a function of increased incident irradiance

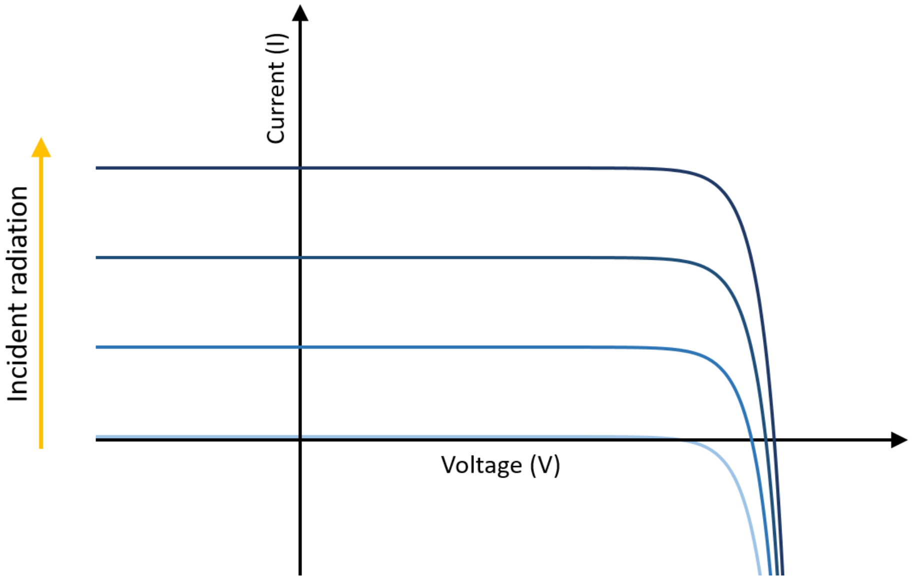


Figure 3. Characteristic curve (IV curve) with increasing incident radiation.

2.6 OPEN CIRCUIT VOLTAGE

The other extreme case aside from the short circuit current is the case when the current becomes zero. We call this case the open circuit voltage, see figure 2. To determine the V_{OC}, we need to solve the equivalent circuit equation for the case when the current is 0.

VOC=VI=0=n·VT·lnIPhIS+1=n·VT·lnISCIS+1

Remember that the photocurrent equals the short circuit current (I_{Ph}=I_{SC}). The +1 term inside the logarithm can be ignored for anything above extremely small currents, so an approximate version of the equation can be written as

VOC≈VI=0=n·VT·lnISCIS

Thus, we can see that the irradiance dependency of V_{OC} to incident radiation is much lower for V_{OC} as compared to I_{SC}. In fact, the open circuit voltage changes with the natural logarithm of the irradiance (remember that the photocurrent is proportional to the irradiance). You can also see this in figure 3, as the V_{OC} is only slightly affected by decreasing irradiance.

2.7 HOW DO SOLAR CELLS WORK?

In order to understand how solar cells work it is important to understand the structure and properties of semiconductors and the operating step. Figure 1 shows the four steps graphically.

1. When sunlight shines on the solar cell, photons (light particles) bombard the upper surface.
2. The photons carry their energy down through the cell.
3. Upon absorption the photon gives its energy to an electron creating an electron / hole pair.
4. The electron moves across the barrier into the upper n-type layer and escapes out into the circuit.
5. Flowing around the circuit, the electron charges the battery.

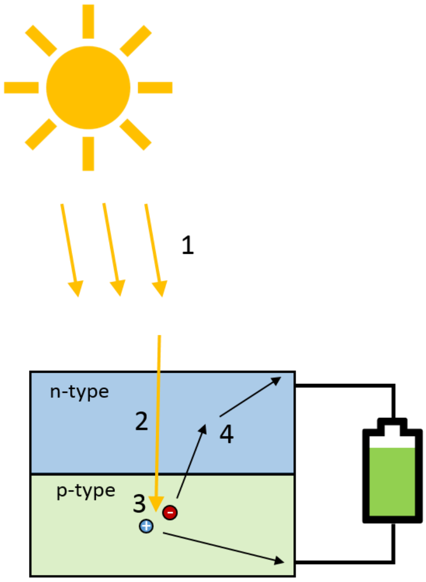


Figure 1. Simplified explanation of the operation of a solar cell.

2.8 THEORETICAL SOLAR CELL EFFICIENCY

When we create solar cells, the efficiency is the parameter that typically gets the most attention. The higher the efficiency, the better we use the available solar resource, and the smaller an area we need. Ideally, a solar cell would use every single photon available and use all of the energy from each photon ensuring that we have a 100% efficient solar cell. However, there are limits to the efficiency we can achieve.

Losses in efficiency include optical losses and electrical losses such as reflection, transmission, contact resistance, recombination sites, and so on.

While we can improve on all of these mechanisms, there are limits to a solar cells efficiency that we cannot overcome, and from these we can determine a theoretical solar cell efficiency.

2.9 SPECTRAL EFFICIENCY

A fundamental limit to the efficiency of a solar cell has to do with the bandgap of the semiconductor used. Photons with energy less than the bandgap does not get absorbed and photons with energy exceeding the bandgap lose their excess energy through thermalization, see figure 1.

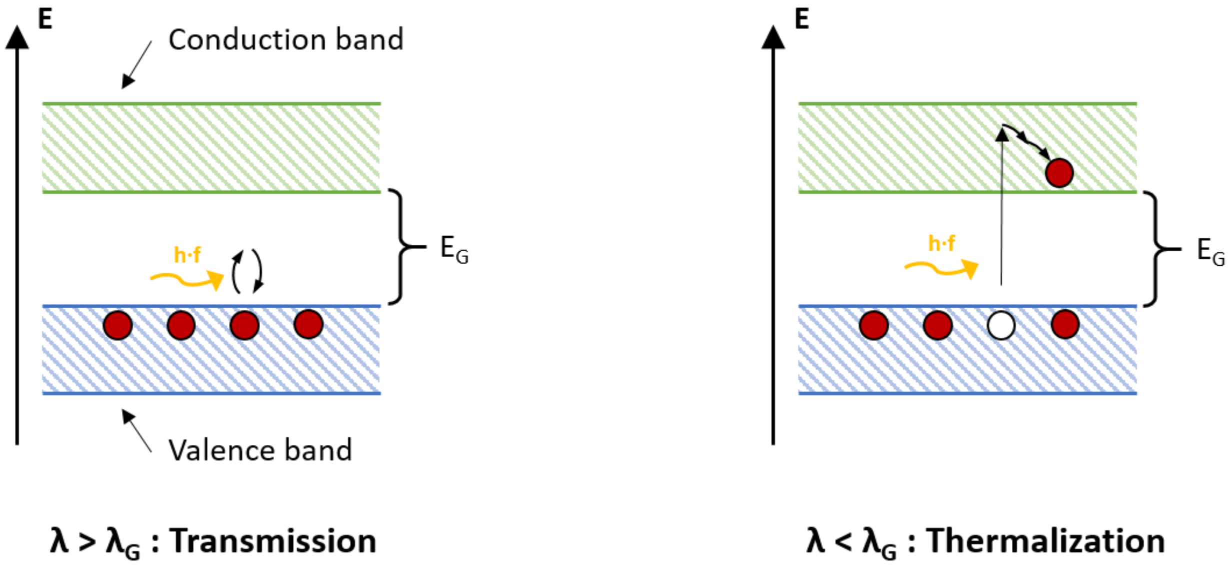


Figure 1. If a photon has less energy than the bandgap (E_G) it will not be absorbed (left). Photons with higher energy than the bandgap lose their excess energy in a thermalization process.

We can define the bandgap wavelength**,** λ_G, in terms of the bandgap

λG=h·cEG\lambda_G = \frac{h\cdot c}{E_G}λG=EGh·c

This wavelength corresponds to the wavelength of light that is just absorbed. The portion of the solar spectrum above λ_G cannot be used for electrical energy, because the photons have less energy than the bandgap. The portion of the light is thus lost as transmission, see figure 1.

For photons with energy exceeding the bandgap ($\lambda < \lambda_G$), the energy is sufficient for absorption. The surplus energy of the photons are, however, given up as the electron relaxes down to the bottom of the conduction band. We call this process thermalization loss. This means that any surplus. In figure 2, you can see a visualization of the spectral usage for a silicon solar cell with a bandgap of 1.11 eV.

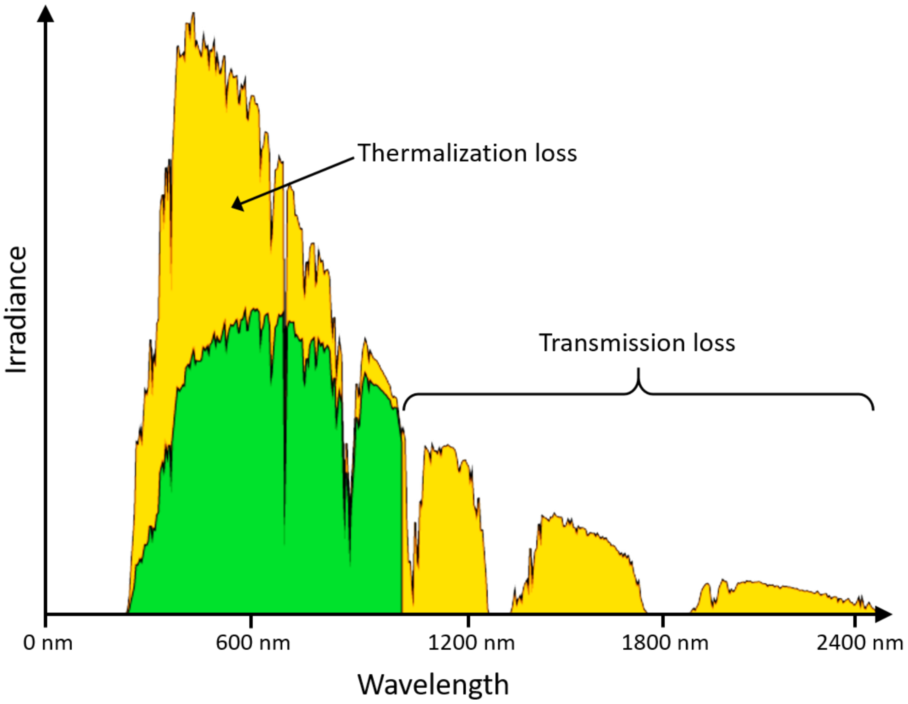


Figure 2. Spectral losses in a silicon solar cell device with a bandgap of 1.11 eV. All photons with an energy lower than the bandgap are lost to transmission, while higher energy photons lose their excess energy to thermalization.

2.10 THEORETICAL EFFICIENCY

When we talk about determining the efficiency limit of a solar cell there are two things we have excluded when we calculated the spectral efficiency. Firstly, in a real solar cell it is not possible to use the full voltage, $V_{Max} = E_G/q$. Secondly, the fill factor cannot be 100% and therefore the maximum power point current and voltage will be lower than I_{SC} and V_{OC}. Both these limitations come from the fact that a real solar cell has a p-n junction. When we include these two limitations it is possible to calculate a theoretical efficiency limit for any given bandgap energy, see figure 3. It is important to note the we assume that all photons are absorbed and contribute to the photo current. For any real solar cell there will be some reflection losses, recombination losses, etc. However, it is remarkable that the record laboratory efficiency for silicon solar cells today is 26.6%, when we know the theoretical limit is 29.4%.

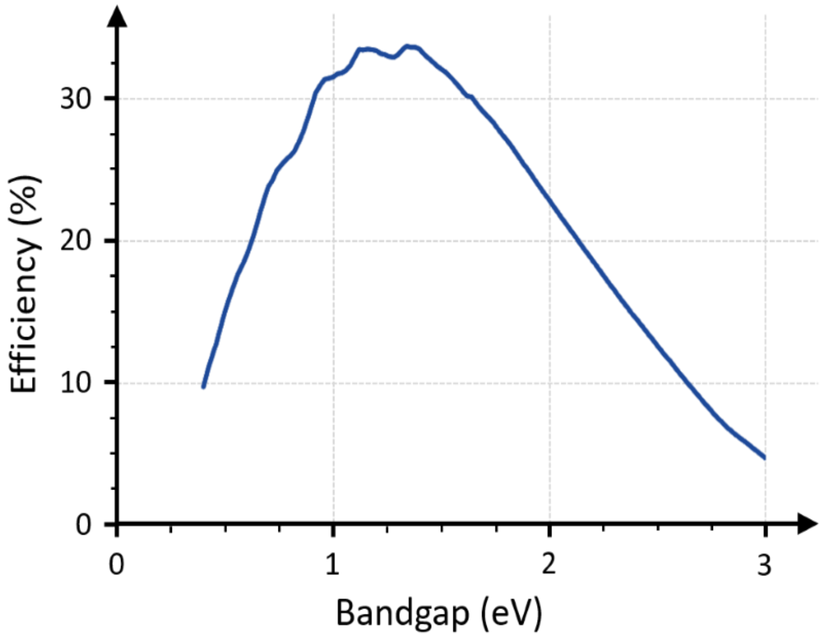


Figure 3. Theoretical efficiency and its dependence on the bandgap energy. The wiggles in the curve are a result of the IR absorption bands in the atmosphere.

2.11TYPE OF SOLAR CELL

2.11.1 CRYSTALLINE SILICON SOLAR CELLS

So far we have learned about the operation of solar cells, how they produce power, and looked at historical milestones in the development of solar cells. Now we will turn to specific solar cell technologies to get some insights into how they are produced, what their traits, advantages, and disadvantages are.

The silicon solar cell was the first truly useful solar cell technology when it was invented, and to this day crystalline silicon solar cells dominate the market with a share of more than 80%. In figure 1, you can see some images of silicon solar cells. For most, the silicon solar cell is the engrained image of a solar cell, a rigid blueish panel with silver stripes. In this section, we will talk about how silicon solar cells are produced and assembled, how they work, and what their advantages and disadvantages are.

Figure 1. Monocrystalline silicon solar cell (left), polycrystalline solar cell (middle), mounted solar panels (right).

Like any other solar cell technology, three basic attributes are required

- The absorption of light, generating electron-hole pairs.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.

2.11.2 THE FILM SOLAR CELLS

Thin film solar cells are made by depositing one or more thin layers, or thin films of photovoltaic material on a substrate, such as glass, plastic or metal. In contrast to silicon solar cells, thin film solar cells use direct bandgap materials, allowing for thinner absorbing layers. Film thickness varies from a few nanometers to tens of micrometers, much thinner than crystalline silicon solar cells which uses wafers with thicknesses of 200 μm. This thinness allows thin film solar cells to be flexible**,** and lower in weight. Examples of thin film solar cells can be seen in figure 1.

Figure 1. Rigid CdTe panels mounted on a supporting structure (left), CIGS solar cell on a flexible plastic backing (middle, source: Wikipedia), and flexible amorphous silicon cells being installed onto a roof (right, source: Wikipedia).

Copper indium gallium selenide (CIGS) is one of three mainstream thin-film PV technologies, the other two being **c**admium telluride (CdTe) and amorphous silicon. With all three materials, the absorbing layers are thin enough to be flexible, allowing them to be deposited on flexible substrates, see figure 1 right. However, all three technologies normally use high-temperature deposition techniques and therefore the best performances comes from cells deposited on glass.

The efficiency of thin film solar cells are generally less than conventional solar cells, especially for commercial solutions. As you can see in figure 2, the world records for amorphous silicon, cadmium telluride, and CIGS are 14%, 22.1%, and 22.6% respectively. This places both cadmium telluride and CIGS above the experimental efficiencies of multi-crystalline silicon solar cells. The market share of thin film technologies market-share has never reached more than 20% in the last two decades and has been declining in recent years to about 9% of worldwide photovoltaic installations in 2013**.** Despite the competition from conventional silicon solar cells, the thin film technologies hold many unique promises, allowing solar cells to be produced with much lower energy payback times, and with much lower material consumption.

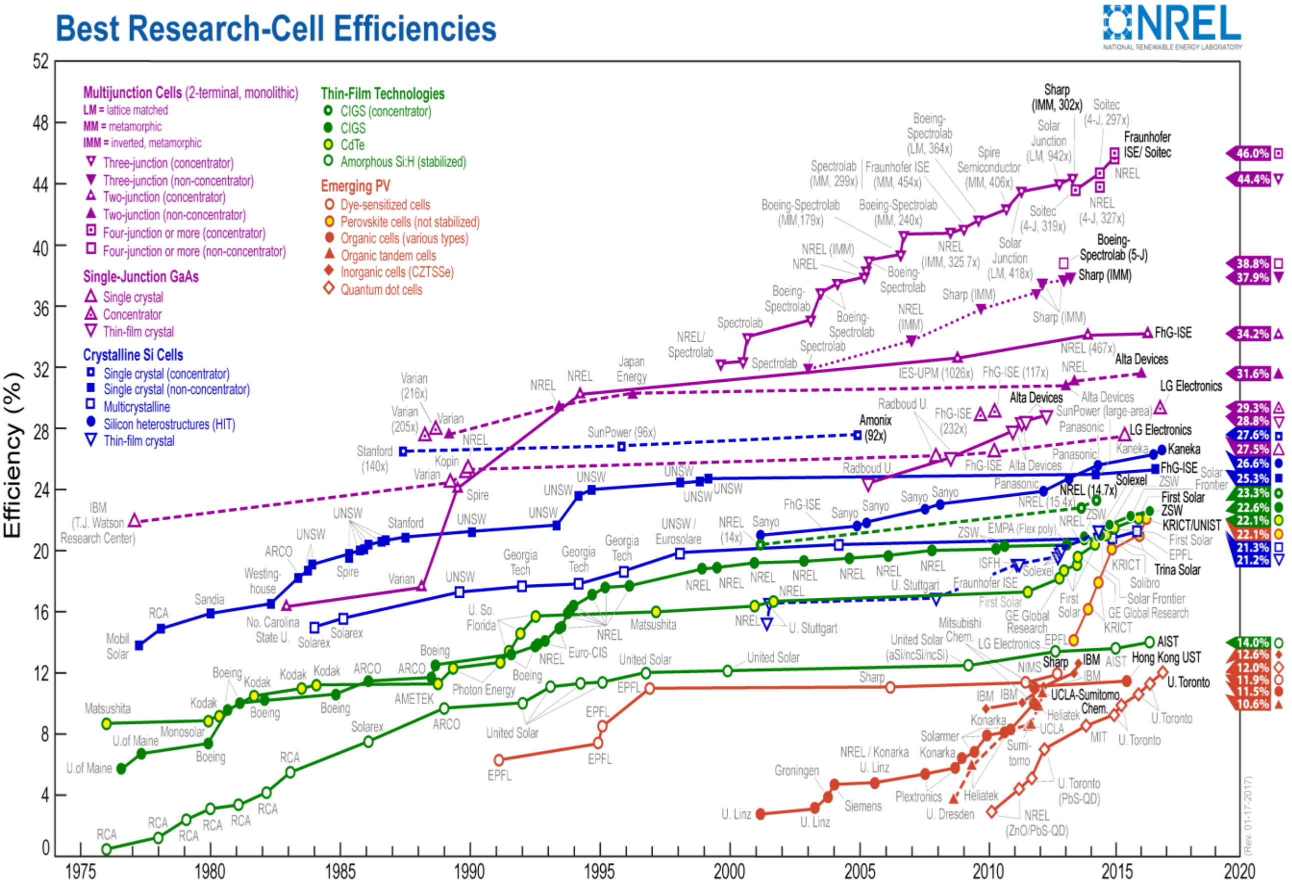


Figure 2. Reported timeline of solar cell energy conversion efficiencies since 1976 compiled by the National Renewable Energy Laboratory. Thin film technologies are represented in green. Source: Wikipedia.

2.11.3 WHAT ARE POLYMER SOLAR CELLS

Polymer solar cells are a photovoltaic technology using an organic material to harvest energy from light. The potential advantages of polymer solar cells are numerous including flexibility, processability, low material cost, and independence of scarce resources.

Figure 1. Examples of polymer solar cells and production. Sources plasticphotovoltaics.com (left image), infinityPV.com (middle and right image).

The material used to absorb the solar light in polymer solar cells, is a conjugated polymer exhibiting semiconducting behavior. The fact that polymers can behave as semiconductors is a discovery which Alan J. Heeger, Alan MacDiarmid, and Hideki Shirakawa received the Nobel Prize in Chemistry for in the year 2000. While the materials are different, the basic principle behind the polymer solar cell is the same as other forms of solar cells, namely the transformation of the energy in the form of electromagnetic radiation (light) into electrical energy (a current and a voltage).

For many years polymer solar cells have lagged behind traditional solar cell technologies on both performance and stability. However, they have always had one huge potential advantage; that is their ability to be produced from solution. This means that they can be printed or coated, instead of using expensive vacuum deposition as for other solar cell technologies. Today, performances of roughly 12% have been demonstrated for polymer solar cells, as can be seen in figure 1. The lifetime has also improved considerably and polymer solar cells with a lifetime of years have been demonstrated. However, polymer solar cells have yet to see a large scale commercial breakthrough.

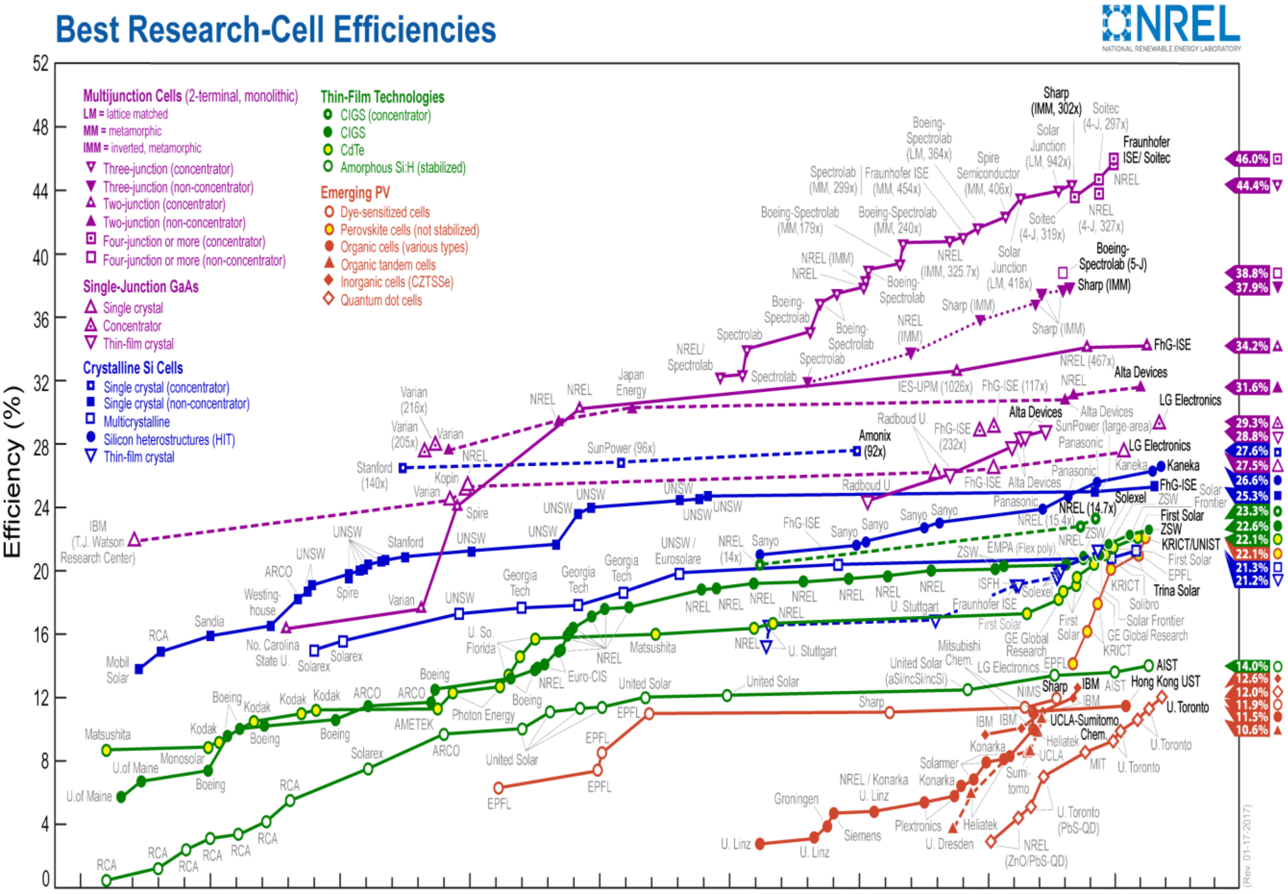


Figure 3. Reported timeline of solar cell energy conversion efficiencies since 1976 compiled by the National Renewable Energy Laboratory. Polymer solar cells are part of the orange emerging PV group. Source: Wikipedia.

2.12THREE GENERATIONS OF SOLAR CELLS

The solar cell technologies are traditionally divided into **three generations**.

The **first generation** solar cells are mainly based on silicon wafers and typically demonstrate a performance about 15-25%. These types of solar cells dominate the market and are mainly those seen on rooftops. The benefits of this solar cell technology lie in their good performance, as well as their high stability. However, they are rigid and require a lot of energy in production.

The **second-generation** solar cells are based on materials like amorphous silicon, CIGS and CdTe, where the typical performance is 10-15%. Second generation solar cells are defined as thin film solar cells, since they use direct bandgap materials and can be made much thinner than first generation solar cells. The second generation solar cells can also be produced so they are flexible to some degree. However, as the production of second generation solar cells still include vacuum processes and high temperature treatments, there is still a large energy consumption associated with the production of these solar cells. Further, second generation solar cells are often based on scarce elements and this is a limiting factor in both the price and their eventual popularity.

The **third generation** of solar cells is a mix of many types of solar cells. One example is organic solar cells, which include small molecule and polymer solar cells (thus, polymer solar cells are a sub category of organic solar cells). The third generation also covers expensive high performance experimental multi-junction solar cells, which hold the world record in solar cell performance, plus novel devices in general. A new class of thin film solar cells currently under investigation are perovskite solar cells and show huge potential with record efficiencies beyond 20% on very small area.

In figure 1, there is an overview of the different solar cell technologies. The blue and green lines represent the first and second generation respectively. The multijunction cell and emerging PV represent the third generation.

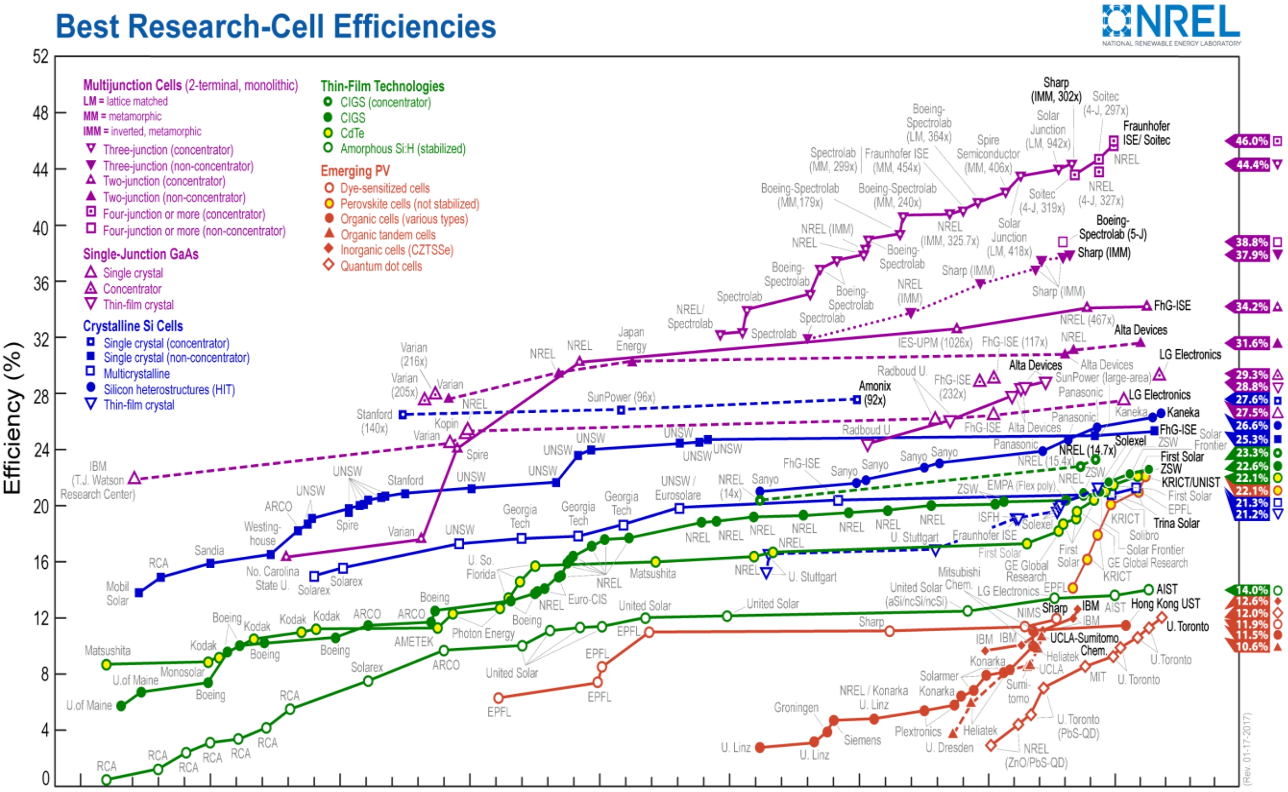


Figure 1. Reported timeline of solar cell energy conversion efficiencies since 1976 compiled by the National Renewable Energy Laboratory. Source: Wikipedia.

2.12.1 EXPLANATORY NOTES FOR NREL’S “BEST RESEARCH CELL EFFICIENCIES CHART

The National Renewable Energy Laboratory (NREL) maintains a plot of compiled values of highest confirmed conversion efficiencies for research cells, from 1976 to the present, for a range of photovoltaic technologies.

Devices included in this plot of the current state of the art have efficiencies that are confirmed by independent, recognized test labs (e.g., NREL, AIST, Fraunhofer) and are reported on a standardized basis. The measurements for new entries must be with respect to Standard Test or Reporting Conditions (STC) as defined by the global reference spectrum for flat-plate devices and the direct reference spectrum for concentrator devices as listed in standards IEC 60904-3 edition 2 or ASTM G173. The reference temperature is 25°C and the area is the cell total area or the area defined by an aperture.

Cell efficiency results are provided within different families of semiconductors: (1) multijunction cells, (2) single-junction gallium arsenide cells, (3) crystalline silicon cells, (4) thin-film technologies, and (5) emerging photovoltaics. Some 26 different subcategories are indicated by distinctive colored symbols.

The most recent world record for each technology is highlighted along the right edge in a flag that contains the efficiency and the symbol of the technology. The company or group that fabricated the device for each most-recent record is bolded on the plot.

The information plotted by NREL is provided in good faith, but NREL cannot accept direct responsibility for any errors or omissions. The plot is not copyrighted and may be used in presentations and publications, with a notation included that states: “This plot is courtesy of the National Renewable Energy Laboratory, Golden, CO

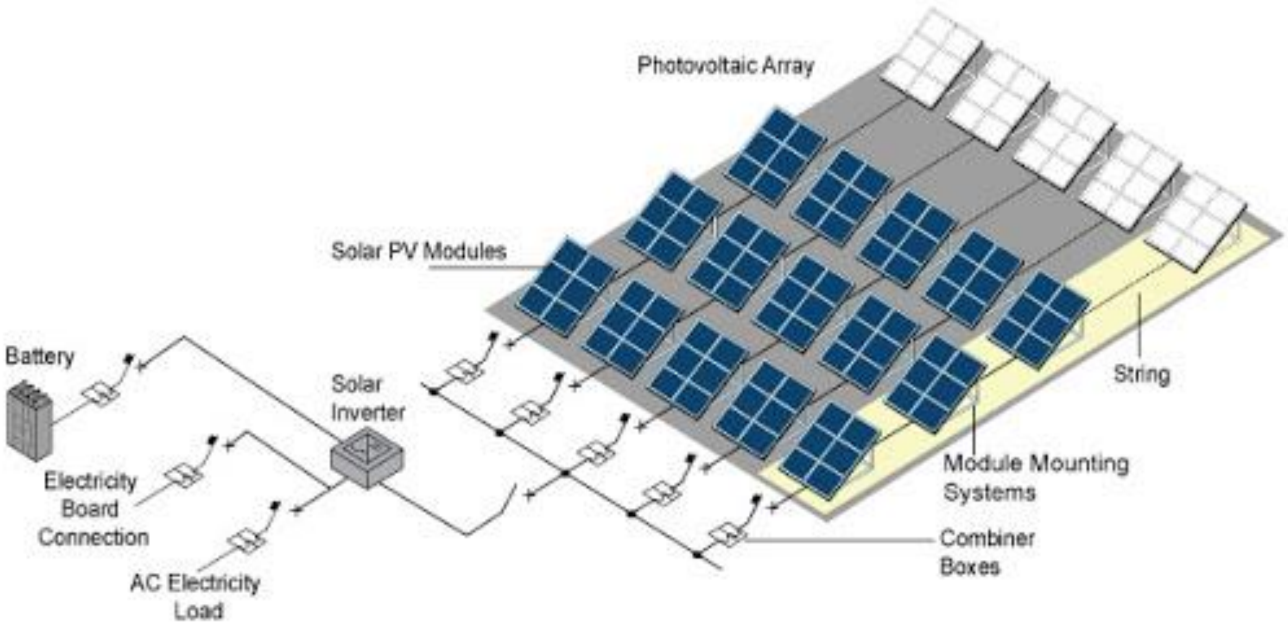
Company/Institution Acronyms or Abbreviations used as Labels on the Efficiency Chart

Label	**Full name**
AIST	National Institute of Advanced Industrial Science and Technology
Alta	
AMETEK	
Amonix	Amonix, Inc.
ARCO	Atlantic Richfield Company
Boeing	The Boeing Company
EMPA	Swiss Federal Laboratories for Materials Science and Technology
EPFL	Ecole polytechnique fédérale de Lausanne
EuroCIS	
FhG-ISE	Fraunhofer Institute for Solar Energy Systems
FirstSolar	First Solar, Inc.
FhG-ISE	Fraunhofer Institute for Solar Energy Systems
GE	
GIT	Georgia Institute of Technology
UGroningen	University of Groningen
Heliatek	
HKUST	Hong Kong University of Science and Technology
IBM	International Business Machines
ISCAS	Institute of Chemistry–Chinese Academy of

	Sciences
IES-UPM	Instituto de Energía Solar–Universidad Politécnica de Madrid
ISCAS	Institute of Semiconductors–Chinese Academy of Sciences
ISFH	Institute for Solar Energy Research Hamelin
JpnEnergy	
Kaneka	Kaneka Solar Energy
Kodak	
Konarka	Konarka Technologies, Inc.
Kopin	Kopin Corporation
KRICT	Korea Research Institute of Chemical Technology
LG	
Matsushita	
Mitsubishi	Mitsubishi Chemical Corporation
Mobil	
Monosolar	Monosolar Company Limited
NIMS	National Institute for Materials Science
NCSU	North Carolina State University
NREL	National Renewable Energy Laboratory
Panasonic	
Phil66	
PE	
Plextronics	Plextronics, Inc.
RadboudU	Radboud University
RCA	
SNL	Sandia National Laboratories
Sanyo	Sanyo Electric Company, Ltd.
Sharp	Sharp Solar
Siemens	
Soitec	
SolarFron	
SolarJunc	Solar Junction Corporation
Solarex	

3 PV PLANT

A photovoltaic system is made up of a set of mechanical, electrical components and electronics that capture energy solar, transform it into electricity, until it is made available for use by users. It will therefore be consisting of the photovoltaic generator, from a conversion and control system of power and, for some types of systems, from an accumulation system. The overall conversion yield of a plant is the result of a series of returns, which starting from that of cell, passing through that of the module, of the power control system and that of conversion, and eventually than that of accumulation, allows to derive the percentage of incident energy that you can find at the exit of the system, in the form of electricity, rendered to the user load.



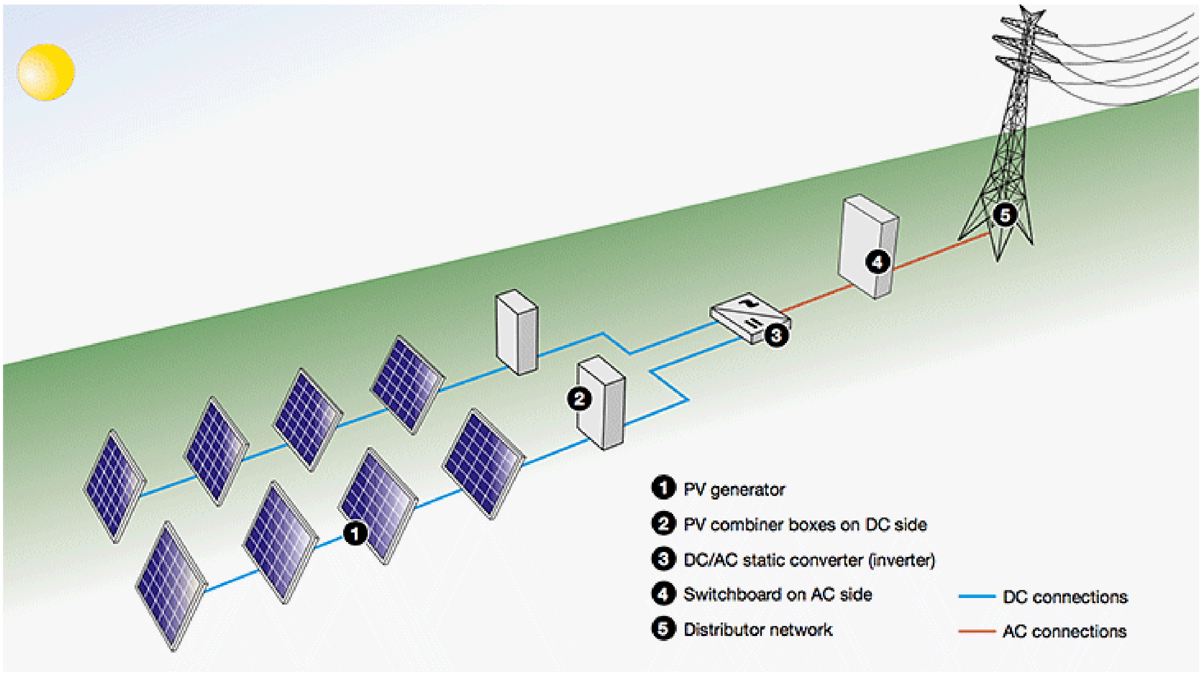
3.1 THE PHOTOVOLTAIC STRING

Photovoltaic strings are made up by individual photovoltaic modules connected in series; the number of modules depends on the voltage of the module (known once identified the type of product) and from that of the whole string.

The string is characterized by:

- maximum voltage equal to the sum of the Voc of the connected modules;
- operating voltage equal to the voltage at the maximum power point (Vm) of the string characteristic.

3.2 THE PHOTOVOLTAIC GENERATOR



A "photovoltaic field" consists of a set of strings of photovoltaic modules mechanically installed in the seat operating and electrically connected between them. From the electrical point of view the PV field constitutes the "generator photovoltaic "of the system. The PV field then, in the case of significant powers, it is consisting of sub fields (link parallel electric of a certain number of strings).

The rated power (or maximum, or of peak) of the photovoltaic generator is the power determined by the sum of single nominal powers (or maximum, or peak) of each module constituting the photovoltaic generator, measured at standard conditions (STC, Standard Test Conditions).

By Standard Conditions (STC) we mean the reference conditions for the module measurement:

- irradiation equal to 1000 W / m2;
- solar spectrum referred to an Air Mass of 1.5;
- cell temperature of 25 ° C.

Typically this measurement is performed in the laboratory with a solar simulator as it is very difficult to reproduce these conditions in an external environment.

The characteristics of the photovoltaic generator are usually defined by two electrical parameters: power nominal Pnom, that is the power supplied from the PV generator in Standard Conditions and the rated voltage Vnom, i.e. the voltage to which the power is supplied par.

In the planning phase of a field photovoltaic is of particular importance the choice of the rated voltage of exercise. Indeed, the high currents that you

manifest for small tensions involve the need to adopt larger cables section and multiple switching devices complex; on the other hand high voltages of work require adequate and expensive protections. Therefore, an appropriate choice of the series / parallel configuration of the PV field allows you to limit losses and increase reliability of the system.

In parallel to the individual modules come by-pass diodes (Dbp) arranged while a blocking diode (Db) is placed in series a each string to prevent it voltage imbalances between individual strings, in the case of imbalance in delivery

of power by them, can give rise to the circulation of a reverse current on the voltage strings minor.

The blocking diodes, sized based on electrical specifications of the photovoltaic field (short-circuit current of the Isc module, voltage a empty of the string Voc), they are generally contained within the framework of parallel strings which collects the electrical contribution provided by the individual string.

The by-pass diode allows, instead, to short-circuit and then isolate the single module, or part of it in presence of two or more diodes per module, in the case of a malfunction, limiting thus the abrupt reduction of the power supplied by the module and / or by the string that would manifest in his absence.

Finally, it should be remembered that energy produced by a photovoltaic generator is proportional to the amount of radiation solar collection on the plane of the modules.

Indeed the latter, in order to optimize electricity production, they come facing south (azimuth angle equal to zero) with an inclination with respect on the horizontal plane (tilt angle) close to the latitude of the installation site so as to make maximum the solar energy collected on them surface.

3.3 THE SYSTEM OF CONDITIONING OF POWER

The characteristic of voltage variability and current output from the photovoltaic generator when the solar radiation changes badly adapts to user specifications, which often requires AC power to power the load directly or for connection to the electricity grid of distribution, as well as a constant value for the voltage output from the generator.

In photovoltaic systems the generator is therefore connected, as the case may be, to battery, to the user devices or to the network, through a conversion system e power control.

The DC / AC converter (inverter) is a device that converts direct current in alternating current. This device assumes the role of conditioning system and control of the power supplied from the generator. It indeed, despite the variability characteristic of the voltage and current parameters supplied by field as the solar radiation changes and the temperature of the PV cells, working like a current transformer continues with transformation relationship variable, endeavors to provide a constant value for the output voltage from the PV generator, despite the fluctuations voltage output from the field.

The maximum power point tracker, MPPT (Maximum Power Point Tracker), is a converter device converter to vary its impedance input to take on the necessary one to achieve maximum transfer of power to the user. This function it is generally done by a first

DC / DC conversion bridge by means of a microprocessor control unit.

In particular, an action is taken voltage regulation or output current (depending on the techniques used) so that the inverter is seen by the network, in the first case, like a voltage generator that regulates its loading angle (phase shift between the generator and mains voltages) for transfer the maximum power, and in the second case, like a power generator

which injects a proportional current into the network at maximum transferable power. A second stage of DC / AC conversion, synchronized with the mains frequency, provides the output power with the desired voltage characteristics e frequency.

In case it is not necessary to carry out a particular voltage adaptation

between the input (PV generator side) and the output (load side or network), the control actions of the MPPT and regulation of output quantities (voltage and current) they can both be done through a single conversion stage DC / AC.

Downstream of the final conversion stage there is always a filtering section injected current harmonics network and protection devices load side interface (generally maximum and minimum voltage devices, maximum and minimum frequency, maximum current) suitable to meet the requirements for connection to the mains established by the reference technical standards.

The block diagram of principle of a converter suitable to be connected

the electrical network is generally attributable to that shown in the figure.

The inverters for stand-alone systems are consisting of a conversion bridge, generally with downstream transformer e by an internal regulator

capable of ensuring a constant voltage value e (frequency) of output as voltage changes continuous entry into a field of established values. At the conversion stage a filtering section follows harmonics and another comprising I load side protection devices. TO depending on the system architecture, inverters may or may not have a transformer inserted in position intermediate between the two conversion stages (High Frequency Transformer, HFTR), or at the exit of the final stage (Low
Frequency Transformer, LFTR).

The transformer allows you to adapt the converter output voltage to that network, and to ensure the condition of metal separation between the system photovoltaic generation and users with the possibility of a different modality of photovoltaic field management.

Research and development efforts supported by main operators in the sector (0.7) requires the use of appropriate systems reactive power compensation.

For these reasons they do not offer any technical or economic attraction for this type of applications.

The choice was therefore directed towards forced switching appliances with regulation and control system based on the PWM modulation technique which allows the realization of equipment less bulky and efficient higher. Also this technique allows to transfer an almost current to the grid sinusoidal and with a controllable phase than the voltage itself to have a factor of practically unitary power.

3.4 SIZING ENERGY OF PLANTS CONNECTED TO THE NETWORK

The sizing of connected plants the network is carried out on the basis:

of economic availability, taking in mind that the cost of the system

it ranges from 5 € / W to 7 € / W; the availability of spaces on which

install the photovoltaic generator, bearing in mind that to install 1

kW takes about 7 m2 in the case of groundwater single or 15 m2 if required the row configuration; the availability of the solar source,

bearing in mind that, depending on the locations, the reduction in self-production plants, of energy expenditure desired, equal to the energy produced multiplied by the cost of the kilowatt hour exchanged (typically 10-20 c€); of the estimated energy gain, this is the case of production plants, given by the multiplied energy produced for the cost of the kilowatt hour sold to network (7-9.5 c€ to which it could be added any incentive rate). It is therefore necessary, during the design phase, evaluate the energy that can be produced from plant (Ep).

It depends on:

from the installation site, characterized from latitude, from solar radiation available and temperature, as well by the reflectance of the front surface photovoltaic modules;

by displaying the forms, through the angle of inclination (tilt) and angle of orientation (azimuth);

by the characteristics of the modules such as rated power, temperature coefficient, angular answer, but also by the uniformity of the electrical characteristics of the various modules (on which it depends power loss due to mismatch);

and, last but not least, the characteristics of BOS (Balance Of System), i.e. from efficiency and losses as a whole of the devices needed to transform and adapt the direct current produced from photovoltaic modules to needs of the user (the device plus important of the BOS is definitely the inverter, but losses should not be overlooked in the cables and the falls on the diodes).

The energy that can be produced by the plant is given
by the expression:

$$Ep = H. S\ Eff.pv.\ Eff.inv = H\ Pnom\ (1 - Ppv).\ (1 - Pinv)$$

where is it:

- Ppv are the losses (thermal, optical, resistive, drop on diodes, mismatch) of the photovoltaic generator, reputable, in first approximation, around the 15%;
- Pinv represents the losses (resistive, of switching, magnetic, power control circuits) of the inverter cautiously assumed equal to about 10%;
- Pnom is the nominal power of the generator photovoltaic, necessary to produce the energy Ep;
- H is the solar radiation incident on the surface of the modules (S).

The latter, as previously seen, is obtained by adding the various
irradiation components reported in terms of photovoltaic modules

(H = Hb + Hd + Ha). The formulas for a surface however exposed they are indicated in UNI 8477 Standards, while accuracy of the calculations depends on the fluctuation actual climate data compared to historical ones.

In summary the data of inputs required for the calculation of H:

average monthly values of irradiation on horizontal surface I (from historical data of the site in question);

diffuse component fraction (formula by Liu-Jordan) or component direct and diffused on a horizontal surface (directly supplied by the UNI standard 10349); site latitude; exposure angles (tilt and azimuth); soil reflectance (albedo factor).

Analyzing the values of H on some surfaces, compared to those on the reference surface (horizontal) shows, for example, that: for a roof facing south, energy accident is 15% greater than to that on a horizontal surface; the same relationship exists for plants installed on the ground;

for a facade not completely exposed to the south the incident energy is instead less than 30% compared to the one on horizontal.

More generally, if the photovoltaic panels they are oriented with an azimuth angle non-zero, i.e. they are not addressed towards the south, the ways in which they are altered energy is collected throughout the day and the amount of energy collected on annual basis.

3.5 ELECTRICAL PANELS

Continuous switchboards must be made to perform the following functions:

string sectioning and connection in parallel, protection of strings with diodes of block, protection of strings from overvoltages induced through arresters towards earth and between polarities, for small systems with switchgear accumulation they also contain devices for battery charge regulation and connection with the battery through switch.

In alternation the paintings must be made to perform the connection in parallel of the inverter outputs and, possibly, to contain the protection interface with the network and the meters of the energy produced.

The paintings are characterized by the degree of IP protection (CEI EN 60529) followed by two digits. The first represents protection against the penetration of solid bodies outsiders while the second digit represents protection against penetration of liquids. For electrical panels it is necessary to calculate the final internal temperature (Tq) at the end to check that the temperature is not exceeded operating maximum of the components inside the switchboard itself.

In particular,

$Tq = Tambiente + Pd \cdot Rth$

where is it:

- Pd is the power that the switchboard must dissipate towards the external environment (date from the rated power of the inverter multiplied by (1 - Eff.inv) plus other dissipations thermal, due to cables, switches, diodes);

- Rth is the thermal resistance of the switchboard, inversely proportional to his surface.

If despite the choice of the framework, Tq results higher than the maximum temperature of functioning of the components internal, the temperature difference must be reduced with the help of fans. In this case the final temperature inside the switchboard is given in first approximation by:

Tq = Ta + 3,5 · Pd / Q where Q is the fan flow in m3 / h.

3.6 CABLE

The electrical connection between modules and strings it must be done via cables normally in insulation class 2, made with materials resistant to UV rays, atmospheric agents and humidity, non-propagating of fire as well as with one low emission of toxic gases.

The sizing is in the planning phase must be done in a way that limits voltage drops (indicatively within 2%) and to ensure a duration of satisfactory life for conductors and insulation subjected to the thermal effects of current. In this regard, the flow rate must be calculated so that the maximum temperature of operation does not exceed the value indicated in CEI 64-8 (for each type of insulation) and must be checked according to CEI-UNEL 35024 tables, according to the laying conditions and temperature environment.

As regards the commissioning instead work, it must take place in such a way simplify wiring operations, avoid any mechanical actions on the cables, mechanically protect the cable descent by installation in pipes, with the same level of protection of the paintings.

3.7 SECTIONING OF STRINGS

Strings must be capable of being broken to perform work on active parts of in the face of an imminent danger or for functional reasons (the functional command yes however, it is typically found inside the inverter).

The organ to be used for sectioning must be an appliance that in the open position ensure adequate sectioning distance. It will be capable of opening and closing the circuit of string when the current is negligible, as well as bring to the closed position the working current (and short circuit). It should preferably be omnipolar and can be established (low voltage) by disconnector, automatic switch, removable fuses or plug connectors Fast. Finally, the maneuvering organ must be compliant with CEI 9 standards (devices in direct current). Anyway, low voltage alternating current devices they can also be used on the current continues as long as the data of plate for the two ways of working. To the about alternating current devices for industrial uses must comply to CEI 17-5 standards while those for domestic use according to CEI 23-3 standards.

3.8 GENERATOR MANAGEMENT PV

Electrical systems can be classified according to the rated voltage as category systems:

0) Vnom <50 Vca or 120 Vcc (very low voltage),

I) Vnom <1.000 Vca or 1.500 Vcc (low voltage),

II) Vnom> 1.000 Vca or 1.500 Vcc up to 30.000 V (medium voltage),
III) Vnom> 30.000 V (high voltage).

Photovoltaic systems are generally systems of category 0 or I and can be connected to category II systems or III via transformer.

In addition, electrical systems can be classified in relation to the neutral state and masses as systems:

- TT) the neutral is on the ground while the masses are connected to a land other than neutral earth;
- TN) the masses are connected to the neutral who is on the ground;
- IT) the neutral is isolated from the ground and the masses I'm on the ground.

If there is a transformer between DC section and network, however the network (TT or TN) is classified, the photovoltaic generator generally comes managed as IT system (masses a earth and floating poles).

In this hypothesis the possible protections from adopt concern:

1. grounding of masses and continuous control of the generator insulation photovoltaics. In this case it is necessary report the occurrence of a prime earth fault without interrupting the service, giving the possibility to eliminate the damage;
2. use of insulation components double or reinforced (class II) in so that failure is unlikely to the ground;
3. choice of rated voltage <120 V (very low safety voltage systems).

In this case the masses do not go grounded and connected to network must be carried out via transformer safety (double insulation or with screen on the ground).

3.9 THE EARTH SYSTEM

For the project, implementation and verification of the earthing system, refer to CEI standards fully applicable also for photovoltaic systems. The earthing system must be set up from a sink (stake or knitted or mixed) and by an earth conductor (connect the ground masses). The earth resistance of a sink (ratio between voltage to earth respect to infinity and the leakage current) depends from the resistivity of the ground and from the dimensions and shape of the sink. The earth conductors must have sections, insulation and typical markings of the conductors used for the earthing system.

3.10 PLANT PROTECTION PHOTOVOLTAIC FROM DISCHARGE WEATHER

A photovoltaic system is potentially subject to electrical discharges of origin atmospheric since photovoltaic modules are usually placed on the top of the buildings. Lightning striking the photovoltaic generator directly, as well as causing damage to the modules and to the conversion electronics, it could use the appropriate electrical conduits to the transportation of the original electricity photovoltaic to reach the plant electric user with risk, in absence of specific protective measures,
to start fires in the building structure host.

The reference legislation for protection of structures from lightning strikes is that issued by CT 81 of the CEI, in particular the rules to be applied are those of the EN 62305 series, or the CEI 81- 10/1, CEI 81-10 / 2, CEI 81-10 / 3 and CEI 81- 10/4.

These standards are the result of a process of European harmonization, they have international validity and report the procedures of design, execution, verification and maintenance of protection systems (Lightning Protection System, LPS), as well as a detailed calculation procedure for the assessment of the risk due to direct and indirect lightning strikes.

It should be noted that the application of CEI 81-10 family standards cannot ensure absolute protection to facilities and people, however it allows to significantly reduce the risk of damage caused by lightning at expected levels acceptable.

3.11 TYPE OF PV SYSTEM

Photovoltaic power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads. The two principal classifications are grid-connected or utility-interactive systems and stand-alone systems.

Photovoltaic systems can be designed to provide DC and/or AC power service, can operate interconnected with or independent of the utility grid, and can be connected with other energy sources and energy storage systems.

3.11.1 GRID CONNECTED PHOTOVOLTAIC SYSTEMS

Grid-connected or utility-interactive PV systems are designed to operate in parallel with and interconnected with the electric utility grid.

The primary component in grid-connected PV systems is the inverter, or power conditioning unit (PCU). The PCU converts the DC power produced by the PV array into AC power consistent with the voltage and power quality requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized.

A bi-directional interface is made between the PV system AC output circuits and the electric utility network, typically at an on-site distribution panel or service entrance.

This allows the AC power produced by the PV system to either supply on-site electrical loads, or to back-feed the grid when the PV system output is greater than the on-site load demand.

At night and during other periods when the electrical loads are greater than the PV system output, the balance of power required by the loads is received from the electric utility

This safety feature is required in all grid-connected PV systems, and ensures that the PV system will not continue to operate and feed back into the utility grid when the grid is down for service or repair.

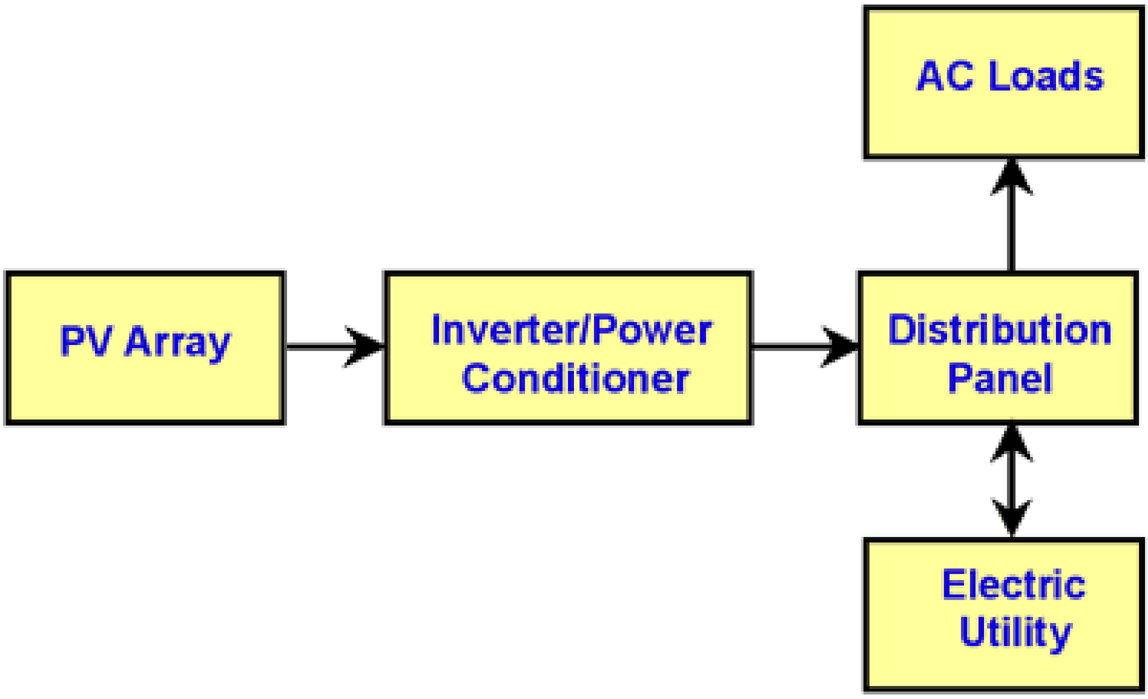


Figure 1. Diagram of grid-connected photovoltaic system.

3.11.2 STAND ALONE PHOTOVOLTAIC SYSTEMS

Stand-alone PV systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC and/or AC electrical loads.

These types of systems may be powered by a PV array only, or may use wind, an engine-generator or utility power as an auxiliary power source in what is called a PV-hybrid system.

The simplest type of stand-alone PV system is a direct-coupled system, where the DC output of a PV module or array is directly connected to a DC load (Figure 3).

Since there is no electrical energy storage (batteries) in direct-coupled systems, the load only operates during sunlight hours, making these designs suitable for common applications such as ventilation fans, water pumps, and small circulation pumps for solar thermal water heating systems.

Matching the impedance of the electrical load to the maximum power output of the PV array is a critical part of designing well-performing direct-coupled system.

For certain loads such as positive-displacement water pumps, a type of electronic DC-DC converter, called a maximum power point tracker (MPPT), is used between the array and load to help better utilize the available array maximum power output.

Figure 2. Direct-coupled PV system.

In many stand-alone PV systems, batteries are used for energy storage. Figure 3 shows a diagram of a typical stand-alone PV system powering DC and AC loads. Figure 4 shows how a typical PV hybrid system might be configured.

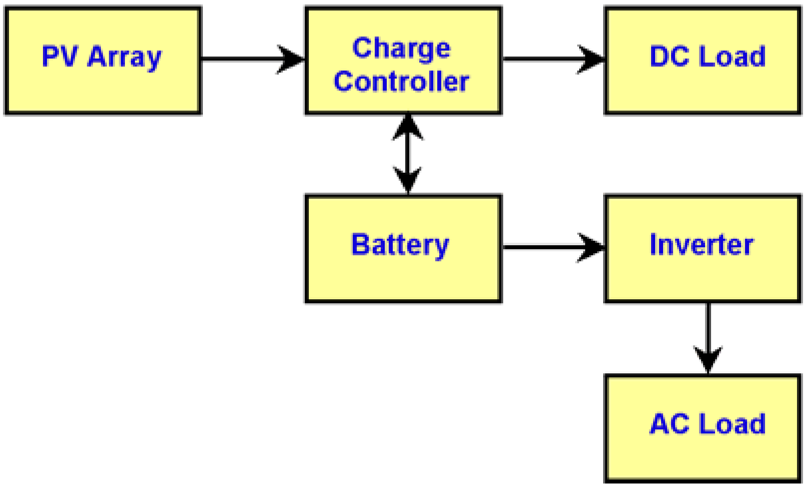


Figure 3. Diagram of stand-alone PV system with battery storage powering DC and AC loads.

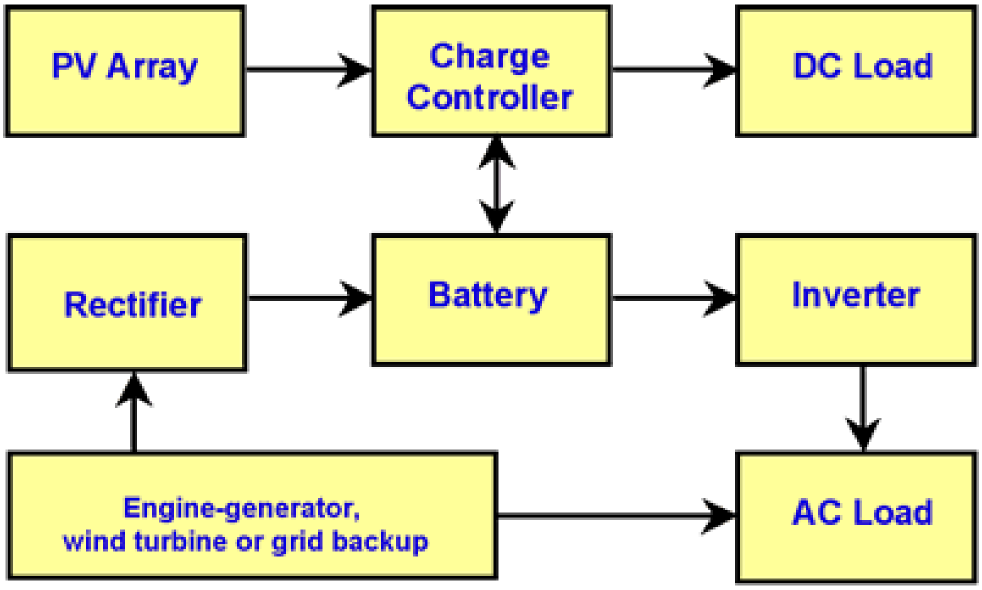
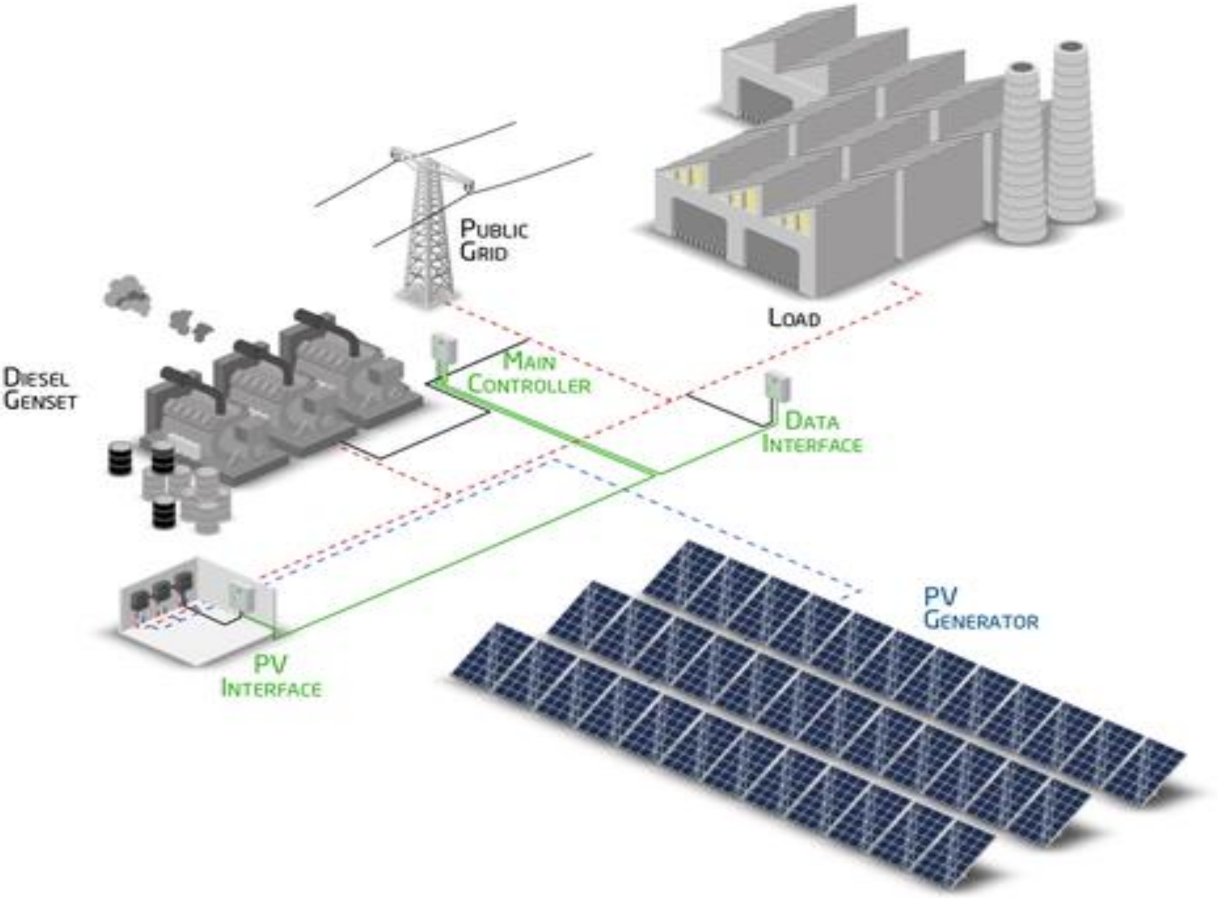


Figure 4. Diagram of photovoltaic hybrid system



3.12SYSTEMS TO IMPROVE THE PV EFFICIENCY

3.12.1 TRACKERS

Solar tracker is a system that positions an object at an angle relative to the Sun. The most-common applications for solar trackers are positioning photovoltaic (PV) panels (solar panels) so that they remain perpendicular to the Sun’s rays and positioning space telescopes so that they can determine the Sun’s direction. PV solar trackers adjust the direction that a solar panel is facing according to the position of the Sun in the sky. By keeping the panel perpendicular to the Sun, more sunlight strikes the solar panel, less light is reflected, and more energy is absorbed. That energy can be converted into power.

Solar tracking uses complex instruments to determine the location of the Sun relative to the object being aligned. These instruments typically include computers, which can process complicated algorithms that enable the system to track the Sun, and sensors, which provide information to a computer about the Sun’s location or, when attached to a solar panel with a simple circuit board, can track the Sun without the need for a computer.

3.12.1.1 ROLL TRACKERS

Roll trackers are devices that, with the help of servomechanisms, chase the Sun along its daily path in the sky, regardless of the season, and therefore rotating every day along a north-south axis parallel to the ground, ignoring the variation of height (daily and annual) of the Sun on the horizon.

This type of tracker, which performs a maximum rotation of +/- 60 °, is particularly suitable for countries such as Italy characterized by low latitudes, since in them the apparent path of the Sun is wider. To avoid the problem of mutual shading that would occur at sunrise and sunset with rows of these trackers, the so-called backtracking technique is used: the modules follow the movement of the Sun only in the central hours of the day, reversing the movement behind the sunrise and sunset, when they reach a perfectly horizontal alignment. The increase in energy production offered by these trackers is around 15%.

3.12.1.2 THE SINGLE-AXIAL TRACKERS

Single-axis photovoltaic trackers are devices that "chase" the Sun by rotating around a single axis. Depending on the orientation of this axis, we can distinguish four main types of trackers: tilt trackers, roll trackers, azimuth trackers, polar axis trackers. They allow an increase in energy production between almost 10% of simple tilt trackers and 30% of polar axis trackers.

Although the most efficient ones, the polar axis trackers are rarely used due to the high profile exposed to the wind.

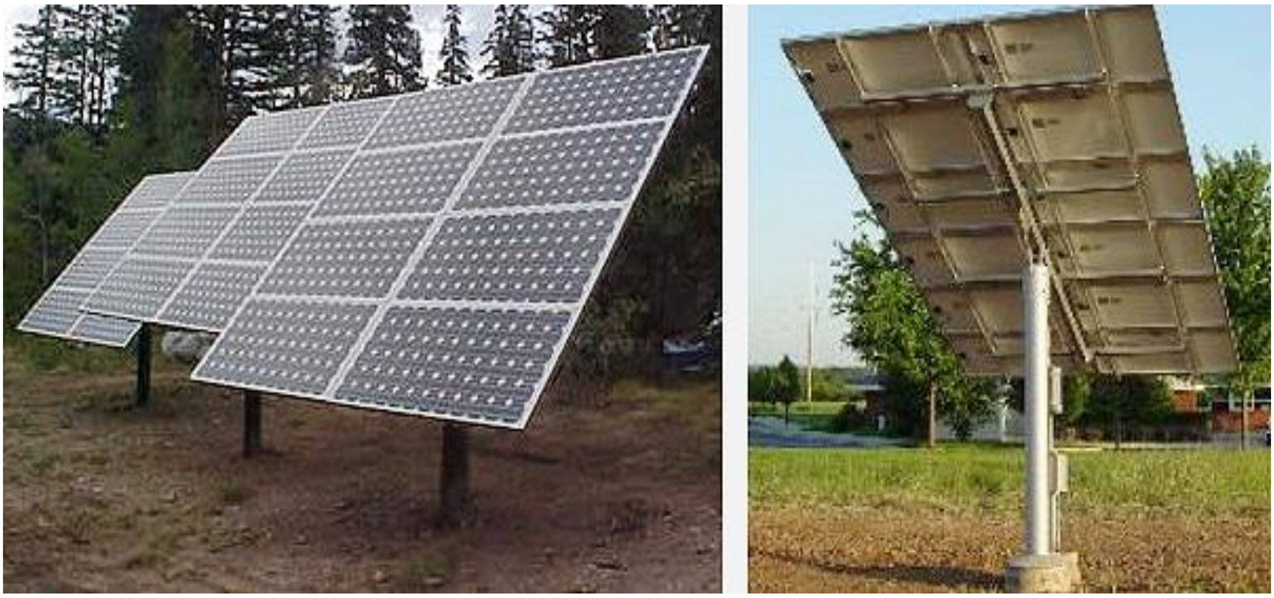
The slightly less efficient azimuth trackers need relatively large spaces on their part to avoid the problem of shading, which in the case of the roll trackers was solved with the backtracking technique.

Finally, the tilt trackers do not have this type of problem and have the advantage of being particularly inexpensive without having servomechanisms.

3.12.1.3 THE TILT TRACKERS

The tilt trackers (or "pitch") - which are the simplest and most economical solar trackers - rotate around the east-west axis.

Since solar panels are normally oriented towards the south, this means increasing or decreasing the inclination of the panel with respect to the ground by a small angle, so that the angle to the ground - called the tilt angle - is statistically optimal compared to the season . In fact, the ideal tilt angle not only varies with latitude (in Italian latitudes the ideal angle varies from 29 ° in Southern Italy to 32 ° in the North), but also over time, since the Sun reaches different heights during the year. This operation is usually carried out manually twice a year, thanks to a special frame that allows the panels to be lowered or raised manually compared to the horizon: since the increase in energy production offered by this type of tracker does not exceed the 10%, the use of a servomechanism would rarely be justified.



3.12.1.4 AZIMUT'S TRACKERS

The azimuth trackers rotate around a vertical axis perpendicular to the ground.

Therefore the panels are mounted on a rotating base coplanar with the ground which, through a servomechanism, follows the movement of the Sun from east to west during the day but, unlike the tilt and roll trackers, without ever changing the inclination of the panel above the ground. Obviously, azimuth trackers normally have solar panels inclined at a certain angle relative to the rotation axis. Projects that use this type of tracker must properly take into account the shading to avoid energy losses and to optimize land use.

However, the optimization in case of close grouping is limited due to the nature of the shadows that are created during the year, therefore they are suitable, substantially, when relatively large spaces are available.

The increase in energy production offered by this type of tracker is around 25%.

3.12.1.5 POLAR AXIS TRACKERS

The polar axis trackers rotate, with the aid of a servomechanism, around an axis parallel to the north-south axis of earth rotation (polar axis), and therefore inclined with respect to the ground. Note that in the roll trackers the rotation axis is equally oriented in the north-south direction but it (and the panels) is parallel to the ground, not to the terrestrial axis. In the polar axis trackers, on the other hand, the rotation axis is inclined with respect to the ground in order to be approximately parallel to the terrestrial rotation axis. The rotation axis of these trackers, therefore, is similar to that around which the Sun draws its trajectory in the sky, but not the same, due to changes in the height of the Sun in the sky in the various seasons. The polar axis trackers, therefore, manage to keep the solar panels approximately perpendicular to the Sun throughout the day (neglecting the aforementioned seasonal height fluctuations) and give the maximum efficiency (+ 30%) that you can obtain with a single axis of rotation.

3.12.1.6 COMPARISON OF THE YIELD OF THE VARIOUS TYPES OF TRACKERS

The two major classes of solar trackers are represented by monoaxial trackers and biaxial trackers, which in turn have numerous possible implementations.

Single-axis photovoltaic trackers are devices that "chase" the Sun by rotating around a single axis.

Depending on the orientation of this axis, we can distinguish four types of trackers: tilt trackers, roll trackers, azimuth trackers, polar axis trackers. Biaxial photovoltaic trackers instead have two rotation axes, usually perpendicular to each other.

Thanks to them, and with the help of a more or less sophisticated electronic instrumentation, it is possible to point the panels perfectly and in real time towards the Sun as it moves on the sky, maximizing the efficiency of the solar panels.

There are two types of very common biaxial trackers, which differ in the different orientation of the rotation axes: the azimuth-elevation and the tilt-roll ones.

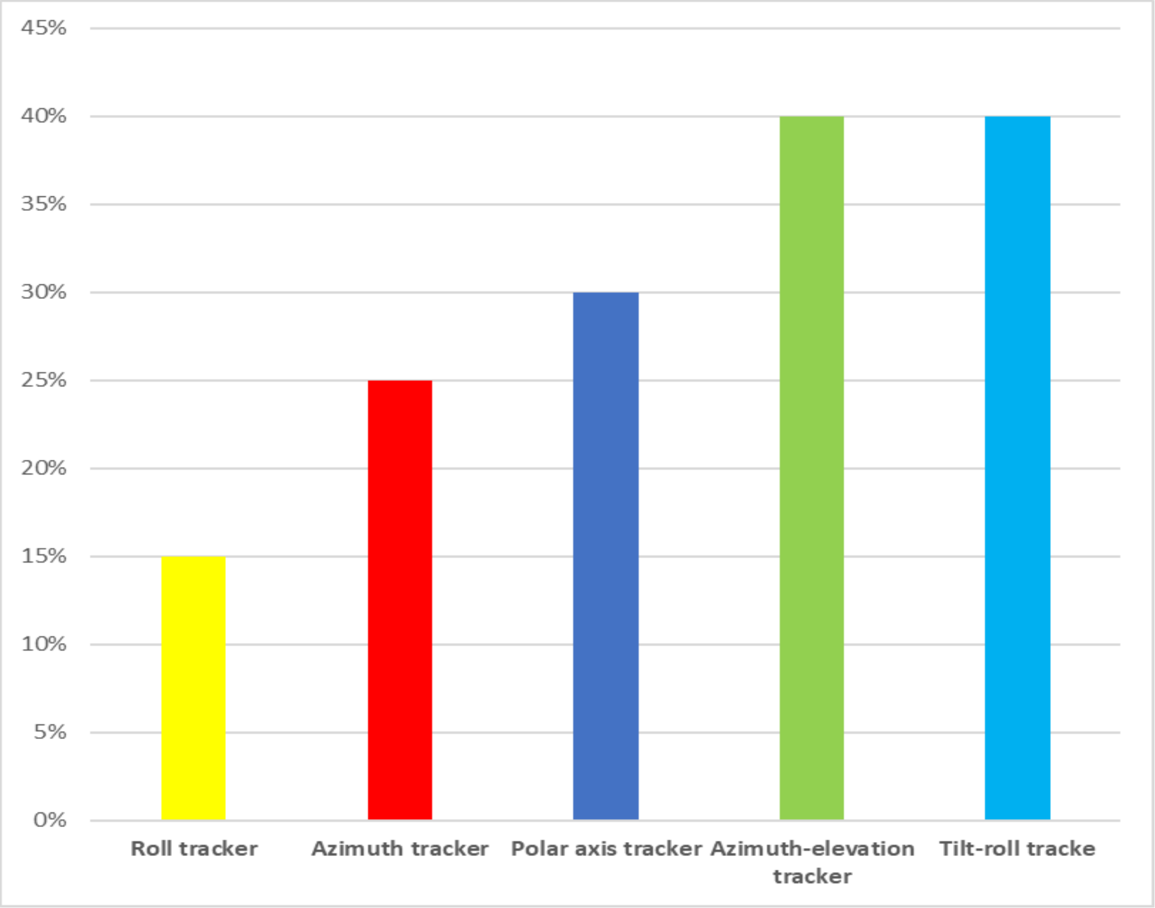


Table. Comparison of the increase in yield between the various types of solar trackers.

Classification	**Type of tracker**	**Increased energy compared with fixed PV system**
Monoaxial	Tilt tracker	<10%
Monoaxial	Roll tracker	15%
Monoaxial	Azimuth tracker	25%
Monoaxial	Polar axis tracker	30%
Biaxial	Azimuth-elevation tracker	40%
Biaxial	Tilt-roll tracke	40%

3.12.2 SOLAR MULTIPLIERS

Solar multipliers are concentrated photovoltaic systems, characterized by an increase in the energy produced which, however, does not exceed 100%.

Since the gain is not very high, it is convenient to use silicon photovoltaic panels which are those that currently have a better yield.

These energy multiplication technologies can also be accompanied by the principle of solar tracking that allows you to make the most of solar radiation throughout the day.

Some types of solar multipliers are listed below.

3.12.2.1 FLAT MIRROR SOLAR MULTIPLIERS

Flat mirror solar multipliers generally use photovoltaic panels with normal silicon technology coupled to flat mirrors and a tracking system (which can be monoaxial or biaxial).

There are various ways of implementing the idea of flat mirrors.

The most common are those of placing them in contact with each other in the middle of two rows of panels - which gives the structure a remarkable stability - or on the external sides of these rows, with the advantage of being able to adjust their inclination and being able to add them to pre-existing structures not designed for the purpose.

The increase in the production of electricity that is thus obtained is 30% - 40% more than the energy produced by the "panels + tracker" system.

The energy produced by the entire system, however, depends on the type of tracker used, bearing in mind that a single-axis tracker can increase the yield of a panel by a maximum of 30%, while a biaxial tracking system increases it by 35-40 %.

3.12.2.2 THE MULTIPLIERS WITH DOUBLE-SIDED PANELS

The two-sided panels are, among the traditional silicon photovoltaic panels, those theoretically best suited to make the most of the potential offered by "solar multiplication".

They have on the back a glass or a transparent surface instead of the standard opaque support, as well as electrodes and electrical contacts less invasive from the point of view of the occupied surface. Combined with flat mirrors placed in the lower part of the structure in order to "illuminate" them from below, and with a very simple and stable single-axis tracking system with polar axis, they allow to generate 50% more electricity than the classic fixed single-sided panels , and seasonally the increase can even reach 75%: therefore it is, in practice, a 1.5 X concentrator.

Part of this extra energy is produced by solar tracking of the type used (which gives an increase of 30%) and it starts, in fact, from the illumination of the lower side of the panel, which makes it return up to 20% more energy.

3.12.2.3 A MULTIPLIER WITH HOLOGRAPHIC OPTICS

An American company has developed an original type of solar multiplier that uses holographic optics and traditional photovoltaic technology.

The planar holographic concentrator at the base of the multiplier uses a thin optical film, which firstly selects the "coldest" part of the solar radiation from a spectral point of view to allow the photovoltaic cells to work more efficiently. In one panel, the holographic film bands are alternated with double-sided silicon cell bands.

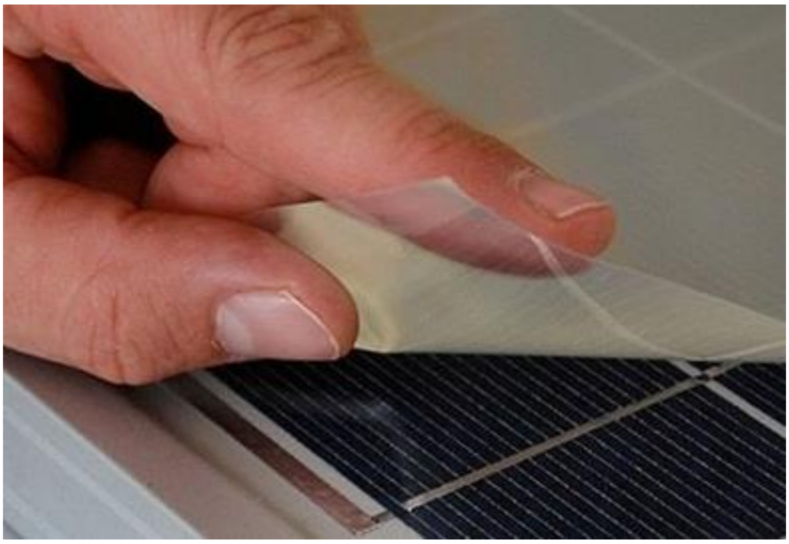
Light that directly hits the photovoltaic band produces electricity in the normal way.

The light that, instead, hits the band with the holographic film is channeled through the glass to the surface of the cells and converted into electricity. The panel thus produces 20-40% more energy than a normal panel of the same size, therefore it is a 1.2-1.4 X solar multiplier. It has the efficiency of a crystalline panel but the cost of a thin film panel.

3.12.2.4 THE FILMS THAT IMPROVE THE EFFICIENCY OF THE PANELS

Nanotechnologies do not just create revolutionary new photovoltaic cells or new types of solar concentrators, but they can also improve the performance of traditional panels, perhaps already installed for some time. Today, in fact, there are polymeric films that can be attached to the surface of already existing panels - or new ones - to increase their efficiency by 10% (which is equivalent to the performance of a 1.1 X solar multiplier) . The thin film used for this purpose is composed of microstructures that curve the direction of the incident light, improving its angle of incidence and causing more light to reach the photovoltaic cells, and therefore more electricity is generated.

Some independent laboratory tests have shown that this technology is currently able to increase the energy produced by a panel even by 12%. Given the ease of application of the film, this is an excellent result.



3.13 APPLICABLE CODES AND STANDARD FOR THE PV PLANT:

- CEI 0-16: Technical rule for the connection of active and passive users to the AT and MT networks of electricity distribution companies;
- CEI 64-8: User electrical systems with rated voltage not exceeding 1000 V in alternating current and 1500 V in direct current;CEI 11-20: Electricity production plants and uninterruptible power supplies connected to I and II category networks;
- CEI 0-2 Guide for the definition of the project documentation for electrical systems
- CEI 82-25 and variant V1: Guide to the construction of photovoltaic generation systems connected to medium and low voltage electricity grids
- CEI EN 60904-1: Photovoltaic devices Part 1: Measurement of photovoltaic voltage-current characteristics;
- CEI EN 60904-2: Photovoltaic devices - Part 2: Requirement for the reference photovoltaic cells;
- CEI EN 60904-3: Photovoltaic devices - Part 3: Measurement principles for photovoltaic solar systems for terrestrial use and reference spectral radiation;
- CEI EN 61727: Photovoltaic (PV) systems - Characteristics of the connection interface with the network;

- CEI EN 61215: Crystalline silicon photovoltaic modules for terrestrial applications. Project qualification and type approval;
- CEI EN 61000-3-2: Electromagnetic compatibility (EMC) - Part 3: Limits Section 2: Limits for harmonic current emissions (equipment with input current = 16 A per phase);
- CEI EN 60555-1: Disturbances in the power supply networks produced by household appliances and similar electrical equipment - Part 1: Definitions;CEI EN 61000-6-4 Electromagnetic compatibility (EMC) - Part 6- 4: Generic standards - Emission for industrial environments
- CEI EN 60439-1-2-3: Assembled protection and switching equipment for low voltage;
- CEI EN 60445: Identification of the terminals and devices and of the ends of the designated conductors and general rules for an alphanumeric system;
- CEI EN 60529: Degrees of protection provided by enclosures (IP code);
- CEI EN 60099-1-2: Unloaders;
- CEI EN 62093 (CEI 82-24) Components of photovoltaic systems - modules excluded (BOS) - Project qualification in natural environmental conditions
- CEI 11-17 Public electricity transmission and distribution production plants - Cable lines

- CEI EN 61724 (CEI 82-15) Survey of the performance of photovoltaic systems Guidelines for measuring, exchanging and analyzing data
- CEI 13-4 Electricity measurement systems - Composition, precision and verification
- CEI EN 62053-21 (CEI 13-43) Apparatus for measuring electrical energy (c.a.)
- Special requirements - Part 21: Counters static active energy (class 1 and 2)
- EN 50470-1 and EN 50470-3 In process of national implementation at CEI
- CEI EN 62053-23 (CEI 13-45) Apparatus for measuring electrical energy (c.a.) Particular requirements - Part 23: Static reactive energy meters (class 2 and 3)
- CEI 64-8, part 7, section 712 Solar photovoltaic (PV) power systems
- CEI IEC 62271-200 Control devices and control equipment in metal casing from 1 kV to 52 kV
- IEC 62271-100 High-voltage switchgear and controlgear alternating-current circuit-breakers
- CEI EN 62271-106 Switch disconnector
- CEI EN 62271-103 disconnectors and earthing switches
- CEI EN 62271-105 Current transformers
- IEC 60298 Prefabricated equipment with metal casing for voltages from 1 to 52 kV

- IEC 60298 (Annex AA) Internal arch, Class A accessibility (criteria 1 to 6)
- IEC 60694 (table 1 / A) - Insulation level (values)
- IEC 60694 Insulation level (Coordination guide according to IEC 60071)
- IEC 60056 Automatic circuit breakers MT
- IEC 60265-1 and 60420 Switch-disconnectors and rotary switches
- IEC 60676 SF6 gas
- IEC 60129 Switch disconnectors with earthing blades
- IEC 60529 Degree of protection (IP)
- IEC 60044-1 MV current transformers (CT)
- IEC 60044-2 MV voltage transformers (TV)

Lighting

- CEI 81-1: Protection of structures against lightning;
- CEI EN 62305 (CEI 81-10) Lightning protection series consisting of
- CEI EN 62305-1 (CEI 81-10 / 1) General principles
- CEI EN 62305-2 (CEI 81-10 / 2) Risk assessment
- CEI EN 62305-3 (CEI 81-10 / 3) Material damage to structures and danger to people
- CEI EN 62305-4 (CEI 81-10 / 4) Electrical and electronic systems inside the structures
- CEI 81-3: Average values of the number of lightning strikes on the ground per year and per square kilometer;

- CEI 81-4: Evaluation of the risk due to lightning;
- CEI 0-2: Guide for the definition of the project documentation for electrical systems;
- CEI 0-3: Guide for the compilation of the documentation for the law n. 46/1990;
- UNI 10349: Heating and cooling of buildings. Climate data;
- CEI EN 61724: Survey of the performance of photovoltaic systems. Guidelines for measuring, exchanging and analyzing data;IEC 60364-7-712 Electrical installations of buildings - Part 7-712: Requirements for special installations or locations Solar photovoltaic (PV) power supply systems.
- Legislative Decree 81/08 and subsequent amendments, for the safety and prevention of accidents at work;
- D. M. 37/08 Regulation concerning the implementation of art. 11-quaterdecies paragraph 13 lett. a of the law n ° 248 of 02.12.2005 concerning the reorganization of the provisions relating to the installation activity of the systems inside the buildings;
- UNI / ISO standards for the mechanical support and anchoring structures of photovoltaic modules
- Decree of February 19, 2007, to encourage the production of electricity from photovoltaic systems.
- AEEG Resolution no. 188/05, for the procedures for the provision of incentive rates.
- AEEG Resolution no. 40/06, to supplement resolution no. 188/05.

For connection to the local electricity network operator:

- ENEL DK5640 "Criteria for connection of active and passive systems to the ENEL Distribuzione Medium Voltage grid"
- AEEG Resolution no. 88/07, Provisions regarding the measurement of electricity produced by generation plants.
- AEEG Resolution no. 89/07, Technical and economic conditions for the connection of the electricity production plants to the electricity grids with the obligation to connect third parties with a nominal voltage of 1 kV or less.
- AEEG Resolution no. 90/07, Implementation of the decree of the minister of economic development, in concert with the minister of the environment and of the protection of the territory and the sea 19 February 2007.
- AEEG Resolution no. 281/05 and as amended AEEG resolutions n.28 / 06 and n.100 / 06, Conditions for the provision of the connection service to electricity grids with a nominal voltage greater than 1 kV whose managers have the obligation to connect to third parties.
- DK 5310, Contractual modalities and conditions for the supply by ENEL Distribution of the connection service to the electricity grid with nominal voltage higher than 1 kV.
- Guide for connections to the electricity network of Enel Distribuzione ed. I Dec. 2008.
- CEI 0-16

Pre-Fabricated Buildings

- Law 5 November 1971 n. 1086 Rules for the regulation of reinforced, normal and prestressed concrete works
- Law 2 February 1974 n. 64 Measures for constructions with particular provisions for seismic areas
- Standards CEI 70-1 Degrees of protection provided by enclosures (IP)
- CEI 11-1 Standards "Electrical systems with voltage greater than one kV in alternating current"
- CEI 11-35 Standards Guide for the execution of MV / LV electrical substations of the customer / end user
- ENEL DG 10061 ed. V Requirements for the construction of prefabricated boxes for electrical equipment
- D. M. of 16.01.1996 "Technical standards for construction in areas seismic "
- D. M. 09.01.1996 "Technical standards for the execution of prestressed concrete works and for metal structures"
- DK 5640 Enel "Criteria for connection of production plants to the BT network of Enel

Cables:

- CEI 20-19: Rubber insulated cables with nominal voltage not higher than 450/750 V;
- CEI 20-20: Cables insulated with polyvinyl chloride with nominal voltage not higher than 450/750 V;
- IEC 60502 (CEI 20-13) cables with extruded rubber insulation for rated voltages from 1 to 30kV
- CEI EN 50266 (CEI 20-22) Test cables do not propagate fire
- CEI EN 60332-1 (CEI 20-35) Test on cables subjected to fire
- CEI EN 50200 (CEI 20-36) Tests on cables fire resistance
- CEI EN 50267 (CEI 20-37) Tests on gas emitted when electric cables burn
- CEI 20-38 Fire retardant cables insulated with rubber and with a low evolution of toxic and corrosive gas CEI 20-45 Fire resistant cables insulated with elastomeric mixture and with nominal voltage Uo / U not greater than 0.6 / 1kV

4 GLOBAL OVERVIEW RENEWABLE ENERGY

Progress in renewables remains concentrated in the power sector, while far less growth has occurred in heating, cooling and transport.

The year 2018 saw a relatively stable market for renewable energy technologies. A total of 181 gigawatts (GW) of renewable power was added, a consistent pace compared to 2017, and the number of countries integrating high shares of variable renewable energy (VRE) keeps rising.

Progress once again was concentrated in the power sector, as renewable energy became increasingly cost-competitive compared to conventional thermal generation. Renewables provided an estimated more than 26% of global electricity generation by year’s end. Uptake has been driven by targets and stable policies. As in previous years, renewables saw far

less growth in the heating, cooling and transport sectors, with progress constrained by a lack of strong policy support and by slow developments in new technologies. Decarbonisation pathways and frameworks were developed further during 2018. At the sub-national level, a growing number of governments in many regions became leaders, setting more

ambitious targets than their national counterparts. Developing and emerging economies continued to increase their deployment of renewables, and distributed renewable energy systems further helped to spread energy access to households in remote areas.

The private sector is playing a key role in driving renewable energy deployment through its procurement and investment decisions. Corporate sourcing of renewables more than doubled during 2018, and renewable energy has spread in significant amounts around the world. While global investment in renewables decreased from the previous year, developing and emerging economies again provided over half of all investment in 2018. The renewable energy sector overall employed (directly and indirectly) around 11 million people worldwide in 2018. As of 2017, renewable energy accounted for an estimated 18.1% of total final energy consumption (TFEC). Modern renewables supplied 10.6% of TFEC, with an estimated 4.4% growth in demand compared to 2016. Opportunities continue to grow for increased use of renewable electricity in end-use sectors. Sector integration attracted the attention of policy makers, and the markets for enabling technologies (such as battery storage, heat pumps and electric vehicles) grew. However, meaningful action to directly support the interconnection of power, heating and cooling, and transport is still lacking. Despite progress in renewables uptake, energy efficiency and energy access, the world is not on track to meet the targets of the Paris Agreement or of Sustainable Development Goal 7.

Global energy-related carbon dioxide (CO2) emissions grew an estimated 1.7% in 2018 due to increased fossil fuel consumption.

Global subsidies for fossil fuel use increased 11% from 2017, and fossil fuel companies continued to spend hundreds of millions of dollars on lobbying to delay, control or block climate change policies and on advertisements to influence public opinion.

4.1 POWER RENEWABLE ENERGY

Renewable energy is expanding in the power sector, with 181 GW newly installed in 2018. However, the rate of new capacity additions levelled off, following years of growth.

Global renewable power capacity grew to around 2,378 GW in 2018. For the fourth year in a row, additions of renewable power generation capacity outpaced net installations of fossil fuel and nuclear power combined. Around 100 GW of solar photovoltaics (PV) was installed – accounting for 55% of renewable capacity additions – followed by wind power (28%) and hydropower (11%). Overall, renewable energy has grown to account for more than 33% of the world's total installed power generating capacity.

Renewable energy has established itself on a global scale.

In 2018, more than 90 countries had installed at least 1 GW of generating capacity, while at least 30 countries exceeded 10 GW of capacity. Wind power and solar PV further increased their shares in some locations, and a growing number of countries now have more than 20% variable renewables in their electricity mixes.

RENEWABLE ENERGY INDICATORS 2018

		2017	2018
INVESTMENT			
New investment (annual) in renewable power and fuels[1]	billion USD	326	**289**
POWER			
Renewable power capacity (including hydropower)	GW	2,197	**2,378**
Renewable power capacity (not including hydropower)	GW	1,081	**1,246**
Hydropower capacity[2]	GW	1,112	**1,132**
Wind power capacity	GW	540	**591**
Solar PV capacity[3]	GW	405	**505**
Bio-power capacity	GW	121	**130**
Geothermal power capacity	GW	12.8	**13.3**
Concentrating solar thermal power (CSP) capacity	GW	4.9	**5.5**
Ocean power capacity	GW	0.5	**0.5**
Bioelectricity generation (annual)	TWh	532	**581**
HEAT			
Solar hot water capacity[4]	GW_{th}	472	**480**
TRANSPORT			
Ethanol production (annual)	billion litres	104	**112**
FAME biodiesel production (annual)	billion litres	33	**34**
HVO biodiesel production (annual)	billion litres	6.2	**7.0**
POLICIES[5]			
Countries with national/state/provincial renewable energy targets[6]	#	179	**169**
Countries with 100% renewable energy in primary or final energy targets	#	1	**1**
Countries with 100% renewable heating and cooling targets	#	1	**1**
Countries with 100% renewable transport targets	#	1	**1**
Countries with 100% renewable electricity targets	#	57	**65**
States/provinces/countries with heat obligations/mandates	#	19	**18**
States/provinces/countries with biofuel mandates[7]	#	70	**70**
States/provinces/countries with feed-in policies	#	112	**111**
States/provinces/countries with RPS/quota policies	#	33	**33**
Countries with tendering (held in 2018)	#	29	**48**
Countries with tendering (cumulative)[8]	#	84	**98**

[1] Investment data are from BloombergNEF and include all biomass, geothermal and wind power projects of more than 1 MW; all hydropower projects of between 1 and 50 MW; all solar power projects, with those less than 1 MW estimated separately; all ocean power projects; and all biofuel projects with an annual production capacity of 1 million litres or more.

[2] The GSR strives to exclude pure pumped storage capacity from hydropower capacity data.

[3] Solar PV data are provided in direct current (DC). See Methodological Notes for more information.

[4] Solar hot water capacity data include water collectors only. The number for 2018 is a preliminary estimate.

[5] A country is counted a single time if it has at least one national or state/provincial target or policy.

[6] The decline in the number of jurisdictions with targets is due primarily to several targets having expired and not having been replaced.

[7] Biofuel policies include policies listed both under the biofuel obligation/mandate column in Table 2 (Renewable Energy Targets and Policies, 2018) and in Reference Table R10 (Renewable Transport Mandates at the National/State/Provincial Levels, 2018).

[8] Data for tendering reflect all countries where tenders have been held at any time up through the year of focus at the national or state/provincial level.

Note: All values are rounded to whole numbers except for numbers <15, biofuels and investment, which are rounded to one decimal point.
FAME = fatty acid methyl esters; HVO = hydrotreated vegetable oil; RPS = renewable portfolio standard.

4.2 SOLAR PV MARKETS

The annual global market for solar photovoltaics (PV) increased only slightly in 2018, but enough to surpass the 100 GWi level (including on- and off-grid capacity) for the first time. Cumulative capacity increased approximately 25% to at least 505 GW; this compares to a global total of around 15 GW only a decade earlier. (p See Figure 25.) Higher demand in emerging markets and in Europe, due largely to ongoing price reductions, compensated for a substantial market decline in China that had consequences around the world. Despite the single-digit growth rate of the global market in 2018, solar PV has become the world's fastest-growing energy technology, with gigawatt-scale markets in an increasing number of countries. Demand for solar PV is spreading and expanding as it becomes the most competitive option for electricity generation in a growing number of markets – for residential and commercial applications and increasingly for utility projects – even without accounting for the external costs
of fossil fuels. Eleven countries added more than 1 GW of new capacity during the year, up from 9 countries in 2017 and 7 countries in 2016, and markets around the world have begun to contribute significantly to global growth. By the end of 2018, at least 32 countries had a cumulative capacity of 1 GW or more, up from 29 countries one year earlier.

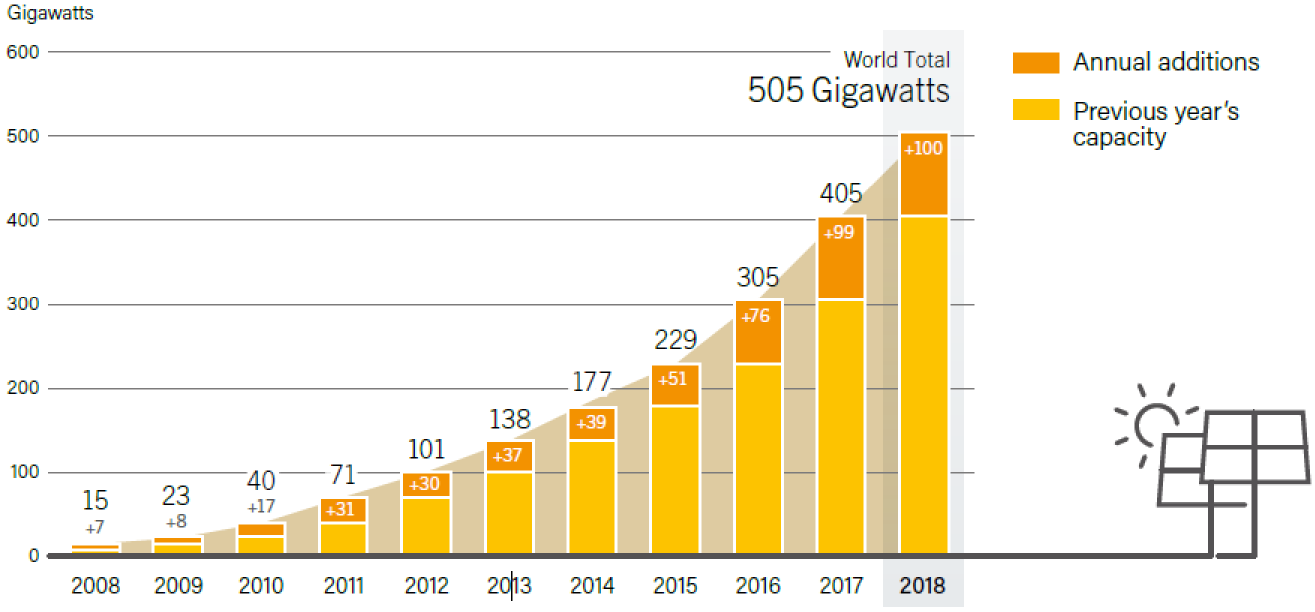
There are still challenges to address in order for solar PV to become a major electricity source worldwide, including policy and regulatory instability in many countries, financial and bankability challenges, and the need to integrate solar PV into electricity markets and systems in a fair and

sustainable manner.8 But solar PV already plays a significant and growing role in electricity generation in several countries. In 2018, it accounted for 12.1% of total generation in Honduras and substantial shares also in
Italy (nearly 8.2%), Greece (8.2%), Germany (7.7%) and Japan (6.5%). By the end of 2018, enough capacity was in operation worldwide to produce close to 640 TWh of electricity per year, or an estimated 2.4% of annual global electricity generation. In most countries, the need still exists for support schemes for solar PV, as well as for adequate regulatory frameworks and policies governing grid connections. Government policies – particularly tenders and, to a lesser extent, traditional FITs – continued to drive most of the global market in 2018. Corporate purchasing of solar PV expanded considerably, and self-consumption was a significant driver of the market for new distributed systems in Europe and the United States. Although still a negligible share of the annual market, a number of purely competitive ("unsubsidised") systems were being constructed in 2018; interest in this segment is significant and growing quickly.

For the sixth consecutive year, Asia eclipsed all other regions for new installations, despite declines in the region's top three markets (China, India and Japan). China alone accounted for around 45% of global additions, but this was down from nearly 54% in 2017. Asia was followed by the Americas. The top five national markets – China, India, the United States, Japan and Australia – were responsible for about three-quarters of newly installed capacity (down from about 84% in 2017); the next five markets were Germany, Mexico, the Republic of Korea, Turkey and the Netherlands.19 The annual market size required to rank among the top 10 countries continued to increase, reaching 1,330 MW in 2018 (up from 954 MW in 2017). At year's end, the leading countries for cumulative solar PV capacity were China, the United States, Japan, Germany and India. (p See Figure 26.)

China's annual solar PV market declined for the first time since 2014 but the country had its second-biggest year so far, with 45 GW newly installed. While down more than 15% relative to 2017, the scale of new installations was greater than expected following significant subsidy reductions by the central government in May 2018, and the country's additions were more than four times those of the next-largest market. (p See Figure 27) By year's end, China's cumulative capacity of 176.1 GW was well beyond the national target of 105 GW by 2020 that was established in 2016.

FIGURE 25. Solar PV Global Capacity and Annual Additions, 2008-2018



Note: Data are provided in direct current (DC).

Source: Becquerel Institute and IEA PVPS.

FIGURE 26. Solar PV Global Capacity, by Country and Region, 2008-2018

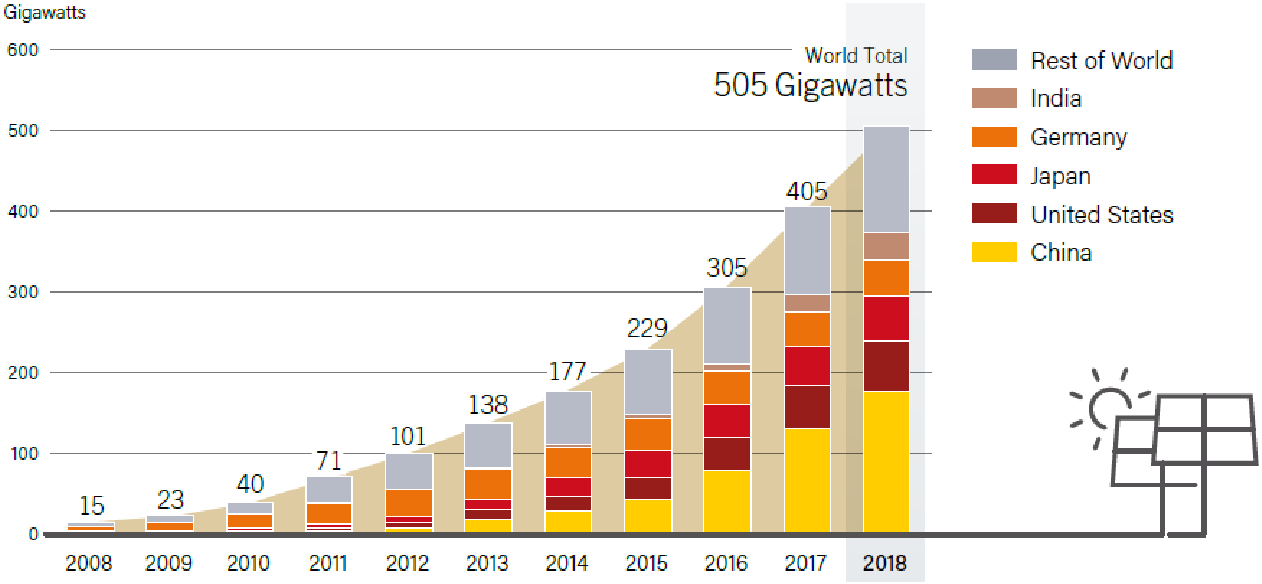
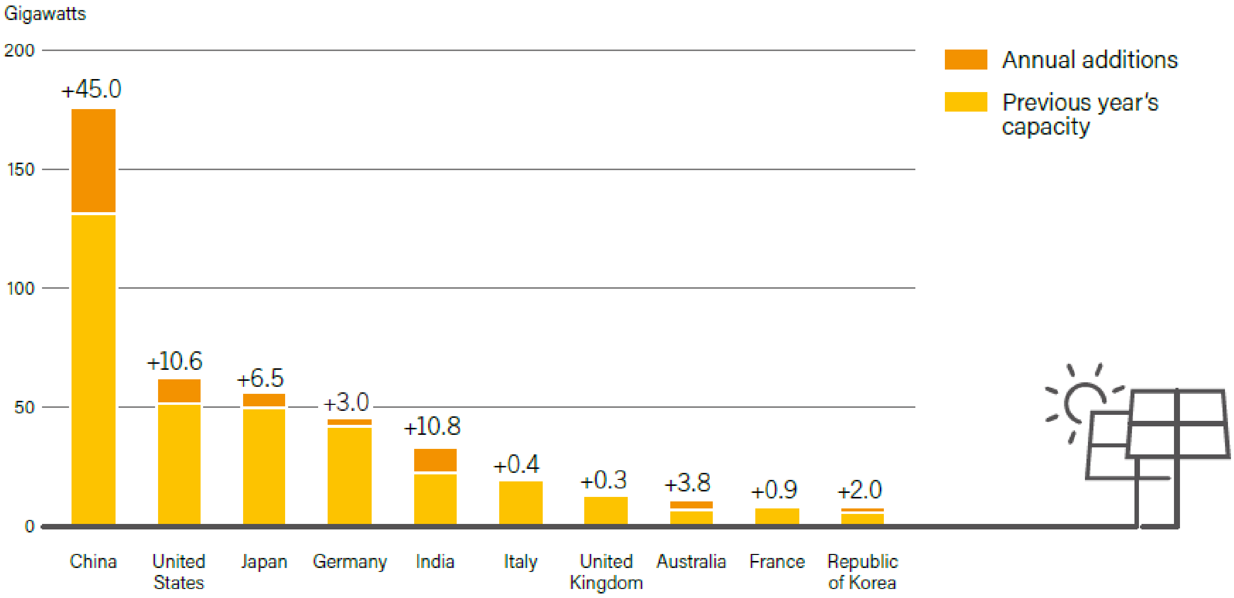


FIGURE 27. Solar PV Capacity and Additions, Top 10 Countries, 2018



These still-substantial additions came despite policy changes in China that reduced the FIT payment for solar generation, capped distributed projects at 10 MW for 2018, and ended approvals for new subsidised utility-scale plants (abolishing the 13.9 GW target for 2018), mandating that they go through auctions to set power prices. The policy changes also shifted project approval to local governments.26 Key factors driving China's policy revisions included a backlog in FIT payments and a growing deficit in the nation's renewable energy fund, as well as concerns about uncontrolled growth and a realisation that bids under the country's Top Runneri programme were much lower than the national FIT. The changes reportedly signalled the central government's shift in focus from high-speed growth and dependence on subsidies, to high-quality development in order to reduce costs through technological improvements.

China's market in 2018 was driven largely by the Top Runner and Poverty Alleviation programmes (and the FIT until late May). Centralised utility power plants (above 20 MW) accounted for nearly 53% of the year's installations (and 71% of the year-end total); the remainder was in distributed systems, which were upconsiderably in both their capacity added in 2018 and their share of total additions relative to previous years.

Curtailment of China's solar PV generation continued to decline, from a national average of 6% in 2017 to 3% in 2018, although curtailment rates remained far higher in the remote provinces of Gansu (10%, down 10 percentage points) and Xinjiang (16%, down 6 percentage points) due to insufficient transmission capacity. Reduced curtailment and rising capacity helped increase China's solar PV output 50%, to 177.5 TWh. As a result, solar PV’s share of total annual electricity generation in the country rose to 2.6% in 2018 (from 1.9% in 2017).

The second-largest market in Asia was India, which added an estimated 10.8 GW for a total of around 32.9 GWi. Installations were down relative to the previous year, for the first time since 2014. The decline was due to several factors, including land and transmission constraints, a safeguard duty on imports from China and Malaysia (the sources of about 85% of India’s imports of solar product), flaws in the tender scheme and uncertainty surrounding the Goods and Services Tax, all of which affected large-scale installations.36 Investment in India’s solar sector fell 27% by one estimate, despite an increase in investment in new manufacturing facilities, because of the decrease in installations and the decline in system costs.(p *See Investment chapter.*)

Even so, solar PV was India’s largest source of new power capacity for the second year running, and, for the first time, it accounted for more than half of the capacity added during the year. India is targeting 100 GW of installed solar PV by fiscal year 2022.

The Indian rooftop market continued to grow rapidly, up about two-thirds during 2018 by one estimate. But total rooftop capacity remained relatively low, reaching as much as a few GW by year’s end, a long way from the national target of 40 GW by 2022. The rooftop market continued to consist mainly of large commercial and industrial companies, as well as government entities and educational institutions, all seeking to reduce their electricity bills; few residential customers can afford the upfront costs.

As in recent years, most of India’s newly installed capacity during

2018 was in large-scale installations, with the bulk of this in five states: Karnataka, Rajasthan, Andhra Pradesh, Tamil Nadu and Maharashtra. At least three of these states (Andhra Pradesh, Karnataka and Tamil Nadu) continued to face curtailment challenges, in the range of 10-25%, which resulted in significant losses to project developers. More than 40 GW of additional large-scale solar projects was tendered in India during 2018.

However, the gap expanded between tenders issued and auctions completed. Many auctions were cancelled retroactively, and several gigawatts of awarded capacity were annulled during the year.

The market in Japan also contracted (down about 13%), for the third consecutive year, with 6.5 GW added for a total of 56 GW. Japan’s market continued to suffer from high prices of solar generation (Japan’s prices are some of the highest worldwide), land shortages, grid constraints and high labour costs. The country’s first three tenders, held in late 2017 and 2018, resulted in relatively high bid prices and were undersubscribed.

Even so, the number of large solar plants in Japan continued to grow, raising some conflicts between developers and local citizens and their governments due to concerns that include potential negative impacts on landscapes and the natural environment. By early 2019, the national government was considering covering solar PV projects larger than 40 MW under a revised national environmental assessment law. Japan’s residential rooftop sector remained fairly stable, and interest expanded in the use of solar-plus-storage for selfconsumption. The market for larger rooftop systems also has grown as falling solar costs relative to electricity from the grid have increased the commercial sector’s interest in self-consumption.

Community power movements in Japan continued to make progress in their financing and business models. For the year, solar PV accounted for an estimated 6.5% of Japan’s total electricity generation (11% in the Kyushu region), up from 5.7% nationally in 2017. Late in the year, Japan’s first curtailment of solar PV (and wind) generation occurred on the island of Kyushu due to periods of high shares of variable renewable output combined with inflexible nuclear generation, which also increased its share in the electricity mix in 2018. Elsewhere in Asia, the Republic of Korea added more than 2 GW to end 2018 with 7.9 GW.57 The market has been driven primarily by a renewable portfolio standard (RPS). Turkey followed, installing 1.6 GW for a total of 5.1 GW, already surpassing the national target for 2023.59 However, Turkey’s additions were down 37% relative to 2017 due to several factors, including uncertainties regarding national support schemes, issues related to land acquisition, permission and financing, as well as delays as project developers await further cost reductions.

Others in Asia to add capacity included Chinese Taipei (almost 1 GW), driven by a FIT and a target of 20 GW by 2025, as well as Pakistan (0.5 GW) and Malaysia (0.4 GW). Several countries in the region held tenders, including Bangladesh and Kazakhstan, which held its first solar auction; in the Philippines, solar PV (and wind power) competed favourably against coal, and several solar PV projects were approved for construction.

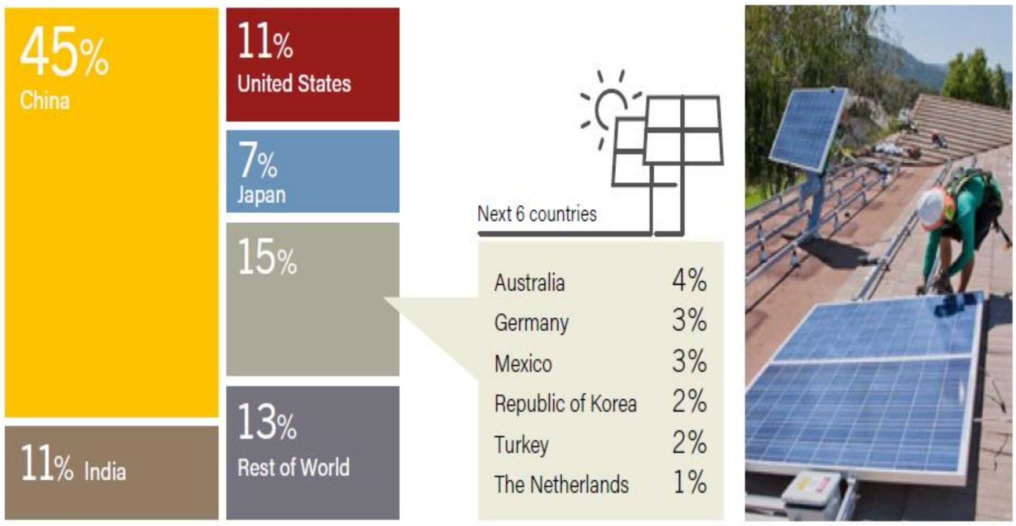
The Americas accounted for around 14.5% of the global market in 2018, due largely to the United States. The United States added an estimated 10.6 GW for a total of 62.4 GW. California again led all states in added capacity (3.4 GW), and during the year it became the first US state to mandate solar installations on most new homes (starting in 2020). California was followed by Texas (added 1 GW) and North Carolina (0.9 GW). Overall, a geographic shift in capacity additions continued, with progress in many states that previously did not have significant markets.

The US market as a whole was relatively stable (down 2%) compared to 2017. The residential sector expanded 7%, driven by emerging state markets, but the non-residential and utility-scale sectors contracted by 8% and 3%, respectively. The decline in new utility-scale capacity commissioned during the year was reportedly due largely to new federal duties on imported solar cells and modules, which led to project cancellations and delays (timelines shifted based on the tariff schedule); the effects of import tariffs were countered somewhat by a global oversupply of modules (resulting from China's policy changes and subsequent decline in module demand), which drove down prices.

The region's top country for additions in 2018 was Mexico, which ranked among the top 10 globally for the first time. (p *See Figure 28.*) Mexico added more than 2.7 GW (up from 285 MW installed in 2017), boosting its total capacity five-fold to nearly 3.4 GW.78 This substantial growth in capacity resulted from the grid connection of several very large projects (a result of auctions as well as private PPAs) and from a significant increase in distributed projects under Mexico's net metering scheme

Europe was the third-largest region for new installations (9.7 GW) but maintained its second-place ranking for total operating capacity. The region continues to represent a shrinking portion of cumulative global capacity as emerging economies with rapidly growing electricity demand deploy more and more solar PV. In 2018, however, demand increased significantly within the EU and beyond, with the cost-competitiveness of solar energy stimulating investment also in Belarus, the Russian Federation and Ukraine. Ukraine installed more than 0.7 GW to nearly double its total capacity (1.6 GW), thanks to a FIT for large-scale installations and net metering for smaller systems enacted in part to address energy security concerns. The EU added around 8.3 GW of grid-connected solar PV in 2018, up 36% over the previous year's additions, bringing total capacity to 115 GW.92 Relative to 2017, 22 of the 28 EU countries recorded higher installations, driven by national binding targets for 2020, which many member states have yet to meet. Other drivers included the removal of tariffs on Chinese solar panels in September; rising emissions prices in the EU's Emissions Trading System, which improved the competitiveness of solar PV relative to fossil fuels; and a continuing decline in solar PV system prices. A significant development in the EU in 2018 was the emergence of direct bilateral PPAs for solar PV. Developers have begun to build projects with plans to sign long-term PPAs with large industrial consumers (or even to sell electricity to utilities at the market price). One estimate shows PPA activity in the region increasing from 360 MW in 2017 to 2.4 GW in 2018.97 By late 2018, about 15 projects that did not rely on direct government subsidies to make a profit were under way in the EU, and banks had begun to provide funding for such projects in Italy, Spain and elsewhere. Germany was the EU’s largest market, regaining the region’stop spot for the first time in five years. The annual market was up more than 70% relative to 2017, to nearly 3 GW, bringing total capacity to 45.3 GW. The main drivers of the increase were self-consumption and feed-in premiums for medium- and large-scale commercial systems.101 By the end of 2018, Germany had more than 1.7 million solar PV systems. More than half of all new systems were installed with storage, and approximately 120,000 solar-storage systems were in operation by year’s end. It also was a successful year for lining up future capacity: solar tenders were over-subscribed, and solar PV won all the capacity in Germany’s first joint auctions for solar and onshore wind power. The country’s solar output increased more than 17% in 2018 (to 46.2 TWh), due largely to unusually dry and sunny summer weather, and amounted to 7.7% of annual gross electricity generation.

FIGURE 28. Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2018



5 CONCLUSION

The electrification of Europe and World economy will bring significant opportunities for the growth of solar, as the most cost – competitive and easily deployed electricity source. Combined with digital and storage solutions, renewable – based electrification connects and empowers key sector of the economy: transport, building, and industry and supports ambitious decarbonization strategies.

Boosting renewable based electrification of the transport, building and industrial sector should be an overarching priority, as it will drive a sustainable decarbonization strategy and accelerate the energy transition.

Ensuring that the right infrastructure is in place will also be crucial for example, the upcoming review of the Alternative Fuel Infrastructure Directive (AFI) will be a key milestone to ensure that Europe has the appropriate infrastructure to host a massive EV fleet, and that these vehicles will play their part in EU's future energy system.

The next European mandate should lead the digital transformation of European energy sector and economy. This is needed to effectively integrate renewables into the grid and empower renewable installations to provide their flexibility services, thus helping contain investments in additional network infrastructure. In November 2017, an IEA report on Digitalization and Energy identified digitalization as Europe's next energy transition challenge. By 2019, very little has been done at the European level to drive this change.

Producing at marginal costs close to zero, the massive penetration of solar and other competitive renewable technologies is a critical prerequisite to enable cost-competitive and fully sustainable sector coupling.

The mass deployment of cost efficient renewable electricity will enable the use of another energy carrier – green molecules. The EU should prepare for this new opportunity and act now to ensure it claims industrial leadership. Hydrogen from renewable electricity is the missing link to fully deliver Europe’s Green Deal, enabling difficult to decarbonize industries to transition to the new economy, and open the door to a competitive future free of high energy cost.

Last but not least, a systemic approach to reducing CO2 emissions across all sectors is needed. An appropriate price on carbon emissions will align investment decisions with EU climate objectives, avoid stranded assets, and support the energy transition placing the Solar at the core of a cost – efficient and fully sustainable electrification strategy.

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“A special thanks to all my
family “

Antonio