Solar energy

Introduction

In our Country (Italy) mean annual solar radiation ranges from 3.6 kWh per square metre per day in the Po river plain area, to 4.7 kWh per square metre per day in Central-Southern Italy, to 5.4 kWh per square metre per day in Sicily: consequently some regions have a production potential that is very high, however, it can be said that the entire national territory is characterized by very favourable conditions for the installation of plants for the production of solar power. Italy is one of the countries with the largest production of solar energy and is in the vanguard also in the sector of research of technological innovations. According to Gestore dei Servizi Energetici (GSE) in 2015 in Italy there were 688,398 solar power plants, with an installed capacity of 18,892 MW. So between 2014 and 2015 the number of photovoltaic installations grew by 6.2%, while the installed capacity of 1.6%.
(*Source: GSE, Rapporto statistico "Energia da Fonti Rinnovabili in Italia – 2015*")

Solar knowledge

What it is

The energy carried by sunrays as a consequence of nuclear reactions (hydrogen fusion) and transmitted to the Earth as electromagnetic radiation is called solar energy. Electromagnetic radiations are made of photons. A photon is a neutral particle that spreads into the air at a speed of 300,000 km/sec, with an energy that depends on its frequency and a mass that is considered as void when at rests (when it is not moving). The intensity of solar radiations that arrive every year to the earth's surface amounts to 80 thousand billion tons of oil equivalent (the so-called TOE, that indicates a quantity of energy that equals the energy produced by a ton of oil). This quantity is infinetisimal if compared to the energy produced by the Sun thanks to nuclear reactions. But it is also a very large quantity, if you only consider that the world energy demand amounts to 8 billion TOE a year. From the flow of solar energy, the following are derived: biomass energy, through the photosynthesis process; hydraulic energy (the Sun, in fact, is the motor of the water cycle); wind energy from which, in turn, wave energy derives. Anything, starting from what we eat every day, is directly or indirectly linked to it. Even fossil fuels, which derive from chemical-physical alterations of prehistoric living organisms, contain solar energy. Solar radiations, although they only reach a maximum power of 1 kilowatt per square meter (soil irradiation in a clear day, sunny, at midday), are the most abundant and clean energy source on the Earth.

The sun

The Sun is the closest star, which makes life on Earth possible. The sun is a sphere with a 1.4 million km diameter (109 times as much as the earth's diameter) and has a mass approximately 300.000 times greater than the earth's mass. 75% of it is hydrogen, 23% is helium and only 2% is formed by heavier elements. It produces its heat by transforming hydrogen into helium in its inner core, where the temperature reaches 15 million °C (the surface temperature is around 6000°C). The transformation reaction is called nuclear fusion and joins together 4 nuclei of hydrogen (protons) to create a helium nucleus, freeing a large quantity of energy, which, as photons, is irradiated towards the space.
A solar constant is the radiation that perpendicularly hits a unit surface positioned at the top limit of the atmosphere and amounts to 1350 watts per square metre. This heat, multiplied by the surface of the earth's section (the squared earth's average radius multiplied by pi Greco) calculates the quantity of energy the earth receives from the sun every second, i.e. 173,000 TW.

The energy balance of the Earth

A sunray reaches the earth's surface after travelling for 150 million kilometres in 8 minutes. The solar energy received by the earth amounts to 170,000 TW approximately (the unit of measurement equivalent to 1012 watts, used to measure

solar energy). 50,000 TW are reflected by the top layers of the atmosphere, 30,000 are absorbed by the atmosphere and 90,000 TW reach the earth's surface.
A big part of them is reflected (by water, for example) or absorbed. A small part is transformed. 400 TW make seawater evaporate and transform it into clouds, 370 TW activate the wind and 80 TW are transformed by the plant's photosynthesis into chemical energy.
The 30,000 TW absorbed by the atmosphere and 90,000 reaching the earth's surface are transformed into infrared radiations towards the space. Thus, the energy balance remains constant, like the temperature of the earth's atmosphere and surface. The greenhouse effect, i.e. the natural phenomenon heating the bottom layers of the atmosphere, which normally makes human existence possible, has been lately increasing due to certain human activities often leading to catastrophic effects (i.e. climate changes).

Distribution of solar radiations

The sun will illuminate and heat the Earth until its hydrogen reserves are depleted, i.e. in approximately 5 billion years. The sun's radiation reaches the earth in a non-homogeneous way because of its interaction with the atmosphere and the angle of incidence of sunrays. The angle of incidence varies according to two factors: the earth's rotation around its axis, which is very important for the alternation of day and night, and the inclination of the earth's axis as compared to the plane of its orbit, leading to a seasonal variation of the maximum height of the sun on the horizon.
When the sun is perpendicular to the earth's surface, the maximum concentration of sunrays on the ground is obtained. On the other hand, if the sunrays reach the earth's surface with a certain inclination, the same amount of energy is dispersed over a larger surface. Therefore solar energy can be highly exploited only within a belt included between 45° latitude south and north.

Useful radiation

Only a part of the huge energy flows that gets from the Sun to the Earth can be transformed into useful energy. The quantity of solar energy that arrives to the earth's surface and that can be usefully "collected" depends on irradiation on the area. Irradiation is the quantity of solar energy that arrives at a surface within a determined time interval, typically one day (it is measured in kWh by square metre by day). Instead, the value of solar radiation that arrives on the surface unit (at a determined moment) is called radiance (it is measured in kW/m2). Irradiation is influenced by local climatic conditions (clouds, mist, etc) and depends on the latitude: as it is well known, it increases when it gets closer to the equator. In Italy mean annual solar radiation ranges from 3.6 kWh per square metre per day in the Po river plain area, to 4.7 kWh per square metre per day in Central-Southern Italy, to 5.4 kWh per square metre per day in Sicily. In some favourable spots it is possible to collect every year around 2,000 kilowatts for each square metre, which corresponds to 1.5 barrels of oil for a square metre.

A bit of history

Mankind has always known what happens when a sunray hits a body. If this is light-coloured or is a mirror, the energy of the sun is reflected. If it is dark-coloured, the sun's radiation is absorbed and the body heats up. The first solar collector is based on this principle. It was invented in 1767 by the Swiss Horace de Saussure: a "black pot" used by the first American pioneers to heat water and cook while they were travelling west. In 1891, Clarence Kemp patented the first solar energy water heater. It was a success, but human beings already knew cheaper and easier ways to heat water. Only after 80 years, following the energy crisis of 1973 and the consequent increase in the oil prices, did Kemp's water heater develop into a more modern form, becoming the solar panel that today is enjoying growing success. Besides the thermal effect, human beings recently learned how to exploit the electromagnetic effect of the sun's radiation. The problem is converting sunrays into electric energy by means of ad hoc devices. The process, known as photovoltaic conversion or photovoltaic effect, was discovered in 1839 by the physicist Bequerel, but its first commercial implementation took place only in 1954 in the U.S., when the Bell laboratories developed the first photovoltaic cell in single-crystal silicon, reaching a 6% efficiency. The first steps of the photovoltaic conversion took place in the semiconductor and IT sectors. The first of such implementations dates back to 1958. Today the main implementations take place on earth and the industrial production of photovoltaic cells has increased from the 1960s to date, with the consequent impact on production prices. Remarkable efficiency was achieved, up to 10-13%, which may render the exploitation of solar energy to produce electricity increasingly competitive. Remarkable yields, of up to 20%, have been obtained, which will make exploitation of solar energy increasingly competitive, for the production of electricity. This means that if the solar energy that strikes a photovoltaic panel is 100, the panel will transform 20% of this energy into useful energy, more specifically into electric energy.

Some figures: worldwide

Photovoltaic capacity installed in the world in 2015 reached 227 GW, due to 50 GW installed during the year. In 2015, Italy held the 5th place for installed power, after China, Germany and in front of the USA. In analyzing the data, the extension of the various States being compared must be born in mind, and it is significant that a small country like Italy can compete with a giant like China and the USA.

If we analyze the data of the different geographic areas of the world, it can be observed that Europe has always been a pioneer in this sector, and it now has the leading position, with the greatest amount of installed power amounting to 95 GW (42% of the world's installed power) versus 25.6 GW in the USA. Due to this difference, it is quite probable that Europe will continue for a long time to be a leader in the photovoltaic sector. Japan is one of the countries that are emerging in this field, and starting from 2007-2008 there have been significant increases also in the rest of the world.

With regard to solar thermal power, the technologies used to heat water with the help of solar energy are spreading to many countries: China, USA, Turkey and Germany have been the protagonist countries in the solar thermal market in 2015. In particular in 2015, China increased its solar thermal capacity and reached 71% of global capacity. In 2015, 21 thermal Gigawatts (GWth) were installed around the world and the total installed power reached 456 (GW_{th}).

(*Source: Renewables 2016 Global Status Report*)

Some figures in Italy

Italy is the country of sunshine, not only in its popular songs and in the image of Italy that all the tourists have, but also from the point of view of energy. In Italy, mean annual solar radiation ranges from 3.6 kWh per square metre per day in the Po river plain area, to 4.7 kWh per square metre per day in Central-Southern Italy, to 5.4 kWh per square metre per day in Sicily: as a consequence some regions have a very high production potential, even though the entire national territory actually has very favourable conditions for the installation of solar energy production plants. Italy is one of the leading countries for the production of solar energy, and it is in the vanguard also in the sector of research and technological innovation.

Starting from 2007, the year in which a boom in solar energy was recorded in Italy, growth has never stopped. In 2015 in fact, a 1.6% increase in installed power, compared to 2014, was recorded. According to GSE – Gestore dei Servizi Energetici (the Italian company for electric services) there were 688,398 solar power plants operating in Italy in 2015 (+6.2% compared to 2014) with an installed power equal to 18,892 MW.

In particular, out of the 688,398 plants, the 58% has power ranging from 3 to 20 kW. In 2015, the small sized plants (<3 kW) were 192,252, with an installed power equal to **627** MW. The average sized plants, from 20 kW and 1 MW, reached 10,566 units, for a total installed capacity amounted to 7,266 MW, while the large plants, with power over 1 MW, reached 1,127 units, for a total installed capacity amounted to 4,126 MW.

In 2015, the Lombardy region was reconfirmed in the leading position for the number of plants (101,403 units) followed by the Veneto region (93,168 units) and the Emilia Romagna region (56,951 units). The regions that showed the greatest growth rates in terms of number of plants, were the Liguria region (+8.8%) and the Lazio and Emilia Romagna region (+8.3%). In terms of power, instead, the leading region is the Puglia region (2,600 MW), followed by the Lombardy region (2,109 MW) and the Emilia Romagna region (1,898 MW). The most relevant variations, compared to the previous year, with regard to the installed power were recorded in the Liguria region (+5.4%) and in Campania (+2.9%). (NOTE: the largest number of photovoltaic plants recorded in the Northern and Central regions is to be attributed to the high

density of the inhabitants in these regions).
44% of the installed capacity is in the North, 37% is in the South, and 19% is in the Central part of Italy. In particular the Puglia region, with 13.8% has the largest amount of installed power, followed by Lombardy (11.2%) and Emilia Romagna (10%). The map of the provinces showing the percentage distribution of the power, highlights the substantial contribution of some Provinces in the North: Cuneo, Brescia, Ravenna and Turin with 2.9%, 2.2% and 2% respectively of the total 18,892 MW. In Southern Italy, Lecce with 3.6% supplies the largest amounts on a national scale. In the Regions in Central Italy, the provinces that stand out are Rome and Viterbo with 2.2% and 2% respectively.
However, an analysis of the numbers, alone, is not sufficient to illustrate the photovoltaic sector in Italy and to identify the more "virtuous" and "sunny" regions. Observing the data, we must bear in mind the population density in the regions, which is very high in Lombardy and very low in regions such as Trentino Alto Adige, Valle d'Aosta, Basilicata and Molise.
GSE periodically publishes the data of the photovoltaic plants in Italy and an atlas which indicates all the photovoltaic power plants in Italy (ATLASOLE).
(Source: GSE, Rapporto statistico "Energia da Fonti Rinnovabili in Italia – 2015")

Energy production

Solar systems

The definition passive solar systems refers to the systems in which solar energy is used directly. For example greenhouses are glass structures that allow the Sun to enter, but do not let the heat escape. In this way they are able to maintain temperatures inside the structure that are higher than those outside. Then there are the solar distillers, in which in a closed space, covered by transparent panels that are exposed to the Sun, sea water evaporates and condenses and forms water that has no salts, and therefore that can be reutilised.
In the active solar systems instead, solar energy is collected and transformed into thermal or electric energy before it is utilized. This type of system includes solar thermal power systems, solar concentrator systems used for the production of thermal energy and solar photovoltaic panels for the production of electric energy. The best technologies also enable the cogeneration of different types of energy, and it is possible to accumulate thermal energy in many ways and for different uses.

Thermal solar panels

Solar panels catch the energy of the sun and use it to produce hot water (up to 60/70°C) which collected in an ad hoc tank, can be used both for household (i.e. for household and water heating) and industrial purposes, as well as for the production of electric energy on a large scale through thermoelectric solar plants.

- Plate panels
- Concentration collectors
- Vacuum-pipe collectors

Plate panels

A solar panel system includes two elements: the actual solar panel and the accumulation tank. The first includes a solar heat accumulator, i.e. a steel or copper panel crossed by the pipes in which the fluid to be heated by the sun flows: generally antifreeze is added to the water in order to tolerate winter temperature. Above the absorber there is a glass panel that lets the incoming sunrays in but does not them out, so that the environment underneath remains hot. The tank includes a heat exchanger that allows the transmission of the heat from the heated liquid inside the absorber to the water of the house hydraulic system. Thermal solar panels are installed in a fixed position, if possible south-oriented, in order to receive the maximum amount of radiation. A square metre of solar collector can heat between 40 and 300 litres of water every day, at 45-60 degrees. The efficiency varies according to climatic conditions and the type of collector by 30-80%. Efficiency ranges from 30% to 80% depending on the climatic conditions and the type of collector. The yield of the solar panels has increased about 30% in the past decade. This means that if the energy from the Sun is equal to 100, the useful energy supplied by a solar panel is equal to 30.

Concentration collectors

Concentration collectors are thermal solar panels that use a mirror system that reflects the sunrays and makes them concentrate on a receiver. Collectors can be linear, when they concentrate sunrays on a segment of a straight line, or they can concentrate sunrays on a single point, heating the out-flowing fluid of the panel at more than 100°C. The thermal energy produced can be directly sent to the users.
Or the heat produced by the various solar concentrators can activate the motors that are activated by the heat at a medium-high temperature (i.e. to pump water or other mechanic applications).
The thermal energy can also be transformed into electric energy thanks to solar thermoelectric power plants. In those plants, the thermal energy captured by the collectors is used to transform water into steam which, in its turn, operates a turbine connected to an electric energy generator (see image). These power plants are environmentally friendly, with a very limited environmental impact as compared to fossil fuels plants, since the only substance to be emitted into the atmosphere is steam.

Vacuum-pipe collectors

Some thermal solar panels are called vacuum-pipe collectors as they are made of special glass vacuum pipes, covered by a layer that transforms the sun light into heat. In this case the heat absorber has a round shape and is hosted inside the pipe vacuum cavity: in this way the fluid that carries the heat evaporates, and by transmitting the heat to the top part of the pipe, it condenses and goes back to the bottom. Differently from plate panels, this type of vacuum collectors does not carry the heat (as air is the best insulator), therefore there is no loss and its performance is higher. These collectors need a smaller exposure surface with respect to the other panels and are able to retain the accumulated heat also in very tough weather conditions, guaranteeing a high and constant performance during the whole year. For these reasons they can be used also with a medium-low sun or under particularly tough weather conditions in winter, like on high mountains or in northern countries.

Thermo-solar energy accumulators

Just like the other renewable sources, solar energy is not constantly available. As a consequence, accumulation systems are extremely important for the evolution and development of technologies.
The energy produced by thermo-solar plants does not have to be limited to sunny hours nor have to be hampered by clouds. For this reason, two techniques have been tested. They also allow a better use of the installation and therefore a lower cost for the production of electric energy:

- accumulation of thermal energy: the heat is used to warm a medium from which, on a specific moment, heat is extracted to produce electric energy. These devices are quite cheap, highly efficient and allow to keep the installation working during peak periods and night hours. They also have the advantage to eliminate, in many cases, fluctuations due to clouds.
- Solar-methane hybrid systems: during prolonged periods where solar heat is absent, the methane can provide the missing energy, with a reduction of costs. A hybrid system can be economically convenient also for the supply of modest solar power.

Photovoltaic solar panels

Photovoltaic technology allows the direct transformation of solar energy into electric energy by exploiting the photovoltaic effect.
The photovoltaic effect is based on the characteristics of certain semiconductor materials such as silicon which, after being ad hoc processed, generates electric energy after being hit by the solar radiation.
Photovoltaic cells are the most basic device capable of carrying out the conversion. Each cell produces around 1.5 watts in standard conditions, i.e. the temperature is 25 °C and it is subject to a radiation power of 100 watts per square meter. The outgoing power in standard conditions is called “peak power” (Wp): it expresses the electric power supplied by a photovoltaic generator with 1,000 watt/square meter irradiation, 25°C system temperature and 1.5 air mass. Actually the electric energy produced is lower than the peak value due to higher temperatures and the lower values of the irradiation. Many cells assembled and connected together into a single structure form a photovoltaic module. The traditional module is made up of 36 cells, with an outgoing power of 50 watts, but at the moment, especially due to architectonic needs, modules with a higher number of cells can be bought, reaching a power of up to 200 watts for each system. In order to increase the electric power it is necessary to connect different modules: several modules form a panel, and several panels form a string.

Solar plants

Thermoelectric solar plants

Solar towers
Concentration collectors include solar towers, which consist of a system of mirrors (called heliostats) that follows the movement of the Sun and that reflects the solar energy on a receptor located on the top of a central tower. The solar heat is collected by a fluid (a melted salt) that has the task to accumulate energy. With the heat accumulated on melted salts, vapour is produced (565°C), in order to make an electric turbo-generator turn (see image).
Linear parabolic mirrors
Linear parabolic mirrors are called SEGS (Solar Electric Generating System): they are used to concentrate sunrays on a long receiving pipe positioned on the concentrator line. A heat-carrier, i.e. oil, pumped by receiving pipes, supplies a plant. The solar heat is transformed into vapour in order to activate an electric turbo-generator. The typical operational temperature is 390 °C. These installations today work with 30-80 electric megawatts and also burn a certain quantity of fossil fuel (sometimes natural gas) in order to produce energy when the solar energy is not sufficient.

Photovoltaic plants

The photovoltaic system includes different mechanical, electrical and electronic components that attract the solar energy, transform it into electric energy until the user can use it.
There are two types of photovoltaic systems: the systems with accumulation and those without accumulation. The former are equipped with lead batteries to accumulate electric energy while the sun shines and use it when the sun is not present.

Solar systems

These systems are not connected to the national electric network and directly supply some equipment. They also have a battery system that guarantees the supply of power even during poor light hours or in the dark. These systems are technically and economically advantageous in those cases where the electric network is absent or difficult to reach. They are particularly popular in developing countries for rural users who also employ them to pump water. In Italy many photovoltaic systems have been created in order to produce electric power in rural and mountain areas, especially in the

South of Italy, on the islands and on the Alps.
At the moment the most spread devices are used to supply:

- equipment for water pumping
- radio relays, survey stations and data transmission centres (weather and seismic), telephone sets
- refrigeration systems, especially for the transport of medicines
- lighting systems
- road, port and airport signs
- supply of utilities on camper vans
- advertising systems, etc.

Systems connected to a network

These systems are permanently connected to the national electric grid. When the photovoltaic generator is not able to produce the electric energy needed to satisfy the demand for electricity, the network provides the requested energy. Instead, if the photovoltaic system produces more energy than needed, the surplus is transferred to the network. These systems do not need any battery, as the distribution network supplies electric power when solar irradiation is absent.
Centralized plants for the production of high-power photovoltaic electric energy have been built. Among the most important solar plants in Italy mention has to be made of the ENEL plant in Serre, near Salerno. It started operating in 1994 and it is the largest plant in Europe, covering a total surface of 7 hectares, with a 3.3 MW power and an annual output amounting to 3,6 million kWh.
Actually at the moment small systems are becoming more and more important, especially thanks to state incentives that do not exceed 20 kilowatts (peak power). The most popular plants have 1.5-3 kilowatt power. These plants are installed on building roofs or fronts and contribute to satisfy the users' demand for electric power.

Installations integrated in buildings

They are among the most promising applications of photovoltaic systems. These systems are installed on civil or industrial buildings in order to be connected to the national electric network. The power generated by photovoltaic modules is supplied to the internal network of the user building and, at the same time, to the public distribution network. In this way, according to the needs, it can be used by local users or supplied to the network.
Photovoltaic modules can be used to cover buildings as a replacement of traditional components. With this objective, the photovoltaic and the building industry have created some architectonic modules that can be integrated with the building structure. They are more and more used on building fronts and to cover buildings. The possibility to integrate photovoltaic modules into architectures and transform them into building components has widened the range of application of the photovoltaic and architectural sector, that exploit this type of energy.
A particularly interesting use consists of "photovoltaic fronts". The modules for each front are made up of two glass sheets with silicon cells between them, and connected by resin sheets.
The dimension of these modules can vary from 50x50 cm to 210x350 cm. Moreover, as the lower is the temperature of photovoltaic modules during solar irradiation, the higher the energy performance, photovoltaic fronts can be better used on "cold" areas of building fronts (parapets, lifts, and other matt surfaces) provided they are oriented towards the South-East or South-West and are not located on shady areas.
The use of photovoltaic modules can be extremely useful as sun-blinds or to create shade on wide areas if they be used as a cover, i.e. as a cover for bus shelters.

Where to position a plant

In order to obtain the maximum energy production, when designing a plant, it is necessary to study the area irradiation and the sun exposure. In this way it will be possible to make decisions on the inclination and orientation of the receiving device.
Considering the latitude of our Country, the best position for the panel surface is on top of the building, oriented towards the South and with an inclination angle of 20-30°C with respect to the horizontal plane. But the front covering gets very good results, too. It is obviously very important to position the panel in order to avoid any shade area.

Thermo-photovoltaic systems

Thermo-photovoltaic co-generation systems include thermo-solar technologies for the production of hot and cold water and thermo-solar systems for the production of electric energy.
An example of these systems are those panels where a thermo-solar collectors and photovoltaic cells are integrated and where the primary energy is the direct solar energy. It is a very interesting system, especially when the thermal fluid is able to regulate the temperature of photovoltaic cells, which are usually more efficient at 20-25°C. A solar thermo-photovoltaic panel is able to produce the same quantity of hot water as a traditional panel, as well as being able to supply 175 watts of electric power on a sunny day.

Thermodynamic solar power

In the thermodynamic solar power process, electric power is obtained by using solar energy to heat water, which is then transformed into steam, which in turn moves the turbines analogously to the traditional thermoelectric power plants. In this case, combustion of fossil fuels to produce steam is not required, the energy to heat the water comes directly from the sun. Since the power plant operates at high temperatures, obviously, standard solar heating panels cannot be used, but particular devices are required to concentrate solar energy in precise restricted points, so that the required high temperatures are reached, similarly to when one wants to light a fire with a magnifying glass and a ray of sunlight! The intermediary is a fluid known as the “thermovector” which has an excellent heat-exchange capacity. The thermovector receives solar energy transformed into thermal energy that it then releases in the water, which, converted into steam, activates the turbines of the power plant producing electric energy. Many of the large power plants that are currently being designed all over the world are of this type. The advantages, when compared with the production of energy using the photovoltaic method, are a greater yield and a smaller surface area occupied by the power plant.
Research in this field is aimed at improving the technologies and the structures to concentrate the solar energy, and studies are carried out to find the best arrangements of the various elements.
As a consequence, power plants of various types have been developed:

- power plants with a field of mirrors and a central tower (Solar Tower), where solar radiation is concentrated by means of concave mirrors, known as heliostats, on a receiver on top of a tower, that is about a hundred metres high: here the thermovector fluid is heated to temperatures reaching hundreds of degrees, which then feeds a traditional thermodynamic cycle for the production of energy. The heliostats rotate so that the amount of solar energy that is concentrated on the receiver remains constant;
- power plants with linear parabolic collectors (Parabolic Troughs): in which there is an alignment of linear parabolic mirrors that do not concentrate the radiations in a single point, but on a receiver-tube that is filled with thermovector fluid;
- power plants with a circular parabolic collector or parabolic solar dish (Dish Stirling): a large parabolic mirror, with a diameter of a few meters, that concentrates solar energy onto a collector placed in the focal point of the mirror, where a thermovector gas flows. The thermal energy is transformed into electric energy by means of a

Sirling engine. The parabolic dishes can be connected to one another in clusters of hundreds of units , thus forming solar farms;

- power plants with Fresnel linear collectors: in this case the heliostats are linear and are arranged horizontally near the ground. They reflect the solar radiation onto a receiver-tube that is positioned about ten metres from the ground. Of all the systems, the Fresnel reflectors are those with the lowest costs.

Environment and territory

Benefits of solar energy

The solar energy does not make any noise, does not pollute and allows to obtain a hot fluid that can be used as sanitary hot water, for heating, or for different industrial tasks.
The environmental benefits that derive from the installation of photovoltaic systems can be expressed in terms of avoided emissions: the emissions that would have been produced for the generation of an equal quantity of electric power with thermoelectric systems can be calculated.
For example it was estimated that a family of four people consumes around 7.7 kWh a day with an electric water heater. In Italy, to produce an electric kWh, thermoelectric plants release into the atmosphere around 0.58 kg of carbon dioxide, one of the main greenhouse effect gases. Therefore, for an electric water heater 4.5 kg of CO_2 are produced on average every day. With hybrid solar-gas plants, i.e. solar plants integrated with gas boilers, that ensure hot water all year long, a four-members family in Rome can save up to 0.69 kg of CO_2 a day.
Therefore solar energy could significantly reduce the use of fossil fuels, since it would be an electric energy source on a large scale, in particular in Italy, where irradiation levels are high. Directly converting the sun into electric energy is a choice that can be extremely advantageous not only in urban settlements, but also in marginalized and remote areas, especially in the Third World. In those areas the combination of photovoltaic systems with other existing renewable sources can bring electric energy to the most isolated villages and communities, to guarantee lighting, telecommunications, pumps, but also to desalinate seawater and brackish water, to preserve fishing and agricultural products, and to refrigerate drugs and vaccines.

Power density of solar energy

In less than an hour, the Earth receives an amount of energy from the Sun that is equal to the world consumption for a year. Solar energy, unlike the other sources of energy , is present in all over the planet (with some differences depending on the latitude) and it is a source that will accompany us for billions of years more. Solar energy, therefore, besides being abundant and well distributed, is also a renewable resource. These characteristics would make the Sun the principal source of energy, only that solar energy has a low power and is intermittent on a local scale. In fact the flow of energy from the Sun depends on the alternating day and night and the variable meteorological conditions.
Not much power from a great energy
A very useful parameter in order to evaluate how much the energy is worth is the power density, also known as radiance, that indicates the solar radiation per surface unit (Watt per square metre W/sq.m). The amount of solar energy that reaches the Earth's surface, after subtracting all the reflections and absorptions that take place in the atmosphere, is equal to 85,000 billion W. Knowing that the Earth's surface is equal to 5.1 billion sq. km, the result is that every square metre of the Earth's surface, receives an energy of approximately 170 W/sq.m. This value decreases remarkably when it is converted into power that can be utilized. The present lifestyles in the industrialized Countries require a power density that ranges from 20 to 100 W/sq.m for homes, to 300 to 900 W/sq.m. for steel industries. It is evident that with the current solar technology it is not possible to make most of the large structures which have a high energy demand, such as the industries and the hospitals, work. The principal technological challenge of our days is to succeed in storing the immense energy that comes from the Sun and make it available at the right intensity where there is a demand for energy.

Impact on the landscape

The environmental impact of a solar power plant must be evaluated considering the entire life cycle and in particular the building stages of the plant, the stage in which the plant is set up and produces energy, and finally the stage when it is no longer used. The impact that derives from the construction of a photovoltaic plant can be compared to the impact generated by the production of any product of a chemical industry. During the manufacture of the panels, in fact, very toxic substances are used, which require particular safety measures in order to protect the workers, the environment and the people living in it. The products that are used vary, depending on the types of panels. For crystalline silicon panels, hydrochloric acid and trichlorosilane are used, while for amorphous silicon panels, silane phosphate and diborane are used. The substances that are used for the panels that are not made with silicon are even more toxic and polluting than the ones mentioned above. For example to produce the CIS (copper indium selenium) panels hydrogen selenide is used, while for CdTe (cadmium telluride) panels cadmium is used, which is toxic and cancerogenic, like hydrogen. However the environmental benefits generated during the life-span of a photovoltaic system (average 20-25 years) are already greatly superior to the damage provoked in the production phases of the panels.

When plant operation comes to a stop, the panels must be treated as special waste, as they contain numerous toxic substances such as lead, cadmium, copper, selenium etc. With regard to the plant operation, the only impact is on the landscape, that varies depending of the type, the extension and the position of the plants. Photovoltaic parks are remarkably large plants, which are usually installed on ground in large open areas, thus subtracting the territory from other uses. The visual impact of photovoltaic power plants is however less than that of thermoelectric plants or any other large industrial plant. This is essentially due to the fact that the plants are much lower than an industrial plant. The visual impact of small and medium sized plants is surely less than that of a large plant and with some adaptations the photovoltaic and solar panels can be fitted well into the landscape. However the compatibility of the landscape for each plant must be evaluated. For example the use of photovoltaic panels should be limited in cities of artistic importance, in the historical town centres and in areas with a high naturalistic value. Instead, the marginal areas that are not used should be exploited, such as the roofs of hangars, or areas that must be reclaimed, or installation of panels on the roofs of houses in the urban areas. The architectural integration of the photovoltaic plants in the buildings allows a remarkable reduction of their visual impact. In fact a plant is considered integrated when the photovoltaic modules become structural elements of the building itself, as for example roofs, facades, windows, etc. In this way the photovoltaic panel, from an external element becomes an integral part of the building.