

Solar energy

Introduction

In our Country (Italy) mean annual solar radiation ranges from 3.6 kW per square metre in the Po river plain area, to 4.7 kW in Central-Southern Italy, to 5.4 kW 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.

2007 was the year of the solar energy boom in our Country, a 500% increase was recorded in total installed power compared to 2006, and a further 429% increase was recorded between 2007 and 2008, with a total of installed power that increased from 78 to 418 MW. In 2010 in Italy there were 155,977 solar power plants, with an installed capacity of 3,470 MW. So between 2009 and 2010 the number of photovoltaic installations grew by 119%, while the installed capacity of 203%.

(Source: *Solare fotovoltaico - Rapporto statistico 2010, GSE 2011*)

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 infinitesimal 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. This energy is absorbed by the atmosphere and the Earth's surface and transforms into wind, hydraulic and chemical energy.

Any form of life on the Earth exists thanks to the energy sent by the Sun. 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 kW/h 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/square metre). 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 the average annual irradiation varies from 3.6 kW/square metre in the plain of the Po river to 4.7 kW/square metre in the Centre-South of Italy, to 5.4 kW/square metre 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.

Some figures: worldwide

Italy is in the 4th position among the major producers of solar energy after Germany, Spain, Japan and the USA (*Renewables 2011 Global Status Report*). When analyzing the data, it is necessary to bear in mind the extension of the various Countries that are compared – It is significant that a Country as small as Italy can compete with a giant like the USA.

If we analyze the data of the various geographical areas in the world, it can be seen how Europe has always had a pioneering role in this field, and at present it is the leader with the largest amount of power installed, with 13.3 GW (80% of the installed power on a world scale), versus 9% in Japan and 6.2% in the USA. And in view of this difference in the percentages, it is quite probable that Europe shall continue for a long time to have the role of leader in the photovoltaic sector. Japan is one of the emerging Countries in this field, and in the two year-period, 2007-2008, significant increases can be seen also in the rest of the world. As for the thermal solar, technologies to heat water by solar energy are spreading in many countries. China, Germany, Turkey, India and Australia were the protagonists of the solar thermal market in 2009. In particular, in 2009, China has increased the capacity of solar heat by 80% over the previous year. In 2010 were installed 25 gigawatt thermal (GWth) around the world and the total installed capacity has reached 185 GWth.

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 radiation ranges from 3.6 kW per m² in the Po river plain, to 4.7 kW in Central and Southern Italy, and to 5.4 kW 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.

2007 was the year of the solar energy boom in Italy and solar energy growth has continued in the following years. In fact, in 2010 there was an increase of 203% of installed capacity compared to 2009. According to the Italian Electricity Service Company (Gestore dei Servizi Elettrici - GSE), there are 155,977 power plants connected to the electricity network in Italy (+119% compared to 2009) with an installed power of 3,470 MW.

In 2010 Lombardy was the leading region for installed photovoltaic power plants with 23,274 solar plants, followed by the Veneto region with 20,336 power plants and the Emilia Romagna region with 14,486 power plants, while the region with the most installed power is Puglia (683 MW), followed by Lombardy (372 MW) and Emilia Romagna (364 MW). The provinces with the greatest amount of power installed are Ravenna, Cuneo and Bolzano in the North of Italy, while Lecce, and Brindisi in the South, Viterbo and Rome in the Centre.

In 2010, electricity generation by PV plants in Italy reached 1,905 GWh, up by 182% from 2009. The region with the highest generation in 2010 was Puglia with 412 GWh (22% of the national total), followed at distance by Lombardia with 190 GWh (10% of the total). Emilia Romagna and Lazio produced 153 GWh and 152 GWh, respectively, each with an

8% share of the national value.

(Source: *Impianti a fonti rinnovabili - Rapporto statistico 2010, GSE 2011*)

Energy production

Solar systems

Passive solar systems

Passive solar systems are those where the solar energy is used directly. For example, greenhouses are glass structures which allow the sunrays to get in, but do not let the heat go out. Thus their inner temperature might be higher than outdoors. Another example is provided by solar stills, in which, in an indoor environment covered by transparent panels exposed to the sun, seawater evaporates, later condensing as salt-free water, which can be used for other purposes.

Attive solar systems

On the other hand, active solar systems collect solar energy and transform it into thermal or electric energy before using it. They include: thermal solar panels; concentration collectors, used to produce thermal energy; fotovoltaic solar panels, used to produce electric energy.

The best technologies make the co-generation of different types of energy possible. It is possible to accumulate thermal energy in several ways and for different aims.

Thermal solar panels

I pannelli solari termici catturano l'energia del Sole e la utilizzano per produrre acqua calda (fino a 60-70 gradi centigradi) 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 let 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%. The performance of solar panels has increased in the last 10 years by 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" (W_p): 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.