SOLAR KNOWLEDGE

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Introduction

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).

What it is

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. 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 10^{12} 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/m^2). 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 2021 reached 942 GW, due to 175 GW installed during the year. In 2020, Italy held the 6th place for installed power, after China, United States, Japan, Germany, India and in front of Australia, Vietnam, South Korea and United Kingdom. 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.

For the ninth consecutive year, Asia dominated all other regions in new solar PV installations, representing 52% of the global added capacity in 2021. It was followed by the Americas (21%), which again surpassed Europe (17%). India was the second largest market in Asia for new solar PV capacity, and third globally. Following two years of contraction, annual solar additions in the country underwent substantial growth in 2021 with an additional 13 GW installed, more than double the amount in 2020 and more than in any previous year, setting a new record.

With regard to solar thermal power, the technologies used to heat water with the help of solar energy are spreading to many countries: China, Turkey, Germany, Brazil and United States have been the protagonist countries in the solar thermal market in 2021. In 2017, 22 thermal Gigawatts (GWth) were installed around the world and the total installed power reached 522 (GW_{th}). (*Source: Renewables 2021 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.

The geographical distribution of Italian photovoltaic installations follows a distinctive pattern compared to other energy sources. The regional and provincial rankings change significantly depending on whether the number of installations or the installed capacity is assessed, since both the average size of the installations and the distribution of solar radiation across the country affect these statistics. Moreover, a lot changes according to whether you look at the overall figures or whether you look at the size of the region or province and population density.

The latest data provided by the Energy Services Operator (GSE), updated to 31 December 2020, were used to get an idea of the distribution of solar photovoltaics in Italy. Starting from the total number of installations and their installed capacity, 935,838 photovoltaic systems had been installed by the end of 2020, with a total capacity of 21,650 MW. During 2020, 55,550 photovoltaic systems were installed in Italy – the vast majority of which were smaller than 20 kW – with a total capacity of 749 MW.

In Italy, use of photovoltaics started in the 1970s: the first system was installed in 1979 at the Mandriola Pass. However, it was not until the 1990s that photovoltaics became more widely used, and this was further facilitated by the first government incentives, known as "Conto Energia", in the 2000s. If we look at the graph on the increase in number and installed capacity of photovoltaic systems in Italy, it can be seen that photovoltaics in Italy started to accelerate at the beginning of this century. What can be observed is the fast initial growth, partly due to the Conto Energia incentives, followed by a consolidation phase starting in 2013, characterised by a more gradual development, due to termination of state subsidies. It should also be noted that the development of photovoltaics received a further boost in 2009, thanks to the European Directive that set the first targets in terms of production and consumption of energy from renewable sources (2009/28/EC).

The distribution of photovoltaic systems by number and installed capacity varies somewhat in Italian regions. At the end of 2020, only two regions accounted for 29.8% of the installations in Italy (Lombardy and Veneto, with 145,531 and 133,687 installations respectively). The national leader in terms of installed capacity is Puglia, with 2,900 MW (13.4% of the national total); this region also has the highest average plant size (53.4 kW). The regions with the lowest number of installations are Basilicata, Molise, Valle D'Aosta and the Autonomous Province of Bolzano.

The installations completed during 2020 did not cause significant changes in the regional distribution of plants. The installed power is concentrated mainly in the northern regions of the country (44.5%), followed by 37.4% in the south, and 18.2% in Central Italy. Puglia made the largest contribution to the national total (13.4%), followed by Lombardy (11.7%) and Emilia Romagna (10.0%). If we consider the number of plants, 55% are installed in the North, 17% in Central Italy and the remaining 28% in the South. The regions with the highest number of systems installed are Lombardy, Veneto, Emilia Romagna and Lazio.
Interestingly, there is no uniformity within individual regions. Indeed, looking at individual provinces, some are particularly unsatisfactory, because installations there account for only 0,1% of the national total, but there are also others whose results are truly excellent, such as Lecce, which alone covers 3.3% of installed photovoltaic power, followed by Cuneo, with 2.7%, and Viterbo and Rome with 2.2% each. Conversely, looking at the provincial map of the number of systems installed, the province of Rome is in the lead with 4.0% of the national total, followed by the provinces of Treviso and Brescia with 3.2%. Of the southern provinces, however, the one with the highest number of plants at the end of 2020 is Lecce (1.8%).
How much photovoltaic energy is produced in Italy. In 2020, the more than 935,000 photovoltaic systems operating in Italy produced a total of 24,942 GWh of electricity. Compared to the previous year, there was a +5.3% increase in production, mainly due to higher solar radiation. An analysis of the monthly trend in 2020 production shows that the highest production occurred in the summer months; July, in particular, was the month with the highest production (just over 3.1 TWh).
Obviously, production is concentrated in the summer months; July, in particular, is the month with the highest production (just over 3.1 TWh). In line with previous years, in 2020 the region with the highest photovoltaic production was Puglia with 3,839 GWh (15.4% of the total 24,942 GWh produced nationwide). Puglia was followed by Lombardy with 2,441 GWh and Emilia Romagna with 2,402 GWh, contributing, respectively, 9.8% and 9.6% of the country's total production. For all Italian regions, positive changes in production were observed in 2020 compared to the previous year; the region with the most significant increase was Sardinia (+16.3% compared to 2019), followed by Veneto (+9.0%) and the Autonomous Provinces of Bolzano and Trento (+8.7% and +8.5%, respectively).
Considering the sectors in which solar energy is used, at the end of 2020 about 81% of installations in operation in Italy were concentrated in the domestic sector; the largest share (51%) of the total installed capacity was in the industrial sector. Looking at 2020 alone, 86% of the systems installed during the year were in the domestic sector; in terms of power, 45% were in the industrial sector.

Environment and territory

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 on 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.

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