Renewable energy is the energy produced by using natural resources that will regenerate in time. Primary sources of renewable energy are water, geothermal heat, wind, and sunlight. The energy produced by using different organic materials, such as wood, agricultural rejects, forestry residues, and urban solid waste (called biomass) is also regarded as “renewable.” According to authoritative international agencies like the United Nations Environment Programme and the Intergovernmental Panel...
on Climate Change, renewable energies represent the most realistic alternative to fossil fuels. At present, renewable sources are employed chiefly in the production of electricity, but also to produce biofuels and to provide heat for industrial and private users. Over the last 10 years, the development of renewable energies has been stimulated by concern over global warming. At this time, it is believed that renewable energy sources will play a key role in limiting greenhouse gases emissions.

**Water**

Hydroelectric energy has represented, and still represents today, the principal source of renewable energy: with reference to the global production of energy, hydroelectric represents 2.15 percent of the total. Concerning the construction of new large-scale hydroelectric plants today, development seems stalled because they require infrastructure (dams, reservoirs, catchment drains) that causes a considerable environmental impact. Although they produce no polluting emissions, they considerably alter the landscape, impair the balance of local ecosystems, and diminish the volume of water available for uses other than energy production. For these reasons, it seems more appropriate to develop hydroelectric plants with less than 10 MW of power production: these are small plants with a low environmental impact that produce energy by utilizing minor streams and river waterfalls. The realization of such small hydroelectric plants creates only modest environmental and technical problems, particularly where the construction of dams is unnecessary, and the cost of the electricity produced more or less equals that of larger plants.

Some countries today are experimenting with new technologies capable of producing power by using energy flows from seawater. Experiments are being conducted to try to exploit tidal power (in France), the energy potential of waves (in the United Kingdom, Norway, and Japan), and the temperature gradient—the difference in temperature that exists between deep and surface waters (in the United States).

**Geothermal**

Geothermic energy is generated by physical processes that occur in deepest layers of the Earth's crust (underground, the temperature rises by 30 degrees Celsius every 1,000 meters of depth). Geothermal heat rises to the Earth's surface, where it can generate a thermal current measuring about 0.065 Watts per square meter. In general, geothermal plants use the following operational procedure: through drilling, the steam produced by the heat of the Earth is brought to the surface and conveyed to pipes that carry it to a turbine, where, by means of a driving shaft, it is turned into mechanical energy, and into electrical power by an alternator. In cases where the geothermal fluid does not reach high temperatures, the required temperatures are reached by using hot water. The resulting heat is used, for example, in district heating plants or by agriculture for heating greenhouses.

With reference to energy production, geothermal energy today represents 0.41 percent of the global total. The principal users of geothermal energy are Iceland, Italy, the United States, Costa Rica, New Zealand, Japan, Kenya, and Ethiopia. From an environmental point of view, the exploitation of the geothermal resource generates carbon dioxide emissions (about 0.2 kg of carbon dioxide per kilowatt hour produced), hydrogen sulfide, ammonia, mercury, and radon.

**Wind**

Wind power—the kinetic energy produced by the wind or the masses of air generated by the uneven heating by the sun of the Earth's surface—is transformed into electrical power by a machine called a wind turbine or windmill. At present, the most common wind turbines are those with a horizontal rotor.
axis set parallel to the direction of the wind. The working of turbines with a horizontal axis is as follows: the blades that make up the rotor are fixed to a hub that connects to a main shaft, rotating at the same angular speed as the rotor. The main shaft is connected to a gearbox, to which a driveshaft is also connected. On the latter there is a brake, and lower down, a power generator, from which electrical cables carry the electricity produced to ground level. Vertical axis turbines also exist; these have a rotor spinning on top of a vertical axis perpendicular to wind direction. These machines have a low rotation speed and modest output, which makes them particularly suitable for mechanical use.

Today, as a rule, wind turbines are installed and connected to the main electricity network, chiefly in the form of multiple installations or “wind farms.” Wind farms are usually installed in places where winds blow at a speed above 5.5 meters per second. Wind farms may be installed on land or offshore; offshore wind farms have important advantages, as offshore winds are more stable and reach higher speeds.

Despite the fact that between the mid-1990s and 2008 wind power represented only 0.2 percent of global energy production, wind power has undergone considerable development, gaining an important share of the market. Between 1996 and 2008, the global cumulative installed capacity has grown by 1,880 percent: in 1996, the global cumulative installed capacity reached 6,100 MW, and in 2008 it reached 120,791 MW. The country with the highest installed capacity is the United States, with 25,170 MW, followed by Germany with 23,903 MW, Spain with 16,754 MW, China with 12,210 MW, and India with 9,645 MW. These five countries possess 72.6 percent of the world's total installed capacity.

The success of wind power—despite the fixed costs of wind plants generally being higher than those of fossil fuels technologies—has been determined by the low variable costs, thanks to low operating costs and the fact that using wind eliminates the need to purchase fossil fuels to produce power. Furthermore, according to the G8 Task Force for Renewable Energy, wind is the energy source with the lowest externalities (costs resulting from the utilization of the plants). The costs of alternate power sources do not fall directly on the producer, but on the community; for example, in the emission of greenhouse gases by hydroelectric plants, or the risk of radioactive leaks in the case of nuclear power plants.

However, although wind power is regarded, along with biomass, as the chief alternative to fossil fuels, wind farms have become one of the main objects of NIMBY protests (the acronym for “Not In My Back Yard,” normally used to indicate public protests aimed against construction of infrastructures of public interest). Among the most famous cases involving wind farms are the constructions in Nantucket Sound in Massachusetts and in County St. Lucie in Florida.

The main concerns with wind farms relate to land seizure, noise, electromagnetic wave diffusion, visual impact on the landscape, interference with birds (the most well-known case is that of birds of prey killed by wind turbines in Altamont Pass, California), and in the case of off-shore power plants, concerns over sea life. Studies carried out so far, however, have somewhat reduced alarm by some in the environmentalist movement.

Over the few last years, “small wind systems” have begun to take shape with the support of environmentalist associations. These are power-generating systems that use turbines less than 30 meters high. These plants are quite common in Great Britain, where, from the early 1990s, they have been supported by the British Wind Energy Association. Compared with the large-scale wind farms, the “small wind system” is easier to integrate into the landscape. These farms may make it possible to
create a self-sufficient network: a string of bioenergetic firms and districts that use a portion of the energy produced and trade a portion on the network, with investment returns possible in just a few years.

Solar

Solar energy, the energy radiating from the sun, can be harnessed to obtain electrical power or heat. At present there are three main technologies employed in the exploitation of solar energy: photovoltaic cells, solar thermodynamic systems, and solar thermal systems. Photovoltaic cells exploit the photovoltaic effect; in other words, the property that some materials have to generate electrical power when directly hit by rays of the sun. The photovoltaic cell constitutes the base element of the process transforming solar radiation into electrical power: assembled cells make a photovoltaic module, which is generally made up of 36 cells, each of them producing around 40 to 50 watts of power. When a number of modules are assembled as a single structure, it becomes a solar photovoltaic panel.

Solar thermodynamic systems instead exploit sunlight to produce electricity from the energy released by heated fluids at a high temperature (about 400 degrees Celsius). This method is the most competitive solar system because it can be put into operation quickly and is the most flexible. At this time, there are three types of solar thermodynamic systems: parabolic dish, parabolic trough, and solar tower. Parabolic dishes concentrate the energy of the sun on a tube placed in the focal line of the collector. Carrier fluid runs inside of the tube, which heats up and transfers its heat to a heat exchanger. The parabolic trough uses concave, dish-shaped reflecting parabolic mirrors to concentrate light on a receiving system placed at the focal point of the dish. Solar towers use a series of mirrors that follow the movement of the sun and reflect the sun's light onto a heat exchanger placed on top of a tower. Thermodynamic solar technologies have been developed chiefly in California, where between the 1980s and 1990s solar power plants were created with a capacity of 350 MW. Recently, a 64-MW thermodynamic solar power plant has been built in Nevada, and two additional solar power plants are being researched in the state of Florida and in Spain.

Solar thermal systems are employed for heating water destined for air-operating domestic heating systems. Solar thermal systems absorb heat through a solar manifold, transferring it to a collecting or using place by means of a fluid carrier (usually water or air). Nowadays, solar energy represents about 0.16 percent of global energy production.

Among the different solar technologies, the one that has scored real success in recent years has been the photovoltaic system. The global installed capacity of photovoltaic systems has risen from 1,200 MW in 2000 to 9,200 MW in 2007—an increase of 667 percent. In 2007, 85 percent of photovoltaic plants could be found in Europe, North America, and the Pacific. In particular, 73 percent of the market was concentrated in Europe, where the photovoltaic system has been promoted by German and Spanish investment. The country with the highest installed capacity is Germany, with 3,800 MW, followed by Japan with 1,935 MW, the United States with 814 MW, and Spain with 632 MW.

According to the European Photovoltaic Industry Association, in the next few decades the photovoltaic market will be dominated by Asia, Africa, and South-Central America; the developing countries, therefore, will be able not only to catch up but also to become the exemplary market for what concerns photovoltaic energy. China in particular will take up the role of leader, with investments that will double the European. Already today, there is a city in China—Rizhao—that can be defined as “a solar energy city.” In Rizhao, in fact, solar thermal systems provide hot water to 99 percent of the families who
reside in the central districts and to 30 percent of those residing in the outskirts. In total, there are 500,000 square meters of solar collectors in Rizhao.

From an environmental point of view, solar energy is, together with wind energy, the energy source with the least negative externalities. During their life cycle (25-30 years), solar plants do not cause risks to the natural environment or to human health. The only negative aspects concerning their use may be represented by the seizure of land (in the case of solar plants) and by the possible alteration of the urban landscape (photovoltaic plants being placed on roofs or on facades of residential buildings). The main environmental impact occurs during the production of panels when toxic substances such as silane, phosphine, diborane, and cadmium are employed. In addition, panels produce a special type of waste, the disposal of which necessitates the recovery of the above-mentioned toxic metals.

**Biomass**

Concerning biomass—organic materials employed to produce energy—wood, woodworking residue, agricultural discards, and the by-products of processing agricultural and industrial products (such as marc or oil-pressing residue) are mainly used to generate power. Also used as biomass is the biogas obtained through anaerobic fermentation of urban solid waste. At present, biomasses (including biogas that is produced by the anaerobic fermentation of organic substances contained in urban waste and waste from animal farms, essentially comprising methane and carbon dioxide) are the most used renewable source in the global production of energy (10.46 percent of the total). This figure is largely because in many developing countries, firewood is still the cheapest fuel and the easiest to get.

In developed countries, wood scrap constitutes 50 percent of the biomass employed in the production of energy. In the United States, for example, 10,000 MW of electricity are derived from the combustion of forest-clearing scrap, and the city of St. Paul, Minnesota, uses a teleheating plant that uses 250,000 tons of wood materials in place of coal, with a reduction of carbon dioxide emissions of 76,000 tons per year. In Europe—where electricity derived from biomass represents 2.4 percent of the total production of electricity—Finland and Sweden are the leading countries in the use of wood scrap, whereas France, Germany, and Austria are the leading countries in producing electricity from burning of urban solid waste.

The use of biomass for the production of energy is curtailed by problems. First, biomass is not always available: one only has to think of seasonal harvests (such as corn) that are only available at a certain time of the year. Second, to have the availability of sufficient quantities of biomass to fuel large plants for the production of electricity, vast agricultural areas would need to be diverted from cultivating food crops: to fuel an electrical plant producing 2,500 MW, it would be necessary to devote about 5,000 square miles of agricultural area to the cultivation of biomass. Third, a forced production of biomass on a large scale (short rotation forestry) would cause environmental problems that have yet to be fully assessed.

From an environmental point of view, the use of biomass would have a more serious impact than that of photovoltaic and wind plants because of emissions deriving from cultivation, cutting, transportation, and combustion activities that, albeit in reduced quantities, would produce nitrogen dioxide.

At present, the chief biofuels are biodiesel and bioethanol. The former is derived by the esterification of rapeseed and sunflower oils. The latter is obtained mainly from sugar cane, corn, and beetroot, through a process of fermentation and esterification. The use of edible vegetables to produce biofuels...
might upset food markets, as is already the case with corn. In addition, forests and grazing land converted to biofuel cultivation might contribute to carbon dioxide emission. (It is believed that the production of biofuels may generate an increase of from 17 to 420 times the annual quantity of carbon dioxide emissions than what might be saved by replacing fossil fuels.)

To avoid such problems, second-generation biofuels are being tested. An example is the production of bioethanol from a hybrid variety of *Miscanthus sinensis* (Japanese silver grass), *Miscanthus giganteus*. It is a grain grass that grows up to 13 feet tall with a very high potential return—equal to 60 tons of dry material per hectare, which is equal to around 60 barrels of oil.

**See Also:**
Carbon Footprints, District Energy, Energy Efficiency, Green Energy, NIMBY

**Further Readings**


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