Renewable Energy Sector

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1 Introduction

Some renewable energy sources have been used by humanity from the beginning of its existence, especially biomass, solar energy, wind energy, and hydraulic energy. We can find some examples for the traditional use of energy resources in sailing, in the windmills and watermills, or in the constructive dispositions of buildings to harness the solar power. However, the invention of the steam engine, at a time when there was no concern about the depletion of natural resources, supposed the end of these energetic uses.

Nevertheless, in the decade of the 70s, renewable energies had an upturn as an alternative to fossil fuels. Besides, the concern about the limited quantity of fossil fuels and their environmental impact, together with the energetic crisis of this decade, led to the appreciation of the renewable energies potential by both governments and researchers, in order to support the energetic demand.

This chapter contains a review of the historic evolution of each technology, from their rudimentary use in the past until nowadays. It also analyzes the improvement and the future potentialities of each kind of energy production.

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2 Solar Thermal Energy

2.1 Low and Medium/High Solar Thermal Energy

At this point we are focusing on the historic development and the improvement in the efficiency of the current technology, used commercially for heating fluids up to low (<100 °C) and medium temperature (100 °C < T < 300 °C): the solar collectors.

It is difficult to specify exactly at what point humans started to harness the solar thermal energy to heat fluids, unlike the photovoltaic solar energy of which we actually know the date of discovery. We can say that solar thermal energy has always been used, to a greater or lesser degree. However, we can know exactly when this technology started to be developed for that purpose and to improve the efficiency of these processes has been improved.

The design of the first solar collector was found in 1767, when Horace de Saussure, a Swiss naturist, invented the self-named "hot box", comprising a box with its inside colored in black and insulation in all its walls, with the exception of the superior face that was made of glass. This device made it possible to achieve temperatures up to 109 °C. However, it was not until 1891 that the first patent of this invention was made, the water heater Climax, capable of heating water with solar power in an efficient enough way to ensure a wide use, especially in the sunny regions of the U.S.A. Later in 1909, an independent accumulation device was included into the design to allow the storage of the heat overnight, constituting the first thermosiphon system.

Unfortunately, the discovery of fossil fuels and the fall in prices of their production stopped the development of solar technology which, just like the other renewable energies, peaked coinciding with the subsequent energy crisis. It can be affirmed that the 70s' energy crisis marked a turning point in the evolution of the water heating technologies by solar power.

However, although the crisis was overcome and the prices of fossil fuels were controlled, the investment and development of new solar energy technologies continued, but in a slower way. Thus, this time the technological development was not suspended again.

Below, the most extensive technological solutions for fluid heating by solar energy at low, medium, and high temperatures are shown.

2.1.1 Low Temperature Systems

Flat Plate Collector

This kind of device is primarily used worldwide. Its technological development can be considered as optimal, but the research in this field is currently looking for new materials which could improve its efficiency, by providing better properties such a better heat insulation, an increase of greenhouse effect by using glass materials, a better design in the regulation and control systems, or by reducing the manufacturing costs.

The evolution of the solar collectors yield has been historically bonded to their market growth. This affirmation can be supported by two facts: the evolution from a craftsmanship to a mass production, causing a cost reduction and the application of quality systems; and the increase in the direct investment from different manufacturers, which allowed the product to be improved, become more competitive, and increase their market share.

In addition to this performance improvement of the solar collectors, also important progresses have been achieved in the auxiliary systems, such as an upgrade in the insulation of the storage systems, a more efficient pumping, the introduction of regulation and control systems, and the use of warning devices about failure and malfunction.

2.1.2 Medium/High Temperature Systems

Vacuum Tube Collector

This kind of collector has a less market share than the flat plate ones, due to their higher manufacturing cost and selling price. Despite the vacuum tube collectors have a performance range from 50 to 200 °C, their optimal efficiency is far from the standard use for domestic hot water production and heating applications, so they are used for this purpose only in those regions with low solar radiation, according to their greater uptake. Thus, these collectors are more useful in industrial processes, where they have to compete with other technologies that achieve higher temperature and maintain a better cost/yield ratio.

The efficiency improvement of this technology follows the same trend and constraints as those set for the solar collectors.

Cylindrical-Parabolic Collector

Talking about the historic development of fluid heating by the use of solar power, it is worth mentioning Mouchot's steam engine. This technology consists of a large parabolic receiver covered with mirrors, which concentrates the radiation at only one point. The heat generated by this device is able to activate a steam engine. This invention can be considered as the precursor to the solar thermal energy concentration technology, in which the parabolic collectors are based. This device can heat a thermal fluid by concentrating the solar energy at one point (as the Mouchot's machine does) or in one line.

The first installation of a parabolic collector was in 1912, being its purpose the generation of steam for the operation of a water irrigation pump. Furthermore, there are commercial plants using this technology since the 80s.

Efforts on increasing the performance of this technology focuses on the improvement of the reflection and refraction of the collectors and the search for the internal fluid with the best features. In addition, there are also auxiliary fields that can be improved for this purpose, such as the control systems, the performance of the electric energy production system, the solar tracking, etc.

2.2 High Temperature Solar Energy. Solar Thermal Power Plants

This kind of technology has only been developed in the modern age, existing solar energy plants are based on in this knowledge since the 60s. However, the first commercial plant in Spain came out in 2007. The PS10 was built in Seville, designed with a power of 11 MW. Thereafter, solar thermal power plants have seen an exponential growth and they have been developed with improved attached technologies to enhance their yield, becoming a big contender for conventional plants, thanks to their versatility.

Unlike low and medium temperature applications, which have a simpler process of heating fluids up to moderate temperatures, high temperature solar systems are based on more complex processes to heat the working fluid up to higher temperatures to produce energy; hence there are more elements involved in the whole process, namely turbines, engines for heliostats, steam generators, etc. This technical complexity, together with having more determining factors, has hampered innovation in this sector, while the low and medium temperature applications may have led to the development of different technologies like flat plate collectors, vacuum tube collectors, parabolic-cylinders, thermosiphon, or forced systems. Thus, the architectural designs of these plants and the original building solution have not been altered significantly, so that the successful technological innovation is focused on the improvement of the process itself, and not in the development of attached technologies. Some examples of technological improvement of these plants are shown below:

- *Storage of molten salts* the first high temperature solar thermal power plants just heated a fluid with the radiation of the sun, stopping the electric power generation when the solar radiation ceased. This supposes a nonmanageable energy production, which means a competitiveness loss related to conventional power plants.

  The first molten salt thermal storage plant in Spain was built in Seville, in 2011. Thus, it supposes the first substitution of the circulating fluid to a molten salt fluid on a commercial scale. The new fluid, besides having a circulation behavior similar to the substituted one, also has higher specific heat and allows easy storage of the salts. Thanks to this innovation, the energy production becomes manageable and can therefore adapt the production to the demand during sunny hours, as well as keeping the energy production when there is no sunlight. This fact notably improves its versatility and ability to compete with conventional technologies.

- *Improvement of the constructive quality for the heliostats* the search for better efficiency of the heliostats focuses on the improvement of their structural design. In the same way as photovoltaic solar energy, the research in this field has served and serves as a spearhead for this sector, but oriented toward aerospace applications.
- *Improvement of the heliostats disposition and monitoring* thanks to the tests carried out at pilot solar stations, a specific software is currently available for designing and calculating different configurations for heliostat solar fields, determining the most efficient disposition for each case. Thus, it is energy efficiency improvement of the plant achieved by the optimization of the heliostat field configuration.
- *Control system upgrade* due to the process complexity and the amount of constraints and elements involved, the improvement of the control systems design must increase the process efficiency. However, current solar power plants are far from excellent in this area. Nowadays, it is not possible to design a solar power plant that is completely automated, with the resulting loss of efficiency due to manual control for such complex technological applications. It is looking for innovation in this regard, but there is still much room for improvement.
- *Other improvements* test of materials and constructive methods have allowed achieving higher temperatures in the central receiver without damaging the material. In addition, other improvements not directly related to the process of capturing solar energy, but to the whole process, such as those related to the steam generation or to the turbine performance, have contributed to the development of these technologies efficiency.

2.3 Other Solar Thermal Technologies

Apart from the technologies mentioned above, there are other technologies without extensive development and/or commercial use like parabolic disk systems, individual units functioning as solar concentrators comprising a parabolic disk that concentrate solar radiation in a receiver to heat a fluid or a gas up to 750 °C and producing electricity by using a turbine. Another technology that fits in this section is the system of compact linear Fresnel reflectors, which is based on a set of almost flat reflectors that concentrate the solar radiation onto elevated inverted lineal receivers, generating steam.

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3 Photovoltaic Solar Energy

The photovoltaic effect was discovered by the French physicist Alexandre Edmond Becquerel in 1838. Becquerel was experimenting with an electrolytic cell of platinum electrodes, when he found that the electric current rises in one of the electrodes due to sunlight exposure.

Later, in 1873, the electric engineer Willoughby Smith found the photovoltaic effect on selenium. Then, the first selenium photovoltaic cell was created in 1877 by William Grylls Adams, an English professor of natural philosophy in the King College of London, working together with his pupil Richard Evans Day.

However, it was not until 1953 that the first electrolytic cell, with an adequate yield to consider a commercial viability for this technology, was manufactured. Investigators D.M. Chaplin, C.S. Fuller, and G.L. Pearson from Bell Laboratory created the first silicon photovoltaic cell and made its official presentation in that year. Nevertheless, despite the technological progress achieved in increasing the photovoltaic cell performance, the cost of this technology at the historical moment was too high and prevented their practical application. An outstanding data is that the cost of an electricity watt produced in conventional power plants in 1956 was set around 50 cents, while that produced by photovoltaic panels reached 300 dollars. This fact avoided the use of this technology as a great quantity electric power supplier.

Since then, the research has been focused on the reduction of the production cost of photovoltaic energy (dollar/kWh), achieving parity and even advantage over the price of conventional energy sources, which were six times cheaper than electricity that came from photovoltaic technology at its early stages, as seen above. This is, thanks to the technological progress and the scale of economy that this technology has undergone, taking into account that the value of the cost also depends on the generation conditions and the country of production today.

The main application that boosted, without any doubt, the technological improvement of this sector was the powering of the space satellites equipment in the incipient space race at the time. In 1955, the United States ordered its industry the task of producing photovoltaic panels to space applications, where the reliable supply of electric power in areas of difficult access is essential. Thus, this year the Hoffman electronic company provided 14 mW photovoltaic cells with a yield of 3 % and a price of 1500 $/W. Two years later, this company developed solar cells with a performance up to 8 %.

In this way, despite the initial misgivings from some directors of NASA, the use of photovoltaic solar technology ended, surpassing other alternative mechanisms for powering satellites such as chemical batteries and nuclear energy. Then, the first photovoltaic powered satellite was launched in 1958. The Vanguard I counted with solar panels as backup power, but eventually became the main power source when batteries, first designed as the main power supplier, were sold out after only 20 days. The device was operational with this configuration for 5 years.

We conclude there was a feedback between the photovoltaic solar energy and the space race. It is true that this energy source had a development boost due to its use in the space race, but the last one could not be possible, in terms we know it nowadays, without the support of the photovoltaic powering.

However, even at this point, solar panels were still too expensive in terrestrial environment to be competitive with conventional energy sources. This issue changed when, in the 70s, Dr. Elliot Berman created a much cheaper solar cell, reducing the cost per watt. The consequent fall in prices allowed using the photovoltaic panel in facilities connected to the mains, starting to be the installation of this device more profitable than tracing an entire cable line or making the periodical maintenance and replacement of batteries. Thus, the practical applications of this technology multiplied, such as communication signal repeaters, lighting railways, marine lighting buoys, lighthouses, etc.

Today, the technological diversity is very wide and varies depending on the material of the panel, the connection type, regulation, etc. We focus on conventional flat panels and electronic inverters, the more widespread current commercial solutions. These modules can be classified according to their comprising cells as monocrystalline, polycrystalline, and amorphous. Their efficiency is greater due to the bigger size of comprising crystals, just like their price, weight, and thickness. The current yield average varies from 20 % of the monocrystalline modules to 7 % of the amorphous ones.

Important progress has been achieved in the manufacture of photovoltaic panels in the recent years. The research in this field has been focused mainly on the reduction of the panel manufacturing cost, the efficiency improvement, and the study of other materials. A summary of the achieved milestones is given below:

- *Reduction of the panel manufacturing cost* thanks to the economy of scale and the improvement in the production methods, it has been possible to reach parity in the mains of more than 100 countries. New materials showing applicable performances and reducing manufacturing costs are currently researched.
- *High efficiency of the photovoltaic effect* in 2014, in laboratory scale, a new record in the conversion efficiency was achieved, reaching 40.4 %. Today, it is not possible at a commercial scale yet.
- *Improvement of electronic invertors performance* the progress in their constructive elements and managing software have allowed to get, among other advances, higher frequencies, the capacity of working in a higher range of temperature with less losses, increase of efficiency at partial shadowing, or a better use of the received radiation when it substantially differs from one module to another at first and last day hours.

- *Study of other materials* for example, organic solar cells, carbon nanotubes, pyrite, magnetite, molybdenite, or graphene. The current use of chemical elements like gallium or silicon in solar panels increases the investment, causing multiple parallel researches looking for substitute materials.
- *Monitoring systems* the inclusion and development of these systems improve the process efficiency. Being able to measure and compute production and solar power consumption data at real-time supposes an advantage and a breakthrough, helping to prevent possible failures in the system by remote warnings about possible anomalies.
- *Other progresses* for example, an efficiency enhancement in adverse weather conditions, the use of flexible materials, the inclusion of control systems for the use in charge mode, and many more research areas.

Investment in photovoltaic solar power development and future forecast are promising. An application of this technology can be found in many areas, such as solar roads capable to charge vehicles that circulate over them, solar photovoltaic cell sprays with application in every surface, printable solar cells on clothing, the use of nanotechnology to improve yield, the synthesis of materials for reducing cost over an estimated 80 %, the enhancement of efficiency by holography solutions, etc. As it can be seen, there is a growing range of possibilities that only need a strong commitment by the regulatory entities. See Chap. 7 for further discussion on the use of solar energy to power and fuels production.

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4 Biomass

4.1 The Use of Biomass

Biomass has been the first source of power for humans and the main fuel until the Industrial Revolution and the beginning of the fossil fuels development. The last ones, counting with a greater calorific value and together with the need for increasingly smaller spaces for the use of fuels, had reduced the uses of biomass to record lows. See Chap. 8 for further discussion on current uses to biofuels production.

4.2 Biogas

This is an alternative energy that has been used for centuries, just like the low temperature solar energy. Biogas is currently used widely all over the world, especially in those areas that do not have reserves of fossil fuels.

The first evidence of the use of biogas came from the tenth BC, in Mesopotamia, where it was used for heating water, although there are historical overviews that show the use of biogas for residue cleaning by Sumerians.

In our era, the Roman scholar Pliny the Elder described the brightness of some lights that appeared below the marshland surface, around the year 50 AC. A long time after Benjamin Franklin referred to biogas as that responsible for a fire in New Jersey and then in November of 1776, the Italian scientist Alejandro Volta published, in a letter called "Aria inflammable native delle Paludi," how an explosive gas was formed in Lake Como when the sediments were stirred. Volta also concluded there was a direct correlation between the amount of decaying organic material found in the mass of water and the volume of flammable gas produced, and he established methane as the main compound of natural gas. The importance of these results was recognized by the scientific community of the time, reflected in the fact that this letter was translated into German only 2 years after its publication. Later in 1804, John Dalton described the chemical structure of methane and related it with biogas, while in 1821 Amedeo Avogadro set the final chemical structure of methane for the first time.

In the mid-nineteenth century, it is important to mention the research carried out in France about removing bad smell from wastewater, which was supposed to be a milestone in biogas technology development. These experiments allowed discovering some of the microorganisms that today are considered essential for the fermentation processes.

In modern times, we have to go to 1859 to review the construction of the first digester in the asylum-hospital of leprosy in Matunga, near Mumbai. The plant worked at purifying wastewater and supplying energy in emergency cases. At the end of the century, Louis Pasteur carried out several researches on biogas formation from animal wastes and suggested its use for streetlights. Then, between 1895 and 1896 in Exeter, United Kingdom, street lamps started to be powered by the gas collected from digesters that fermented sewage sludge. At this time, the first biogas plants, similar to the current ones, were built in China.

Until then, biogas was considered as a process with poor energy performance and without any parallel technological development. A biogas plant comprised a storage tank where the material was introduced without further elaboration than a closure to ensure certain tightness, just like a covering fabric, avoiding the entire leak of the produced gas when this material decomposed.

In the 30s of the twentieth century, the search for the energy efficiency of these applications started when the development of microbiology allowed identifying anaerobic bacteria and better conditions for the enhancement of methane production. The operating plants at this time were kept rudimentary or nonexistent, but the scientists began to understand being understood the reaction performance of the biogas production process and the use of catalyst was started, improving the efficiency by producing more volume of biogas in less time.

Thus, since then it is difficult to talk about innovation in this field, looking for an increase in the energy efficiency in this field. The studies and breakthroughs carried out in the past years are aimed at finding out which kind of substances can be used and in what quantity, to maximize the production, the search for the optimal mixtures and the best catalyst for the process, the study of material resistance against gas corrosion, etc. This is due to the relatively simple technology and construction of the biogas production, that makes unattractive the development of new technologies. The rest of the progress is therefore aimed at reducing the construction cost of the plants by achieving better constructive processes or the development of an economy of scale.

The most important improvements in the production of biogas are shown below:

- *Efficiency enhancement of the chemical process* maximizing the production by using the best substances in their optimal quantity, achieving the most productive mixtures, using the catalyst with the best performance, determining the optimal temperature in each step of the process, etc.
- *Improvement of the accumulation system* commercial biogas plants include hermetic accumulators to produce biogas in optimal conditions and without any leak. Some of the added breakthroughs are the heating and cooling systems for achieving the optimal temperature in each process step, the installation of agitators/aerators to move the decanted substances and maximize the biogas production or the equipment of inlet and outlet gates to assure a continuous process.
- *Improvement of the control system* today we cannot talk about totally automated biogas plants, but integrated services are increasingly included in the design with the consequent reduction of manual control and an efficiency improvement.

On the other hand, it should be pointed out that there is a difference between agricultural biogas source and waste biogas source.

4.2.1 Biogas from Agricultural Holding

There is still a lot of work for the expansion of this technology, which today has more interest from the point of view of sustainability than from achieving parity with the mains. Although there are many facilities all over the world, most need subsidies for viability and their objective is not mainly electricity generation. This kind of plants takes into account other purposes such as having economic benefits by including residues with inerting cost, getting environmental benefits, the zero waste policies or the lack of other energy sources in rural areas and developing countries.

4.2.2 Biogas from Wastes

Here are included rubbish dumps, wastewater treatment plants, and any regulated source of residues. In this case, there is neither movement nor elaboration costs; these existing processes already produced biogas by themselves and thanks to the increasing electric power price, together with the strict regulations for the gases released to the atmosphere, has made the implementation of this technology viable. For example, in the US, biogas plants have only been installed in 3 % of agricultural facilities considered as viable, while 33 % of wastewater treatment plants and 58 % of rubbish dumps have been covered.

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5 Wind Energy

We can consider wind power as a variant of solar energy as it comes from the warming of the atmosphere and landform variation, so its use dates back to several millennia. First, wind power was essential in sailing, evidence of which exists in Egyptian drawings up to 5,000-years old showing the sailing boats used to cruise the Nile River. Later, 4,000 years ago in Babylonia and China, windmills were used to lift water for irrigation, which were the first wind turbine models.

The first wind machines date from the sixth century, which were of vertical axis type used for grinding and water pumping in the region of Scythia, situated between Iran and Afghanistan. After that, especially in the Mediterranean Greek islands, horizontal axis windmills were developed, whose main feature was their blades were triangle sails. They are still used today to grind grain in the Greek island of Mikonos.

In the eleventh century windmills were widely used in the Middle East, but they were not introduced in Europe until the thirteenth century, as a consequence of the Crusades. Many of them were built during the Middle Ages and were of great importance, reaching to the extent that feudal lords reserved to themselves the authorization of their construction, as a way of forcing the subjects to grind grain in their own windmills and taking a part. Even planting trees near them was forbidden to ensure a good incidence of the wind.

Next, in the fourteenth century, the most important progresses in windmill technology were achieved in Holland and they started to be used extensively for draining water from the marshy area of the Rhine Delta. Subsequently, at the end of fifteenth century, the first windmills were built for producing oil, paper, and processing wood in sawmills. The number of these facilities kept growing, achieving in the middle of the nineteenth century over 9000 windmills operating for different purposes. However, the introduction of the steam engine after the Industrial Revolution supposed a negative effect for this technology and less than a thousand windmills kept working during the middle of the twentieth century.

Another country where wind power was widely used is Denmark, where about 3000 windmills were used for industry purposes and nearly 30,000 for domestic use in houses and farms. Nevertheless, as in other regions, the emergence of cheaper alternatives for power supply made them to be gradually replaced by thermal machines or electric engines fed by the mains.

As noted above, this technology disappeared from the energy supply issue and was replaced in navigation by steam machines and post technologies. However, in 1802, Lord Kelvin coupled an electric generator and a wind machine and later in 1850, once the dynamo was discovered, the wind turbine was created. Then, Charles F. Brush designed in 1888 the first wind turbine for electricity generation and, around 1890, the Danish meteorologist Paul la Cour started up the first machine specifically designed for electricity generation from wind power.

Despite the drop of this technology in the nineteenth century, as has been observed in previous cases, the energy crisis in the 70s took into account the wind power potential and boosted its progress. Thus, German and Danish engineers developed the first wind turbines with a profitable commercial use for this kind of technology.

The main component of these facilities is the wind turbine or aerogenerator, which we take as a whole due to its complexity. It is designed to receive the impact of wind and is connected to a dynamo that provides electricity. The innovation efforts in this technology focus on these two points, together with achieving more efficient constructive processes. The most widely traded model is the upwind three-bladed horizontal axis turbine, although there are some alternatives and the engineers keep looking for other configurations. We show some of them below:

- *Darrieus wind turbine* it was patented by the French aeronautical engineer George Darrieus in 1931 and commercialized by the American company

FloWind until its bankruptcy in 1997. This turbine is a vertical axis type and consists of a number of curved aerofoil blades mounted on a vertical rotating shaft or framework. The main advantage of this technology is that guidance systems are not needed, but it is less efficient than a horizontal axis turbine, requires starting assistance, and receives less wind as a consequence of being low to the ground.

- *Single-blade, two-blade, three-blade, and multi-blade wind turbines* The first aerogenerators counted with a big number of blades. It has been reduced until the three they generally have, being the least number of blades that provides more stability and simultaneously allows material and weight savings. Some models use two-blade and single-blade rotors, achieving even greater savings, but resulting less efficient and more complex control systems for stability improving must be included.
- *Leeward rotor turbine* Wind turbines usually have their rotor located upwind, in front of the nacelle, avoiding that any element could stop the wind or create turbulences. However, there are also models whose rotors are located leeward, where its blades are at the rear of the nacelle. This design could be interesting in small machines to make the housing of the nacelle work as a vane, in order to guide the turbine to the wind direction without requiring other devices.

The research in this technology is focused on reducing the size of the engines, improving the reliability of the machines, increasing their power and achieving a better integration to the mains. In 1980, the average power of a wind turbine was 50 kW developed by a rotor of 15 m diameter, while in the year 2003, the average power was a hundred times greater with an average diameter of 124 m.

Today, despite the innovation in this technology is still growing, the research is more focused on offshore wind facilities, which still represent a small ratio related to the whole power installed in the world. The first offshore wind farm, Vindeby, was built in the Baltic Sea in 1991 and it was composed of 11 turbines of 450 kW. A decade later, in 2002, after the start-up of many wind farms of different power, was built in Denmark one of the greatest offshore wind farms of today. The Horns Rev counts 80 wind turbines developing together a power of 160 MW.

The main disadvantage of this technology is the high investment. Although nowadays its value is declining, it is still much higher than the onshore facilities, due to logistic and installation issues. We refer the reader to Chap. 6 for current development of wind as a source of energy.

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