THE ENERGY SYSTEM

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THE ENERGY SYSTEM

Introduction

All organisms need energy to live. Energy is connected to all human activities: whenever we think or move, we use the energy that is stored in our body and all the objects that we use or that surround us need energy to work or needed energy when they were built. Energy illuminates us and warms our houses, allows us to move, feeds the tools we use to produce food, and so on.

The man and Energy

Energy has by now become an inseparable partner of human beings, who use it at any time every day in all their activities. To ensure the possibility of benefiting from that resource in a simple, stable and constant way, mankind had to conduct studies and research for a long time, and only during the last decades of the 19th century did many nations, but not all, succeed in developing "energy systems" ensuring the quality and quantity of energy necessary for development.
With the term "energy system" we usually indicate the set of processes involving production, transformation, transport and distribution of energy sources. Energy systems are usually extremely complex, and require skills from all fields of science in order to build and manage them. In fact, just as it is simple to use the energy that is made available to us at home (we press a switch and the light turns on) so is it difficult and complex to produce that energy and bring it right into our homes.

Distribution and transformation

Non-homogeneous distribution of primary sources. The first is that the production of the currently most exploited energy sources (fossil fuels) is concentrated under the surface of few countries, often far from the consuming countries. Therefore, finding and extracting the energy source and developing ad hoc agreements between producing and consuming countries is necessary to ensure a stable and lasting provision of fossil fuels to the latter. Finally, the physical transportation of the energy sources from the producing to the consuming countries is to be taken care of.
Energy sources are not always usable as they are naturally (primary sources). They often need to be transformed to make their use by final users easier and more effective (witness the electric energy obtained from coal combustion, or petrol obtained by refining crude oil). Such energy sources artificially produced by human beings are called secondary sources and are the most widely known since they are used every day. Also, the processes of transformation from primary sources into secondary sources and the organization of their distribution to the final users are complex and require many people and much knowledge to be managed in the best possible way.
Safety. The problem of "the best possible" management leads to a third complexity factor: safety. In other words, all the activities making up the energy system need to be carried out in safety conditions for human beings and the environment. If control is lost over the energy sources, very serious damage to the health of human beings and the environment may ensue (just think of sea pollution caused by a damaged oil tank or the dreadful consequences of a leak of radioactive

material from a nuclear power plant in case of accident). Therefore, human beings constantly need to study and implement technologies capable of rendering the different stages of energy production, transportation, transformation and distribution to the final user safer. Much has already been done since the first years of intensive use of energy sources but a lot can still be done, by implementing new technological discoveries.

Energy: yesterday and today

The history of mankind has always been characterized by the search for new sources of energy: to ensure survival at first and then to improve the standard of living. At the beginning energy meant manpower, often supplied by slaves and beasts of burden; later the energy of wind (windmills) and water (water mill wheels and similar machines) started to be exploited. Towards the end of the 19th century, thanks to the development of the industrial civilization, the need for energy was met thanks to the intensive use of coal. From the technological viewpoint a big step forward was made with the realization that heat, through the production of steam, could be transformed into mechanic energy. The first implementation of this new source of energy was the steam engine invented by Watt, which replaced traditional horses with the more modern “horse-power”.

During the first decades of the 20th century, after a promising start of the hydroelectric energy, great oil field were discovered in the Middle East: the “black gold” rush had started. During the 1960s, after half a century of unmatched domination by oil, natural gas proved to be a valid alternative, especially as regards domestic use (cooking and heating) thank to its smaller environmental impact. At the beginning of the 1970s some countries started to develop nuclear energy, mainly to produce electricity. The development of nuclear energy, just like other alternative energy sources, can be explained by means of the marked increase in the oil prices caused by the “oil crises” which took place in 1974 and 1979 following the corresponding embargoes against the Arab oil exporting countries and, in 1990, during the Gulf war.

The range of currently available energy sources includes oil, natural gas, coal, hydroelectric energy and nuclear energy according to a variable percentage distribution depending on the country. Other sources can be added to the main sources. Although their quantity is still limited, they are renewable: geothermal energy, solar energy, wind power, the energy obtained from waste or from biomass. What sources will supply all the necessary energy to mankind? The availability of fossil fuels will be increasingly reduced over the years (owing to the depletion of resources) and to meet the growing demand for energy new sources will need to be exploited, especially renewable sources with a smaller environmental impact. One of the possible alternatives to oil is hydrogen. Hydrogen is an element contained in many substances, (from water to natural gas) and widely available on Earth. Hydrogen can be used in fuel cells: a device capable of activating a chemical-electric process transforming the energy contained in hydrogen into electricity and heat avoiding combustion, which is the cause of numerous polluting emissions in the air.

The implementation of fuel cells will become possible in many sectors: transports (buses and cars), households (hot water production, heating and air conditioning) and electronics (mobile phones and

computers). Currently available technologies for the production, preservation and use of hydrogen must be further tested and improved before this resource can be used on a wide scale.

The energy balance

The importance of energy in modern society led man not only to create complex “energy systems”, but also to try and measure how much energy he uses each year and understand which source he gets it from and from which Country he imports it from. These problems have been solved by using adequate energy measurement units and a scheme representing the energy flows that enter a country and how energy is used in the different sectors along the year: the National Energy Balance.

The national energy balance

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primary energy available is achieved (also said primary energy consumption or gross domestic consumption).

Information obtained from the NEB

The National Energy Balance is drafted every year. Thus, comparing and contrasting the energy consumption is possible over the years by analyzing the different origin (whether imported or home produced), the different composition (which energy sources were exploited) and the development of national consumption (whether increasing or decreasing) of energy.

The information that can be obtained from the comparison of the energy consumption over the years is very important. For example, by comparing the primary energy consumption with the production data of a country one can see whether, over the years, the country succeeded in achieving a better management of the energy available, by using less energy to produce more. Else, one can check whether the renewable energy sources or those causing less polluting emissions in the air have progressively replaced the most polluting energy sources. A further useful piece of information is whether the country depends upon of energy imports. In countries like Italy, for example, energy resources under the surface are limited and there is a need to import over 80% of the primary energy from abroad. Since great part of our development and daily prosperity depends upon the energy available, countries like Italy, which are markedly dependent upon foreign energy supplies, need to maintain good and stable relations with the energy exporting countries.

Final use of energy

How does a country use the annual primary energy sources available? The answer is provided in the second part of the NEB containing data on the finale use of energy. Energy uses include the energy consumption of households and enterprises (of course enterprises producing electric energy to be destined to final uses are excluded). Therefore, part of the energy available as a primary source needs to be transformed to be used. As seen before, the most important transformation is the thermoelectric transformation, i.e. fossil fuels becoming electric energy.

By moving from primary consumption to the final consumption we see that the composition of energy sources varies because the quantity of fossil fuels decreases and that of electric energy increases. Besides in the composition of energy sources, there is a variation also in the quantity of available energy for final uses. The quantity which can be actually destined to final uses is smaller than the primary energy available because the transformation processes involve consumption and losses. For example, the use of fossil fuels (coal, oil, natural gas) to produce electric energy approximately involves a 60% average loss of the energy originally contained in the fuel. It means that if among the primary sources 100 Tonne of oil equivalent of coal are available to produce electricity, at the final use stage only 40 Tonne of oil equivalent of electric energy will be available. The remaining 60 Tonne of oil equivalent were lost during the electric transformation process and cannot be used by households or industrial plants (final uses).

At this stage of the National Energy Balance we have the available energy quantity for the final uses, i.e. the quantity of energy consumed by industries (plants), transports (cars, lorries, trains, buses), citizens (households), agriculture and finally bunkering (the fuel consumption of ships).

Environment and territory

Energy is an indispensable element to guarantee the well-being and development of the planet. Without a regular supply of energy, cities, industries, transportation and infrastructures would come to a halt. Moreover, the growth of the world economy and consumption in the 20th century, has been based mainly on exploiting fossil fuels: first coal, then petroleum and natural gas. These sources of energy, however, are not renewable and are destined, in the future, to become depleted. Furthermore, these sources of energy emit polluting substances during combustion, even if the amounts vary greatly, depending on which fuel is used.

Impacts and protection of the air

Among the most important substances are: carbon oxides (COx), sulphur oxides (SOx), nitrogen oxides NOx), volatile organic compounds (VOC) and total particulate solids (TPS). These pollutants can be harmful for human health and for the environment if they exceed determined concentrations in the air. Among these are: the greenhouse effect, acid rain, air pollution caused by traffic in the cities and all the serious problems that experts and communication media discuss extensively for which, very often, a solution still has not been found.

The desire to protect the environment, the oil crisis of the Seventies and Eighties, and the current increase in the price of petroleum, have led the Governments of a number of industrialized countries to incentivize the development of sources of energy that are alternative to the ones that are dominant today. Notwithstanding these incentives and the rapidity of scientific and technological progress, it is estimated that these sources will cover a significant share of energy consumption only in many years' time. And therefore, in the short and medium period, most of the energy required by man will probably still be provided by the traditional fossil fuels (specially petroleum and natural gas). However, man must learn to use the energy produced by fossil fuels in an increasingly efficient manner, (with a decrease in the amount of waste and an increase in the energy yield of different production processes) and must search for and make use of technological applications which will lead to a decrease in the emissions of pollutants in the air provoked by their combustion.

Challenges of the renewable energy sources

81% of the world energy is obtained from fossil fuels which are precious sources that, however, are not renewable. And it is for this reason that it has become necessary to develop and increase the renewable energies, but to do so, a few rather difficult issues must be overcome. First of all it is necessary to successfully produce energy from the renewable sources so that they are economic and competitive when compared to the traditional energy sources. Secondly, so that the source of energy is profitable, it must be in a concentrated form that can be stocked and transported. Energy

must be made available in a concentrated form in order to satisfy the large demand of energy, there must also be the possibility of stocking energy so that it can be accumulated and transported, in order to satisfy the demand of energy in areas that are distant from the area of production. The success of fossil fuels in fact is due to the fact they satisfy these three essential requirements, while the renewable sources still have some limits which prevent their diffusion on a wide scale. According to the aims set by the European Union, 20% of the energy requirements will have to be from renewable sources by 2020, and in particularly favourable areas the percentage of renewable energy may increase to much higher percentages. It is therefore evident that without opportune energy management strategies, the present electricity network will not be able to support these increases. Furthermore, we must not forget that renewable sources of energy are characterized by a great variability, therefore the greatest challenge is to successfully satisfy the demand of energy at peak times, exploiting sources of energy that are discontinuous and intermittent.

Energy transition

The expression '**energy transition'** refers to the move towards sustainable economies, through the use of renewable energy, the adoption of energy-saving techniques and sustainable development. Energy transition is a process that has accompanied the human race from the very beginning and has enabled the development and progress of human civilisation.

What does 'energy transition' mean?

There are two fundamental elements that characterise an energy transition. The first is that it is a complex and time-consuming process, as it involves structural changes in the way energy is produced and used. The second concerns the impact of the energy transition on economic development, quality of life, social organisation and the environment. If we consider, for example, those countries that have not yet been decisively affected by the last energy transition, i.e. the one triggered by the Industrial Revolution, it is easy to see what the social benefits could be if modern energy sources were to become more widely available. Just think, for example, of the benefits electricity would bring to societies that still light their houses with candles or oil lamps, or the introduction of machinery into rural agriculture that relies mainly on human and animal power.

One or many transitions? To be precise, we should speak of energy transition in the plural, because there are 'multiple transitions' that interact with one another and affect several components of the energy system. The components of an energy system that may be involved in an energy transition are:

- primary sources of energy, such as fossil fuels;
- machinery and technologies for energy transformation (e.g. turbines or electric motors);
- energy vectors, such as electricity or hydrogen, which originate from the transformation of primary sources;
- the energy services required, such as heating, lighting or recent sustainable mobility.

What can such multiple transitions be triggered by? Again, there is no single process that leads to change, but many variables come into play. If changed, these can cause the energy system to evolve in one direction or another. The mechanisms driving an energy transition can be grouped into four broad macro-categories:

- availability and competitiveness of new energy sources;
- availability and competitiveness of new machinery and technologies for energy transformation;
- adoption of new energy and environmental policies;
- a change in the type of energy services required by consumers.

A little history

Energy transitions have always accompanied human history. This has involved a continuous process and the time limits between transitions are not always easy to identify. For this reason, the classification by Vaclav Smil, a scholar of energy history who identified four epoch-making energy transitions, is given here.

The first features primitive man. At that time, early humans relied exclusively on their own energy, i.e. the energy derived from converting food into muscle power, to harvest plant-based food or kill animals. So, the primary source of energy was biomass, which is the basis of food chains, and the primary driver was man's muscle power.

The **first energy transition** took place when humans learned to control fire, an event that perhaps may have occurred as early as 800,000 years ago. This discovery provided them with their first external source of heat, made their food more palatable and their nights safer. Biomass fuels – not only wood, but later also charcoal obtained by pyrolysis of wood and various residues from agricultural activities – continued to be the only source of energy from prehistoric times until the early stages of industrialisation. In France, for example, coal only began to provide more than half of the energy from fuel in 1875; in the United States this happened 10 years later and in Japan in 1900, while in China the switch did not take place until the mid-1960s.

The **second energy transition** occurred when humans went from being hunters and gatherers to breeders and farmers. This transition has often been improperly referred to as the 'Neolithic agricultural revolution', but in reality, it was a gradual evolutionary process (from 12,000-8,000 BC to 3,500 BC) lasting several thousand years with a gradual transition from nomadic to sedentary behaviour, through cultivation of crops and domestication of animals. Agriculture and animal husbandry provided mankind with a more reliable and constant source of food energy, and domestic animals became useful 'machines' used by man for agricultural work, building construction and transport. Suffice it to say that an ox has a work capacity equal to that of at least 3-4 humans, a good horse equals that of 10 humans. Animals have accompanied man throughout history, only ceasing to be used for work after the onset of modern industrialisation.

The **third energy transition** was a long and patchy process, which saw the introduction of new types of primary engines, this time mechanical, driven by water and wind. These were the water mills and windmills, which contributed to the prosperity of many European countries until the 18th century.

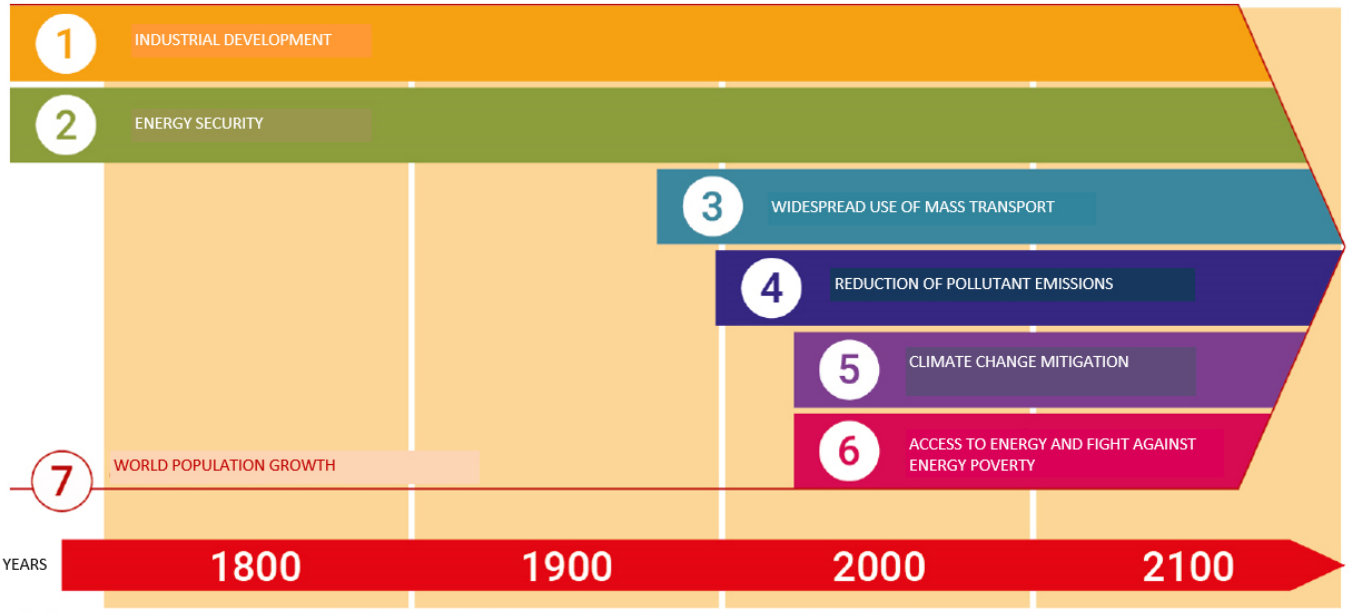
The **fourth energy transition** was a more complex process than its predecessors, and its constituent elements were the relatively rapid replacement of biomass fuels by fossil fuels, the introduction of electricity as an energy carrier, i.e. as a more convenient and flexible form of energy, and the invention and diffusion of new machinery, much more powerful than ever before, and driven by fossil fuels. The key event in this fourth transition was the Industrial Revolution, which prompted research and development of powerful engines powered by readily and widely available energy sources in order to increase the productivity of the workforce to meet an ever-increasing demand for goods. The first energy source capable of meeting these needs was coal, followed by oil and then by natural gas at the end of the 19th century.

The origin of the energy transition: mega-trends

Development of an energy system is driven by major forces of growth and change, which modify and shape the entire social organisation and production system and direct the collective consciousness and the main choices of entrepreneurs, consumers and policy-makers. These forces are referred to as mega-trends. Indeed, mega-trends are what drive the new energy transition and its timing, as they influence:

- political decisions, for example, inducing legislators to enact more or less restrictive environmental regulations or to favour the use of certain energy sources over others;
- technological innovation, for example, by directing industry and research to develop and market new technologies that meet emerging needs;
- consumer preferences, changing the composition of demand and consequently the supply mix, for example, by making the technologies and energy sources available on the market more or less competitive.

The end result is the achievement of a new energy model, which reflects the various objectives of the individual mega-trends in action in a mediated way.



Source: *Giuseppe Sammarco, "LA TRANSIZIONE ENERGETICA", Published by Eni SpA, Piazzale Enrico Mattei, 1 - 00144 Rome*

This image shows some of the most important mega-trends guiding the development of the energy system. Source: Giuseppe Sammarco, "LA TRANSIZIONE ENERGETICA" (ENERGY TRANSITION), published by Eni S.p.A., Piazzale Enrico Mattei, 1 – 00144 Rome

Let's find out the main mega-trends guiding the development of the energy system:

- **Industrial development**. Since much of the world has yet to experience widespread industrial development, we can assume that the mega-trend has not exhausted its driving function and, by continuing to fuel economic growth in developing countries, will trigger a cascade of persistent increases in global energy needs.
- **Energy security**. One of the key issues for the future is to ensure that we have a reliable and stable flow of energy that is adequate to meet the growing demand and maintain the level of prosperity we have achieved. All the more so if, as mentioned in point 1, industrial development continues to affect ever-widening sections of territory and population.
- **Widespread use of mass transport for people and goods.** Like industrial development, the phenomenon is still unknown in many countries and will have a high impact on the world's overall energy needs in the coming years.
- **Reduction of emissions of pollutants related to the energy sector**. The focus on reducing local impact emissions of pollutants caused by the production and use of energy sources has led to the introduction of increasingly stringent emission standards and triggered important technological innovation processes.

Sustainable energy for all, the challenge of the century

Of the mega-trends driving the energy transition today, three stand out in terms of relevance and impact:

- **Climate change mitigation**. This is one of the most recent mega-trends, but it has rapidly gained importance on the agendas of policy-makers as well as a considerable grip on public opinion. The current energy system is the main cause of climate change: combustion of coal, oil and natural gas to produce energy leads to emission into the atmosphere of carbon dioxide, one of the main greenhouse gases (read more about climate change in the climate change section – link). From here it is easy to understand how the issue of climate change mitigation is closely linked to that of the energy transition towards a system able to supply the energy necessary for production processes while reducing greenhouse gas emissions to zero. There is now a great deal of social and political attention to climate change, and this has led to the renowned agreement between countries at the Paris conference at the end of 2015 (COP15).
- **Access to energy and the fight against energy poverty**. Having access to modern forms of energy in sufficient quantities is not only a basic prerequisite for giving everyone an opportunity for economic growth and social development, but is often a matter of survival. Energy poverty still afflicts a large part of the world's population. The International Energy Agency (IEA) estimates that around 1.1 billion people do not have access to electricity and

that 38% of the world's population (almost 50% of the population in developing countries) do not have access to clean cooking solutions. Biomasses such as wood and charcoal are used to cook food in stoves that are not suitable for use in closed, unventilated spaces. The World Health Organisation estimates that in 2016 alone some 3.8 million premature deaths were due to this practice.

- **World population growth**. The elimination of existing inequalities in the living conditions of populations today requires global growth in both the economy and the availability of energy; growth which – to be fair and sustainable – should be compatible with environmental, climate and social objectives. Yet when additional population requiring the opportunity to achieve a minimum level of quality of life is added to this, the pressure intensifies and the search for a new energy model that meets all needs becomes even more of a challenge.

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