Renewable energy technologies, storage systems, and energy transition challenges: a comprehensive review

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ABSTRACT

This work focuses on the theoretical aspect, as the widespread use of renewable energy in all sectors contributes to enhancing energy security by reducing countries' dependence on imported fossil fuels. Renewable energy sources are often more diverse, thus reducing the risk of supply disruptions. Therefore, renewable energies (REs), such as solar, wind, and hydroelectric power, can be produced domestically. However, the fundamental challenge lies in how to encourage and incentivize countries to transition to clean energy, as this transition faces several political and economic obstacles, infrastructure problems in most countries, instability, storage issues, initial costs, the need for large areas, and a lack of expertise and technical support, all of which hinder countries from moving forward toward a secure and clean future. Therefore, this study provides an analysis of various types of renewable energy, their operating principles, and their requirements, aiming to clarify and encourage the selection of energy sources based on each country's financial and geographical capabilities. The study concludes with several findings, including that leading countries in this field have achieved profits, self-sufficiency, expanded their investments, and created numerous jobs – a strategic approach to protecting themselves from the volatility of fossil fuel prices in global markets. Advances in what we call new energies offer a glimpse of a more stable, sustainable, and livable future. This transformation is also essential for economic, environmental, and geopolitical reasons if we are to preserve our planet.

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1. INTRODUCTION

The on fossil fuels, which dominate global energy consumption, constitutes the largest share of global energy use. According to the International Energy Agency, in 2023, fossil fuels accounted for approximately 81% of global primary energy consumption, a slight decrease compared to previous years, but still representing a significant majority. This explains the large carbon emissions, which in turn translate into widespread environmental risks, such as increased air pollution, accelerated habitat degradation, and a greater frequency of extreme weather events due to climate change. If this problem is not addressed, global temperatures could exceed critical thresholds, potentially leading to irreversible climate change and severe impacts on ecosystems, human health, and the economy. In response to these challenges, the international community is accelerating the energy transition from fossil fuel-based energy production and consumption systems, including oil, natural gas, and coal, to renewable energy sources. The International Renewable Energy Agency (IRENA) projects that the share of renewable energy in the global energy mix will rise from 16% in 2020 to 77% by 2050, according to a 1.5 °C scenario [1].

The term renewable energy refers to energy sources that are, at least on a human scale, inexhaustible and available in large quantities. There are five main types of renewable energy: solar, wind, hydroelectric, biomass, and geothermal. Renewable energies (or REs) refer to a range of methods for producing energy from sources or resources that are theoretically unlimited, available without time limits, or can be replenished at a rate faster than they are consumed. We generally speak of REs as opposed to fossil fuels, whose reserves are limited and non-renewable on a human time scale, such as coal, oil, and natural gas. This research addresses the gap in understanding renewable energy by providing a comprehensive study of all its types, including their varieties, operating principles, and storage methods. However, the main challenge lies in the economic costs and weak policies that encourage the limited use of these energy sources. Therefore, this work presents a set of solutions, recommendations, and incentives for transitioning to and utilizing natural resources more effectively. This article also presents a model of policies implemented by leading countries in this field to motivate and encourage other countries to learn from these experiences. It aims to examine the differences between various energy sources that each country can utilize according to its geographical characteristics, thereby contributing to job creation and economic growth.

2. GENERATION OF ELECTRICAL ENERGY

The electricity network is the set of infrastructures used to transport electrical energy from production centres (power plants) to electricity consumers. An electricity network must also ensure the dynamic management of the production-transmission-consumption system, implementing adjustments to ensure the stability of the whole [2]. The smart grid ecosystem will thus be based on three systems modifying the current grid system based on unidirectional management from upstream to downstream through integrated multi-level and bidirectional systematic management: from centralized generation to decentralized production. The three levels of systems that will interpenetrate each other are as follows:

- Conventional and renewable energy production systems, which bring together all the production capacities of the electricity vector.
- The local system, which corresponds to the activation of energy intelligence in industry and residential, tertiary or collective buildings, and the integration of REs, storage systems and electric vehicles.
- The transversal system, which is made up of active distribution and transmission networks, is controlled and adjusted in real time between the supply of conventional and REs, and the demand of the local system.

The combination of these three systems, therefore, constitutes the smart electricity grid and meets the priorities of the new electricity economy, which can be summarised in three main use values:

- the integration of renewable, intermittent energies and new electrical uses.
- the flexibility of production and consumption for the reduction of the electricity peak.
- the management of bidirectional information and energy flows between the three levels of systems [3].

2.1. Origin of electrical energy

Electrical energy is a secondary energy that is produced from primary energy contained in:

- uranium (fission energy used in nuclear power plants).
- water (potential energy in hydroelectric dams).
- coal and petroleum (combustion energy).
- wind (kinetic energy of the air transformed by wind turbines).
- the sun (solar radiation transformed by photovoltaic cells or by power plants with reflectors).

In almost all cases, primary energy is transformed into energy in power plants with the help of turbines. The turbines are directly coupled to alternators that produce electrical energy in the form of three-phase voltages of constant frequency and amplitude**.** All power plants have an alternator. It is the alternator that converts mechanical energy into electrical energy. Power plants therefore differ only in their primary source of energy (wind, water, nuclear, thermal, etc.). There are two types of primary energy:

- so-called REs: which come from inexhaustible sources (energy from the Sun, wind, tides, geothermal energy) or renewable sources on the scale of human life (wood, plants) [4].

REs are divided into 5 categories [5]: 1) hydropower, 2) wind energy, 3) biomass energy, 4) solar energy, 5) geothermal energy. Examples: [4], [6].

a) Wind turbine: renewable energy is wind. The mechanical energy of the wind causes the blades of the wind turbine to rotate, which drives an alternator. The latter transforms this mechanical energy into electrical energy.
b) Solar: renewable energy is the sun. We don’t use alternators but photovoltaic cells. It is these cells that convert the light energy of the sun into electrical energy.

c) Hydroelectric dam: renewable energy is the waterfall. The mechanical energy of the water as it falls turns a turbine.
d) Tidal power plant: renewable energy is the tide. The principle is similar to a hydroelectric power plant except that the mechanical energy is provided by the tide.
e) Biomass: renewable energy is organic matter. There are different processes: thermal (pyrolysis, gasification, direct combustion) or biochemical (anaerobic digestion or methanization). In the first case, the energy is thermal (as in a thermal power plant, natural resources are burned). In the second, energy is chemical.
f) Geothermal: renewable energy is the heat from the ground. The energy is thermal (recovered from the ground).

- Non-REs whose reserves are limited and are being depleted (uranium, oil, gas, and coal).
  Examples: (a) Nuclear power plants: Nuclear fuel is burned. Nuclear power has the advantage of providing a lot of electrical energy for little fuel, but the installations are expensive, and we do not yet know what to do with nuclear waste. We use the nuclear energy of atoms. (b) Thermal power plants: fuel such as coal and gas, is burned. They are little used in France because they release carbon dioxide, a gas responsible for global warming. Thermal energy is used. They are non-renewable because these fuels burn and disappear.

2.2. The production principle

The principle of producing electrical energy is always the same: you need an alternator and an energy source. The energy received is mechanical: it is a moving object that will turn a turbine and set the alternator in motion. For example, the propellers of a wind turbine are driven by the wind (moving air). There is an alternator in each wind turbine that will transform this movement into electricity. The alternator is said to convert energy: it receives mechanical energy that it transforms into electrical energy [6].

3. ELECTRICITY PRODUCTION IN ALGERIA

Algeria is initiating a green energy dynamic by launching an ambitious program for the development of REs and energy efficiency. This vision of the Algerian government is based on a strategy focused on the development of inexhaustible resources such as solar energy and their use to diversify energy sources and prepare the Algeria of tomorrow. Thanks to the combination of initiatives and intelligence, Algeria is embarking on a new sustainable energy era. The program consists of installing nearly 22,000 MW of renewable power between 2011 and 2030, of which 12,000 MW will be dedicated to covering national electricity demand and 10,000 MW for export. The renewable energy and energy efficiency programme is developed in five chapters [7].

- The capacities to be installed by energy field of activity.
- The energy efficiency program.
- The industrial capacities to be developed to support the programme.
- Research and development.
- Incentives and regulatory measures.

The programme includes the construction of around sixty photovoltaic and solar thermal power plants, wind farms and hybrid power plants by 2020. Renewable energy projects for the production of electricity dedicated to the national market will be carried out in three stages (Figure 1):

- A first stage, between 2011 and 2013, will be devoted to carrying out pilot projects to test the various technologies available.
- The second stage, in 2014 and 2015, will be marked by the start of the deployment of the programme.
- The last stage, from 2016 to 2020, will be that of large-scale deployment.

The renewable energy programme is defined as follows for the different phases:

- by 2013, a total capacity of around 110 MW is planned.
- by 2015, a total capacity of nearly 650 MW would be installed.
- by 2020, a total capacity of around 2,600 MW for the domestic market and an export opportunity of around 2,000 MW is expected.
- by 2030, it is planned to install an output of almost 12,000 MW for the domestic market as well as an export option of up to 10,000 MW.

The consistency of the renewable energy programme to be carried out for the needs of the national market over the period 2015-2030 is 22,000 MW, of which more than 4500 MW will be completed by 2020. The distribution of this program by technological field is as follows (Figure 2):

- Solar photovoltaics: 13,575 MW
- Wind power: 5010 MW

- Solar thermal: 2,000 MW
- Biomass: 1,000 MW
- Cogeneration: 400 MW
- Geothermal energy: 15 MW

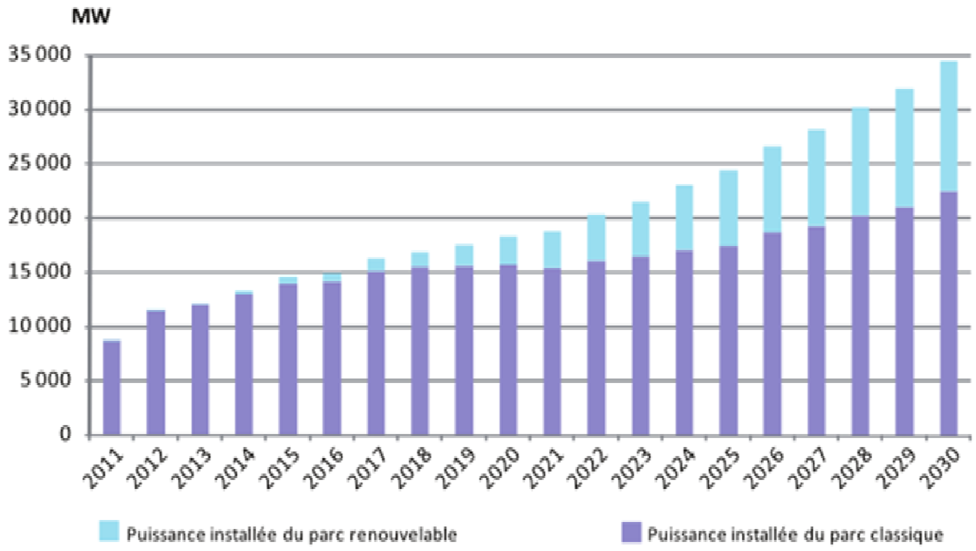

Figure 1. Structure of the national production fleet in MW

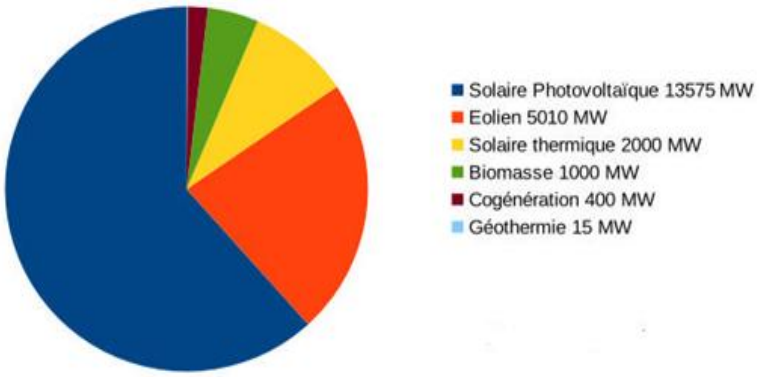

Figure 2. Objectives of the Algerian renewable energy programme 22 GW by 2030

The implementation of the programme will make it possible to reach a share of renewables of nearly 27% in the national electricity production balance by 2030 (Table 1). The volume of natural gas saved by the 22,000 MW of renewables will reach about 300 billion m3, a volume equivalent to 8 times the national consumption in 2014 [7].

Table 1. The renewable energy development programme

Renewable energy source	1st Phase (2015–2020) [MW]	2nd Phase (2021–2030) [MW]	Total [MW]
Photovoltaic	3,000	10,575	13,575
Wind	1,010	4,000	5,010
CSP	=	2,000	2,000
Cogeneration	150	250	400
Biomass	360	640	1,000
Geothermal energy	5	10	15
Total	4,525	17,475	22,000

4. DETAILS OF THE MAIN MEANS OF PRODUCTION

4.1. Hydraulic dams

The dam opposes the natural flow of water; it is capable of storing huge quantities of it (reservoirs) (Figure 3). All you have to do is open the valves to start the electricity production cycle. Water then rushes into a penstock or a gallery dug into the rock, depending on the installation. At the exit of the pipe, the pressure or speed (or both at the same time) causes the rotation of the turbine, which produces the energy produced by dams is close to 70 billion kilowatt hours per year [8].

Figure 3. Hydraulic dams

4.2. Wind turbines

The energy of the wind comes from that of the sun, which heats the air masses unevenly, causing differences in atmospheric pressure and therefore air circulation movements. Wind energy is a renewable energy, available everywhere (albeit in different quantities) and of course, without polluting emissions into the atmosphere. The wind turbine transforms the power of translation of the wind into rotational power. An alternator is mechanically coupled to the axis of the blades (rotor) to produce the three-phase voltages. A regulating device makes it possible to obtain a constant rotational speed compatible with the frequency of the network (50 Hz) (Figure 4) [8].

Figure 4. Wind turbines

4.3. Nuclear power plants

The “fuel” used in nuclear power plants is uranium, a metal that is relatively abundant in the Earth’s crust. The nucleus of uranium-235, when struck by a neutron, breaks into two smaller nuclei. U-235 is said to be fissile. This fission gives off energy, especially in the form of heat. As the atom breaks, it releases two or three neutrons that will, in turn, break other nuclei. This is called the chain reaction. The heat, in contact with water, provides pressurized steam that makes it rotate the turbine to which the alternator is coupled, which generates electricity. When the turbine comes out of the turbine, the steam is cooled, transformed back into water, and returned to the steam generator. The output of a large nuclear reactor is 1500 MW (Figure 5) [8].

Figure 5. Nuclear power plants

4.4. Thermal power plants

A fuel (oil, gas, coal, etc.) is burned and provides heat in a steam generator where water is vaporized under pressure. The steam is then “expanded” in a turbine, which means that it goes from an initial high pressure (165 bar) to a low pressure (50 millibars). The expansion of the steam caused by this drop in pressure makes it possible to drive the turbine and the alternator that produces electricity. The steam is then liquefied in a condenser and then recycled. The production of a thermal power plant can be up to 700 MW (Figure 6) [8].

Figure 6. Thermal power stations

4.5. Solar energy

The energy received by solar radiation is converted into electrical energy. A first process consists of using mirrors to concentrate the flow of energy to a fireplace, where water is vaporized to drive an alternator. Another process uses photovoltaic cells (solar panels) that directly convert light into electricity. Several cells are connected to each other on a photovoltaic solar module. Several modules are grouped to form a solar installation in a private home or in a solar power plant. Photovoltaic, which feeds an electrical distribution network. This energy can be stored in batteries and used to generate electricity at night (Figure 7) [8], [9].

Figure 7. Photovoltaic system solar panels

4.6. Geothermal energy

Geothermal energy consists of extracting energy from the ground to use it, for heating or to transform it into electricity. The heat that has accumulated in certain parts of the subsoil (water tables) is exploited by drilling more or less deep depending on the desired temperature. Three types of geothermal energy can be distinguished according to the level of temperature available at the farm:

- High-energy geothermal energy or geothermal energy is preferred; it exploits very hot hydrothermal springs. This geothermal energy is mainly used to produce electricity.
- Low-energy geothermal energy: it uses deep aquifers (the depth can range from a few hundred to several thousand meters) at temperatures between 30 and 100 °C. It is mainly used for district heating networks.
- Very low energy geothermal energy: geothermal energy from shallow depths with temperatures between 10 and 30 °C. It is mainly used for individual heating and air conditioning [6].

4.7. Biomass

The word biomass refers to all organic matter of plant, animal, or fungal origin that can become a source of energy by combustion or after new chemical transformations. The energy derived from biomass is considered renewable and sustainable as long as this resource is not overexploited. Biomass releases CO2 by burning like coal, gas or oil, but this carbon has recently been extracted from the atmosphere via photosynthesis and can be captured again by plants, whereas this process took place millions of years ago for fossil resources, and marine plants and algae are no longer sufficient to absorb carbon that comes from fossil hydrocarbons (Figure 8). Biomass can be taken from nature, or it can be cultivated. Man has been using biomass since he learned how to use fire. Biomass is therefore a real energy reserve captured from the sun through photosynthesis. Energy can be produced by burning it in a boiler. Biogas can also be produced by anaerobic digestion, which will be converted into energy [6].

Figure 8. Biomass source

4.8. Biogas

Biogas is a renewable energy source obtained through the fermentation of organic matter placed in an oxygen-free environment. This natural fermentation process is called anaerobic digestion. Methane can be produced naturally in certain natural environments, such as marshes or rice fields, but also in landfills. Today, biogas is part of the category of REs, in the same way as solar, wind, or hydropower. But to obtain biogas in large quantities, humans must intervene by artificially causing the fermentation of organic waste from animal manure, livestock manure (manure, slurry, etc.), fats, sewage sludge, or effluents from the agri-food industry. This waste is then placed in an oxygen-free environment. Anaerobic digestion then produces:

- Biogas composed of methane (50 to 70%), carbon dioxide, hydrogen sulphide, water, and various impurities;
- Digestate, a solid residue from the anaerobic digestion process, which is used for spreading or composting [10].

5. DETAILS OF WIND AND SOLAR RENEWABLE ENERGIES

5.1. Wind turbines

The wind turbine is composed of several parts (Figure 9) [11], [12]:

a) The nacelle contains almost all the elements of a wind turbine, for example the generator or the gearbox. Access to the nacelle for personnel is possible via the wind turbine tower.
b) The rotor is composed of 3 blades (in general) and on the other hand a collector that supports the blades on the shaft.
c) The tower of a wind turbine must support the nacelle and the rotor. The tower is most often around 70 m because it is better to be high to capture the most fast and strong winds. This corresponds to a 20-storey building. The towers can be either tubular or latticework.
d) The rotor blades capture the wind and transfer its power through the rotor. A wind turbine blade measures about 25 to 35 m depending on the capacity of the wind turbine. Most blades are made of plastic (polyester or epoxy) reinforced with glass fibers.
e) The control system is considered the brain of the wind turbine. It is used to monitor that the wind turbine is operating normally and to control the steering device. In the event of a problem, the computer locates where the fault is, shuts down the entire wind turbine and sends the owner a message via a telephone modem.
f) The multiplier is used to multiply the spin speed. The rotor rotates slowly when the wind blows but with a lot of force. The mission of the multiplier is to accelerate the movement and convert this force into speed because in order to create electricity, the mechanism must rotate very quickly. The rotor makes about 22 revolutions per minute while the small arm at the end of the multiplier rotates at 1,500 revolutions per minute.
g) The generator works like a bicycle dynamo, it creates electricity when it runs. It is connected to the gearbox that transmits the rotor force.
h) Breake disc: it is triggered at a predetermined threshold by a speed detector (anemometer). This device allows the wind turbine to be completely shut down.
i) The main shaft: it is to this large arm that the rotor on one side and the multiplier on the other side is attached. This shaft drives all the manganite when the rotor rotates. It therefore allows the full force of the wind to be transmitted.
j) Orientation system: a wind turbine to be at its maximum capacity must be facing the wind. This device is operated by the control system and informed by the wind vane. A small motor is placed in the system which allows it to rotate a few degrees at a time when the wind changes direction.
k) The anemometer is very important because it allows the wind turbine to be safe. It measures wind speed and transmits to the control system. The computer then knows if it can start the wind turbine or if the wind is too strong to make it work.
l) The transformer: this machine transforms the raw electricity produced by the wind turbine into electrical energy that can take over the EDF electrical circuits.

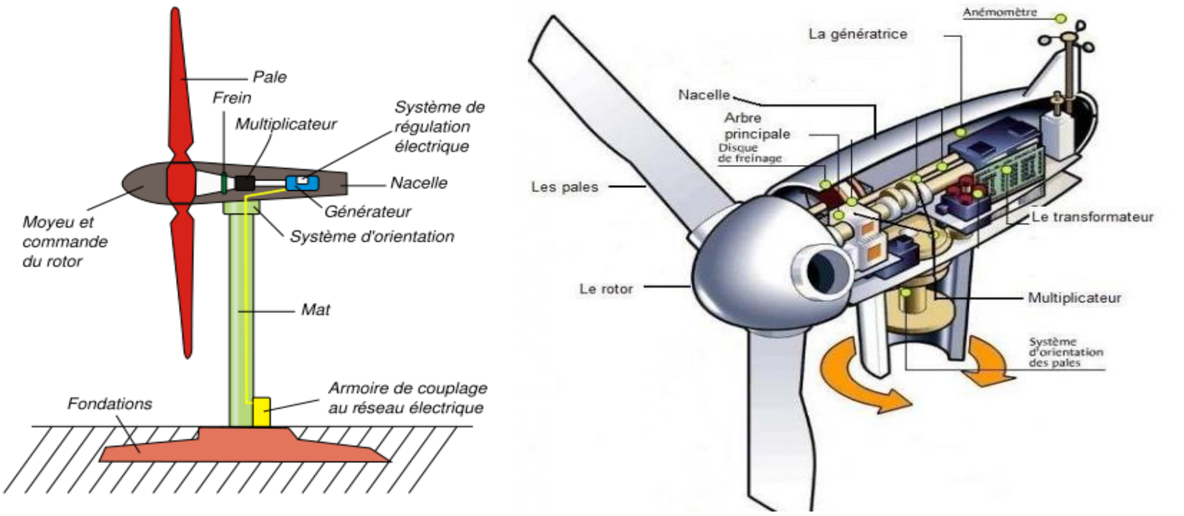

Figure 9. Diagram of a wind turbine

5.2. Solar energy

5.2.1. Introduction

Solar energy is one of the alternatives to replace fossil fuels, such as oil. As long as the sun lives, this energy will be available. It's just that the systems to capture the sun are quite expensive, but saving the planet is priceless. During the night, the sun is not out. Wind energy could replace solar, as wind is available almost 24 hours a day. Because oil is running out, it causes pollution in the air when it is burned. The sun cannot be bought; it is free. In addition, this fossil fuel can cause ecological disasters, such as an oil platform that can explode because of a defective part. It can be very damaging to the ecosystem of nature and animals [13].

5.2.2. Types of solar energy

a). Passive

Consists of benefiting from the sun's rays directly without the use of special sensors. The thermal insulation of houses allows this type of energy to optimize passive solar gain, compared to heating and lighting the house or building. This sort of energy from the sun just requires more windows or insulation (Figure 10) [13].

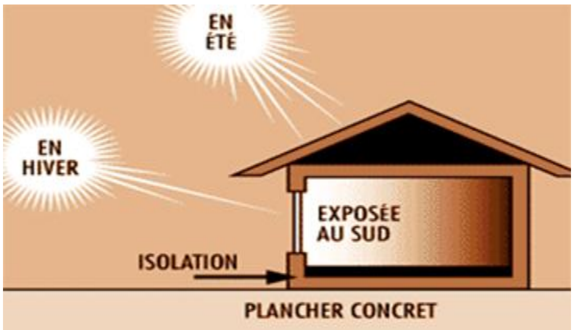

Figure 10. Kinds of passive solar energy

b). Thermal

Solar thermal energy belongs to the family of REs whose resources are inexhaustible. Its peculiarities and characteristics are that it allows heating with solar radiation (Figure 11), such as a solar water heater is the most widespread application in the world, and solar heating is its main use. Solar and thermal panels make it possible to capture solar energy and transform it into heat.

Solar thermal energy is free, reliable, and non-polluting. Energy source: there are two types:

- At low temperatures: the sun's rays are trapped by glazed thermal collectors, which, through metal absorbers, heat copper pipes. This allows the water to be heated.
- at high temperature: solar radiation is concentrated in a catchment surface that allows very high temperatures (between 400°C and 1,000°C) to be obtained.

Solar thermal energy consists of using the heat of solar radiation with a thermal panel. This radiation is done in different ways:

- Direct use of heat: solar water heaters and heaters, solar stoves and dryers.
- In indirect use, the heat is used for another purpose: solar cooling, thermodynamic solar power plants [13]-[15].

c). Thermodynamics

Thermodynamic solar energy is a solar technique that uses solar thermal energy in large quantities to produce electricity, on the same principle as a conventional power plant (production of high-pressure steam that is then turbined). Possibly directly from mechanical work (the term mechanical solar is then used).

Thermodynamic solar power plants do not directly convert sunlight into electricity. As in a thermal or nuclear power plant, it is pressurized water vapor that drives a turbine connected to an electric generator. The heat needed to transform water into steam, resulting from the combustion of a fuel (coal, oil) or from nuclear reactions in conventional power plants, is provided here by the sun's rays. Thermodynamic solar energy is much less expensive and more suitable for the production of large quantities of electricity (Figure 12) [13], [16].

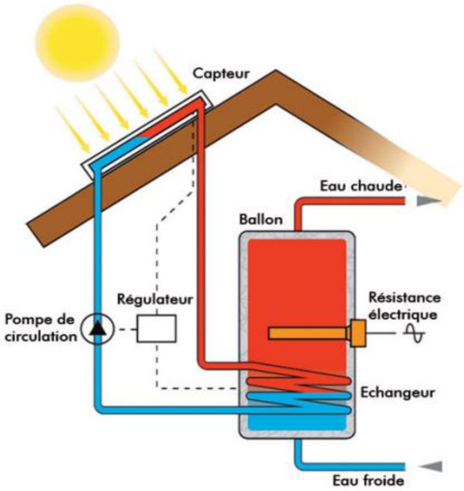

Figure 11. Types of solar energy thermal

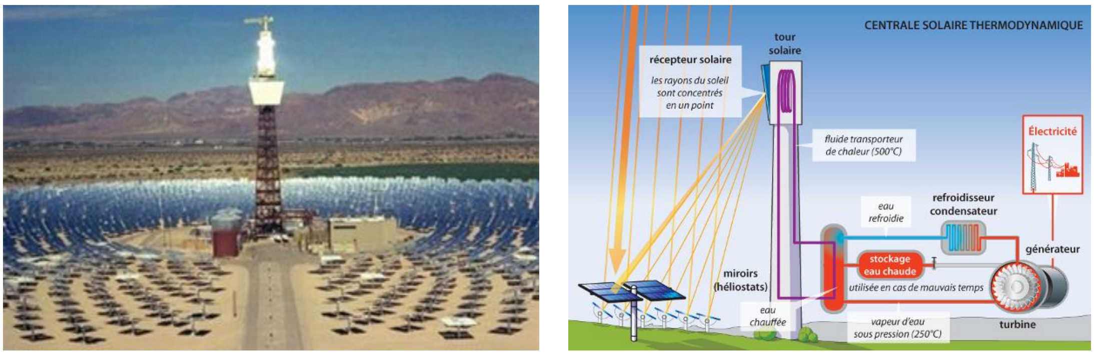

Figure 12. Solar power plant thermodynamics

6. PRINCIPLE OF OPERATION

6.1. Hydroelectric power plants

A hydropower plant uses the energy provided by a moving body of water to produce electrical energy (Figure 13). A dam holds a large amount of water in the form of a reservoir. To produce electricity, the dam’s gates are opened, water rushes into a pipe drilled into the dam, and its speed increases. At the outlet of this pipe, the water turns a turbine, which itself drives an alternator that produces a sinusoidal alternating voltage. The water is then released at the foot of the dam and resumes the normal course of the river. Several variants of hydropower plants exist. Some work by harnessing energy provided by the tides or by the waves. However, their number remains very limited. Hydroelectric power plants can range from a few thousand watts for an individual power plant (intended to supply a single home) to 500 MW (megawatts) for a large dam [17].

6.2. Wind turbine

Based on the operating principle of windmills, wind turbines are currently a rapidly developing method of producing electrical energy. The most obvious advantage of this type of power plant is the inexhaustible nature of the energy it uses. This is called a renewable resource. Several types of wind turbines exist; however, the current trend is to build medium-sized wind turbines grouped together in the same place. The machine consists of 3 blades (in general) carried by a rotor and installed at the top of a vertical mast. This assembly is fixed by a basket that houses a generator. An electric motor allows the upper part to be oriented so that it is always facing the wind. The blades are used to transform the kinetic energy (energy that a body possesses due to its movement) of the wind into mechanical energy. The wind causes the blades to rotate between 10 and 25 revolutions per minute. The speed at which the blades rotate depends on the size of the blades. The larger the blades, the slower they will turn. The generator transforms mechanical energy into electrical energy. Most generators need to rotate at high speed (1,000 to 2,000 revolutions per minute) to generate electricity. Thus, the role of the multiplier is to accelerate the slow movement of the blades. The electricity produced by the generator has a voltage of about 690 volts. As it cannot be used directly, it is processed through a converter, and its voltage is increased to 20,000 volts. It is then injected into the electricity grid and can be distributed to consumers. Wind turbines operate at wind speeds between 14 and 90 km/h, and after that, they stop for safety reasons. Electricity production varies according to wind speed. It is with winds of 45 to 90 km/h that the wind turbine produces its maximum power [9], [17].

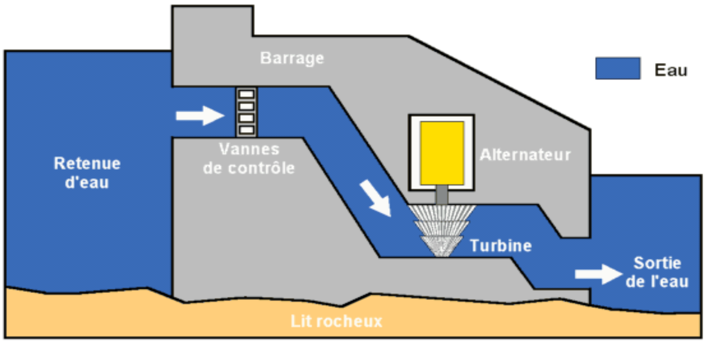

Figure 13. Working principle of the hydropower plant

6.3. Photovoltaic power plant

Photovoltaics is the cleanest way to produce electricity. It occurs quietly, without mechanical parts and without the release of toxic products (Figure 14).

- The solar panel (module): the sun’s energy is captured by modules or “solar panels”. The majority of solar modules use silicon in crystalline form as a conductor. Solar panels generate direct current.
- The charge controller: it controls the energy sent from the solar panels to the batteries. This serves to protect the latter against current overloads.
- Batteries (batteries): photovoltaic energy storage equipment. They come in different capacities and sizes. It depends on the needs of use and consumption. The principle is exactly the same as traditional car batteries, except that those used for solar are more robust and last longer.
- Inverter (inverter): it converts the direct current, which comes out of the batteries, into alternating current. This is in order to be able to use all types of domestic or other electrical appliances. There are many models and different capacities. They are used according to individual needs. The inverter is a simple wall-mounted enclosure.

This alternating current is then injected into the public network and counted and sold to EDF via your production meter, which allows you to see your electricity production daily. Energy production is close to the consumer, decentralized, thus reducing losses related to electricity transmission [3], [18].

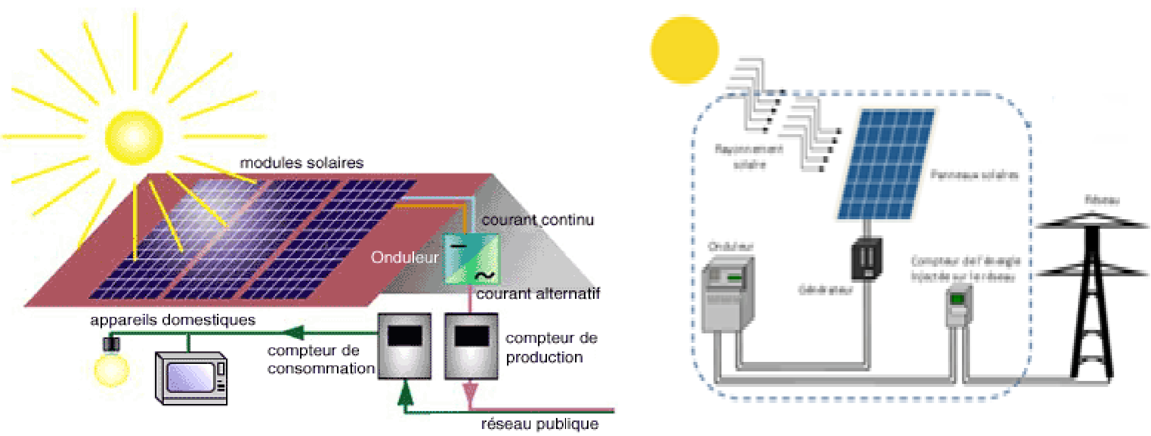

Figure 14. Operating principle of a photovoltaic power plant

7. RENEWABLE ENERGY STORAGE

Renewable energy storage technology will be recognized when it is able to offer a cost-effective way to collect renewable energy and use it when necessary. There are basically four types of renewable energy storage solutions: hydraulic energy storage, thermal energy storage, mechanical energy storage, and battery energy storage systems.

7.1. Hydraulic storage by pump

It consists of pumping the water upstream (Figure 15), storing it in a reservoir, and releasing it using turbines. According to the IEA's renewable energy report, more than 50% of new hydropower capacity in Europe in 2025 will come from pump storage, particularly in Switzerland, Portugal, and Austria. The same will be true for China between 2023 and 2025 [19].

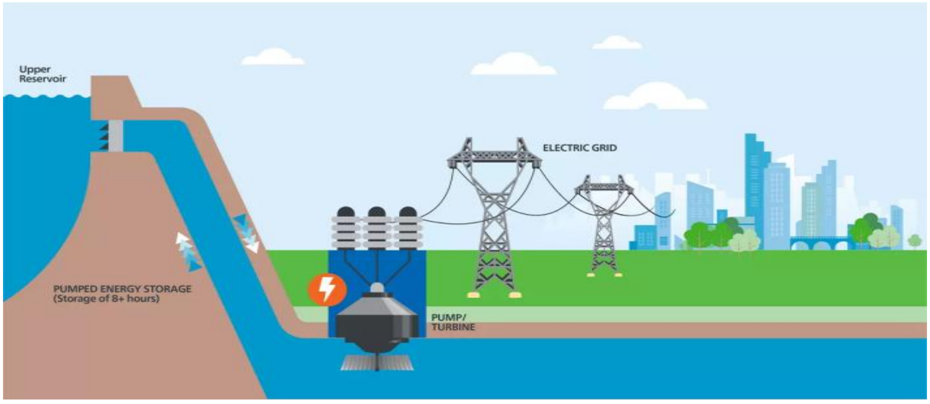

Figure 15. Pumping of hydraulic storage

7.2. Thermal energy storage

It involves storing surplus energy, usually from renewable sources or waste heat, for later use. Water, sand, and rocks can store thermal energy, and the IRENA estimates that thermal energy storage could reach 800 gigawatt hours (GWh) of installed capacity by 2030 (Figure 16) [19].

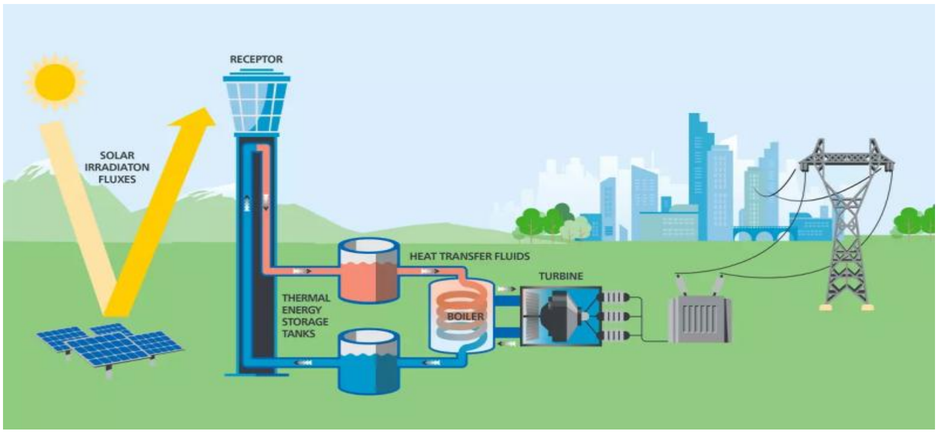

Figure 16. Thermal energy storage

7.3. Mechanical energy storage

It uses gravity or movement (like with a steering wheel) to store electricity. Mechanical energy storage (Figure 17) can also include compressed air or gas storage, which is then heated and expanded using a turbine.

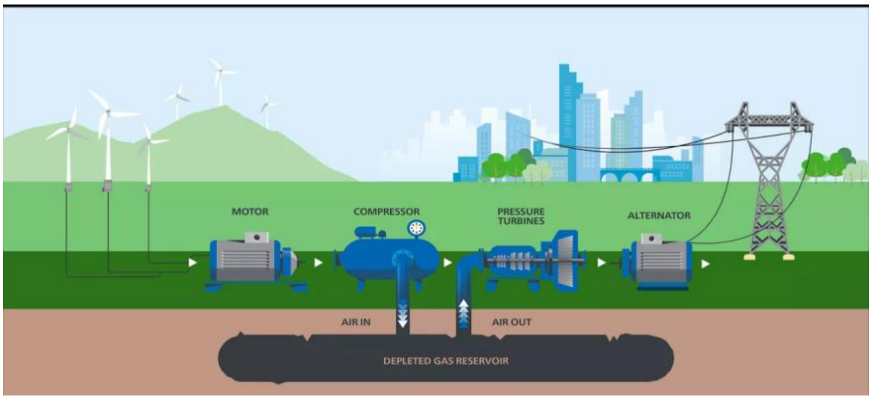

Figure 17. Mechanical energy storage

7.4. Battery energy storage

Renewable battery energy storage systems are widely recognized as the most efficient way to store and, therefore, supply energy from renewable sources (Figure 18). The more renewable battery energy storage is used, the less energy sources used to date will be needed [19].

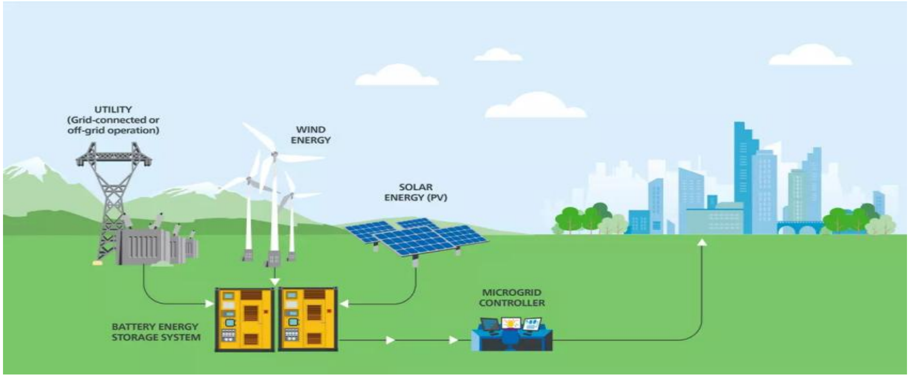

Figure 18. Battery energy storage systems

7.4.1. Lithium-ion batteries for renewable energy storage

The use of Li-ion batteries for renewable energy storage provides users with above-average energy distribution, combined with unmatched durability, flexibility, and ease of use. With two modes of operation (standalone or hybrid when used with a generator), li-ion battery energy storage systems such as Atlas Copco’s ZBP and ZBC units can address different levels of energy requirements, reduce operating costs, and minimize total cost of ownership (TCO) (Figure 19). When paired with a renewable energy source, like the ones mentioned above, these renewable energy storage solutions can be 100% sustainable [19].

Figure 19. Atlas Copco ZBC energy storage system to store solar energy

7.4.2. Other battery-based technologies for renewable energy storage

The most efficient systems using battery storage for renewable energy are based on rechargeable lithium-ion (Li-ion) batteries. These lightweight yet high-density batteries have become the preferred option for many reasons, including the ability of a 1 kg li-on battery to store 150 watt-hours per kilogram (Wh/kg). A nickel-metal (NiMH) hybrid battery typically stores between 60 and 70 Wh/kg and a 6 kg lead-acid battery can only store about 25 Wh/kg. If we compare lithium-ion batteries to lead-acid batteries, the former technology offers longer life and better performance for unpredictable and variable loads and in high temperatures. The performance of nickel-metal hybrid batteries is superior to that of lead-acid batteries, although it is still lower than that of lithium-ion batteries [19].

8. ECONOMICS AND POLICY OF RENEWABLE ENERGIES

8.1. Savings from renewable energies

Solar, wind, biogas, and REs are now the leaders of the global energy transition. In addition to their ecological benefits, they pave the way for promising economic opportunities. Job creation, technological innovation, economic growth... Alpiq reveals the many economic opportunities associated with REs. Renewable energy is not only an environmentally beneficial energy solution, but it also opens up new economic opportunities that benefit the countries that adopt it. 4 economic opportunities offered by REs:

- Job creation: REs supply both electricity and the employment sector. Indeed, more and more jobs related to REs are being created in many countries. The renewable energy sector offers a multitude of job opportunities: from infrastructure design and installation to maintenance and management services. Thus, in just 10 years, jobs in the renewable sector have almost doubled. According to data from the International Labour Organization (ILO), the number of jobs in the renewable energy sector increased from 7.3 million in 2012 to 12.7 million in 2022. And the trend will intensify even more, since according to studies by IRENA, by 2050, there will be no less than 43 million jobs related to REs worldwide.
- Profitable investments: investing in REs is becoming more and more interesting for companies and investors because the more these energies develop, the lower their cost, which makes investments in this sector very interesting. Investors are therefore looking for opportunities in projects such as solar, wind, hydroelectric power, etc., as investing in them promises attractive long-term profits.
- Economic growth thanks to emerging sectors: new markets are emerging in the field of renewable energy, which is great news. This creates significant opportunities for investment and growth. Demand is increasing for services such as: on-site energy generation, energy storage, charging stations for electric cars, microgrids, and smart heating substations. One particularly promising sector is the development of green hydrogen. Innovative start-ups are investing in these new sectors, which is driving economic growth. However, they still need a few years to fully deploy their technologies in the market. This is where the emergence of artificial intelligence becomes interesting to speed up the process.
- Towards more energy independence: energy independence is the ability of a country to meet its energy needs "autonomously". The transition to REs is, in part, the solution [20].

8.2. Renewable energy policy

8.2.1. Support policies to promote the emergence of green energy

A renewable energy policy is a set of measures and regulations to promote the use of sustainable energy sources such as solar, wind and biomass. With a very positive impact on the economy, green energies are the subject of particular support from the public authorities.

- The purchase obligation to support renewable producers

Intended for individuals and professionals who install renewable infrastructure, the purchase obligation requires certain approved operators to buy back the production from solar, wind, and hydroelectric power plants at a price set by the State, over the long term. The best known is the photovoltaic purchase obligation mechanism. Offered to individuals and businesses, it requires an approved operator, such as EDF OA to buy back all or surplus electricity generated by solar panels at a feed-in tariff determined by the public authorities.

- Aid to create companies in the renewable energy sector.

Different countries and regions have used a range of devices to encourage the development of renewable energy capacity. They exploit a wide range of techniques. A considerable part of the discussion among politicians, universities, and other actors, including associations, is moving towards the conclusion that the combination of devices is necessary for the goals of renewable energy policies to be achieved [20]-[22].

8.2.2. The basis of government policy on renewable energy

Government renewable energy policies are designed to support the development, implementation, and use of renewable energy sources such as solar, wind, hydro, and biomass. These policies can take a variety of forms, including financial incentives, subsidies, tax breaks, and regulatory measures aimed at both producers and consumers. The aim is to reduce dependence on fossil fuels, reduce greenhouse gas emissions, and promote sustainable development. Example: the feed-in tariff (Feed-in-Demand) system, which pays renewable energy producers a premium price for the electricity they generate and feed back into the grid, encourages investment in and adoption of renewable technologies. These policies can help to:

a. Stimulate economic growth by creating green jobs and new industries
b. Improving energy security by diversifying the energy mix
c. Reducing carbon emissions and fighting climate change
d. Ensure stable energy prices by reducing dependence on imported fuels.

In addition, policies that mandate the use of renewable energy in government buildings and encourage the installation of renewable energy systems in homes and businesses can significantly increase the demand for renewable energy [21].

8.2.3. The economic effects of adopting renewable energy policies

The adoption of renewable energy policies also has profound economic effects. These policies generate jobs, foster innovation, and stimulate new industries around green technologies. By reducing energy imports, countries can achieve greater energy security and energy price stability, which benefits the entire economy. Investments in renewable energy infrastructure can drive economic growth, with the sector creating more jobs per unit of electricity generated than the fossil fuel industry. In addition, renewable energy projects often bring development to rural areas, contributing to regional economic development [21].

8.2.4. The future of renewable energy policy

Renewable energy policy is essential to shaping the future of global energy systems. It involves strategies that governments will adopt to increase the adoption of renewable energy, with the aim of achieving a sustainable, low-carbon future. As technology advances and public awareness increases, these policies are expected to evolve, presenting both challenges and opportunities [21].

9. TECHNOLOGICAL INNOVATIONS AND RESEARCH

Technological innovations play a central role in shaping future renewable energy policies. These include advancements in solar photovoltaic (PV) technology, wind turbine design, battery storage solutions, and smart grid technologies. For example, improving battery storage capacities makes it possible to store the surplus energy generated by renewable sources, which helps to solve the problem of intermittency. Smart grids, on the other hand, allow for better integration of renewables into the existing grid, facilitating a smoother transition from fossil fuels to renewables [21].

10. ENERGY TRANSITION

The notion of the energy transition was born out of the German anti-nuclear movement. It was formalized in 1980 in a text by the Öko-Institut, whose translation of the title was: Energy Transition.1 The environmental challenges of global warming and the foreseeable depletion of fossil fuel resources have encouraged many more people to think about the energy transition, which consists of exploiting cleaner and more sustainable energies. The energy transition can be defined as “an operation, a transformation without explaining its content”. The term of the energy transition is based on four elements [23]:

- Energy transition and politics: it is the drafting of a law that consists of defining a perimeter of intervention for public action. This law has just defined the energy transition as the transition from an energy system based on the massive exploitation of fossil fuels and nuclear energy to an energy system based on a growing share of the exploitation of REs. In this context, the public authorities in Algeria must react as a regulator through strategic planning, agreement between the different stakeholders, as well as the various interests.
- Energy transition versus energy: it is a question of setting a strategy for a special energy transition for each player: energy producers, industrial users, consumers.
- Energy transition and community: it happens through the circulation of information between the different regions of the world. Decision-making in this area must be done collectively.
- Energy transition and governance: at this stage, governance is a complex process; each state must have particular dynamics to face the multiple challenges of climate change and the preservation of fossil fuel resources.

10.1. Challenges

The transition to renewable energy presents several challenges but also opens up many opportunities. Key challenges include the intermittency of renewable energy sources, the high upfront costs associated with technology and infrastructure development, and existing regulatory and market barriers that hinder the rapid deployment of renewable technologies. However, these challenges also present opportunities for innovation, economic development, and green job creation. Policies that encourage research and development, provide financial incentives, and support public-private partnerships can address these challenges and stimulate the growth of renewable energy sectors. But in the face of the depletion of oil, gas, coal, and uranium stocks, a transition to 100% REs is inevitable in the more or less long term. Before that date, there will also come a time when these resources will be so difficult to extract that their cost will no longer be competitive enough compared to green energies. While the transition to 100% renewable energy is technically possible, several critical points will have to be overcome to make it a reality, including the following three [21], [24]:

- Mitigating consumption peaks: most energy transition scenarios project a future decrease in energy consumption. To achieve this, they call for the sobriety of consumers and businesses; For example, they will have to turn off shop windows and offices at night. They are also counting on a better energy efficiency of the efficiency of electrical appliances, but also of buildings, thanks to the insulation of those considered as thermal sieves. Even if all these changes take place, the question of managing consumption peaks remains a crucial point to consider.
- Multiplying green energy sources: when we talk about REs, we immediately think of photovoltaics and wind power. But these two modes of electricity production cannot be the only sources of green energy in the territory, otherwise their intermittency will require the use of important solutions to store the energy produced. The multiplication of other renewable energy sources will then be one of the alternatives to limit dependence on wind and solar.
- Rethinking land use planning: the installation of solar panels on roofs will not be enough to cover all the needs. While one hectare of land is needed to produce 1 MW of electricity, the deployment of photovoltaics will require large areas. The question of sharing the territory with agriculture will therefore become more and more important.

10.2. Solutions

To succeed in the ecological transition and reduce our greenhouse gas emissions, the major economic and political players must have a global and precise vision of the challenges of energy. They are the key players in meeting the challenges of the energy transition. It is on the strength of this conviction and the desire to support political and economic players in their transition process that we have identified, with the experts of the HUB Institute, the 10 major challenges of the conversion of our energy model. The gradual depletion of resources and the environmental impact of our energy model, which is still largely dependent on the extraction of fossil fuels, raise questions about the sustainability of such a model. To get out of the impasse of a socio-technical system based on the use of fossil fuels, public and private actors must engage in a deep reflection to co-construct a sustainable energy model. To successfully transition to an energy system based on REs, it is not only a question of substituting energies but of completely rethinking the organisational structure and the nature of our productive activities [25].

- Production and transformation: it will be necessary to increase the production capacity of REs that are already well established in the territory and to invest more in REs under development, in particular marine REs (tidal energy and wave energy).
- Packaging and storage: the acceleration of the development of REs poses a new challenge for energy experts, that of storing and conditioning the electrical energy produced. Indeed, unlike fossil fuels and with the exception of hydroelectric dams, REs cannot be controlled, as their production capacity is not constant. Hence the need to be able to store surplus production in order to reuse it at the best times. Solutions are currently being developed to address these issues, including “Power to Gas” technology, which makes it possible to store the overproduction of REs by generating hydrogen by electrolysis. This technology has a lot of potential.
- Transport and distribution: the emergence of new energies and the deployment of new modes of transport will change the way energy is distributed. For example, electric cars will significantly increase the demand for electricity on the grid, they will also be able to act as a backup power supply if the power grid requires it through the deployment of smart grids. As far as liquid hydrogen is concerned, maritime transport solutions are currently being developed, and will allow it to be commercialised on a larger scale.
- Consumption and performance: it is important to think about intelligent consumption with a view to energy sobriety. It is imperative for us to change our consumption habits, and to collectively turn to a more energy-

efficient lifestyle while continuing to improve existing technologies to improve the energy performance of our systems.

- Recovery and circularity: in the energy mix of a sustainable model, recovered energies are complementary energies to REs. As their name suggests, it is a question of recovering energy that would otherwise be lost. The heat released by the combustion of waste, by data centers or from various industrial processes such as metallurgy can be recovered thanks to heat exchangers and then used to heat nearby buildings. It can also be converted into electricity without additional CO2 emissions. Recovered energies make it possible to limit energy losses as much as possible and promote the development of intelligent and virtuous territories.
- Financing and competitiveness: investments to convert the entire energy model are immense, whether through the redefinition of activities or simply in terms of energy infrastructure Politicians, public and private investors, all efforts must converge to promote a long-term transformation of the existing energy model.
- R&D, digital, and technical innovation: the success of the energy transition depends on the maturity of a set of technical and technological solutions. The shift to a new energy model will be enabled by innovations at all stages of the energy value chain. Optimising energy data management is, for example, one of the key challenges to accelerate the energy transition. Energy data, which is already essential for identifying levers for optimising renewable energy production, can also be used to secure purchasing contracts and manage the balance between energy production and consumption.

11. RESULTS AND DISCUSSION

Using renewable energy produces significantly fewer emissions than burning fossil fuels. To address the climate crisis, it is essential to shift from fossil fuels, currently the primary source of emissions, to renewable energy sources, which are available in most countries and provide three times the number of jobs.

This study provides a comprehensive analysis of various types of renewable energy, outlining their operating principles, basic components, and the equipment and methods required to determine their suitability for specific needs. Energy storage methods are crucial, considering storage capacity and how to maintain the required output. This work addresses these aspects to facilitate the selection of renewable energy types based on each country's available resources. In reality, energy is not merely a "variable" driving the technological system; it encompasses all political, social, and economic actors. A sustainable energy transition requires more than simply replacing fossil fuels with renewable; it necessitates a global structural shift. The energy supplied by fossil fuels cannot be fully replaced by renewables alone, whether due to the vast reserves of fossil fuels or the need to extract rare minerals. With production models and energy consumption patterns being redefined, there are still many transformations to be identified to ensure a global energy transition.

12. CONCLUSION

In this work, we have presented: a) So-called REs, which come from inexhaustible sources (energy from the sun, wind, tides, geothermal energy) or renewable sources on the scale of human life (wood, plants). b) Non- REs whose reserves are limited and are being depleted (uranium, oil, gas, coal). c) Storage of REs. d) Economics and policy of REs. e) Technological innovations and research. f) Energy transition: challenges and solutions. The world's nations must rely on renewable energy, which offers a clean, flexible, and scalable path to eliminating carbon emissions and mitigating the catastrophic risks of climate change and its negative environmental impacts.

This study provides a comprehensive analysis of various renewable energy sources in terms of their components, uses, storage, and distribution. The report also outlines Algeria's advanced prospects up to 2030 and its efforts to reduce reliance on non-renewable energy sources, with plans to install approximately 12,000 megawatts of generating capacity for the domestic market, in addition to the potential to export up to 10,000 megawatts. The study also addresses the adoption of policies and economic models by countries that have contributed to job creation, profitable investments, and the emergence of new sectors. The transition to renewable energy in most countries faces numerous challenges, including the intermittent nature of renewable energy sources, the high initial costs associated with developing technology and infrastructure, and existing regulatory and market barriers that hinder the rapid deployment of renewable energy technologies. This necessitates greater efforts and increased government support, requiring further research to develop more robust, easily implementable, and cost-effective solutions.

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