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HYDROGEN AND THE ENERGY TRANSITION

L’IDROGENO E LA TRANSIZIONE ENERGETICA

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Alla mia famiglia,
per avermi costantemente spronata
a dare il meglio di me
e ad ambire sempre più in alto.

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ABSTRACT

Today on a global level among the energy sources the fossil share still prevails clearly, but we have reached a moment in which the energy transition is the only way if we want to safeguard the environment and the health of human beings. The purpose of this study is to suggest an optimal path for the energy transition. Over the years, scholars have made many assumptions about the possibility of carrying out the transition using hydrogen as an energy vector. In this research study this possibility has been considered, analysing hydrogen, from the point of view of production, uses, possible advantages, but also limits and risks, to make a comparison and reach a clear conclusion. Furthermore, considering global and single country emissions, non-renewable and renewable resources distributed not equally in the world, investment in renewable natural resources, and considering technological leadership, a distinction has been made on the countries that could benefit from the transition and those who will be most disadvantaged by it.

SINTESI

Oggi a livello globale tra le fonti energetiche prevale ancora nettamente la quota fossile, ma siamo giunti a un momento in cui la transizione energetica è l'unica via se vogliamo salvaguardare l'ambiente e la salute degli esseri umani. Lo scopo di questa ricerca è quello di suggerire un percorso ottimale per la transizione energetica. Nel corso degli anni gli studiosi hanno avanzato numerose ipotesi sulla possibilità di effettuare la transizione utilizzando l'idrogeno come vettore energetico. In questa ricerca è stata considerata questa possibilità, analizzando l'idrogeno, dal punto di vista della produzione, degli usi, dei possibili vantaggi, ma anche dei limiti e dei rischi, per fare un confronto e giungere ad una conclusione chiara. Inoltre, considerando le emissioni globali e dei singoli paesi, le risorse non rinnovabili e rinnovabili distribuite in modo ineguale nel mondo, gli investimenti nelle risorse naturali rinnovabili e tenendo conto della leadership tecnologica, è stata fatta una distinzione sui paesi che potrebbero beneficiare della transizione e quelli che saranno più svantaggiati da essa.

INTRODUCTION

Global emissions have reached levels never seen before, this is causing temperature rises, melting glaciers, human diseases and many other disasters and terrible events. We have reached a point of no return, and governments seem to have finally understood the gravity of the situation. In fact, many States have begun to take measures and implement policies in favour of the environment to reduce emissions, but the road is still long, the damage caused is enormous, a radical change is necessary, an energy transition in the world is essential. In this research, the current global situation will be analysed first, in terms of emissions and environmental damage. To better understand the situation, the emissions will be divided by sectors and energy resources, including an estimate of the variation in emissions and energy consumption in the past and in the future. Then we will focus on the fundamental policies implemented over the years for the protection of the environment, such as, for example, the Kyoto Protocol of 1997 and the Paris Agreement of 2015, to understand what the actual effort of countries is towards of environmental protection. From the analysis it is necessary to start countries towards the energy transition and the way that many scholars have suggested to achieve is to use hydrogen as an energy transition vector. Others, however, are sceptical about this point, so to clarify the analysis proceeds by demonstrating the pros and cons of this element. Starting from the availability on Earth, from the subsequent production and uses in various sectors, we will arrive at the possible advantages of hydrogen. We will then analyse in the third chapter the risks due to the physicochemical properties of the element and the limits in terms of production costs to arrive at what are the real criticalities of hydrogen.

The last chapter will focus on a detailed study of the distribution of renewable and non-renewable resources in the various countries of the world, to clarify in this way the disadvantages / advantages that exporters and countries dependent or not on oil will find in the transition. Technology leadership was also chosen as a key factor in understanding this distinction. The last part of the fourth chapter will be devoted to a suggestion for a possible optimal way to reach the energy transition soon using hydrogen as an energy vector.

CHAPTER 1: WORLD ENERGY SITUATION

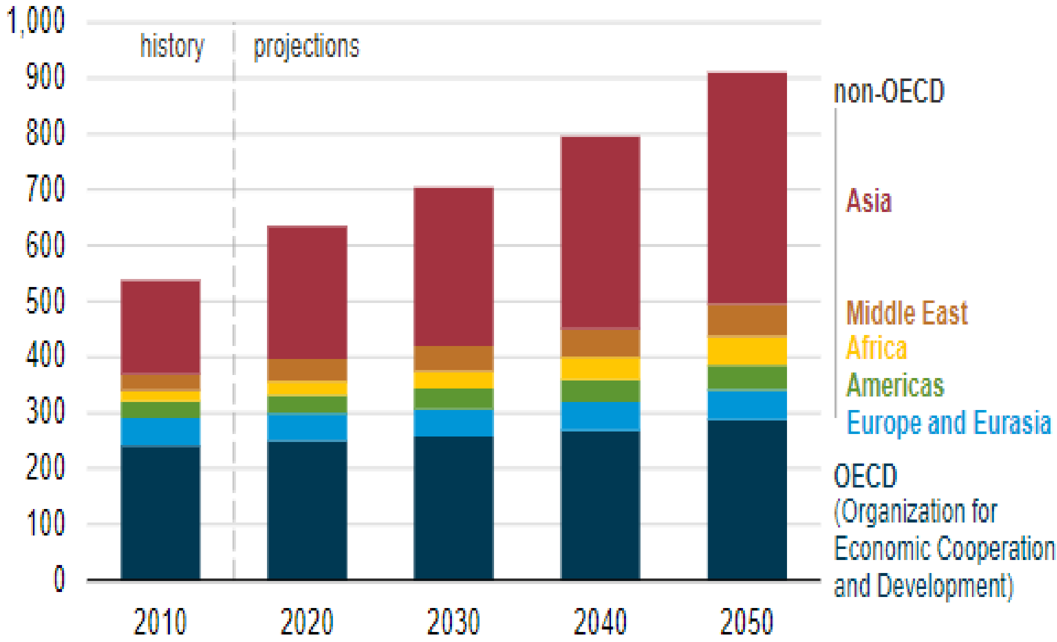
1.1 INTRODUCTION

We will begin the chapter by dealing with global energy demand and production, to understand how the energy situation is evolving over years and to analyse future forecasts. To better understand the trend in demand we will focus on regions and then we will continue with the analysis of global emissions, and what they entail. Lastly, we will report what are the fundamental political milestones as regards the road to the energy transition, as the support of governments is essential to implement a change that is fundamental.

1.2 WORLD ENERGY DEMAND AND PRODUCTION

According to the reference scenario of the World Energy Outlook 2019, world consumption of primary energy will grow by almost 50% between 2018 and 2050. Growth will focus mainly on the industrial sector. The largest energy consumers in the world are industrialized countries, although they represent 15% of the global population, their energy consumption exceeds 50% of the energy consumed in total. Primary energy consumption in the world grew rapidly in 2018, thanks to the increasing exploitation of natural gas and renewable energy sources.

Fig. 1.1: Global primary energy consumption by region (2010-2050).

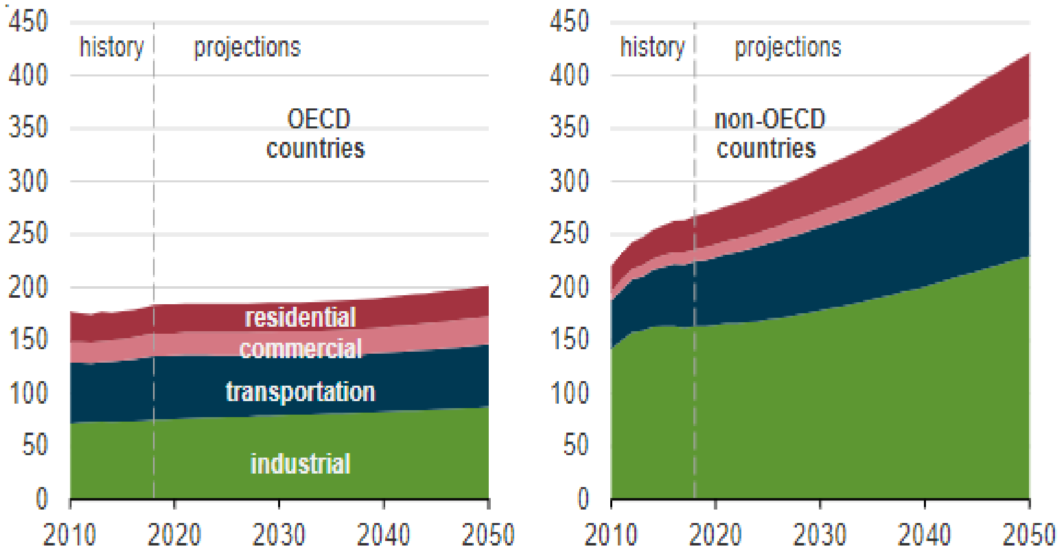


Source: International Energy Outlook 2019

As we can see from Figure 1 most of this growth comes from countries that are not in the Organization for Economic Cooperation and Development (OECD), and this growth is focused on regions where strong economic growth is driving demand, particularly in Asia.

Considering the end use of energy consumption according to IEA, the industrial sector, which includes activities such as extraction and refining, manufacturing, agriculture, or construction, will continue to represent the largest share of energy consumption on end uses, increasing by 30% between 2018 and 2050 as consumption of goods increases. By 2050, global industrial energy consumption reaches about 315 quadrillion British thermal units (Btu). An even greater increase (+ 40%) awaits energy consumption related to transport; as well as for the industrial sector, also in this case the responsible for the growth are largely non-OECD countries, where energy consumption for transport increase at almost double rates (+ 80%). The "building" sector, which groups residential and commercial structures, will undergo the greatest increase in relative terms (+65%), between 2018 and 2050, from 91 quadrillion to 139 quadrillion Btu, induced by the improvement of styles of life, increasing urbanization and increasing access to electricity. Strong growth across all three sectors will require a 79% increase in electricity generation over the period.

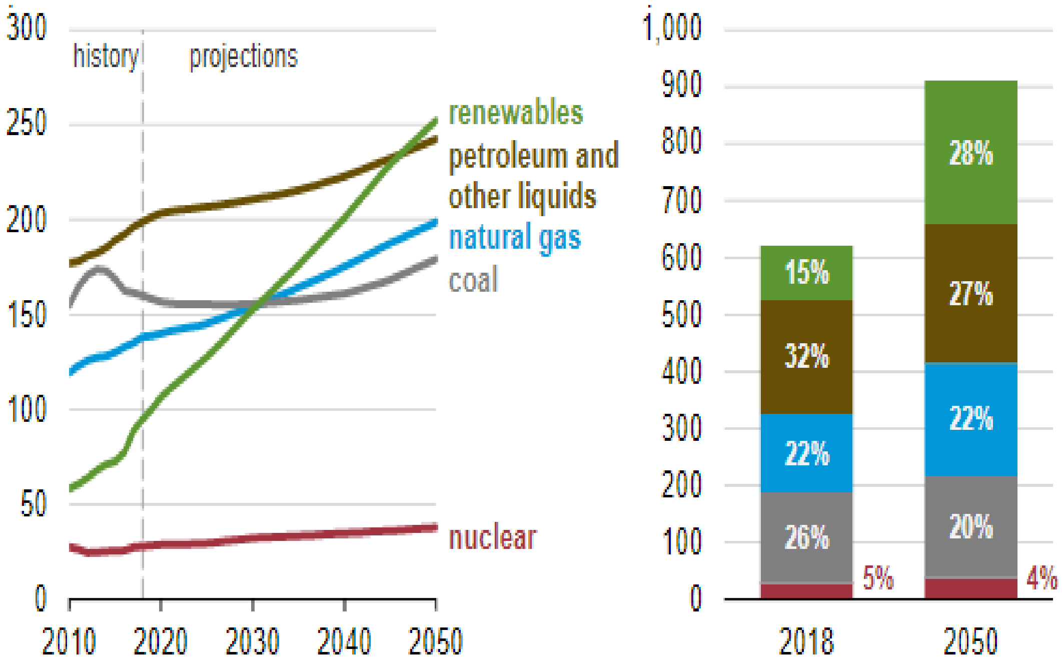
Fig. 1.2: Global energy consumption by sector (2010-2050)



Source: International Energy Outlook 2019

In 2030, fossil fuels will make up over three-quarters of the primary energy source mix and demand for oil will grow by 0.8% per year, remaining the dominant fuel, although its total energy share will drop from 32% to 27% in 2050, mainly due to the decline in its use in favour of coal, nuclear and renewable energy in sectors other than transport. The demand for natural gas will increase by 1.1% per year and its total share will settle at 22%, reaching a total consumption of nearly 200 quadrillion Btu by 2050. In addition to the natural gas used in electricity generation, the consumption of natural gas increases in the industrial sector. The production of nuclear energy, on the other hand, will grow in all the most important geographical areas except in Europe, but the total share will decrease throughout the reference period from 5% to 4% in 2050.

Fig. 1.3: Global primary energy consumption by energy source (2010-2050)



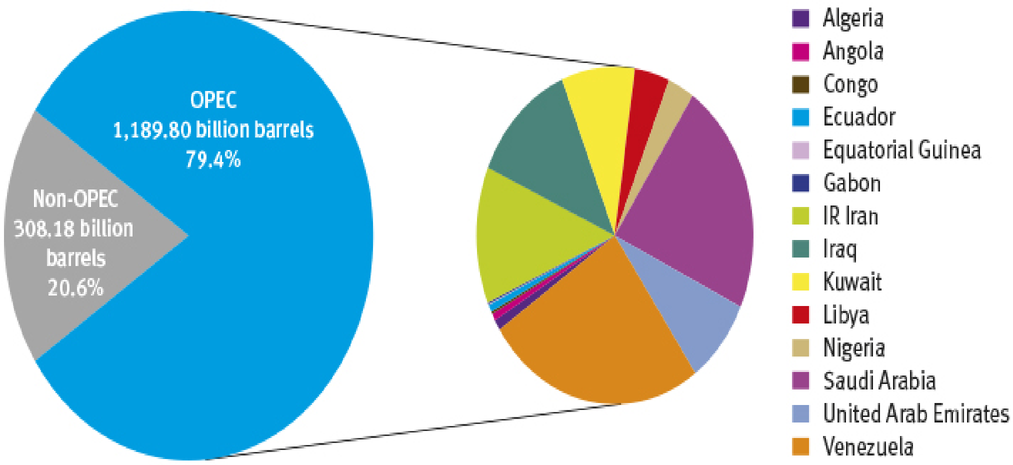
Source: International Energy Outlook 2019

The fastest growing energy sources between 2010 and 2050 is renewable energies. World consumption of renewable energy increases 3.1% annually between 2018 and 2050, compared to 0.6% annual growth in oil and other liquids, 0.4% growth in coal, and 1,1% annual growth in natural gas consumption.

As we mentioned previously and as can be easily understood from Figure 1 and Figure 2, the ASEAN countries play an increasingly important role in the world energy markets, in fact these countries will increase their primary energy consumption by 76% between 2007 and 2030, with an annual growth of 2.5%, considerably higher than the world average. As reported by the “Oil and Gas Journal”, 56% of the world's oil reserves are in the Middle East and 80% are concentrated in only 8 countries, of which only Canada and Russia do not belong to OPEC. OPEC countries, due to their availability of fields, could sustain an even faster increase in production with relatively low development costs.

The world is not yet short of oil or gas, the overall reserves are large enough to support the projected increase in production beyond 2030.

Fig. 1.4: OPEC share of crude oil reserves, 2018



OPEC proven crude oil reserves, at end 2018 (billion barrels, OPEC share)

Venezuela	302.81	25.5%	Kuwait	101.50	8.5%	Algeria	12.20	1.0%	Gabon	2.00	0.2%
Saudi Arabia	267.03	22.4%	UAE	97.80	8.2%	Ecuador	8.27	0.7%	Equatorial Guinea	1.10	0.1%
IR Iran	155.60	13.1%	Libya	48.36	4.1%	Angola	8.16	0.7%			
Iraq	145.02	12.2%	Nigeria	36.97	3.1%	Congo	2.98	0.3%			

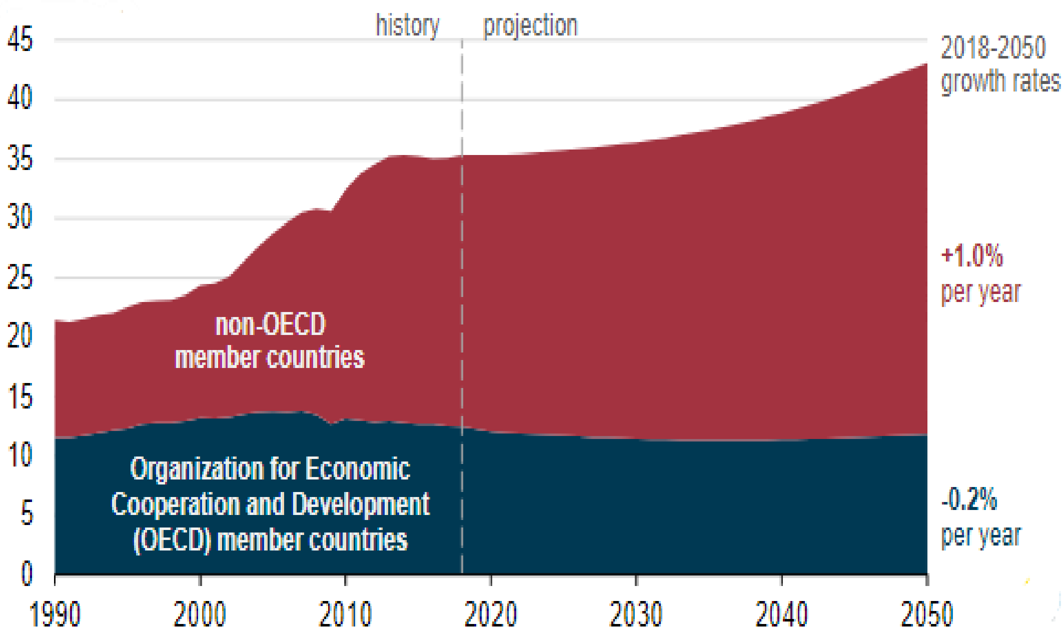
Source: OPEC Annual Statistical bulletin 2019

Ultimately, oil and gas resources may still be abundant, but there can be no guarantee that they will be adequately exploited to meet the level of demand forecast in the baseline scenario.

1.3 GLOBAL EMISSIONS

Due to the pandemic in 2019, there was a reduction in CO_2, which however are cancelling the increases of 2020 and 2021. In the latest report released by the IEA, "Global Energy Review 2021", an increase of 1.5 billion tons is expected in 2021, marking a + 5% on 2020 with a total of 33 billion tons (Gt, gigatons) released into our atmosphere from energy uses. In December 2021, global carbon dioxide emissions will be just below the level of 2019 (400 million tons less, approximately -1.2%). The IEA expects an increase in global carbon dioxide (CO_2) emissions from energy-related sources in the coming decades. However, it should be noted, that this growth is not evenly distributed throughout the world, as it mainly concerns countries outside the Organization for Economic Cooperation and Development (OECD). This is because countries outside the OECD collectively have more population, a larger gross domestic product, higher energy consumption and higher energy-related CO_2 emissions than the aggregate values of OECD countries.

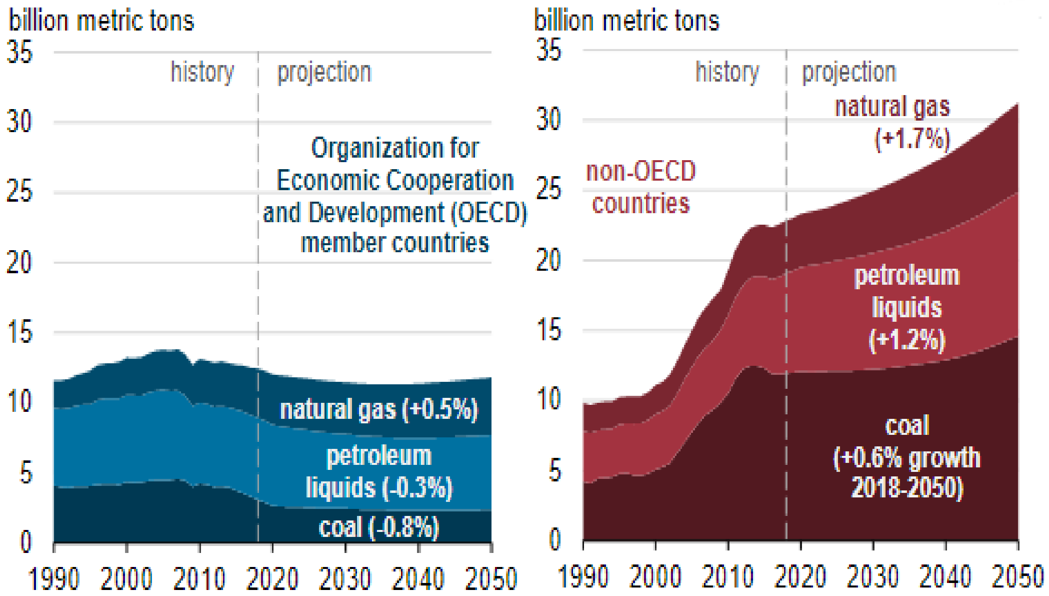
Fig. 1.5: Global energy- related carbon dioxide emissions (1990-2050)



Source: International Energy Outlook 2019

In non-OECD countries there is an expected energy consumption of 1.6% per year from 2018 to 2050 and energy-related CO_2 emissions will increase by 1.0% per year, but the growth in emissions of Coal-related CO_2 will be slower paced than other fossil fuels as natural gas replaces coal in power generation and industrial applications.

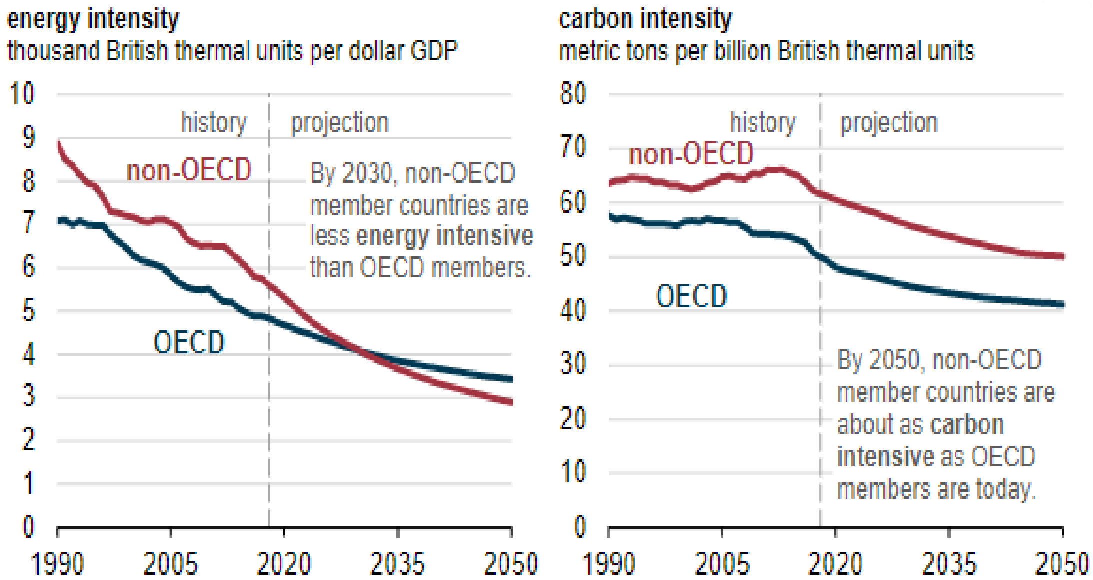
Fig. 1.6: Energy-related carbon dioxide emissions (1990-2050)



Source: International Energy Outlook 2019

The OECD is moving from energy-intensive production to lower energy-intensive production and commercial services, therefore economic activity continues to become less energy-intensive, slightly decreasing energy-related CO_2 emissions (-0.2%) from 2018 to 2050. In these countries, however, there is an increase in emissions from the consumption of natural gas. As for non-OECD countries, less energy use to generate economic activity is expected by 2032. However, they will continue to generate more CO_2 emissions per unit of energy consumed until 2050, so they remain more carbon-intensive than OECD countries.

Fig. 1.7: Global energy and carbon intensities IEO2019 Reference case (1990-2050)



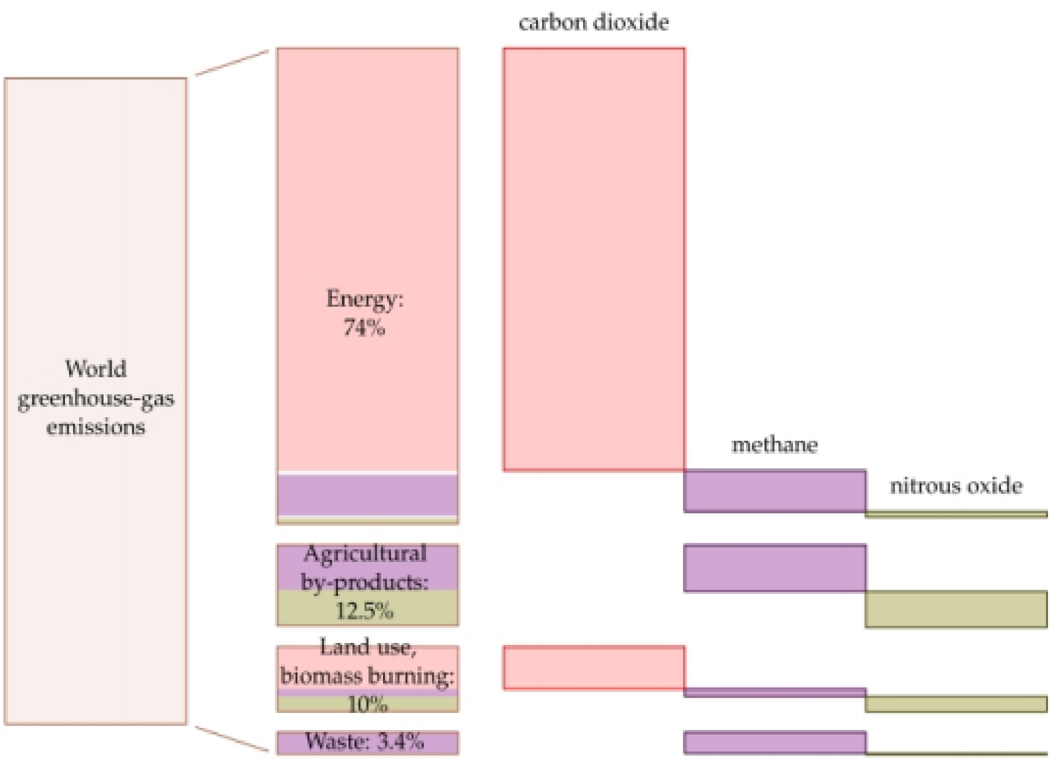
Source: International Energy Outlook 2019

By 2050, non-OECD economies will be as carbon intensive as OECD economies are today. If the trends expressed in the baseline scenario were to materialize, the expected growth rate of fossil fuels would result in a long-term concentration of greenhouse gases in the atmosphere above 1000 ppm CO_2. This would almost certainly cause severe climate change, with irreparable consequences for the planet. Therefore, it is necessary to change course and implement corrective energy policies as soon as possible.

1.4 TOWARDS ENERGY TRANSITION

The activities that release greenhouse gases into the environment are manifold. The sector that contributes almost three quarters of the total is that of energy, while 26% of emissions are due to the combustion of non-renewable biomass, deforestation, waste disposal and agriculture.

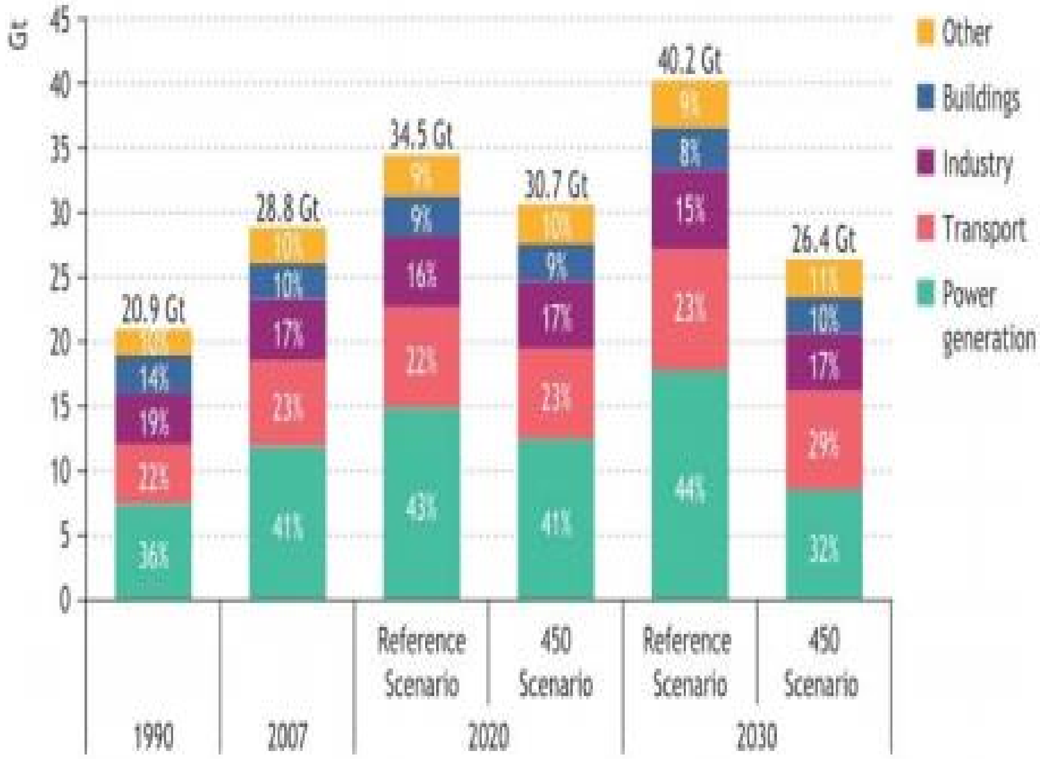
Fig. 1.8: World greenhouse gas emissions by cause and type of Gas.



Source: Fonte sustainable Energy

The scientific community is converging towards the need to limit global warming to a maximum of 2 ° C. Currently, greenhouse gas emissions related to the energy sector are mainly determined by the production of electricity for 40%, from transport for 25%, from the industrial sector for 15% and from domestic activities for 10%.

Fig. 1.9: World emissions from the energy sector.

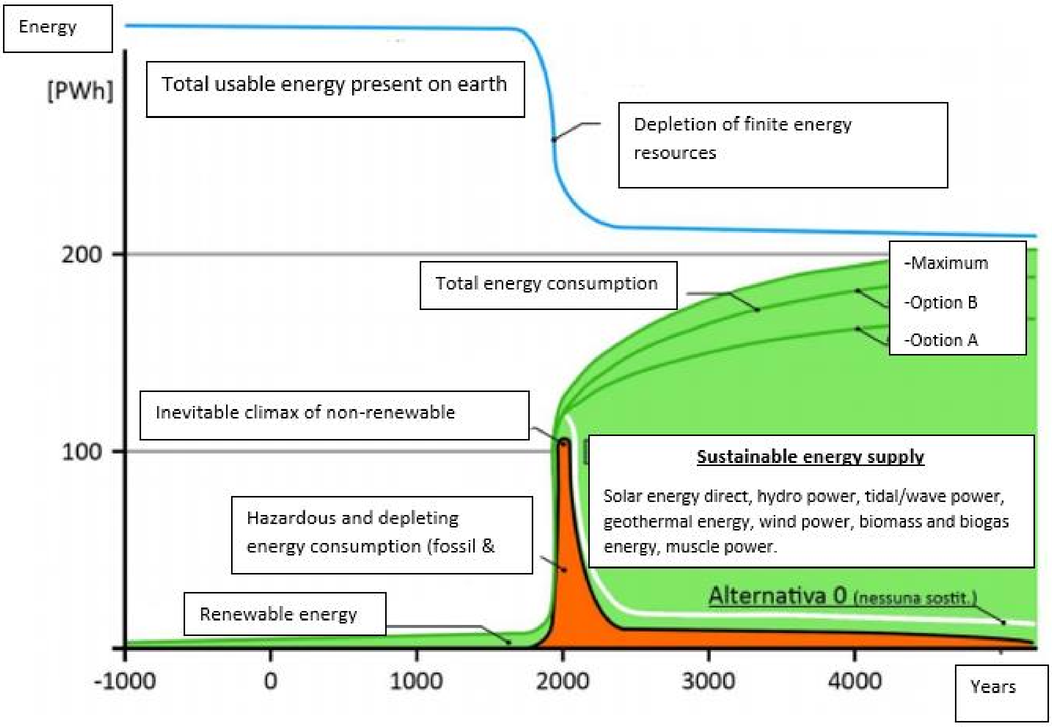


Source: WEO

The commitment of world governments to achieve this result must be strong and coordinated and must involve all sectors of energy production and consumption. Any agreement will have to take into consideration the importance of the participation of the main emitters, the five largest CO_2 producers, China, the United States, the European Union, India, and Russia, which together account for almost two thirds of total emissions.

In a scenario of this type, therefore, it is necessary to switch to so-called “alternative” renewable energy sources, since the massive use of fossil energy resources is incompatible with sustainable development. Renewable sources are preferred, because, as they are not exhaustible, they do not have the classic bell shape, but an "S" shape in which the growth phase is represented by the construction of plants in the available areas and ends with the achievement of their saturation and the consequent stabilization of the trend.

Fig. 1.10: Transition to sustainable energy economy



Sources: I.I.A.S.A.

In the early 70's, during the first oil crisis, was born the interest in hydrogen as a source of energy. Due to the conditions that the crisis had created, several scholars began to consider the fundamental role that hydrogen could play in the energy field. In the 1980s, efforts were intensified to develop technologies that would strengthen the link between hydrogen and alternative sources to reduce, if not eliminate, dependence on traditional fossil fuels.

Nowadays, hydrogen represents for many an extraordinary resource to quickly reduce CO_2 emissions, especially in certain areas, such as road, ship and air transport, some industries that are difficult to electrify and in heating. Hydrogen has all the potential to decarbonize those sectors that are most intensive in emissions and environmental impacts, replacing the use of fossil fuels and other industrial processes to reduce polluting emissions, such as steel production, chemistry, metallurgy. Furthermore, renewable hydrogen represents an option to reduce emissions in thermal energy consumption, especially in regions with a colder climate.

1.5 MILESTONES TOWARDS THE ENERGY TRANSITION

Tab. 1.1: Stages of energy transition

Year	Stage	Purpose
1992	Rio de Janeiro Conference;	combat overheating - United Nations Framework Convention on Climate Change
1995	Conference of the Parties in Berlin	strengthen the commitments of developed countries - Berlin Mandate
1997	COP3-Kyoto Protocol (ratification 1998/ entered into force in 2005)	reduce emissions, promote energy efficiency - Clean Development Mechanism
2009	COP15- Copenhagen Conference	investing in renewable sources, keeping temperatures below 2 ° C, Green Climate Fund (30 billion dollars a year, after 2020, 100 billion dollars)
2012	Doha Conference	extend the validity of the Kyoto Protocol until 2020
2015	COP21-Paris Conference	keep the temperature increase below 1.5 ° C
2018	COP24- Katowice Conference	make the Treaty of Paris operational with common rules and guidelines
2019	COP25-Madrid Conference	maximum ceiling for CO_2, nitrogen oxide and ozone killer gas emissions
2019	European Green Deal	Sustainable Development

Source: unfccc.int

Scientists are concerned about the continued rise in global temperature which has increased by an average of 0.85 ° C since the 19th century. The increase in temperature above 2 ° C would have catastrophic consequences worldwide, and it is for this reason that the international community has recognized the need to contain the temperature increase below 2 ° C if we do not want to have irreversible consequences on the environment.

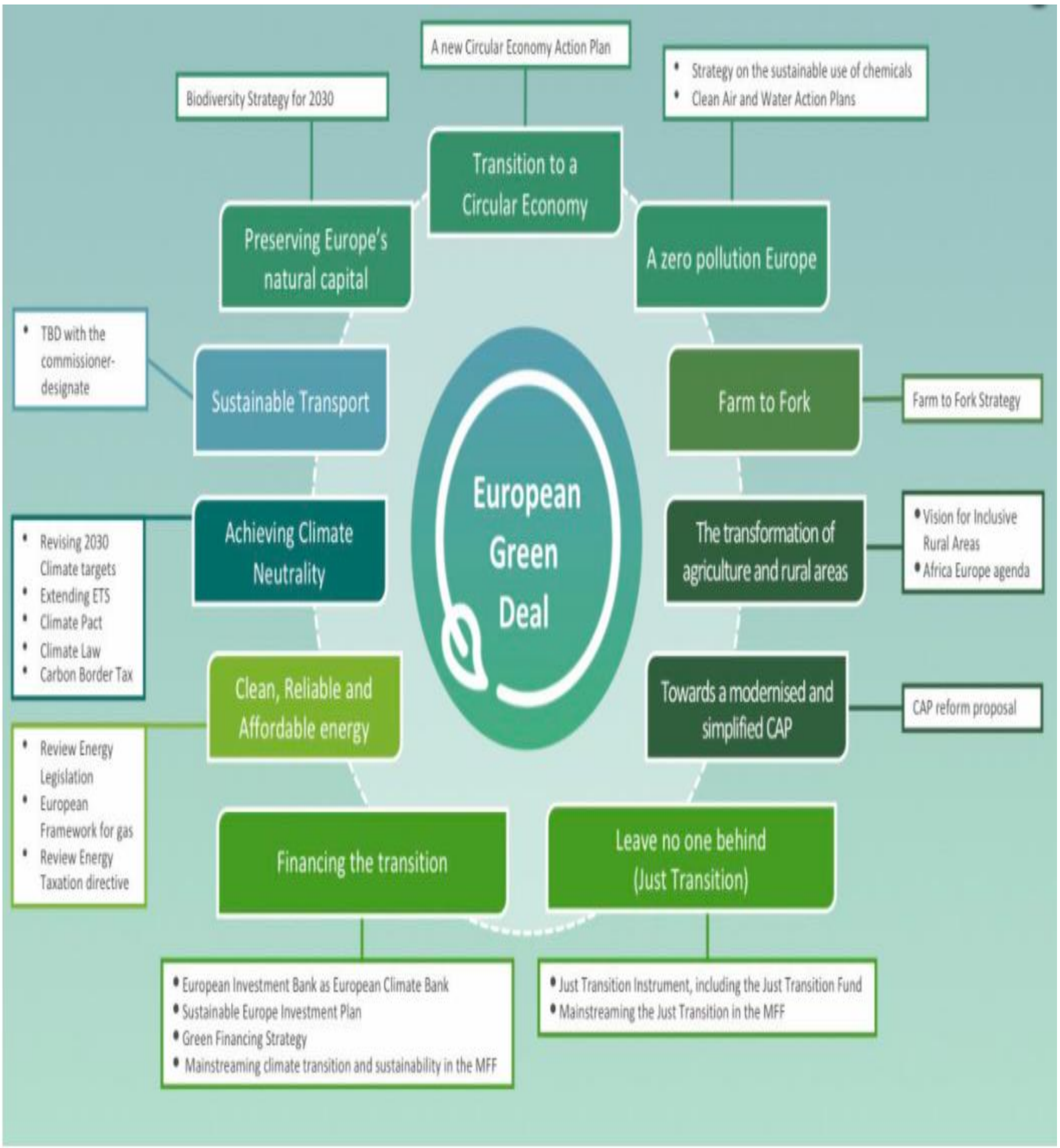
According to current state policies, the deterioration process seems unstoppable due to the growing demand for energy, while scenarios studied by the International Energy Agency and the European Union show feasible room for improvement.

Attention to the environment, however, is a recent reality as it was only in 1992, with the Rio de Janeiro Conference, that there was talk for the first time of climate change due to human activity. At this meeting, was adopted the United Nations Framework Convention on Climate Change, seen as the starting point for a future synergistic development to combat overheating. Right from the start, was highlighted the difference in responsibility between industrialized and developing countries, which obviously had a significantly smaller role in climate change. Subsequently, with the Conference of the Parties in Berlin, it was understood that the objectives of the previous conference were insufficient, and this was answered with the adoption of the "Berlin Mandate" and with the opening of further consultations to strengthen the commitments of the more developed countries. Two years after the Berlin Conference of the Parties, was organized in Kyoto one of the most important international meetings, which ended with the stipulation of the famous "Kyoto Protocol" which committed the Parties to improve energy efficiency, to promote clean energy sources, to develop CO_2 capture and storage technologies, always keeping in mind the attention to financial aspects and collaboration between states for the transfer of technologies to developing countries, also allows to treat emissions as an asset that can be traded through the Clean Development Mechanism (CDM). With the Doha Conference, held in December 2012, this Protocol was extended until 2020. There are therefore two phases: one that goes from 2008 to 2012 and one after 2012. In the first period, 37 industrialized countries and the European Union had to commit to reducing emissions by an average of 5% compared to 1990 levels. With the second phase, countries undertake to reduce emissions by 18% in the period from 2013 to 2020. Environmental conferences are held annually to try to reduce greenhouse gas emissions globally and keep public attention high. Another milestone for the energy sector and for the transition to a future system based on low carbon energy is COP21, held in Paris which commits the signatories (197 countries) to keep the temperature below 1.5 ° C. Upstream of COP21, the Parties presented their Intended Nationally Determined Contributions (INDCs) in which they describe all their initiatives to reduce emissions. When the Parties ratify or otherwise access the Paris Agreement, they must sign their Nationally Determined Contributions (NDC), which would be nothing more than their initial INDC project which, by joining automatically becomes official.

Another fundamental point of the agreement is undoubtedly transparency. In fact, the agreement provides for the timely communication by each country of the programs by 2020 and subsequently every five years of the results achieved. Furthermore, industrialized countries must report to the United Nations the support provided to developing countries.

The European Union and the ONU have made further steps forward, from an institutional and regulatory point of view, to fight climate change and to try to achieve the objectives set by the COPs over the years. Some of the main ones are the 2030 framework for climate and energy, which collects directives on the efficiency of energy sources and on renewable energy sources themselves, the European strategy for plastics in the circular economy, aimed at protecting the environment from plastic pollution and at the same time promoting growth and innovation, the 2030 Agenda for Sustainable Development, an action program for people, the planet and prosperity, signed in September 2015 by the governments of the 193 member countries of UN 13, which collects 17 sustainable development goals to be achieved by 2030. Lastly, the European Green Deal was presented by the von der Leyen Commission on 11 December 2019. A set of political initiatives carried out by the European Commission, an integral part of implementing the sustainable development goals taken in accordance with the 2030 agenda; this introduces a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient, and competitive economy, in which there are no net greenhouse gas emissions in 2050 and in which economic growth is decoupled from resource use.

Fig. 1.11: European Green Deal



Source: ec.europa.eu

At this point of the analysis, it was understood that change is necessary, and must be fast and efficient. This change must take place through renewable energies and here that hydrogen comes into play as an energy transition vector, as its advantages are innumerable, both from the point of view of physicochemical properties and from the point of view of advantages. In the next chapters we will focus in detail on the production, advantages, and limitations of this vector.

CHAPTER 2: THE ROLE OF HYDROGEN IN THE ENERGY TRANSITION

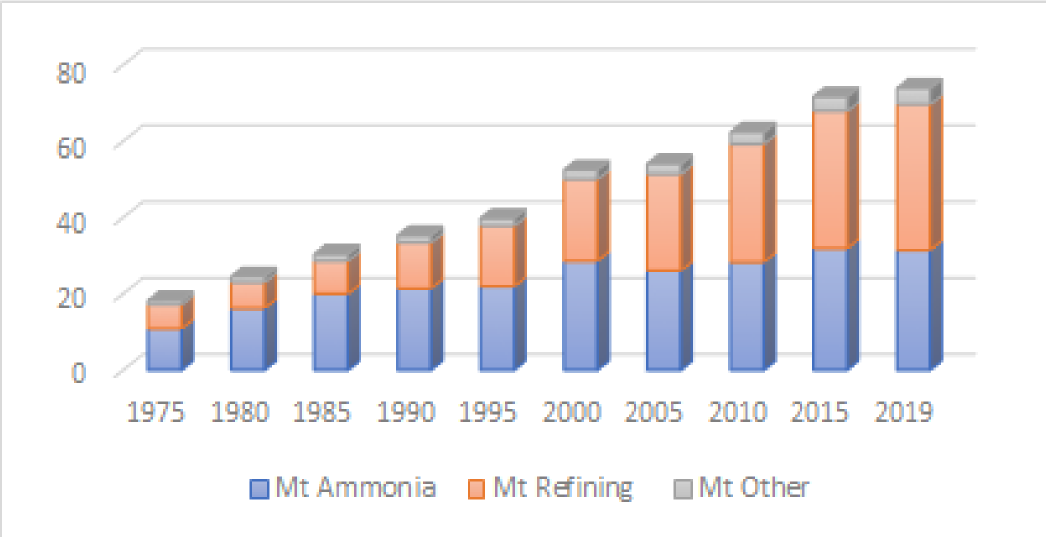
2.1 INTRODUCTION

In this chapter, following the analysis of the global, European, and national energy system, we will focus on what is considered the vector of the energy transition: hydrogen. We will analyse in detail the properties of the latter starting from its availability on Earth and proceeding with the various possible uses, advantages, and investments for the progress of this matter. We will focus on the distinction between the various types of hydrogen, that is, green, blue, grey, and purple, and then go into more detail on the possible implications of the different methods and technologies of hydrogen extraction in the next chapter (chapter 3).

2.2 AVAILABILITY AND PRODUCTION

The demand for hydrogen since 1975 has tripled and continues to grow almost entirely supplied from fossil fuels, with 6% of global natural gas and 2% of global coal going to hydrogen production.

Fig. 2.1: Global demand for pure hydrogen, 1975-2018 (Mt/y)



Source: International Energy Outlook 2020

2.2.1 Properties of Hydrogen

Hydrogen (symbol H) is the most common element in the universe, we find it in all organic compounds and in all living organisms. It is the lightest and simplest and in the elementary state, it exists in the form of a diatomic molecule (H2). At atmospheric pressure and room temperature (298K), it is a colourless, odourless, tasteless, and highly flammable gas. It is not very common in our planet in pure form, in fact, it is detectable in the free state only in volcanic gases and in some natural gases. Its lightness, in fact, makes it escape from the earth's gravity and its extreme reactivity causes it to form numerous chemical compounds. As a component of compounds, hydrogen is the tenth most abundant element on earth, present mainly in water, minerals, and hydrocarbons such as oil and natural gas. One of the main properties of hydrogen is precisely that of forming compounds with all known elements except noble gases, this is due to its electronegativity (2.2), which allows it to react with both metals and non-metals.

2.2.2 The discovery of hydrogen

Tab. 2.1: The discovery of Hydrogen

Year	Discoverer	Discovery
Early 16th century	T. Von Hohenheim (known as Paracelsus)	Production of hydrogen in its pure gaseous form, dissolving iron "in vitriol alcohol".
1671	Robert Boyle	Production of pure hydrogen.
1766	H. Cavendish	The gas was extraordinarily light, with a density equal to one fourteenth of that of the air itself and had the curious property of generating water if burned, which is why he named it "inflammable air ";
1785	Antoine Lavoisier	new nomenclature by giving the name of hydrogen to the new element, from the Greek "water generator";
1931	Harold Urey	One of the three isotopes of hydrogen, namely deuterium;
1934	Ernest Rutherford, Mark Oliphant, Paul Harteck	Identification of another isotope, known as tritium.

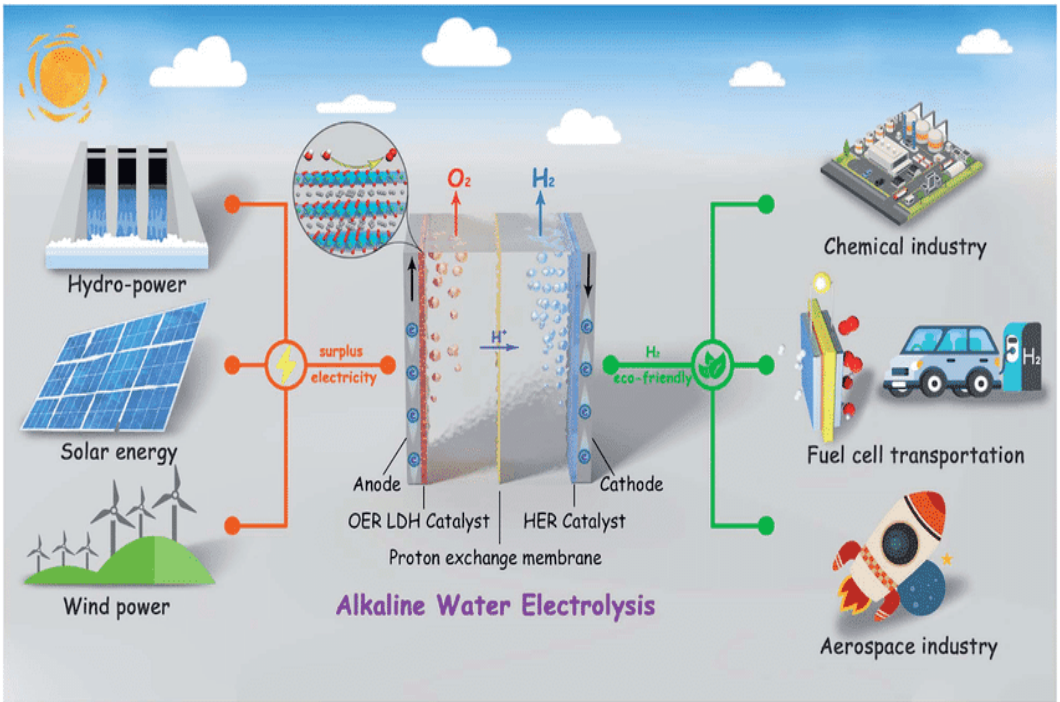
2.2.3 The production of hydrogen

We previously emphasized that hydrogen is founded in abundance in the universe, but this does not take away from the fact that the production in large quantities of this element remains difficult. Hydrogen must be produced from its compounds since its presence in the free form is scarce on our planet. Furthermore, as we have already mentioned in the properties chapter, hydrogen does not have a colour: it is a transparent and invisible element when it is in a gaseous state. However, in jargon, a chromatic attribute is assigned to different types of hydrogen depending on the way in which its extraction is carried out from the molecules in which it is combined and its environmental impact. These colours are grey, blue, green, and purple. Later we will discuss the main methods of hydrogen production that are electrolysis and steam reforming.

Electrolysis

Water electrolysis is a process that allows transforming electrical energy into the chemical energy of hydrogen. The reaction takes place in the electrolytic cells, into which an aqueous solution is poured. As the current passes, the ions migrate to the electrodes of the cell where they discharge their electrical charge, breaking down the water molecule and releasing hydrogen in the cathode and oxygen in the anode. This transformation takes place with the yield of about 70%.

Fig. 2.2: The process of electrolysis of water using renewable energy



Source: Research Gate: Sustainable energy system based on an integrated water electrolysis system for renewable hydrogen fuel generation.

With the electrolysis process, we can obtain two types of hydrogen:

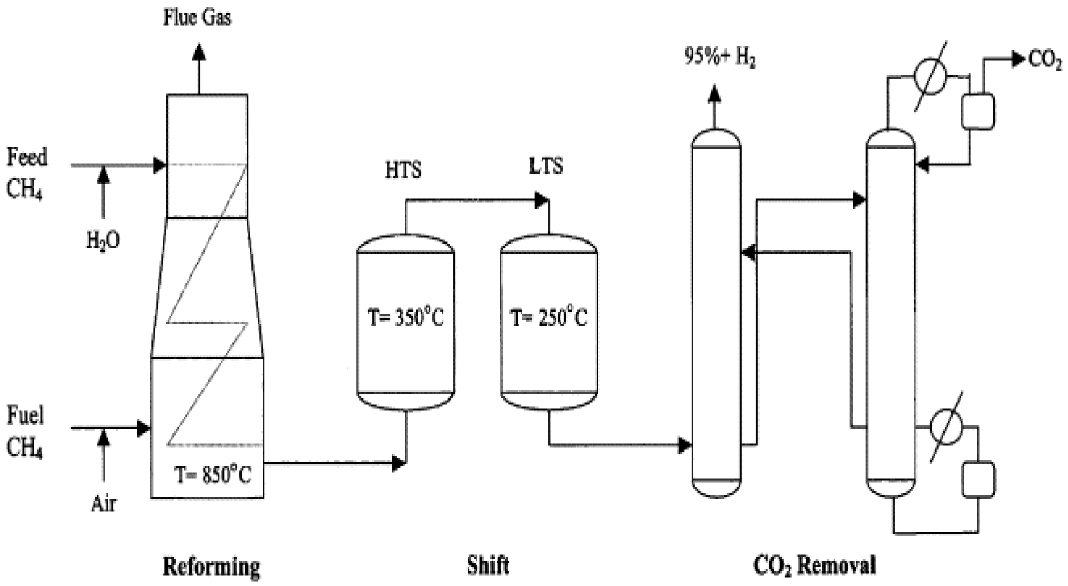
- Green hydrogen: it is obtained by feeding electrolysis plants with renewable energy, which is why it is called renewable hydrogen. Among the various types of hydrogen, it is the cleanest as it is completely decarbonised (as no amount of carbon dioxide is released into the atmosphere for its production).

- Purple hydrogen: it is obtained by feeding electrolysis plants with nuclear energy, in this case, we speak of hydrogen with a low-carbon footprint, (this type of hydrogen is decarbonised).

Steam Reforming

97% of hydrogen is now obtained from so-called reforming processes, which use fossil fuels. The most used is methane reforming.

Fig. 2.3: Steam-methane Reforming



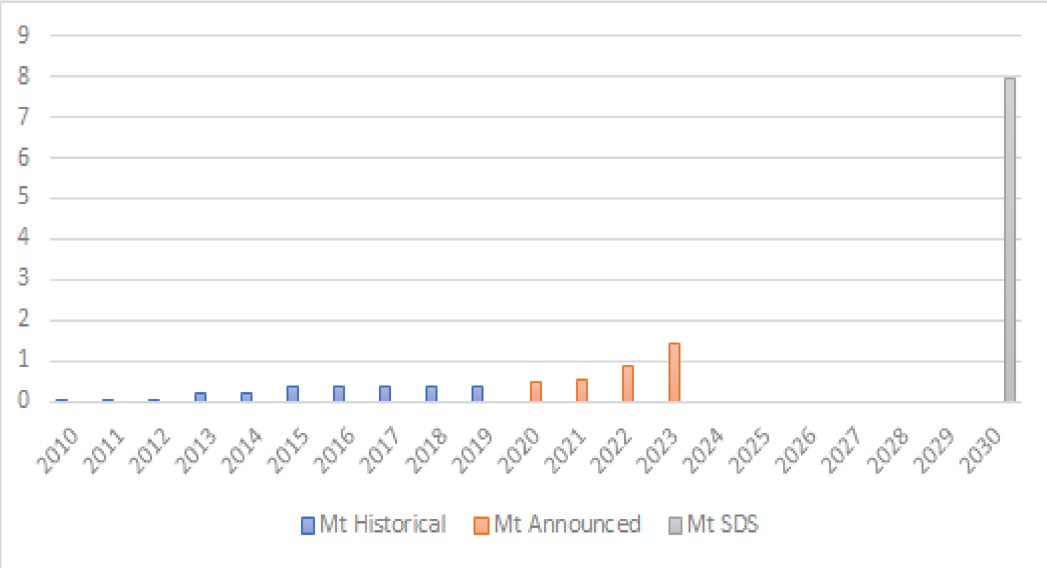
Source: ScienceDirect

With this process, we obtain two different types of hydrogen:

- Grey hydrogen: it is obtained from natural gas or from the gasification of coal and through a thermochemical conversion process that, however, also produces CO_2. Grey hydrogen, so called because it derives from a polluting process, is the worst quality one, but now it constitutes the largest amount of hydrogen produced in the world (around 95%).
- Blue hydrogen: it is obtained with a process similar to that of grey hydrogen, it differs from it during the process when carbon dioxide, instead of being released into the atmosphere, is captured and injected stably, for example in the same reservoir from which methane is extracted (today about 90% can be captured).

Therefore, the largest amount of hydrogen produced in the world remains grey hydrogen, produced through fossil fuels. There is a need to implement electrolysis processes to ensure that low-carbon replaces high carbon hydrogen production, since despite the increase in electrolysis processes in 2019, the figures are self-evident, low-carbon production capacity remained relatively constant and is still off track with the SDS.

Fig. 2.4: Low-carbon hydrogen production, 2010-2030, historical, announced and in the Sustainable Development Scenario, 2030 (Mt/y)

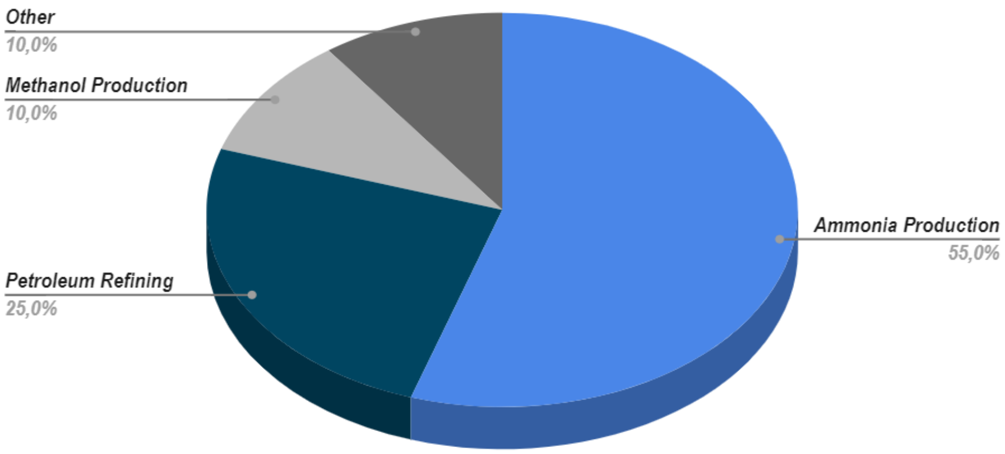


Source: International Energy Agency-Tracking Energy Integration 2020, Hydrogen.

2.3 APPLICATIONS AND USES

Hydrogen is considered as an enabling solution for a Sustainable 21st Century as it can provide an efficient, clean, and reliable source of power and heat for a suite of applications using a range of energy sources. In fact, the sectors in which hydrogen is used, as we will see by proceeding in the analysis, are many, and the forecasts for 2050 make us note that we do not intend to stop using today's hydrogen but to involve hydrogen in greater quantities in industrial activities that we will see later.

Fig. 2.5: Global hydrogen consumption by industry



Source: WHA International-Hydrogen Industry Applications

Tab. 2.2: Common industry applications of hydrogen

Industry	Applications of hydrogen
-Agricultural/Chemical Industry	fundamental raw material needed to produce ammonia (NH3), an important part of fertilizers used in agricultural industries around the world.
-Petroleum Refining Industry	commonly used in hydrocracking to create petroleum products, including gasoline and diesel.
-Food	used to turn unsaturated fats into to saturated oils and fats, including hydrogenated vegetable oils like margarine and butter spreads.
-Medical	used to create hydrogen peroxide (H2O2). Recently, hydrogen gas has also been studied as a therapeutic gas for a number of different diseases.
-Metalworking	used in multiple applications including metal alloying and iron flashmaking.
-Transport	Nine of the major auto manufacturers are developing hydrogen fuel cell vehicles (FCVs) designed for personal use.
-Power generation	used for cooling power plant generators, but it also provides a promising means of electrical grid stabilization.
-Global logistics	Dozens of companies with large warehouse and distribution needs are turning to hydrogen fuel cells to power trucks, forklifts, and more.
-Aviation	Several experimental programs have utilized hydrogen fuel cells in projects like the Pathfinder and Helios unmanned long duration aircraft.

The following assumptions have been made for each of the sectors in the table for 2050.

Tab. 2.3: Predictions on common industrial applications of hydrogen for 2050

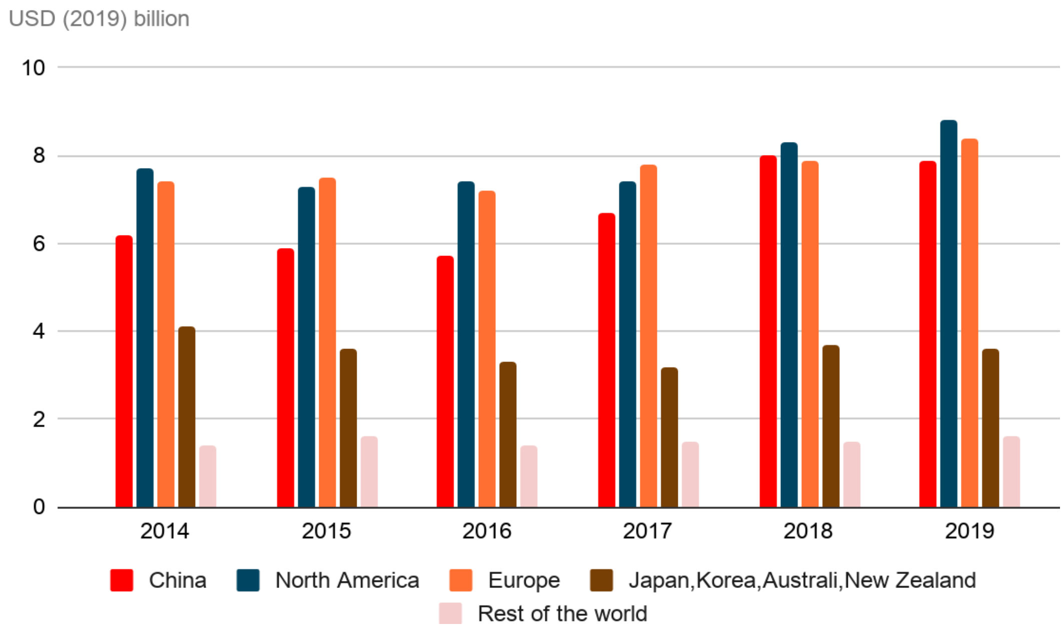
Industry	Clean hydrogen from natural gas with CCS is assumed to be used as feedstock in chemical industry, replacing the use of hydrogen from natural gas without CCS in refineries, ammonia production and production of methanol. Annual reduction of CO2 emissions of 60Mt CO2.
Transport	Hydrogen is assumed to replace fossil fuels in the heavy-duty segment of road transport and of trein sector,, currently emitting 27% of the greenhouse gases of the transport sector, with corresponding reduction of CO2 emissions of 276 Mt CO2.
Residential and Commercial	Hydrogen is assumed to replace fossil fuels used for heating. Assumed a reduced energy consumption of the residential and commercial sectors of 38% and 15% respectively. Annual CO2 reduction potential of 301 Mt CO2.
Power	Hydrogen is assumed to replace natural gas in power production. Annual CO" reduction potential of 29 Mt CO2.

So, as we can imagine, the goal is to create an energy system based on hydrogen, with the construction of plants to produce energy that use the hydrogen produced by the electrolysis of sea water. Even if the research has reached appreciable goals, all the technologies related to the use of hydrogen are still to be developed and perfected and there are considerable obstacles to overcome for this vision to become a reality.

2.4 GLOBAL R&D SPENDING ON ENERGY

The rudder that guides the progress of research is the investment that each nation makes in their respective R&D. Analysing the IEA data on investments in R&D, we immediately notice that there was an increase in 2019 of 3% in Government energy R&D spending. At 80%, more public energy R&D went to low-carbon technologies in 2019 than the prior year, but the near-term outlook depends on the inclusion of clean energy R&D in recovery measures.

Fig. 2.6: Spending on energy R&D by national governments and the European Union, 2014-2019



Source: IEA-Innovation

The primacy on spending as we can see from the graph is held by North America followed, and overtaken in 2017 and then back in second place in 2018, by Europe. China has relatively constant spending over time with a sudden rise in 2018. Spending data for Japan, Korea, New Zealand, and Australia are relatively low and constant over time. Lastly, we find other countries of the world, their spending is low over time and remains constant without ever increasing. In fact, data have been aggregated because they are not relevant from the positive point of view of the growth of progress, but we can interpret them negatively as, there is a need for a change of course for these countries if they want to close the gap with the rest of the world.

Tab. 2.4: Global spending on energy R&D, 2014-2019

Year	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Global spending on energy R&D	26.8 USD (2019) billion	25,9 USD (2019) billion	25 USD (2019) billion	26,6 USD (2019) billion	29,4 USD (2019) billion	30,3 USD (2019) billion

Source: Source: IEA-Innovation

Analysing the data on global spending on energy R&D we notice a decrease in expenses in 2015 and 2016, and then witness a sudden increase in expenses starting from 2017, then exceeding in 2018 and 2019 the spending levels of 2014, reaching spending on energy R&D 30.3 USD (2019) Billion. This increase is due to the increase in the number of countries with polices that directly support investment in technologies, production, and development.

As for hydrogen, around 50 targets, mandates and policy incentives are in place today that directly support hydrogen, most of which are transport focused. International cooperation is required to stimulate investments in factories and infrastructure that will reduce costs and enable the sharing of knowledge and best practices. Cooperation is essential to accelerate the growth of versatile and clean hydrogen around the world. The hydrogen trade will benefit from common international standards. In support of this cooperation, we have the IEA, the global energy organization covering all fuels and technologies, which will continue to provide rigorous analysis and policy advice to support international cooperation and to monitor progress over the years to come.

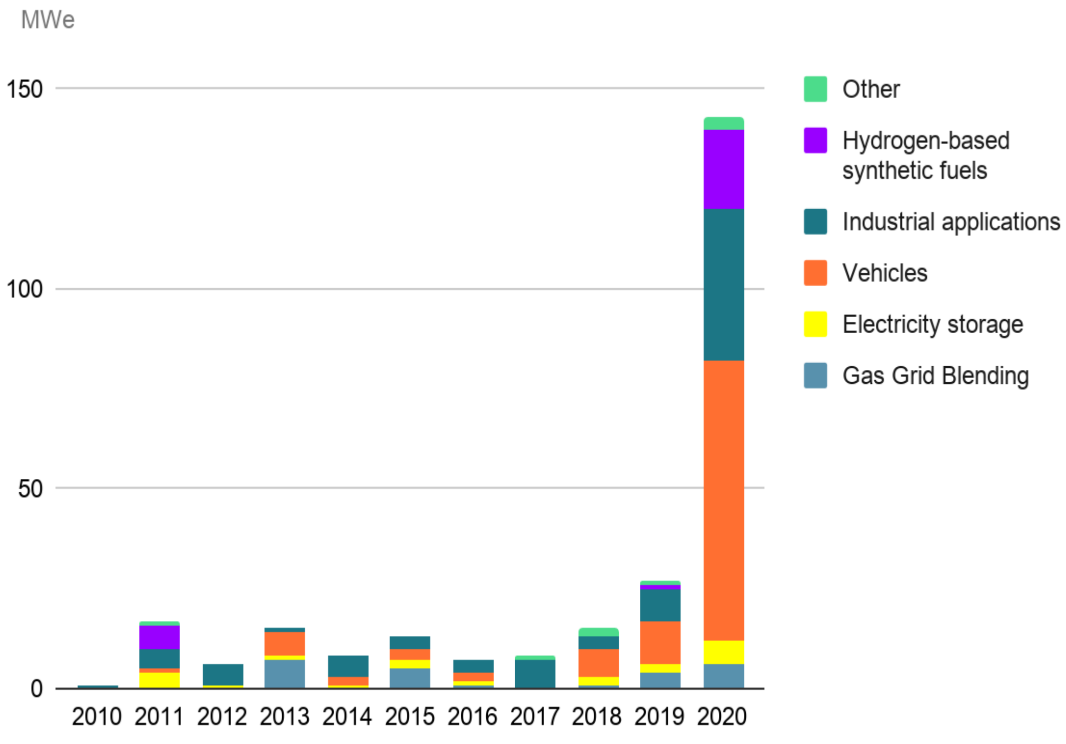
IEA offers some key recommendations to help governments, companies, and others to seize this chance to enable clean hydrogen to fulfil its long-term potential.

Tab. 2.5: Roadmap for the future

1. Prioritise, track and adjust	Review the processes for selecting technology portfolios for public support to ensure that they are rigorous, collective, flexible and aligned with local advantages.
2.Raise public R&D and market led private innovation	Use a range of tools – from public research and development to market incentives – to expand funding according to the different technologies.
3.Address all links in the value chain	Look at the bigger picture to ensure that all components of key value chains are advancing evenly towards the next market application and exploiting spillovers.
4.Build enabling infrastructure	Mobilise private finance to help bridge the "valley of death" by sharing the investment risks of network enhancements and commercial-scale demonstrators.
5.Work globally for regional success	Co-operate to share best practices, experiences and resources to tackle urgent and global technology challenges, including via existing multilateral platforms.

Hydrogen as an alternative source to fossil fuel in a diverse range of uses, from powering vehicles to storing electricity, refining oil, heating homes, and producing synthetic fuels such as methane or ammonia, has been attracting increasing attention in recent years. This grow in attention is reflected in the investments that have grown over the past two years. In 2019, Electrolysers installed represent capital expenditure of around USD 40 million, while those in construction may be worth over ten times more.

Fig. 2.7: Capacity of electrolysers for hydrogen production by commissioning year and intended use of hydrogen, 2010-2020.



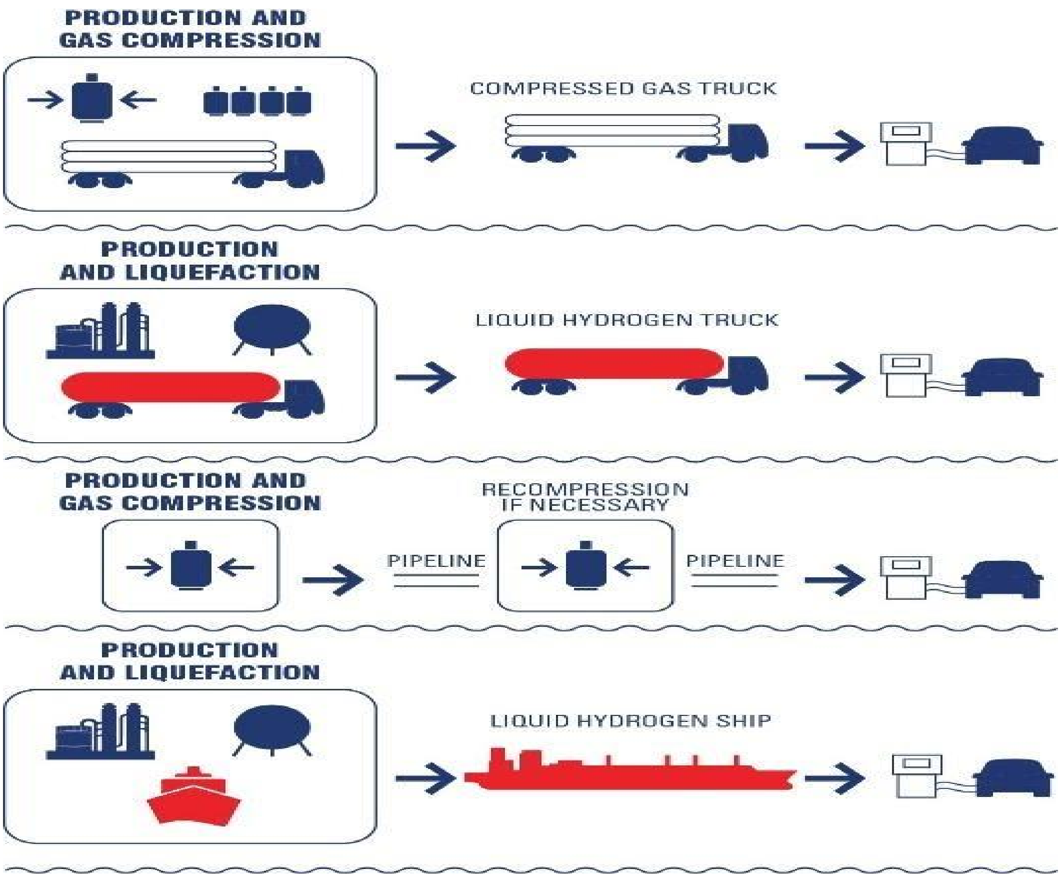
Source: IEA-Data and Statistics

Following elements analysed in this chapter we can say that hydrogen is on track to become the vector of the energy transition, thanks to its properties, its availability on earth, its uses in multiple fields and its countless advantages listed above. In addition, Nations are increasingly turning to hydrogen and thanks to new energy policies, investments, and expenses in this field, it will be possible to speed up the various production processes and reduce costs by progressing in technological research. As well as pros, unfortunately, hydrogen also has cons, mainly related to production costs, but we will see this in the next chapter.

2.5 ADVANTAGES

The characteristics of hydrogen make it an ideal energy source. It is now considered the fuel of the future. An advantage lies in one of its production processes, in fact, it can be produced from any source of energy, including renewable ones. Resuming the production processes, we know that to produce hydrogen we need water, and this is an advantage as there is plenty of water on our planet. Hydrogen is compatible with the environment, in fact green, purple and blue hydrogen do not emit greenhouse gases into the environment by retaining CO_2 in production processes, thus reducing air pollution. A further advantage of hydrogen is that it can be transported easily as storage can take place both in liquid and gaseous form and in the form of metal hydrides. The main solution for hydrogen transportation now is divided into road transportation, rail transportation and hydrogen pipelines. Hydrogen ocean transportation is also emerging as a promising alternative that will be available soon.

Fig. 2.8: Transportation of Hydrogen



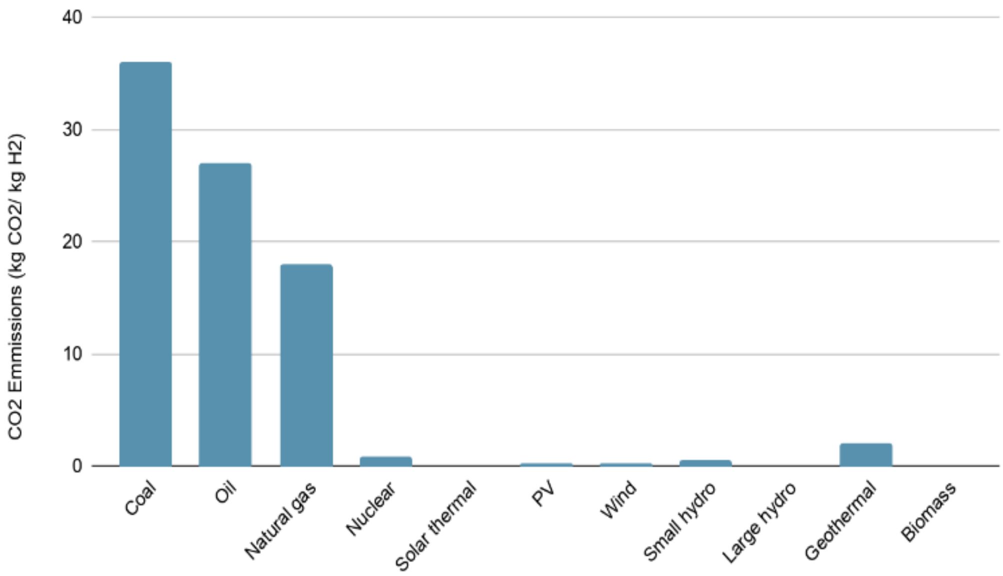
Source: Hydro Ville, "How is hydrogen transported?"

Another advantage of hydrogen is the possibility of converting it into other forms of energy in different ways, for example through catalytic combustion, electrochemical conversion, creation of hydrides, etc. Therefore, taking stock of the situation, summarizing the general characteristics of the hydrogen, and taking up the various fields in which it can be used, the advantages or pros of hydrogen are:

- Greenest energy source
- Renewable and sustainable
- Almost no emissions
- Carbon-free energy source
- More efficient compared to other energy sources
- No noise pollution
- No visual pollution
- Hydrogen power may be perfect for remote region
- Fuel cells could be used for several devices
- Lower dependence on fossil fuel

In addition to the mentioned benefits of hydrogen, unlike other alternative energies such as wind power or biofuels, hydrogen energy has no real visual pollution effects as hydrogen power plants are quite clean and do not need much space to function and there is literally no noise pollution. Then if we stop to think, we also understand how hydrogen can be a huge advantage for rather remote regions that are not well connected to the public electricity grid, as fuel cells could be a good alternative for generating energy in the next decades and precisely thanks to the use of fuel cells, countries could become independent from the fossil fuel supply from other countries and could therefore also guarantee their independence regarding their political attitudes.

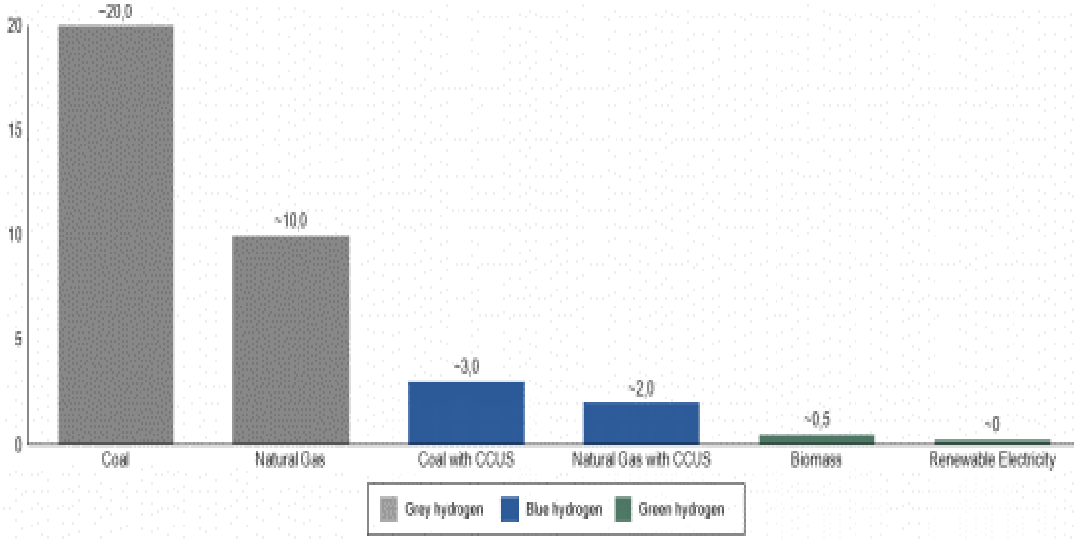
Fig. 2.9: CO_2 emissions during hydrogen production from different energy sources.



Source: Alternative fuels data centre-Hydrogen

In the figure above we can understand why the use of hydrogen represents an advantage as regards CO_2 emissions. It affirms the fact that the CO_2 emissions emitted during the production process of hydrogen from renewable sources are practically zero while sources such as coal, oil and natural gas represent the causes of CO_2 emissions on earth. If we take up the distinction of hydrogen in various colours made previously, for the quantity of CO_2 emitted during the production process, grey hydrogen, i.e., that produced from fossil sources, obviously cannot fall within the idea of hydrogen as an energy transition vector.

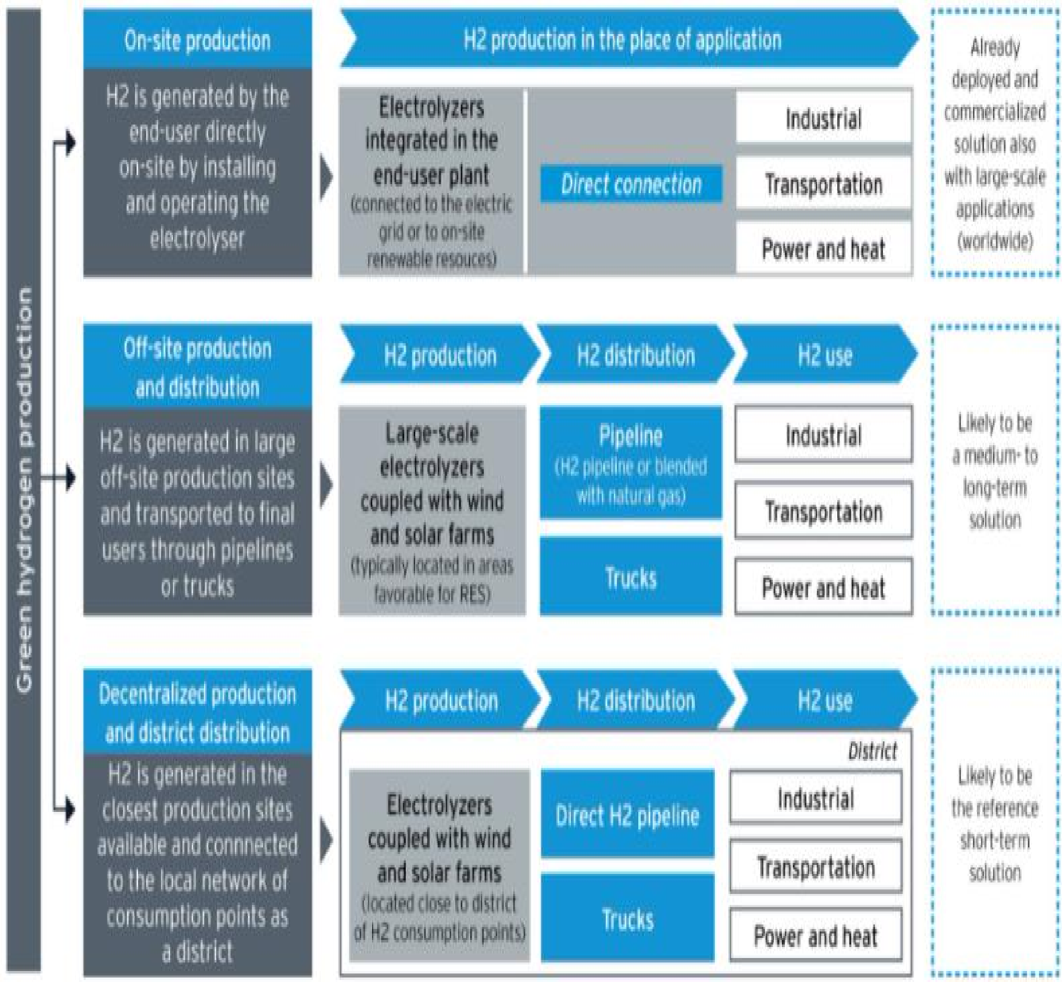
Fig. 2.10: H2 carbon intensity – comparison between grey, blue and green H2 (kg CO_2 /kgH2)



Source: Alternative fuels data centre-Hydrogen

Green hydrogen, as discussed above, is the lowest carbon intensive option, nonetheless several limits related to its production exist, and we will discuss about them in the next chapter. The main reason is attributable to a green hydrogen's non-competitive cost of production. Therefore, current industrial hydrogen consumers and potential future consumers are called to act and contribute to industrialize the existing technological solutions in the realm of green hydrogen rendering it financially feasible. In any case, green hydrogen, thanks to its use in the decarbonization process and thanks to the advantages that we have previously listed, is considered an excellent vector for the energy transition.

Fig 2.11: Green Hydrogen Generation: Three Supply Chain Models Available



Source: EY-Parthenon analysis

The advantages of on-site are the transport costs do not present and the non-need for transport infrastructures, those of off-site distribution, mass consumption and lower production costs based on economies of scale and finally the benefits of generation decentralized are the lower production costs based on economies of scale and the limited time for the development of the hydrogen network.

Therefore, having reached the end of this chapter, hydrogen seems to have all the credentials to trigger the next zero-emission evolution. However, much research is needed and the infrastructure around production technologies needs to be improved to make it a suitable alternative to other energy sources. In the next chapter we will see in fact what are the limits and risks of this vector.

CHAPTER 3: LIMITS AND RISKS OF HYDROGEN

3.1 INTRODUCTION

To switch to a Hydrogen Economy, it is necessary to calculate, at least approximately, the advantages and inconveniences that such a change would bring. In this chapter we will examine risks and limits of hydrogen. We will start from the risks deriving from the chemical-physical properties of the element, namely the explosion, the fire, its danger when it is at low temperatures and what it causes when it is at high pressures. We will proceed by evaluating the costs of hydrogen production and transport.

3.2 CHEMICAL-PHYSICAL PROPERTIES

Tab. 3.1: Chart showing Hydrogen Flammability Limits (in air), Explosion Limits (in air), Ignition Energy (mJ), Flame Temperature in air, and Stoichiometric Mixture (in air) as compared to Gas Vapor and Natural Gas.

	Hydrogen	Gasoline Vapor	Natural Gas
Flammability Limits (in air)	4-74%	1.4-7.6%	5.3-15%
Explosion Limits (in air)	18.3-59.0%	1.1-3.3%	5.7-14%
Ignition Energy (mJ)	0.02	0.20	0.29
Flame Temp. in air (°C)	2045	2197	1875
Stoichiometric Mixture (most easily ignited in air)	29%	2%	9%

Source: Research gate

Hydrogen Hazard

Tab. 3.2: Hydrogen Hazard

Combustion	Low temperature
Pressure	Health

The properties of table 1 classify hydrogen as highly flammable, in fact, as can be seen, the flammability range is wide and goes from 4 to 74%. For this, innumerable precautions must be taken during the production, storage, transport and use of this substance. Even weak sparks can ignite a leak of hydrogen, resulting in an invisible, very narrow, directional flame that focuses energy on a small surface. Furthermore, hydrogen can form potentially explosive mixtures with air, oxygen, and other oxidizing gases. Due to its low density and viscosity, there is a risk of leakage from circuits and materials that are normally impermeable to other gases. Explosions can be generated, for example in the event of the presence of air in a circuit or due to gas leaks in closed environments. An explosion caused by hydrogen can occur in confined spaces (e.g., small unventilated rooms, containers, vessels), mixing with air or oxygen. Another hydrogen hazard is low temperature, in fact liquid hydrogen can be dangerous due to its low temperature (-253 ° C at 1 bar) as it causes cold burns, can make normally ductile materials fragile, can cause blocking of equipment or devices and due to freezing of the air can create explosive atmospheres, (LH2 / oxygen frozen at temperature <-212 ° C). Accidents that occur due to hydrogen are distinguished by the resulting dangerous consequences.

Tab. 3.3: Consequences caused by accidents due to hydrogen on a sample comprising of 213 cases with known consequence.

Consequences	On a sample comprising 213 cases with known consequences	
	Nb of cases	%
Deaths	25	12
Serious injuries	28	13
Injuries	78	33
Internal material damage	183	86
External material damage	17	8
Internal operating losses	89	42
Evacuated population	8	3,8

Source: Aria-European Industrial accident

It must be noted that the human consequences for hydrogen-related accidents mainly target employees of disaster sites. Rescue workers and the public are only rarely affected. Thus, all mortal accidents whose deaths are detailed concern employees. These facts are related to the accident typology involving hydrogen, as well as the rapid kinetics of the underlying phenomena: 84% of the studied events include fires and/or explosions. The remaining 16% concern non-ignited H2 leaks, runaway reactions without explosion or corrosion detected prior to accident.

The main sectors of activity concerned by accidents involving hydrogen can be identified by two types:

- activities where hydrogen is either produced or used: chemical, refining, transport, packaging, nuclear industry.
- activities where hydrogen is accidentally produced: metallurgy and metal works, sanitation, waste treatment and recycling.

Tab. 3.4: Main sectors affected by accidents caused by hydrogen on a sample of 213 cases.

Activities	On a 213 cases sample	
	Nb of case	%
Chemical sector*	84	39
Refining/petrochemical industry*	47	22
Transport, packaging and storage	35	16
Metallurgy/metal works Waste	17	7,9
treatment/recycling	8	3,7
Nuclear industry	5	2,3

*Excluding transport, packaging, and storage

Source: Aria-European Industrial accident

So, as we can see from the table above risks involving hydrogen concern many activities that use or produce the gas such as chemical, pharmaceutical, oil refining, nuclear or transport industries, as well as metallurgy, metal processing and recovery or sanitation for which the risks are even more pernicious as hydrogen is often generated accidentally. Regard to the origin of accidents involving hydrogen, the analysis shows that in over 70 % of the cases “organisational and human factors” contribute to the deep-rooted causes of the accidents. Constant vigilance must be called for at all hierarchical levels in the facility - management, supervisory staff, technicians, subcontractors – while bearing in mind that there is a permanent risk of ignition in the presence of hydrogen.

3.3 LIMITS

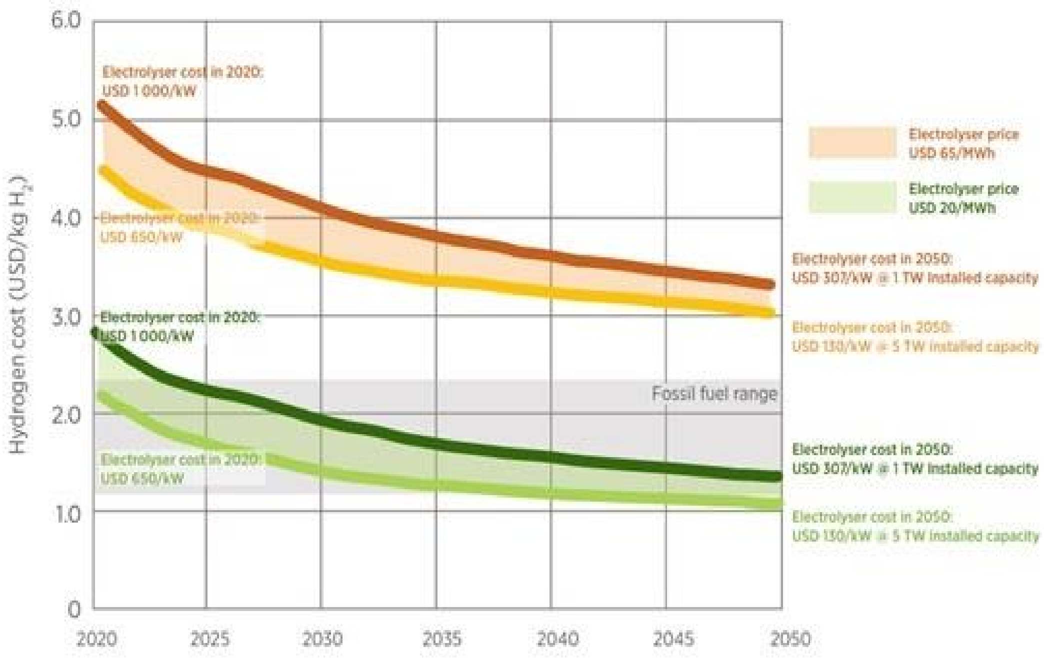
As regards the limits of hydrogen, starting from the principle and the analysis made previously, it is necessary to consider the fact that hydrogen must be produced. On Earth, hydrogen is not found in a pure state but only in a combined form in molecules with other chemical elements. When it is in the combined state, however, hydrogen does not produce energy, so to obtain it in its pure state it is necessary to separate it from other atoms that make up the molecules and this process requires energy consumption. This is one of the reasons that many times leads the use of hydrogen to be considered an inconvenience, but it all depends on the energy consumption necessary for its production. In fact, it remains essential to remember that hydrogen on Earth is not a source of energy but an energy carrier. As for the matter of hydrogen as a vector of clean energy, we must consider the fact that this depends on the energy used to produce it. Hydrogen is a vector of clean energy only when it is produced using clean energy sources, such as renewable energy, when fossil sources are used instead, pollution is produced and as we have seen previously in the analysis, currently 95% of hydrogen is produced using sources fossils therefore releases CO_2 into the air in the production phase. To underline this negative element of the analysis is also added the fact that currently, in terms of production costs, neither renewable hydrogen nor that based on fossil fuels with carbon capture can compete with hydrogen based on fossil fuels.

Reporting in more detail some numbers we find that:

- the cost of producing grey hydrogen is € 1.25-1.5 / kg ($ 1–1.80 / kg per kilogram in the USA). We obtain this result considering the amount of energy contained in methane (the price of the potential energy contained in methane is about 25 € / 1000 kWh, or 0.025 € / kWh) needed to produce 1 kg of hydrogen with "reforming" (about 50 kWh).
- the cost of producing blue hydrogen is around 2 € / kg ($ 1.40-2.40 / kg per kilogram in the USA). We obtain this result by adding to the cost of "grey" hydrogen (see above), even those for the sequestration of CO_2 which increase plant costs because it becomes more complex. The efficiency of the process is reduced from 75-80% of the grey to about 69%.
- the cost of producing green hydrogen is about 7-8 € / kg (costs between $ 2.50-6.80 per kilogram in the USA). We obtain this result by considering the costs of the electrolysers, the renewable electricity used and the depreciation costs of the plants. Today, the efficiency of an electrolysis plant is between 56 and 60% in the long run, the efficiency should still improve up to 67-75%.

Despite these considerations it must be considered that the production costs of renewable hydrogen are rapidly falling. Those of electrolysers have already decreased by 60% in the last decade and are expected to halve by 2030 thanks to economies of scale. According to a new report from the International Renewable Energy Agency (IRENA), the hydrogen produced with electricity from renewable sources could compete in terms of costs with fossil fuels by 2030 and facilitate the achievement of climate goals. To make this overtaking possible should be the drop in the costs of photovoltaic and wind energy, necessary to power hydrogen production processes in a renewable manner and the best performance and economies of scale for electrolysers. These aspects will be key in boosting the spread of hydrogen in the EU economy. Furthermore, CO_2 emissions will make grey hydrogen more expensive as many EU states have already mobilized to set a minimum price of CO_2 that will gradually increase from around € 30 to € 40 per ton over the next 10 years, (currently in emissions trading system of the European Union, the price of CO_2 is between 20 and 25 euros per ton). This implies the possibility of adding around € 0.50 to the price of a kilo of grey hydrogen in Europe, bringing the total price to around € 2. So, as we have already mentioned above, green hydrogen could play a crucial role in the decarbonisation of sectors where direct electrification is more difficult, such as steel, refining, chemicals, long-range transport, shipping, and aviation. However, regulations, the way the markets are structured and above all the costs of producing electricity and electrolysers are still an important barrier to the spread of green hydrogen. In the next graph we see the strategies that IRENA has proposed for governments to reduce the cost of electrolysers by 40% in the short term and up to 80% in the long term, based on different electricity prices.

Fig. 3.1: Irena’s strategies for governments reduction costs of electrolysers based on different electricity prices.



Source: IRENA

The cost of producing green hydrogen is determined by the price of renewable electricity, the investment cost for the electrolysers and its hours of operation. Renewables have already become the cheapest source of electricity in many parts of the world, with auctions being awarded at record prices below $ 20 per megawatt hour (MWh). However, the reduction in investment costs for electrolysis plants must also be added to the reduction in the cost of electricity if the aim is to make the price of green hydrogen competitive with that of fossils. It is important to note that in countries where there is an abundance of wind and sunlight, such as in the Middle East, North Africa and Latin America, green electricity prices have fallen to around 2-euro cents per KWh. A further decrease is expected in the future. As for the USA, on the other hand, a drop in prices of up to 1.5 US cents per KWh is expected. There is a real prospect in these countries of mass production of green electricity for domestic use and of green hydrogen for both domestic applications and export markets. To achieve the objectives set, energy policy plays a fundamental role, for example through measures such as the minimum CO_2 prices we discussed earlier, therefore the authorities must absolutely favour the energy transition to ensure that this happens quickly.

In addition to the costs of hydrogen production, the costs for its diffusion must also be considered, the so-called transport costs. However, research has shown that these costs are not a limit for the hydrogen economy but rather make it very attractive. In fact, in most cases a network of ducts is used to transport hydrogen. This transport does not need additional energy as production takes place on the plain and the pressure drop to the end customer does not require further pressurization. As we have already found in the advantages, unlike natural gas, hydrogen does not cool down during expansion towards the next pressure threshold, so the many heaters in the network can be turned off. Furthermore, despite having a lower energy density, hydrogen can maintain a slip stream three times greater at the same pressure drop compared to natural gas. To find the cost of transport, a calculation of the average costs per KWh will suffice since already more than half of the existing homes and practically all commercial activities are connected to the gas network. The following data refer to a model that estimates the cost of supply of residential homes, and were collected by Karl-Heinz Tetzlaff, a chemist expert in the development of fuel cells.

Tab. 3.5: Costs of supplying hydrogen to residential homes

Type of costs	Incidence of costs for domestic users (cents / kWh)	Incidence of costs for industry (cents / kWh)
Production	2,5	2,5
Distribution	0,6	0,2
Concession fees	0,008	0,08
Total costs	3,18	2,78

Source: "The Hydrogen Economy by Karl-Heinz Tetzlaff'

From the table we see that the cost of procuring residential homes is estimated at € 0.006 / kWh, further increasing by 40% if we consider out-of-the-way places, such as skyscrapers or large residential areas. The 'replacement cost of natural gas' amounts to 0.002 € / kW and should be paid as rent to a gas company which on average has to pay out around 700 million euros per year under the municipal concessions, this involves an addition of 0, 08 cents / kWh. Instead, the cost of production is estimated by taking into consideration a 500 MW hydrogen factory which with a full annual use of 6000 hours produces 3 TWh and adding up the costs of raw materials, costs deriving from capital and costs for personnel. amount is estimated at 2.5 cents / kWh. Considering that in 2006, families paid around 6 cents / kWh for natural gas, the price of hydrogen is very attractive.

In summary, it can be said that hydrogen is unfortunately a highly energy-intensive storage method, especially when compared with the methods that dominate the market today, which also have lower costs. Based on these concepts, according to most operators and institutions operating in the sector, hydrogen will not dominate the energy storage sector of the future. Others, on the other hand, have a totally different vision, considering hydrogen the vector of the energy transition, supporting the development of a system that allows investments in this matter and that leads to the creation of a real hydrogen market.

3.4 THE CRITICALITY OF HYDROGEN

Once we have analysed the disadvantages from the point of view of physicochemical properties and the limits mainly due to the huge costs that do not make it competitive with respect to other fuels, the criticality of hydrogen should be emphasized in a more precise way, that is, as we have already said previously, hydrogen is not present in nature, before being used as a fuel it must be produced. It is not a source of energy but only an energy carrier, a "battery", and not all systems to produce it have a low environmental impact.

Hydrogen will also need to be transported and stored, that is, an entire industrial supply chain should be set up to use it, a supply chain that is currently still non-existent, or at least extremely limited. Moreover, many of the technologies needed to produce and distribute it in a cost-effective manner are still experimental, and there is no guarantee that they will really work on a large scale.

In short, the investments required in this sector are enormous, and it is not clear whether its benefits can match. Another critical point of the transition to a hydrogen economy is that nowadays the presence of fossil fuels is still very present, the resources we have are not finished and therefore it is difficult to move all combustion to renewable sources and hydrogen. Methane predominates, it is in daily use and practically present in all our homes, its radical replacement is complicated and expensive and the technology to ensure that green hydrogen predominates over other fuels still seems to lack. So, the option that many governments and national bodies have turned to is that of blue hydrogen. That is, producing hydrogen through steam reforming with the capture of CO_2 in order not to damage the environment, but obviously this option has its pros and cons. In fact, fossil fuels are used for production, and even though CO_2 is not released into the atmosphere it is captured and subsequently sequestered underground and in the long term it will certainly have its negative repercussions.

In this regard, in the next chapter we will examine which countries and sectors have a greater penetration of the use of hydrogen and we will analyse the possible determinants of this diversity.

CHAPTER 4: A WAY TO ACHIEVE ENERGY TRANSITION AND ITS POSSIBLE EFFECTS ALL OVER THE WORLD

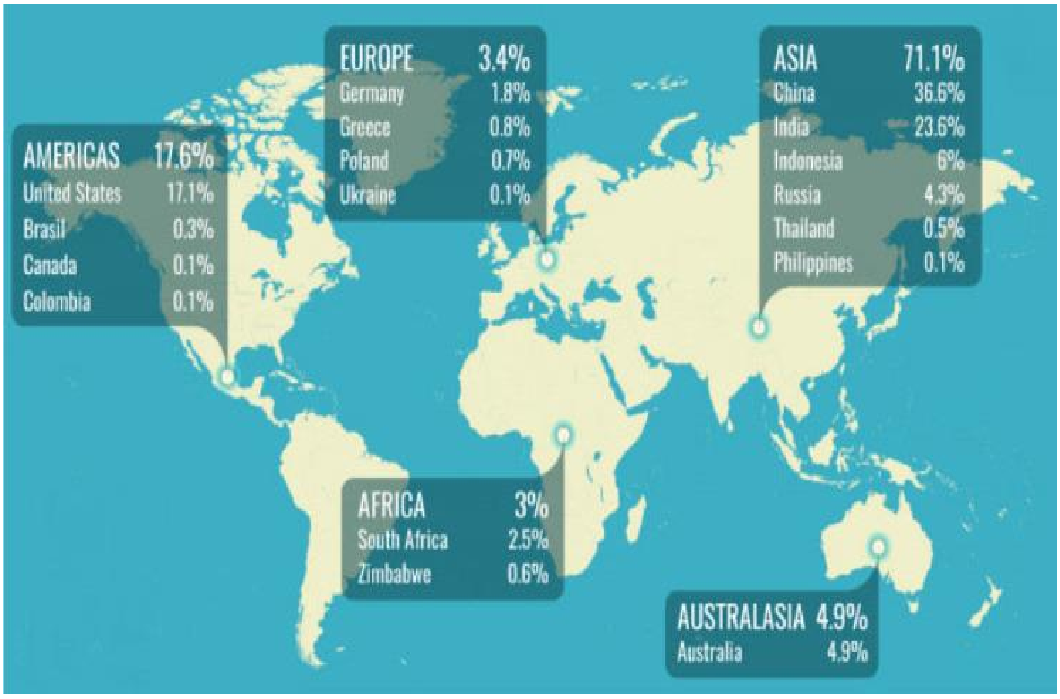
4.1 INTRODUCTION

We have dealt in previous chapters with the pros and cons of hydrogen as an energy transition vector and we have evaluated its critical points compared to the resources already present and widely used today. We will continue the rest of the analysis by showing the presence and distribution of non-renewable and renewable resources in the world and we will focus on the technological leadership of countries. From this survey, we expect to have a clearer view of the countries that will have the most ease in moving to a hydrogen economy and of those that will have to make a huge effort. We will end with a conclusion of what could be a possible way for the energy transition of the world, moving to an electrification process and using hydrogen as a vector.

4.2 NON-RENEWABLE MINERAL RESOURCES

As we can well imagine fossil fuels, non-renewable energy sources formed over a million years, are not uniformly distributed on the earth's surface. Millions of years ago, depending on climatic conditions, parts of the earth's masses were conducive to the growth and prosperity of organic matter. Over the course of geological eras, these land masses have shifted, and some regions are richer in fossil fuels than others.

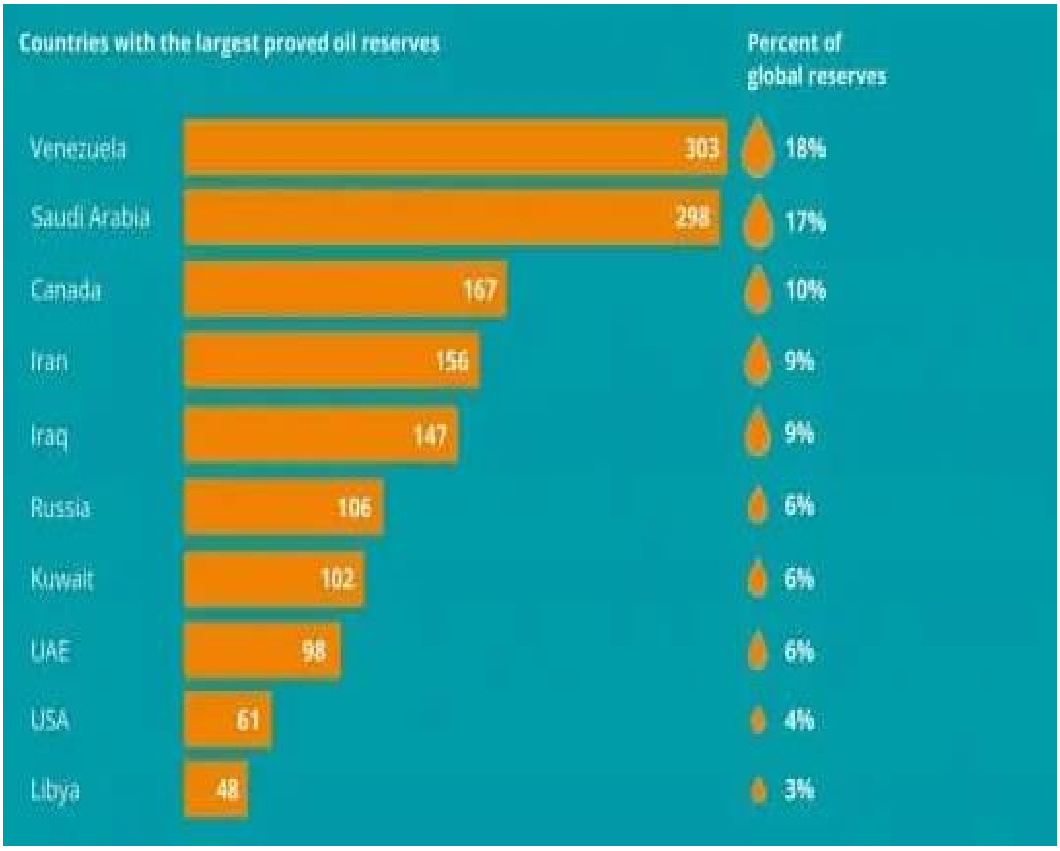
Fig. 4.1: Distribution of coal reserves in the world, 2019



Source: "The globalization of the world coal market"

From figure 4.1 we note that the holders of the highest percentage of coal reserves are Americas and Asia, more precisely the US and China followed by India, Australia, and Russia. Europe, like Africa, on the other hand holds a much lower percentage of coal reserves than the countries listed above. In addition to coal, another fossil fuel considered the lifeblood of the industrial product, of mobility and of our daily life, is oil. It is the most precious asset in the world, but also the one that creates the most conflicts and imbalances in global geopolitics. So much so that there have been several wars over oil resources, their transportation and consumption. In fact, half of the interstate wars since 1973 have been linked to oil. This fossil fuel plays a vital role in a country's prosperity. Oil has always been a very valuable resource and has acquired immense significance with the advent of the industrial age. Today we are experiencing a phase of renewed competition for renewable energies, with a strong push towards decarbonisation, towards a world without oil. A transformation that will neither be immediate nor without consequences.

Fig. 4.2: The countries with the largest oil reserves



Source: Statista.com

Some of the largest oil reserves in the world are found in Saudi Arabia, Canada, and Venezuela. According to data from the Organization of Petroleum Exporting Countries (OPEC), with about 1.73 trillion barrels of oil reserves in the world, Venezuela is the leading country in terms of oil reserves, with 300.3 billion barrels. It owns 79.4% of the world reserves. Oil reserves, however, do not always last. One of the significant ratios for measuring the age of a reserve is the ratio of reserve to production (R / P). Furthermore, the volume of a particular oil reserve does not necessarily determine the rate of production. If we consider the case of Venezuela, even though it holds the ownership of the largest oil reserves in the world, the country's reserves collected only 1.6% of the total production volumes in 2019. Venezuela's production rate decreased significantly to because of the frictions in progress. Comparing this case to the situation in the United States, (maximum withdrawal of 4.4 million barrels of crude oil per day and a total of 727 million barrels of crude oil), we note that despite the country having significantly lower oil reserves than Venezuela, were the first oil producing country with an average of 17.87 million barrels per day, equal to 18% of world production. Also, when it comes to oil reserves, P / R ratios are affected by various factors such as machinery, engineering, conflicts, and conflicts with oil rich countries with other nations. The countries of the Middle East in the 1980s enjoyed the advantages that South American countries enjoy today. The fall of the Middle Eastern countries has added a factor to production that has fallen too much.

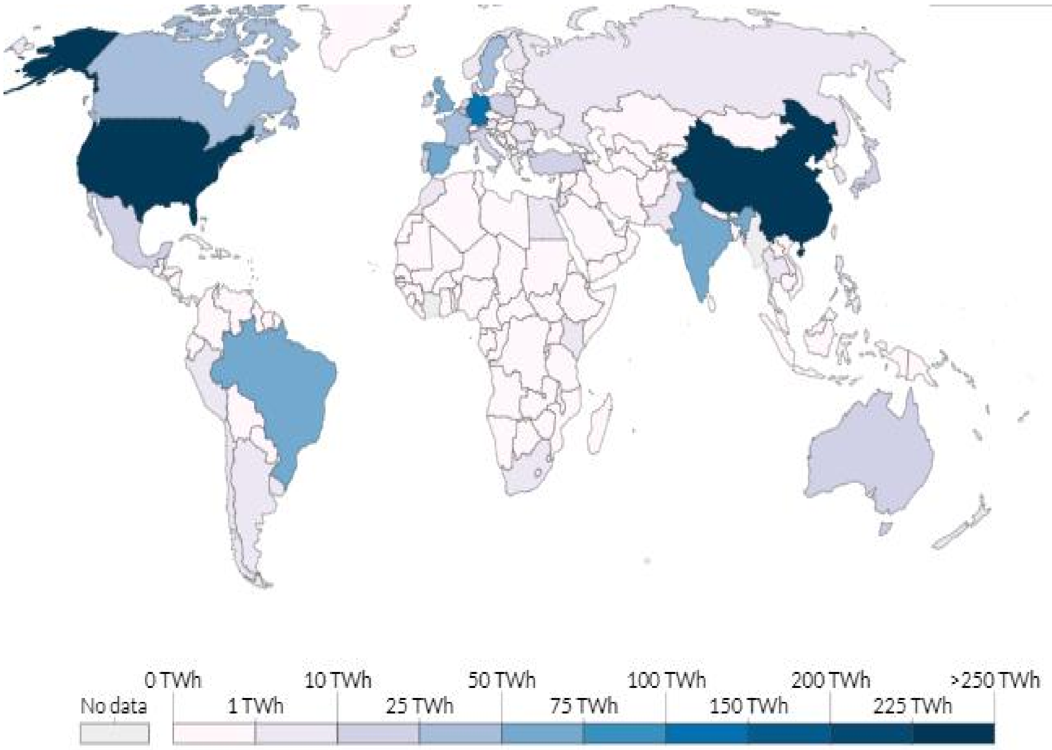
4.3 RENEWABLE RESOURCES

Fossil fuels have dominated the energy mix in most countries of the world since the industrial revolution. The global climate and human health have suffered from all the repercussions that follow from this domination, as there are approximately 5 million premature deaths each year due to health problems caused by the large amounts of local air pollution emitted by the combustion of fossil fuels. to produce energy. The solution to reducing CO_2 emissions and local air pollution is to rapidly switch to low-carbon energy sources.

Renewables will play a key role in the decarbonisation of our energy systems in the coming decades. The forecasts for 2021 are those of greater additions of wind energy (+ 8%) and hydroelectric (+ 43%), while the growth of solar photovoltaics will remain stable. More PV systems will be installed on an industrial scale. The main source of renewable electricity production remains hydroelectric energy which, however, will decrease to below 50% for the first time in 2024. The generation of combined wind and solar photovoltaic energy will double. In the European Union and the United Kingdom, the demand for electricity is expected to increase nine times and the increase in US demand almost three times. Instead, in China and India, renewables are expected to cover nearly 65% of demand growth, while in ASEAN countries fossil fuels dominate generation increases, preventing an increase in the share of renewables.

4.3.1 Wind

Fig. 4.3: World wind power generation, 2020 (Measured in terawatt-hours (TWh) per year. This includes both onshore and offshore wind sources.)



Source: Our world in data

Large-scale wind generation is a relatively modern renewable energy source, but it is growing rapidly in many countries around the world. Expansion of onshore wind capacity is expected to accelerate in 2021, thanks to delayed commissioning of projects in France, Germany, Sweden and the Netherlands and faster growth in

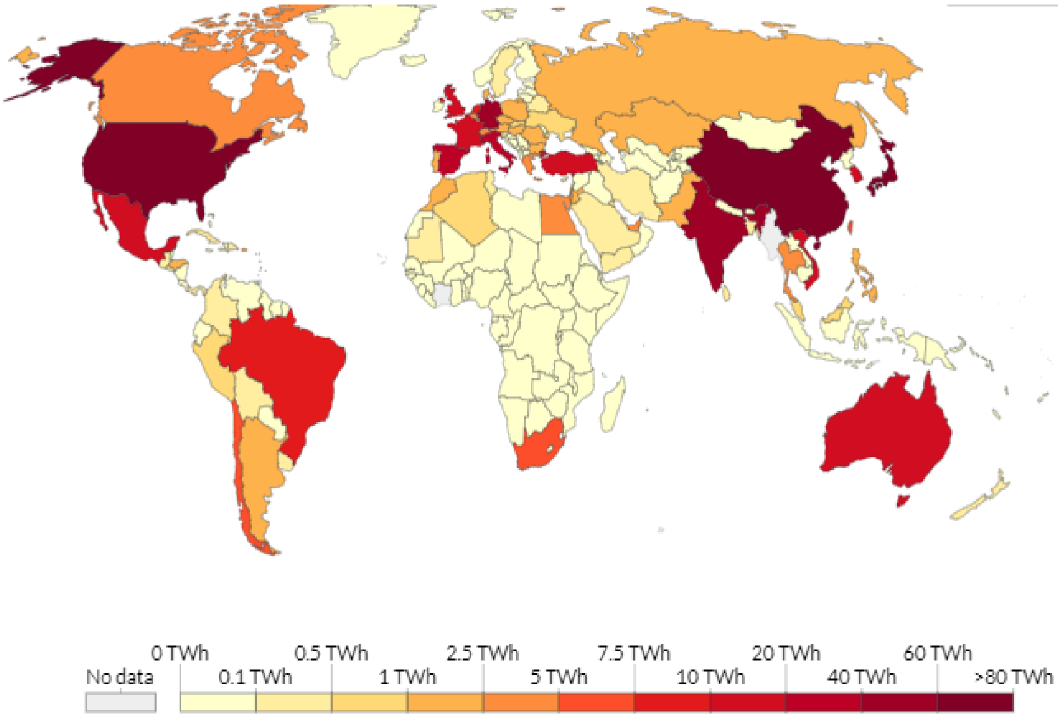
India and Latin America. For 2022, a slowdown in global distribution is expected, mainly due to small integrations in China and the United States caused by planned changes in support policies, and delayed auctions in Brazil, Chile, and Argentina this year, due to a lower-than-expected demand and macroeconomic uncertainties. It currently accounts for more than half of the global expansion of offshore wind power for China, while European countries provide the rest. In 2022, despite the slowdown in China, offshore capacity is expected to further increase thanks to greater uptake in the UK and France and other Asian markets. In 2024, according to forecasts, the United States will become one of the largest offshore markets. The main drivers of wind development will be support policies and continuous cost reduction. In 2023, a further decrease in additions is expected due to the political transition in Vietnam. In Thailand and Indonesia, wind deployment remains blocked by the limited availability of suitable land and the lack of support policies. In the Philippines, capacity increases are expected starting in 2022. Wind capacity additions in Germany decreased in 2020 due to the pause in offshore wind project development created during the political transition, on the contrary, onshore wind capacity is slightly increased. In the same year, Europe also suffered a decrease in wind capacity additions by approximately 18% compared to 2019. The contraction derives from the slowdown in offshore wind gas pipelines in the United Kingdom, Germany, and Denmark; transitions to auctions for onshore wind in France and Italy; and sharp declines in Spain after a commissioning deadline spurred growth in 2019. These declines offset growth seen in other markets such as the Netherlands, Norway, and Poland.

However, expansion returns in 2021, led by rebounds from onshore wind in France and Poland, as new auctions begin to produce growth and several offshore projects are commissioned in Denmark.

Despite this year's slight increase, onshore wind additions in 2019 and 2020 are significantly below historical levels due to poor auction capacities over the past five years. In Kenya, Ethiopia and Tanzania, wind energy development has been slow, due to a few risks, including financial exposure, land acquisition problems and a lack of critical infrastructure for energy projects.

4.3.2 Solar

Fig. 4.4: World solar power generation, 2020 (Measured in terawatt-hours (TWh))

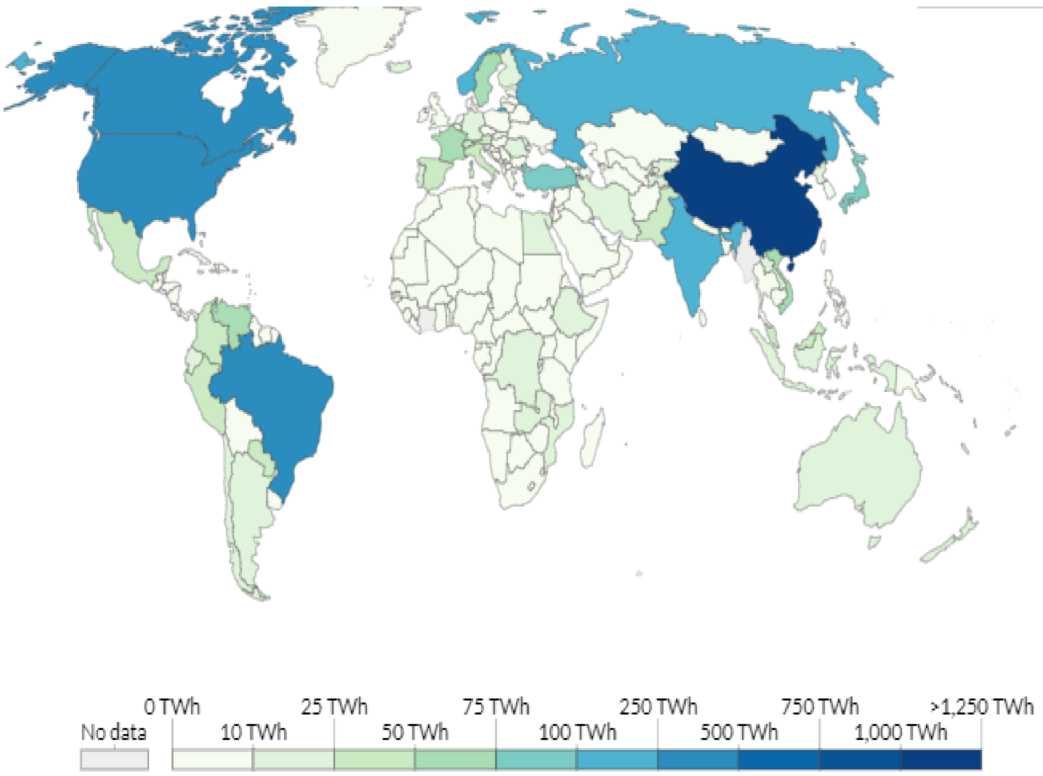


Source: Our world in data

The forecasts for photovoltaics are not the best. In markets such as China and the United States, deployment of distributed photovoltaic applications remains slow, although activity in most European markets, Australia and Brazil has not been significantly hampered. Indeed, the share of distributed applications in the total PV implementation will decrease to 37% this year, the lowest since 2017. Further decreases in additions are expected in 2022 due to the phasing out of subsidies in 2020/21, followed by uncertainties on the new policy framework and objectives in the next 14th five-year plan. An emerging development program shows plans for a pipeline of grid parity projects with 20-year contracts at administratively set provincial energy prices, but incentives for solar PV projects are limited. Further slowdowns in average annual growth are expected in 2023 due to uncertainty about future energy demand, potentially questioning the financing of new unsubsidized projects.

4.3.3 Hydropower

Fig. 4.5: World hydropower generation, 2020 (Measured in terawatt-hours (TWh))



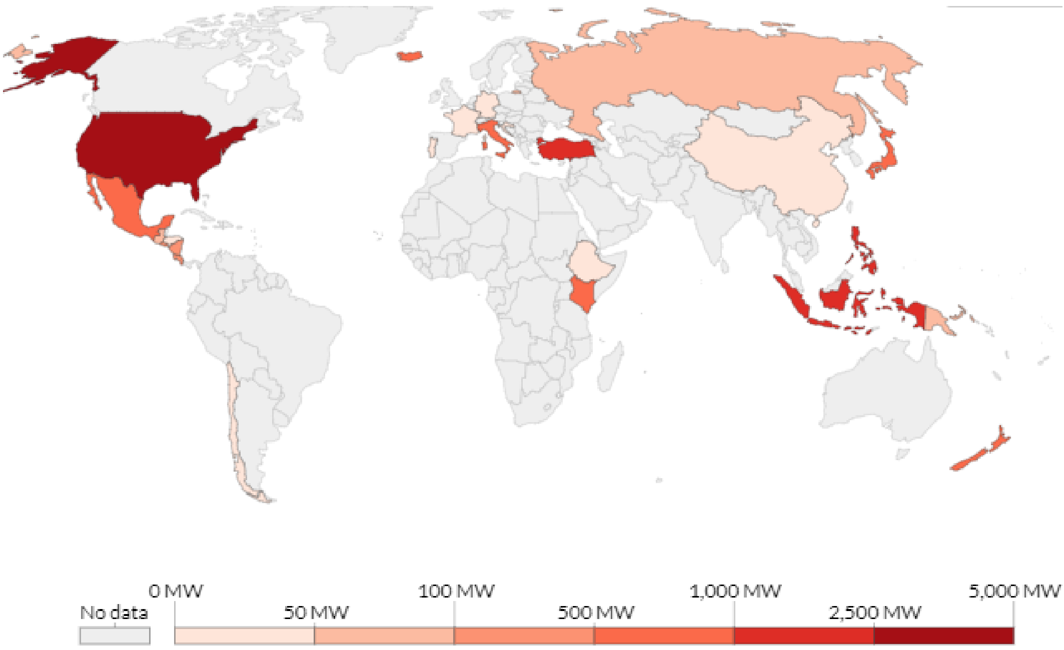
Source: Our world in data

In 2020, we saw an increase in global annual net hydropower additions due to increased activity of major projects in China. Asia contributes 24% of global additions, with significant capacity from the Lao People's Democratic Republic ("Laos PDR"), India, Nepal, Vietnam, and Indonesia. The 2020 European increase is due to large dams in Turkey and pumped storage in Portugal, Switzerland, and Austria. However, Norway, Spain and France were affected by the reduction in rainfall and the increase in heat. As for Latin America, the forecasts are positive. Colombia, Argentina, and Brazil will account for more than half of the growth in 2021-25. In the United States, however, hydroelectric power generation declined due to drought and forest fires in the Pacific Northwest, while drought also caused substantial drops in Argentina, Paraguay, and Mexico. Finally, on the African continent, the development of hydroelectric power is driven by the commissioning of units in Ethiopia, Nigeria, and Angola.

By 2025, hydropower will represent 16% of world electricity production, of which 40% will come from countries with fleets over 40 years old, so they will need major renovations to maintain or increase performance, which will involve major investments in renovation and modernization. About two-thirds of this generation are found in North America and Europe, where the weighted average age of the fleet is between 45 and 51 years.

4.3.4 Geothermal

Fig. 4.6: World installed geothermal capacity, 2020 (Cumulative installed capacity of geothermal energy, measured in megawatts.)



Source: Our world in data

Global cumulative geothermal capacity growth of 7% is expected by 2022, led by Indonesia, Kenya, Turkey, and the Philippines, responsible for two-thirds of this growth, thanks to the implementation of new projects and significant investments in the field. Indonesia, Kenya, and Turkey will continue to cause capacity increases beyond 2022 according to forecasts. Oil companies are also showing interest in geothermal as it is recognized as an opportunity to diversify businesses while capitalizing on drilling skills.

4.4 TECHNOLOGICAL LEADERSHIP

Renewable energy technologies allow us to create electricity, heat, and fuels from renewable sources.

Solar, wind, hydro, wave, heat exchange, tidal, wave and bioenergy technologies are all powered by the sun and moon directly or indirectly. Bioenergy technologies allow us to convert solar energy stored in plants, food waste, agricultural waste, forest waste, wastewater and algae into heat, electricity, and fuel, using a variety of approaches. These technologies allow us to heat and cool our buildings, generate electricity and travel by land, sea and potentially even by air without generating dangerous greenhouse gases and other forms of pollution.

Tab. 4.1: Renewable energy technology

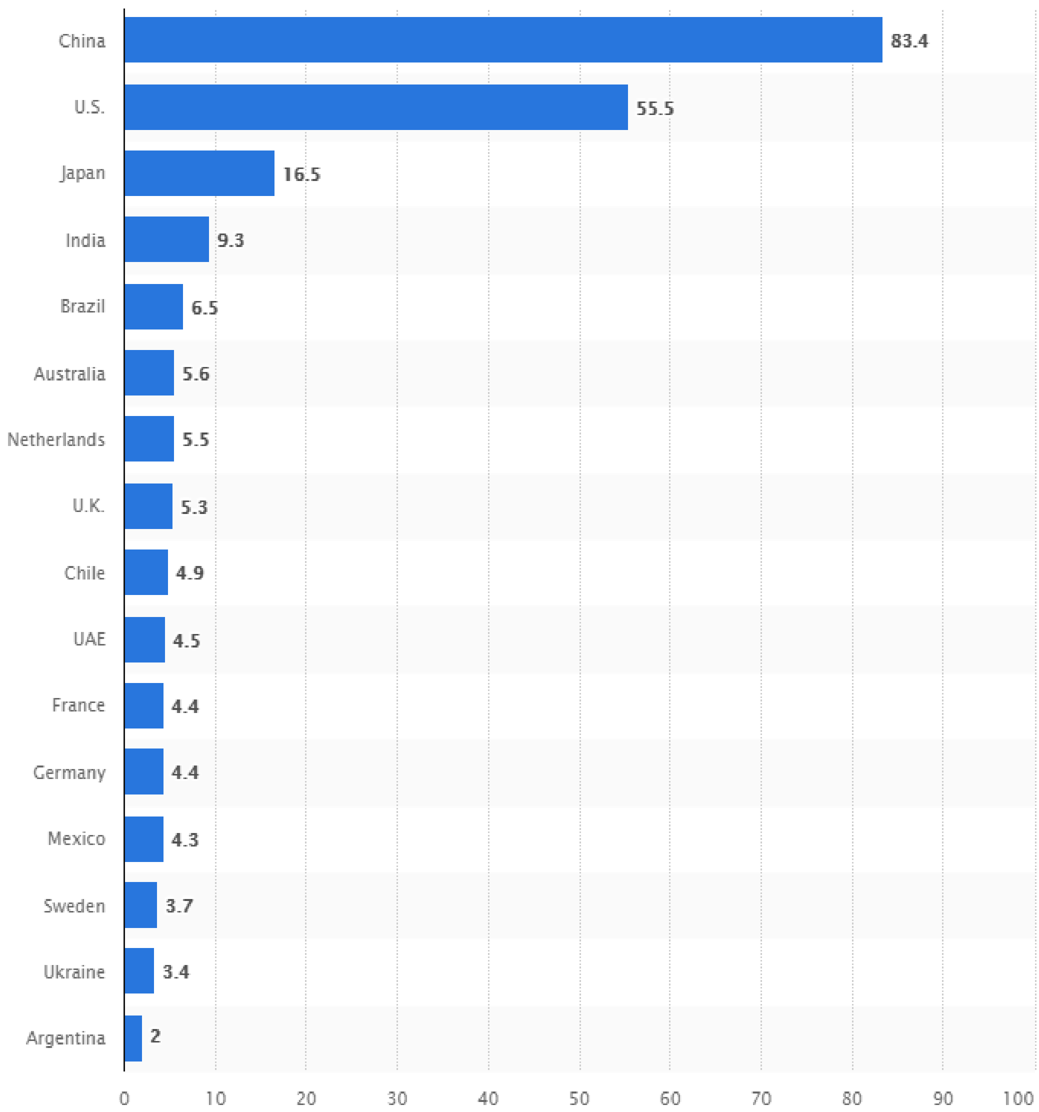
Renewable energy technology	Energy service/application	Area of application
Wind turbines – grid-connected	Residential and industrial electricity, supplementing mains supply	Mostly urban
Wind Turbines – stand-alone	Power for lighting (homes, schools, streets), refrigeration (vaccine) and other low-to medium electric power needs (telecommunications, etc.) Occasionally mechanical power for agriculture.	Urban and rural
Wind pumps	Pumping water (for agriculture and drinking)	Mostly rural
PV (solar electric) – grid-connected	Residential and industrial electricity, supplementing mains supply	Mostly urban
PV (solar electric) – stand-alone	Power for lighting (homes, schools, streets), refrigeration (vaccine) and other low- to medium-voltage electric needs (telecommunications, etc.)	Urban and rural
Solar PV pumps	Pumping water (for agriculture and drinking)	Mostly rural
Solar thermal power plant – grid-connected	Residential and industrial electricity, supplementing mains supply	Mostly urban
Solar thermal – water heaters	Heating water	Urban and rural
Solar thermal – cookers	Cooking (for homes, commercial stoves, and ovens)	Mostly rural
Solar thermal – dryers	Drying crops	Mostly rural
Solar thermal – cooling	Air-conditioning (centralized system for buildings, etc.) Cooling for industrial processes	Mostly urban
Solid biomass	Cooking and lighting (direct combustion), motive power for small industry and electric needs (with electric motor)	Mostly rural
Liquid biofuel	Transport fuel and mechanical power, particularly for agriculture; heating and electricity generation; some rural cooking fuel	Urban and rural
Large hydro – grid-connected	Residential and industrial electricity, supplementing mains supply	Mostly urban
Small hydro	Lighting and other low-to-medium voltage electric needs (telecommunications, hand tools, etc.), process motive power for small industry (with electric motor)	Mostly rural
Geothermal	Grid electricity and large-scale heating.	Urban and rural
Village-scale	Mini-grids usually hybrid systems, solar and/or wind energy with diesel engines. Small-scale residential and commercial.	Mostly rural, some peri-urban

Source: “Renewable energy technology”

Most renewable energy systems are still considered risky and complicated, as well as not cost-competitive with alternative systems. But now these systems are technically mature and tested and work effectively. In renewable energy systems, the initial problems of the development period are no longer present, they have become accessible and often cheaper than conventional alternatives. Furthermore, these systems provide energy for income-generating activities and therefore offer social and environmental benefits. To ensure that there is awareness and understanding, both at the local and institutional level, there is a need for dissemination of information at all levels. However, a problem that often has repercussions in the accessibility of renewable energy systems is that of the lack of capital to pay for renewable energy equipment and services. This happens more frequently with people living in rural areas who want the benefits that electricity brings but cannot afford them.

Speaking of capital, to understand who holds the technological leadership in energy matters, we need to focus on the investments made by the various nations.

Fig.4.7: Investment in clean energy globally in 2019, by select country (in billion U.S. dollars)



Source: Statista.com

The highest investment in clean energy in the world is China's. As we see from Figure 4.7, China pumped about 83.4 billion US dollars into clean energy research and development in 2019. The United States and Japan had the second and third highest clean energy investments, to 55.5 billion and 16.5 billion US dollars, respectively. These three countries accounted for approximately 71% of total investments. All other countries selected together spent US $ 219.2 billion on alternative energy technologies.

In 2020, the most attractive countries for investments in renewables were the United States, which stole the lead from China, thanks to an extension of the production tax credit (PTC) and greater attention to future offshore wind installations. They took the top spot due to existing government policies and implementation opportunities within the country.

On the other hand, China is burdened with a huge daily demand for energy. Government consciousness has awakened about air pollution and its impact on the health of its most vulnerable citizens, making it more aware of the need for a shift towards renewable energy.

4.5 THE WAY OF ENERGY TRANSITION

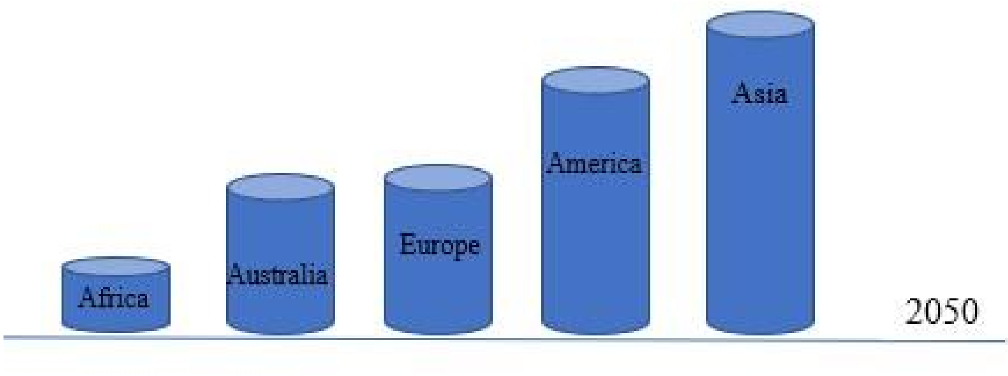
Having reached this point of the discussion, we can understand that the road to the energy transition certainly cannot be defined as easy, indeed it is convoluted and full of difficulties, but we have come to a point where undertaking it has become necessary, above all due to the emissions of CO_2 in the air from fossil fuels which have devastating effects on both the atmosphere and human health.

The path of hydrogen as a vector for the energy transition is not mandatory, you can obviously electrify everything without hydrogen, but bringing a system to the transition with it has many advantages, just think for example of electric batteries, which otherwise would require large quantities of raw materials that are not infinite. All countries must be on the same line for the energy transition but obviously not all countries will have the same level of difficulty. For this reason, to somehow understand which countries will find the advantage in the transition and which will be the disadvantaged countries, I have focused the previous chapters in the analysis of three factors: the availability of non-renewable mineral resources, the availability of renewable resources and technological leadership.

Indeed, we understand that the countries that export oil are the ones that will have the greatest difficulties in the transition, as they are dependent on it. The countries that have invested in the research and production of high-cost oil have realized that today it is not very effective, the case of the United States stands out, which is reinvesting and converting to renewables. In investments for renewables, those of China, which held the record in 2019, should also be highlighted.

The transition will also be advantageous for those countries that from a geographical point of view abound in renewable resources, for example in Europe the countries that are leading the transition to sustainable energy are Sweden, Norway, Denmark and Switzerland, but we must always compare this extra point with the ability to exploit these resources, therefore consider the technological development in this matter, as for example Africa abounds in solar energy but from a technological point of view it is very backward. Disadvantages in the use of renewables are also found in those countries where there are political or economic conflicts.

Fig.4.8: Forecasts for the countries that will lead the energy transition.



However, fossil fuels still abound in many countries, the use of these is daily, so we cannot expect the switch to renewables to be imminent. The way that many governments suggest is that of blue hydrogen, that is to produce hydrogen through the methane while capturing the CO_2 emissions. What I suggest based on the data obtained from the analysis is to use the steam-reforming of methane with the subsequent capture of CO_2 at the initial stage of the transition, in this way to end the abundances of the fossil, and for the benefit economical as it is less expensive. I believe that hydrogen is very useful, used in large plants already present in many countries. I suggest a complete electrification which, however, for electricity production is based on a mixed system made up partly of renewables and partly of hydrogen, since not everything can be based on renewables as they depend on various environmental and geographical factors. Using hydrogen as a vector also frees us from the so-called curse of resources, as there is no risk of passing from dependence on oil to that of other energies.

CONCLUSIONS

This research aimed to demonstrate the importance and need for an energy transition. The data relating to CO_2 emissions into the atmosphere underline the environmental disaster we are facing. The percentage of oil that is used as fuel is still high in the world. So, the transition is urgent to deal with the situation and all countries must be in line with each other, but obviously not all countries will have the same difficulties or the same advantages. The main factors considered to analyse the transition gap between countries were the distribution of renewable and non-renewable resources around the world and technological leadership. From the analysis it emerged that the oil-dependent countries will be the ones that will find themselves most in difficulty in the transition process, while the countries that thanks to their geographical position abound in natural resources and those who have invested and converted to renewables will be those who will benefit most from the transition. At the end of the research study, the solution proposed as a way for the energy transition is to use the so-called blue hydrogen obtained from the methane steam-reforming process with subsequent CO_2 capture in the initial phase of the transition, in this way to put an end to the abundances of fossils and for the economic benefit, as it is less expensive. Hydrogen as a vector, from the analysis of its advantages, is proposed as suitable used in large plants already present in many countries. A complete electrification is suggested which, however, to produce electricity is based on a mixed system composed partly of renewables and partly of hydrogen, since not everything can be based on renewables as they depend on various environmental and geographical factors. This solution promises to be optimal, as using hydrogen as a vector also frees us from the so-called curse of resources, as there is no risk of passing from dependence on oil to that of other energies.

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