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How the European Union and China consider green hydrogen as part of their environmental strategy

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Abstract

The European Green Deal and China's pledge to become carbon neutral by 2060 are considerable environmental goals. To achieve the proposed results, both economic blocks considered green hydrogen has a pivotal technology to ensure that renewable energy can be stored and distributed. While offering a solution to the intermittency problem, carbon neutral hydrogen production can also be considered for other structural obstacles, such as granting energy security, contribute to the electrification of heavy industry and the transportation sector, and to create opportunities for added-value chains. As it is a relatively unexplored topic, this work intends to give some insights on what is being discussed and expected regarding green hydrogen in the energy sector. The maturity of the technology and the motivations to promote it differ between the EU and China, and it is important to identify the trends that will shape the geopolitical context in the next decades, as other nations will have to adapt and to consider what is their position towards this new technology.

Key Words: Environment; Hydrogen; Geopolitics;

JEL Codes: N74; N75; O13; O44; P48

Resumo

O Acordo Verde Europeu e o compromisso da China em se tornar neutra em carbono até 2060 são objetivos ambientais consideráveis. De forma a atingir os resultados propostos, ambos os blocos económicos consideraram o hidrogénio verde como uma tecnologia fundamental para garantir que a energia renovável possa ser armazenada e distribuída. Enquanto oferece uma solução para o problema da intermitência, a produção de hidrogénio neutro em carbono pode também ser considerada para fazer face a outras questões, como garantir segurança energética, contribuir para a eletrificação da indústria pesada e do setor dos transportes, e para criar valor cadeias de valor acrescentado. Tendo em conta que é um tópico relativamente inexplorado, o presente trabalho pretende dar algumas perspectivas em relação àquilo que está a ser discutido e às expectativas para o futuro do hidrogénio verde no sector energético. A maturidade desta tecnologia e as motivações que levam a União Europeia e a China a promoverem o hidrogénio verde são diferentes, sendo importante identificar tendências que possam moldar o contexto geopolítico nas próximas décadas, visto que as outras nações irão ter de considerar a sua posição relativamente a esta tecnologia.

Palavras-Chave: Ambiente; Hidrogénio; Geopolítica;

Códigos JEL: N74; N75; O13; O44; P48

"The purpose of science in understanding who we are as humans is not to rob us of our sense of mystery, not to cure us of our sense of mystery. The purpose of science is to constantly reinvent and reinvigorate that mystery."

Robert Sapolsky

Index of contents

Index of tables

Index of figures

List if Acronyms

BRI: Belt and Road Initiative

EKC: Environmental Kuznets Curve

EU: European Union

EV: Electric Vehicle

FDI: Foreign Direct Investment

FCV: Fuel Cell Vehicle

GDP: Gross Domestic Product

GNP: Gross National Product

IEA: International Energy Agency

OPEC: Organization of the Petroleum Exporting Countries

SRI: Social Responsible Investors

1. Introduction

1.1 Framework

Economic models, such as the Solow Growth Model, attempt to predict long-run economic growth taking in account increases in capital, labor and increments in productivity from technologic progress (Solow, R. M., 1956). This paradigm of economic growth as the fundamental measure of well-being is constantly being updated and complemented with more recent scientific investigation, like Romer's Endogenous Economic Growth Model, that suggests that more factors should be taken in account, as human capital, and innovation (Romer, P. M., 1990). Although being useful for measuring and achieving higher economic output and productivity, this paradigm lacks to acknowledge the discrepancy between the increase in wealth and in quality of life. Different developing countries manifest a significant increase in their Gross Domestic Product (GDP) without demonstrating a proportional increase in their population's standards of living. Some countries belonging to Organization of the Petroleum Exporting Countries (OPEC) have experience a decrease in their Gross National Product GNP *per capita* in the second half of the last century, even though being rich in natural resources and land (Gylfason, T., 2001).

In the 20^{th} century the idea of Economic Development emerged as a more robust concept, which takes in consideration not only economic results but also the quality of public services as health and education, social disparities, and the key concept of sustainability (Greenwood, D. T., & Holt, R. P., 2014). Nations should seek a holistic improvement in their growth, evaluating the quantitative data as well as the qualitative results. This evolution of economic thought created a divergence between those who argue that financial results should prevail above all and those who defend that a more careful and balanced approach should be prioritized, as short-term results become innocuous if not followed by more substantial consequences. Corporate Social Responsibility matured, with companies recognizing that there is a need for self-regulation and should take in consideration more than their own self-interest to achieve better results for stakeholders (Carroll, A. B., 1991). The paradigm is changing, and the concept of Economic Development must include Nature as a stakeholder.

Sustainability became the goal to pursuit, with the environment as the focus of its attention. The idea that "what is good for the environment is bad for business" started to fall in discredit and companies that want« to thrive should get along with the environmental regulations, and not against it (Romm, J. J., 1994). Since the Industrial Revolution, crescent greenhouse gas emissions started to counter the more positive forecasts, with new records being broken almost in a continuum. Unrestrained anthropogenic carbon dioxide emissions, derived from various sectors such as the energy, transportation, agriculture, and industry, not only cause the natural mean levels of surface temperatures to rise far above the natural cycle but also have vast side effects, as acidifying ocean chemistry in an unprecedent way (Hofmann, M., *et al.*, 2019). The global warming phenomenon and subsequent environmental repercussions such as extreme climate events and loss of biodiversity are the paramount global risks in 2020 (World Economic Forum, 2020).

In this scenario, the necessity to decarbonize the economy, and having international efforts to tackle the externalities created by pollution, led to various agreements and treaties to be signed, either to better understand the problem and to achieve high-standard results. The Kyoto's Protocol emerged as the most relevant consequence of several international agreements in the turn of the millennium (Oberthür, S., & Ott, H. E., 1999), with countries committing to cut their emissions to lower levels. Although ambitious, this protocol ended its term in 2012, with the need to revise and raise the goals for a more determined attitude, and to broad the number of signature state-members.

This situation created a window of opportunity for what is the most aspiring accord until now, the Paris Agreement. As it was settled in 2015 amongst 189 nations (United Nations, 2020), there must be a serious international cooperative response to the threat of global temperature rise in this century and keep it below 2 degrees Celsius is mandatory, although the 1.5 degrees Celsius ceiling is the most desired scenario (United Nations for Climate, 2021). Different economic blocks opt for different strategies to face their objectives, which as expected will result in distinct outcomes. Regardless of the strategy adopted, the goals of the political agenda should address carbon neutrality and increased energy efficiency as mandatory conditions. It is known that a more structural approach is essential for any serious sustainable growth (Stiglitz, J. E., 2015), with capable long-term policies and a planned infrastructure being crucial for the next decades' progress.

With every nation having to manage their investment portfolio to suit a carbon neutral economy, the share that they want to allocate to each technology depends on how well different technologies are understood and how reliable are the forecasts of their implementation. Of all the decarbonization paths that are currently being considered, this thesis will focus on Green Hydrogen, with both scientific and political communities demonstrating increasing interest in it, in the past few years.

1.2. Green Hydrogen Planning

The International Energy Agency praised the "vast potential" of Hydrogen related technologies (IEA, 2019), and the opportunity to develop a cleaner and more efficient economy, with the main economic blocks opting to start investing in it and planning their strategy to adapt their energy portfolio and security. There are some main features of its utilization, such as storing surplus renewables power when the grid cannot absorb it, help decarbonize hard-to-electrify sectors such as long-distance transport and heavy industry and replace fossil fuels as a zero-carbon feedstock in chemicals and fuel production. All these are important to any serious commitment to decarbonize in the next decades.

To comply with established Climate Agendas (2030, 2050), the EU strategy affirms that "the transition to climate neutrality will bring significant opportunities, such as potential for economic growth, for new business models and markets, for new jobs and technological development. Forward-looking research, development and innovation policies will have a key role" (European Commission, 2019). Green hydrogen suits this frame, being featured in all the European Commission net zero emissions scenarios for 2050 (van Renssen, S., 2020). It is important to investigate how the adoption of these strategies will affect the economy and how it can be modernized to accommodate the demanding climate goals.

China recently stated its pledge to be carbon neutral in 2060, with the need to invest in low-carbon energy sources and in negative emissions technologies (Fuhrman, J., *et al.*, 2020), such as carbon capture and afforestation. Being the major pollutant country, and although having increased their renewable sources share (IEA, 2020), with its population and income *per capita* growing, the energy demand will continue to increase, and China has to find a solution to this problem of energy production and consumption balance, while taking in consideration pollution levels. Green Hydrogen can be part of the solution to this, structurally addressing the climate conjecture and offering an efficient and reliable investment.

1.3 Research Question

The way Green Hydrogen can fit both the European Union and China carbon neutrality agendas and how it might impact the energy sector in terms of prices and expectations will be the focus of this dissertation. Therefore, the research question can be stated as follows: "How the European Union and China consider green hydrogen as part of their environmental strategy?"

1.4 Dissertation Structure

This dissertation will be structured in the following way: after this introduction, Chapter 2 will present a literature survey having in mind to identify the rationale of Green Hydrogen production inclusion in geopolitical strategies; Chapter 3 will analyze the Energy Geopolitical framework in which the European Union and China's are developing their energy and environmental strategies, attending decarbonization goals; Chapter 4 will overlook both EU's and China's Hydrogen Strategies, based on data analysis, case studies from research literature, and national and international reports. The purpose of this investigation consists of critical, comparative analysis of both strategies and goals. Literature review is made on the course of this dissertation. Finally, chapter 5 will present conclusions.

2. Energy Paradigm Shift

This chapter intends to explain how the evolution of technology redirects societies' needs, what triggered the paradigm shift that the economic blocks are going through, and how continuous investment on innovation and R&D is essential to adapt to new information about our circumstances and to improve our response to them.

There is no single measure that could deal with the various problems that currently exist and might emerge in the future, as consequence of the global warming and consequent climate change. By analyzing the emissions levels from different economic activities, it is possible to conclude that the answers to GHG emissions must be diverse, adaptable, and not only act in terms of mitigation but also in a precautious way (Nordhaus, William D., 2013).

The risk of natural hazard is increasing as the absolute values of emissions continue to rise and if policy makers are not able to approximately estimate risks and not prepare our economies to eventual large negative shocks, the impacts can be much more costly (Taleb, N. N., 2007). Financial markets need incentives and a certain degree of stability, to align public policies with projects developed by the private sector, essential to a full clean transition.

Although there is not direct relation between these subjects, the Covid-19 crisis allowed economists and policy makers to better understand the consequences of not correctly prepare for the impact of a potential pandemic event – even though there was enough evidence pointing to that (Jonas, O. B., 2013). The power generation planning should be considered in addressed for short, medium, and long-term (Das, P., *et al.*, 2018).

For a predominant renewable energy capacity in this century, designing policies, infrastructure and financial support is very important. As mentioned before, preventive, diverse, and proactive policies need to be harmonized and implemented at an international scale, to prevent a widespread of natural disasters, economic and social crisis in many regions in the planet. An option that has been studied for some time is Hydrogen.

Hydrogen's potential as an energy carrier that can act as an energy vector is being recognized (IRENA, 2018), and offers solutions for various issues regarding renewable energy sources, such as intermittency, lack of energy storage and transportation capacity. In this chapter, there is a discussion on status of renewable energy and expectations of growth, Hydrogen as the catalyst for the energy transition and a major step towards a neutral-carbon economy and a consequent sustainable development for global economies.

Energy is a very important and complex aspect of countries' macroeconomics planning (Sovacool, B. K., & Saunders, H., 2014), while also being one of the most relevant sectors in the decarbonization process. Each stage of economic development has been accompanied by a characteristic energy transition from one major fuel source to another (Timmons, D., Harris, J. M., & Roach, B., 2014). Coal had the primacy over other fossil fuels during the 19th and part of the 20th centuries, while currently oil takes the number one spot.

This hegemony originates in oil's competitiveness in terms of energy prices and, although shocks in global supply chains - like the 1973 embargo from the OPEC (Organization of Arab Petroleum Exporting Countries) and the Iran's 1979 oil shock crisis - can threaten energy security, coordinated international policies resisted these incidents throughout the last century. The spillover effects of oil's price volatility on stock markets exist and are documented (Arouri, M. E. H., Jouini, J., & Nguyen, D. K., 2011), but nations have been able to manage their long-run expectations with quite firm ground. The wealth provided by oil enabled prosperous economic growth around the world, but it did not come without some heavy, counterpart costs.

With an increase of already 1°C since the pre-industrial mean temperature's levels, and with various working papers finding evidence of how some countries' economic and political systems may be affected by the fragilities that oil creates - like heavy dependence on its exports (Benedictow, A., Fjærtoft, D., & Løfsnæs, O., 2013) and even a lower likelihood of democratization (Anyanwu, J. C., & Erhijakpor, A. E., 2014) - the threat to a sustainable life, with global warming and all its direct and indirect consequences, emerges as the most crucial adversity that needs to be tackled.

The depth of impacts may not ever be well understood. As an example, between 2007 and 2010, hundreds of thousands Syrian people went through a rural exodus because of a severe drought during these years. The lack of resources and the social clashes that originated in period eventually led to the stage of an armed conflict that would turn to the known Syrian Civil War (Selby, J., 2017). The heterogeneity of impacts across regions varies considerably. Using a Gini coefficient for climate change (Tol, R. S., et al. 2014) argue that the increasing inequality will continue, and the vulnerability to natural disasters must be studied not only in terms of income *per capita* values, but also in terms of geographical differences. Political trust in science and market competitiveness for a sustainable alternative, all related in a multi-linear web of interactions.

A proactive action regarding the risk of aggravated climate disasters and the 2°C ceiling defined on the Paris Agreement is required, where developed countries must recognize their obligation to make a more significant effort in terms of financial support, since developing countries contributed far less to global emissions. Taking in account the complexity of the consequences of this whole subject, an overview of concepts will be done in this chapter, to better map the situation and to better understand the development of sustainable alternatives at an international scale.

2.1 From the First Industrial Revolution to the Present

Throughout history, economic development was gradual but there are moments where innovation and new technologies alter the existent paradigm, creating vast prosperity in a relatively short period of time. Moments such as Industrial Revolutions are examples of these phenomena, although they are difficult to characterize in a precise way (Hoppit, J., 1987), depending on the field that is being studied. For what concerns this dissertation, they will be defined as significant shifts in the Economy, laid on three pillars: an emergence of new energy sources, innovation in the way societies communicate, and changes in how the transportation's sector works. Based on scientific progress, there are broad results that can be observed for each one, from boosts in economic production, to increased income *per capita*, specialization of economic activity, social movement from rural to urban areas, among others (Deane, P. M., & Deane, P. M., 1979).

The First Industrial Revolution started in Britain between 1760 and 1820, where printing and the telegraph massified information, steam locomotives allowed to cover great distances on land with constant routes for people and goods, and coal started to being used as an energy resource (Deane, 1979). Although viewed as the first important step in world's economy, some of the most promising results, like real wages increases and total-factor-productivity growth, were not as relevant as initial studies concluded and some authors argue that leisure time declined, child-labor was very common and material consumption hardly rose (Voth, H. J., 2003). Nevertheless, by the 1850 there had been a reallocation of labor input to manufacturing industries, and population growth in this period also contributed to this increase of work supply, which culminated in a relevant economic growth.

From 1870 to the beginning of the first World War in 1914, the Second Industrial Revolution started in the United States of America, with the invention and widespread of electricity as a catalyst for many new technologies (Atkeson, A., & Kehoe, P. J., 2001), such as the telephone and radio. These transformed the economy, with communication becoming much more mainstream and direct. Internal combustion vehicles enabled the massification of personal transportation, increasing social mobility in an unprecedent way and oil became the predominant energy source that sustained all this evolution, being more energy efficient than coal. The second Industrial Revolution also featured changes in the organization of production, witnessing the rise of large economies of scale (Mokyr, J., 1998) and a more modern appreciation of the value of the labor factor (AT&T, 1973).

The third Revolution, also known as the Digital Revolution and the beginning of the Information Age (Greenwood, J., 1997), started in the second half of the 20th century and continues to the present days, with great continuous advances in computation systems, as Moore's Law observes (Schaller, R. R.,1997). Some authors argue that we already are on the brink of a fourth Revolution with the fusion of various technologies allowed by the exponential innovation (Schwab, K., 2017), with an unprecedent connectivity between international and interstate grids, intelligent and efficient electricity consumption and a better regulation between offer and demand.

As Great Britain and the United States led the before-mentioned industrial revolutions, Europe and China are the main economic blocks in charge of the shift in the present energy sources paradigm (Rifkin, J., 2019). The one that can achieve more ambitious goals will prevail as the leader in geopolitical influence and determine the pathway for the next decades.

2.2 Renewable Energy Expansion

The share of renewable energy in the total energy production has increased substantial in the past two decades (IEA, 2021). This renewable's share rise is the result of economic investment to achieve international sustainability goals, to maintain market competitiveness in the energy sector and to guarantee energy security. Although countries must consider their geographical, economic, and political context, and adequate their transition to it, (Gökgöz, F., & Güvercin, M. T., 2018) demonstrate empirical evidence for a substitution effect of renewable energy for energy imports, associated also with positive spillover effects in the technology sector.

Considering the case of Chlorofluorocarbons (CFCs) success, where the success of the Montreal Protocol in the reversion of the destruction of the atmosphere's ozone layer is considered as a bright example of international cooperation on environmental results (Albrecht, F., & Parker, C. F., 2019), it has been shown that it is possible to act coordinately and face complex geopolitical problems, which further positively reinforces high expectations on achieving more ambitious expectations, such as to create a global sustainable, carbon neutral and prosperous economy. Nevertheless, the difficulty of the task is much higher and complex, and countries will not all act at the same speed to meet the global standard goals.

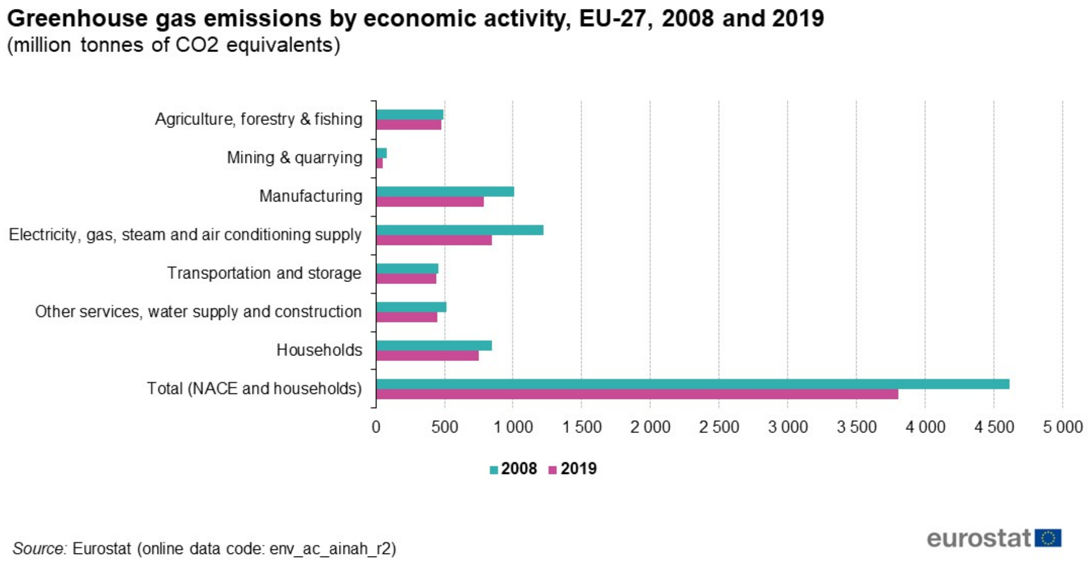

Figure 1. GHG Emissions by Economic Activity. Source: Eurostat.

By analyzing Figure 1 - which is a representation of Greenhouse Gas Emissions in Europe, by comparing 2008 and 2019 levels of CO2 equivalents and divided by Economic Activity – it is observable that the data above gives a fundamental insight previously mentioned: to decrease the total levels of emissions, it is useful that scientists must look at the various sources of those emissions and plan multiple strategies to face each one. As it can be noticed, household's energy consumption, construction (and its inherent activities, such as production of steel and concrete), transportation, the energy sector and heavy industry are the main activities that lead to the highest levels of pollution.

Each one of these activities is a very important part of the economy and describes interconnected areas of potential intervention and action. Diverse strategies can and must be used to address CO_2 levels (Laurikka, H., & Springer, U., 2003), as for instance: adopting improved agricultural practices - such as organic agriculture, stopping subsidizing fossil fuels, and substituting energy sources to more sustainable alternatives (Fawzy, S., *et al.*, 2020).

Renewable energy is leading the shift of the current paradigm, creating opportunities for long-term viable economic planning with guaranteed energy security, with all the benefits that derive from the net zero carbon emissions and the stabilization of energy prices, compared to the current fossil-fuel models. Renewable energy capacity grew around 45% during 2020, mainly due to an expansion of global wind capacity of nearly 90% and a global solar capacity of 23%, in comparison to 2019 levels (IEA, 2021).

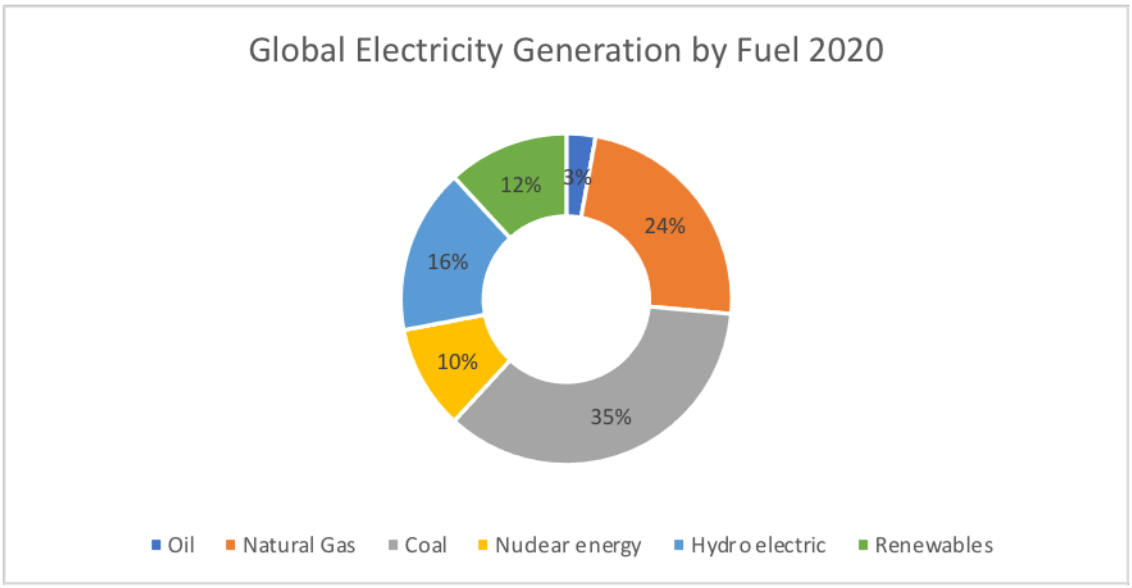

Figure 2. Global Electric Generation by Fuel 2020 - BP Statistical Review 2021

Figure 2 illustrates the contributions of each energy source for electricity produced globally in 2020. Renewables, hydroelectric and nuclear energy represent 25% of the total produced and with only renewables growing in 2020 (IEA, 2021), the pathway for a green economy transition has some cornerstones, but it needs to improve its results at an increasing rate. The dependency on non-renewable energy sources remains still 75% and all the emissions generated will continue to impact very negatively the proposed international goals.

With a series of obstacles to a clean transition, policy makers must consider not only how to expand their renewable share - in terms of financial incentives, remodeling their national energy infrastructure, and expanding the research and innovation on new technologies –

but also how to develop an economic and political withdrawal from fossil fuels and their establishment in the current energy sector (Kaufman, R., 2010). A brief analysis of different energy sources is going to be performed, to better understand the context and the expectations towards the evolution of each one.

2.2.1 Variable Renewable Energy Sources

As previously mentioned, energy demand is expected to increase substantially in the following decades (EIA, 2020), with not only ethical but mainly economic reasons dictating the pace of the progress made. To correspond to the expectations, there has been investment in renewable energy, especially in hydro, solar and wind. Solar energy is predicted to have the most expressive growth, while hydro should register the most modest evolution in that period

Although renewable energy is currently growing each year and investing in it became a mainstream strategy for most nations, they seem to be insufficient due to a few factors, which if not addresses may jeopardize the energy systems and threaten the reliability of these power systems (Sinsel, S. R., *et al.,* 2020).

2.2.1.1 Price competitiveness

In terms of financial attractiveness, carbon neutrality still poses a challenge, as fossil fuels technology is more mature, and the global economy was built around them. This, aligned with the fact that an increase in variable renewable energy will likely increase mismatches between supply and demand (Sinsel, S. R., *et al.,* 2020), does not incentivize long-term investment. Governments should adopt measures to reduce this competitiveness gap and provide investors with fiscal incentives, and with clear, transparent, and accessible information.

Net Energy or Energy Return on Invested (EROI) is a concept developed by (Cleveland, C. J., 1991), which translates in the amount of energy necessary to get more energy. Different sources, even for the same resource, have different EROI's: for example, oil found on the surface is much easier to extract than deep-sea oil, where drilling turns the investment more risky and less profitable for the same amount. Energy concentration is a relevant in-

dicator in terms of performance and one of the main obstacles for renewables is to compete with the vast energy available for each gallon of oil.
In the case of renewable energy, understanding the different technologies and applications that exist is key. Economic agents should consider which ones are more suitable for each individual situation, taking in account aspects such as geographical condition, energy efficiency and ease of implementation.

2.2.1.2 Infrastructure

To better integrate the energy that derives from other resources besides natural gas, coal and oil, a capable infrastructure is required. The way modern economies are built around fossil fuels generates a huge obstacle to an energy reform. (Goldthau, A., 2014) refer scale, decentralization, and polycentrism as possible solutions to defy the inertia that national grids currently deal with and the institutional lock-in around outdated policy drive. Regulation adaptation ability to meet the requirements for a modern and well-functioned grid is of utterly importance.
The comparison of production and storage prices between various energy sources can be made by calculating the levelized cost of energy (LCOE), (Timmons, D., *et al.*, 2014). LCOE gives the present value of any given power plant over an assumed lifetime, taking in account future expectations about price fluctuations. Biomass and Hydropower are, for quite some time, able to allow relatively low prices of energy production but they still can be vulnerable to natural discrepancies in levels of energy output. The question is if over time renewables can provide sufficient energy in a constant way.

2.2.1.3 Intermittency

Renewable energy has a knowable intermittency problem, varying in its production capacity throughout the day and throughout the year, with solar being a prominent case, with its well-known Duck-Curve (Lund, H., 2007). Solar panels are becoming more efficient but its industry still usually over evaluates their performance and they present a seasonal difference that needs another energy source to be reliable (Imteaz, M. A., & Ahsan, A., 2018). Photovoltaic energy can offer the equivalent power generation as hydropower dams, with just a small percentage of the territory (Waldman, J., et al., 2019), which in turn opens the space for the debate around how to develop the proper approach, taking in consideration multiple perspectives.

As the electricity market needs to match supply and demand at any given moment, addressing the intermittency makes this even more relevant. Wind power is growing at very high rates (BP, 2021), but its irregular energy generation is recognized (Barton, J. P., & Infield, D. G., 2004). In a very detailed paper, (Enevoldsen, P., *et al.*, 2019) project that, even with due constrains, Europe might be able to produce more than 50TW of wind power until 2050 and offer some recommendations for policy makers. Nevertheless, these projections should consider the capacity to storage energy in a secure and reliable system.

2.2.2. Nuclear Energy

As the global energy consumption will continue to increase over the years, especially in countries such as China and India, where coal still represents an important part of their energy portfolio, nuclear energy technology role should be discussed. Even though it is a non-consensual debate in the energy sector (Prăvălie, R., & Bandoc, G., 2018), it has many advantages, such as very low levels of emissions and the potential to provide a continuous and long-term reliable energy generation. Together with the fact that nuclear energy technology has made progress in terms of safety around aspects, like the power plants' architecture and nuclear waste disposal procedures, the requirement of human intervention has decreased over the years. In addition to this, the relatively stable financial return on nuclear investments might allow the opportunity to develop further nuclear plans that are desirable for policy makers.

In an interview with a pro-nuclear scientist Kerry Emanuel (Stover, D., 2017), the example of France is covered, as nuclear energy represents around 70% of its total produced energy. This turned the country into a net exporter of electricity in 15 years, which demonstrates that the capacity to adopt a viable nuclear energy strategy can lead to positive performing results. Even though it has passed the Energy Transition for Green Growth bill in 2014 with one of the aims being to reduce the share of nuclear to 50% and promote citizen information (Valls, M., & Royal, S., 2014), France will still yield an important asset to its economic and sustainable growth, and it can act as a success model for other nations.

On the other hand, the concerns over nuclear waste radiation and contamination of the environment, alongside with the serious risks of human error and natural disasters on nuclear power plants, as Chernobyl and Fukushima, respectively, poses a great risk for regions with nuclear prospects (Ho, Shirley S., Kristiansen, Silje, 2019). There are many other spheres of consideration regarding nuclear energy, such as radioactive waste management, nuclear weapons proliferation, public opinion and political acceptance towards new power plants projects, and a transparent and independent organization to overlook the safety and security of current nuclear facilities (von Hippel, *et al.*, 2010).

Nuclear energy, being almost carbon-neutral and not having the intermittency issues as photovoltaic (PV) and wind sources, is a strong candidate to become a power source for large-scale hydrogen production. With increasing economies of scale, and as more scientific research and breakthroughs are made, nuclear energy will become more price competitive than natural gas (Verfondern, K. (Ed.), 2007). If at the same time safety risks can be significantly reduced and an independent international organization for control of nuclear energy production is established, there are conditions to consider enhancing the synergy between nuclear and hydrogen, either through electrolysis (low or high temperature), hybrid cycles, or thermochemical cycles (Forsberg, C. W., 2009).

2.2.3 Coal Phase-Out

Electricity generation by coal represents the largest share, around 35% of the total produced – yet, after a more careful examination of the data, it should be noted that this trend is only supported by the Asia Pacific region, while all the others, such as Europe, North America, Middle East and Africa all prioritize natural gas as the main energy source (BP, 2021). This Asian dependency context is explained by different individual countries differences, such as economic development and energy efficiency rates. (Chapman, A., Fujii, H., & Managi, S., 2018) suggest that improving cooperation and integration across the different regions and countries have a positive correlation with technology diffusion and know-how spillover effects, as the more dependent and less developed ones have greater opportunities to converge, and the overall energy efficiency of the continent will subsequently increase.

This situation of China, and by extension, the world, of high dependency on coal, with it being such a great pollutant, derives from decades of economic growth without enough regulatory and environmental barriers. An overcapacity of coal power plants, according to (Ren, M., *et al*, 2019) explain this trend and the fact that only until recently, China did not have to effectively allocate their resources for a sustainable economic development, result-ed in almost half of their coal plants reporting financial losses in 2018. Entering in a new phase, with the country needing to maintain its prosperity levels, the requirement for a clean transition has increased and even thought that, as mentioned before, the country is the largest global investor in renewable energy, China is still very reliant on new coal power plants. Political discontent emerges in some regions that have large quantities of this natural resource, creating conflicting interests between national and regional governance - a phase-out of coal must be approached with the due care.

Europe also has internal disagreements regarding its countries' national energy agenda, with the most prominent cases being Poland and Germany. As is the case with China, European nations with an historical mining and use of coal as a power generator have institutional carbon lock-in, especially in economies where the state has protective measures to certain fossil-fuel industries (Rentier, G., *et al.*, 2019). This might difficult a smooth transition and will impose challenges to these economies, compared to more liberal markets economies.

The option of Carbon Capture and Storage (CCS) in coal power plants has been target of some interest, but the positive impacts are residual. Looking over a case study of implementation of CCS in a coal-fired power plant, (Atmo, G., Otsuki, T., & Kendell, J. (2018) found that the financial viability is highly dependent on the carbon price, and it may not be sustainable if the prices increase, as it is expected.

Considering the limited scope of effectiveness that CCS has at a global level, because of the finite quantity of land available and the inherent difficulty of associated logistics, CCS technologies have more significant results as a symbiotic technology rather than an isolated attempt to mitigate emissions. With this concern in mind, there is a need to search for solutions both in terms of scale and in terms of long-term planning. Solutions like Hydrogen as an energy vector arise and have been studied as a reliant alternative to the current models.

2.2.4 Natural Gas Role

Natural Gas has been increasingly produced worldwide, with over 4 billion cubic meters produced in 2020 (IEA, 2021), although in this same year occurred the first fall in production since the financial crisis. This natural resource has different methods of extraction, from the conventional method to fracking, it is distributed mainly via pipelines or as Liquefied Natural Gas (LNG), and while the production, storage and commercialization benefit from market competition, its distribution and transport should be regarded as a public utility.

The role that natural gas may have in the future is debated and researchers divide themselves around the subject. An important shift in the world's energy dynamics was the discovered shale gas access that North America had in the 2000-2010 decade, where the United States went from being a large importer of natural gas to one of its biggest producers (Wang, Q., *et al.*, 2014). Shale gas production over this period may be the main responsible for the increasing levels of methane (Howarth, R. W., 2019), which is even more pollutant than carbon dioxide, and therefore, should not be considered as part of a carbon neutral solution in the long-run, as the large GHG emissions defy the purpose of using natural gas as a bridging fuel for a carbon neutral economy.

The act of flaring gas, primarily upstream flaring, is also a polluting activity, although its contribution is somewhat overlooked. (Elvidge, C. D., *et al.*, 2018) state that specific countries, usually high dependent on their fossil fuels, such as Algeria, Gabon, Iran, Venezuela, and Yemen, could almost meet their targets for reducing emissions by decreasing their flaring and find alternative solutions. Abandoned oil and gas wells are also a high methane source to the atmosphere – (Kang, M., *et al.*, 2019) affirm that plugging these wells and mitigating the emissions that derive from them over the years have positive cost-benefits results, especially when estimating the environmental, social, and economic costs of these methane emissions.

Although shale gas and flaring do not align with carbon neutrality, (Safari, A., *et al.*, 2019) consider that a rough take on fossil fuels may not be the most prudent solution and that considering the impact that oil and gas will still have in the coming years, short and medium-term plans must include a strategic planning of these resources, for a successful transition into low-carbon economies. Natural gas role in Hydrogen production, known as Blue Hydrogen, is very important and will be overlooked more attentively in this dissertation.

2.3 Sustainable Development Mechanisms

The concept that what is good for the environment is contrary to what is good to the economy was refuted decades ago, where along with technological progress, environmental regulation can spur technological innovation by identifying resource inefficiencies, creating more equal opportunities for market players during the transition period, providing more information to companies and reducing uncertainty for investors (Porter, M. E., & Van der Linde, C., 1995).

The Clean Development Mechanism is a financial tool that ensures investments that reduce GHG in other countries contribute to the emissions target of the investing country. Indirect effects on environment, as is the case with the health sector, are also less costly to prevent than to repair, incentivizing proactivity on the public sector, with environmental policies wielding productivity growth-promoting effects. (Chen, Y., & Lee, C. C., 2020) provide insights on how innovation brings positive technological spillovers, especially for countries more open to globalization.

There are various mechanisms for nations to deal with their emissions goals, and each one is more suitable according to policy objective and the context where they are being implemented. A detailed overview of green mechanisms will be presented, having as basis the (Griffith-Jones, S., *et al.*, 2012) paper:

2.3.1 Mechanisms to alter the economics of renewable energy

There are three direct ways to economically sustain the paradigm shift in the energy sector:

1. Lower the costs of renewable technologies, either by financially support Social Responsible Investors (SRIs) through subsidies - which in turn revert to upgrading the infrastructure, innovating processes, and adapt the energy grid – or by investing in R&D, developing university research programs and technology hubs.
2. Raise the cost of fossil fuels, as they lead to some of the worst negative externalities that are reported in this decade (World Economic Forum, 2020), and as they do not represent their cost value over the long-term. Taxes on carbon, direct or indirect, derive different results, economically and politically speaking, and need to be considered by their effectiveness on the long-run. Nevertheless, they inform the

consumers about the real price of the emissions released by oil and gas production, distribution, and consumption.

3. Boost the returns from renewables, providing premiums for electricity producers that opt by sustainable resources. The success of Germany is being followed by other countries and with its widespread, the penetration of renewable energy will increase gradually.

2.3.2 Mechanisms to increase the supply of appropriate finance

Issuing financial instruments such as a bond that has its price varying on the level of emissions from the purchasing country, could give certainty towards investors that make sustainable projects in developing countries, bringing positive economic results – and their holistic contribution to the well-being - which in turn help achieving the target of sustainable growth.

Green bonds allow Development Financial Institutions (DFIs), supported financially by the sovereign states, to allocate resources towards SRIs. With this level of low risk credit access, companies - especially those that follow a more progressive and sustainable approach – are incentivized to seek for business opportunities in a variety of projects, both inside the developed and in developing countries, such as:

- Solar and wind installations
- Funding for new technologies that permit significant reductions in GhG emissions
- Rehabilitation of power plants and transmission facilities to reduce GhG emissions
- Greater efficiency in transport, including fuel switching and mass transport
- Waste management (methane emissions) and construction of energy-efficient buildings
- Carbon reduction through reforestation and avoided deforestation

Other type of bonds might include an energy efficiency bond, where quality and circular economy concepts promote the use of high quality goods that provide long-term utility. This type of bond is an example of a win-win situation, where international standards would rise and more developing countries would have a faster, and especially, less costly transition to higher efficient technologies.

Investment in innovation and R&D must be closely followed by regulators, as there is space for undesired results if negative externalities occur due to its progress. Unfair market competition benefit companies that are ahead in technological progress and, as an example, might use Planned Obsolescence to create recurring demand for their products over short periods of time. (Malinauskaite, J., & Erdem, F. B., 2021) argue that the EU economic and environmental regulations' framework are not properly suited to address this issue and more insight is required in order to further develop technological progress without some of its constraints.

2.3.3 Mechanism to reduce uncertainty

Variable taxes that would be inversely related to oil and gas price levels, to stabilize their value and subsidizing the renewable sector and inherent sustainable projects with those cashflows – note that this differs from a direct "blind" tax. Grants for keeping competitiveness in times when sudden falls in fossil fuels' prices happen, would also make returns more viable for renewable energy projects during that period, by issuing a putting position on carbon prices, lowering the risk for investors even with sudden shocks.

Carbon trading schemes and considering a clearer financial regulation towards specific targets, such as a percentage of lending only allowed for more sustainable projects, enhance both private polluting companies – where they can design their own strategy, by opting on the amounts to pay and the amounts to receive from the allowances - and banks to comply with emission goals.

For low information and communications technology (ICT) countries, green taxes and trading schemes incentivizes investment and productivity, whereas in high-ICT countries, non-market policies (such as command and control regulations and performance standards) may increase productivity, although it may also lead to a lower redistribution of resources by capital accumulation in the high-ICT sector (De Santis, R., *et al.*, 2020).

2.4 Hydrogen

2.4.1 Hydrogen as an Energy Vector

Being the most abundant element on earth, Hydrogen as an energy carrier is not a recent technology (JO'M, B., 2002). The Club of Rome's controversial 1957 report on the "Limits to Growth" (Meadows DH, 1972) and the first major oil crisis of 1973, were the motivation to first consider hydrogen in a time of supply uncertainty. With no emissions with its use besides water vapor, Hydrogen can act as an energy carrier and is a solid candidate to provide a medium-long term solution to a global economy that is in need to grow while reducing its emissions (Hosseini, S. E., & Wahid, M. A., 2016). In 2003 the United States of America president, George W. Bush, stated that a hydrogen economy was necessary (Stetson, N. T., *et al.*, 2016) and that he believed that a transformation of the economy towards this energy vector was strategic, with the example of a significant share of hydrogen cars in the future being a reality.

The Hydrogen Council, a global organization for promoting hydrogen economy, issued a report, where it predicts that in the following decade, the costs inherent to hydrogen will be halved by 2030 for various applications, which will increase hydrogen's competitiveness, in comparison to both pollutant and low-carbon alternatives (Hydrogen Council, 2020). The International Energy Agency also praised the "vast potential" of hydrogen related technologies (IEA, 2019), allowing an opportunity to develop a cleaner and efficient economy, with economic blocks opting to invest in it and ensure their energy security. This is a key technology and opportunity for many countries to achieve cleaner transition, with some of the features of its' utilization being observed areas such as energy storage and distribution, hard to electrify sector, replace chemicals in feedstocks and be a solution for decarbonization building heating.

2.4.2 Hydrogen Types

There are various types of Hydrogen production, to its energy source, which are given different "colors":

White Hydrogen it's referred to the naturally occurring one that might rarely be found in underground deposits. Since there is no viable plan to its use it is not considered to be part of any economic strategy.

Brown/Black Hydrogen is produced from fossil fuels without combustion but with high temperatures. If it is derived from lignite it is known as brown hydrogen and if it comes from bituminous coal, it is known as black hydrogen. It's highly pollutant and it should be avoided in any sustainable planning.

Grey Hydrogen is the most common one, which comes from natural gas, via steam reforming. Its problem is that it also produces carbon dioxide and carbon capture is not contemplated at all.

Blue Hydrogen in this process, carbon capture techniques are combined with steam reformation, to reduce, or at least, balance the carbon emissions. This process has mixed reviews, with some authors enhancing the effort to transition into a cleaner economy and others pointing that it's not enough and should not be regarded as a sufficient measure.

Green hydrogen is an option that is being studied for some time (Clark II, W. W., & Rifkin, J., 2006), with renewable sources of energy being capable to produce the electricity which in turn, produces hydrogen. Photovoltaic, waste management, wind, small sustainable hydropower, geothermal, and even wave power, among others can be explored and combined with each other to achieve the carbon neutral requirement. While the prominent role of hydrogen in a sustainable energy future is widely accepted, the way for the transition from fossil fuels to a sustainable hydrogen economy is target of discussion (Muradov, N. Z., & Veziroğlu, T. N., 2008).

Hydrogen production can derive from many processes, presented below:

Table 1. Hydrogen Production Process. (Verfondern, K. (Ed.), 2007).

Technology	Benefits	Barriers
Steam Reforming: Splitting of hydrocarbons with heat and steam;	Well understood at a large scale, where it is commercially viable; widely available feedstock; ideal for centralized production;	Not possible on a small-scale; polluting emissions, such as methane; subject to natural gas price fluctuations;
Gasification: Splitting of heavy hydrocarbons and biomass into hydrogen and other gases for reforming.	Well understood at large scale and can be used for solid and liquids, with an abundant coal supply being available.	Less hydrogen-rich than methane, which leads to lower efficiency; CO2 emissions from coal; low energy density for biomass; Hydrogen requires a cleaning, prior to use.
Electrolysis: Splitting water into hydrogen and oxygen, through electricity	Well-known technology; commercially viable with proven technology; high purity hydrogen; modular and convenient for renewable energy; ideal for distributed production;	Electricity prices affect greatly the costs of production; efficiency in the whole chain is low, which requires additional input; market competition with direct use of renewable energy
Thermochemical Cycles: Splitting of water using cheap high temperature heat from nuclear or solar	Potentially massive production at low cost; no GHG emissions; high energy efficiency;	Not commercially viable and chemically aggressive; high temperature nuclear reactor deployment and high initial capital amounts needed;
Biological Production: use of algae and bacteria to produce hydrogen under certain conditions;	Potentially large resource, with no feedstock required;	Low efficiency and slow production rates; large areas needed; still in early stages of R&D for real applications;

As it can been observed in the Table 1, large scale implementation, energy efficiency and polluting emissions are not easy to conjugate between all the alternatives. Electrolysis appears to be the long-term optimum strategy, as the main problems derive from price volatility and some efficiency losses and, with significant renewable energy supply, there is potential to overcome them.

Considering Power-to-Gas procedure, where there is a possibility to use the renewable energy surplus to produce hydrogen through the process of electrolysis – the energy carriage capacity of hydrogen allows this alternative to support different other activities, from residential, to commercial, transportation and industrialization use (Walker, S. B, et al. 2016). The design of this technology, with its benefits, allows for a more integrated energy supply, where the source and the use of the produced hydrogen can vary, adapting to the needs of the economy at any given moment.

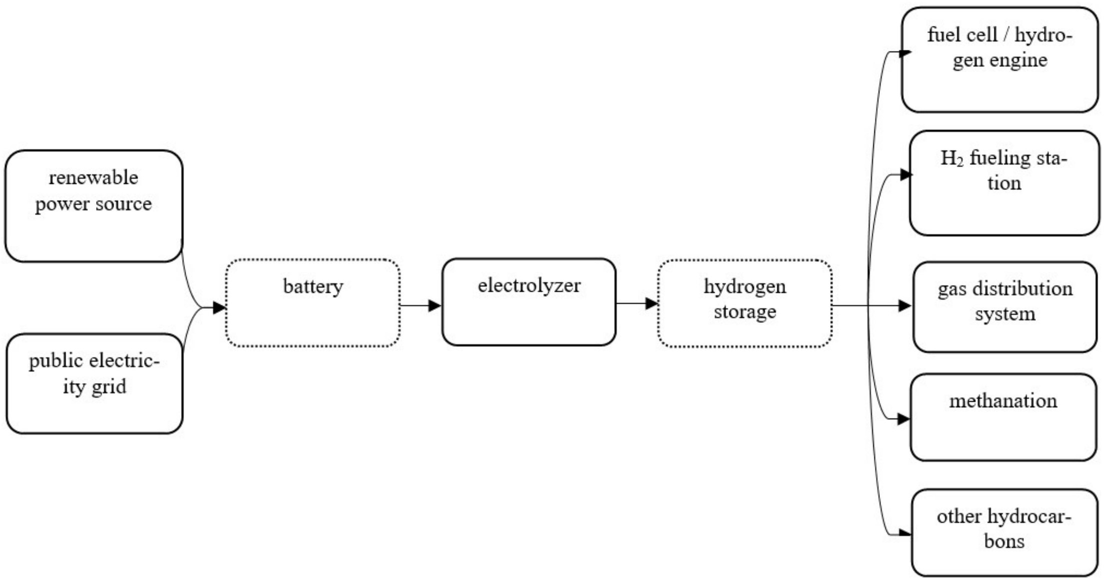

Figure 3. Power-to-Gas System Gahleitner, G. (2013).

Figure 3 presented helps visualize and explain how a Power-to-Gas System is designed, with batteries and storage being included or not depending on what type of project is being considered. As it can be seen, the multiple scopes of action of this technology enables a resourceful approach (Gahleitner, G., 2013).

To successfully store and distribute hydrogen in the power grid, investment in infrastructure, such as electrolysers, pipelines, and fueling stations, is essential. Research in symbiotic technologies, such as investment in hydrogen vehicles is also very important, as the scale leads to efficiency gains and costs reduction over time.

2.4.3 Renewable Energy Storage and Distribution

A problem with energy production surplus is its' difficulty to be stored in a reliable way, which usually leads to it being sold at a reduced price, sometimes even at negative values to balance the system. Power-to-Gas technology offers advantageous long-term storage and is reliable to be distributed in the existing natural gas system. The ability to stabilize the grid from renewables' overproduction and to enable a large-scale efficient clean energy integration is essential to granting energy security and to designing reliable macroeconomic strategies.

Presenting a real case study in Alberta, (Olateju, B., *et al.*, 2016) model a wind-hydrogen system to compare with the highly polluting Steam Methane Reform (SMR) that is still the most used method to produce hydrogen. Wind-hydrogen systems have the lowest GHG life cycle of all systems, and, besides hydropower, it has also the lowest cost to produce electricity. While concluding in their study that it was not yet economically competitive at the time, a dynamic energy storage – with the use of fuel cells or batteries - allows economic agents to take opportunities and gain competitive advantage in the differential prices during real time trading - by a comparative analysis, the authors found that the use of fuel cells was costlier and less efficient.

Interestingly, in their research with fuel cells, (Beccali, M., *et al.*, 2013) manifest the positive results in the implementation of hydrogen systems and potential to turn green hydrogen competitive. Systems of wind-hydrogen-transportation are optimized for high wind-power, and subsequent higher hydrogen production projects, and with electrolyzed oxygen being sold for cost reduction The range of action and technological progress in this area allows for creative and coordinated solutions for storing and distributing energy in an efficient way.

2.4.4 High Pollutant Sectors

Long-distance transport and heavy industry are the main global contributors to pollution (Eurostat, 2020a), and it is hard to decarbonize them because of the large costs and difficult logistics of implementing clean energy processes. With its characteristics, hydrogen can provide a way to deal with these high levels of emissions sectors and to materialize the hypothesis of a carbon-neutral economy, collaborating with other technologies, as fuel cells.

(Manoharan, Y., *et al.* 2019) investigated hydrogen-based energy using fuel cells and their use in hybrid vehicles, along with controlling systems strategies.
It was concluded in their study that large-scale production, commercialization, and implementation of fuel cells will lead to a reduction of costs and its' prominence in the transportation sector. They perform better than batteries-based electric vehicles in some aspects, as they have lower costs (because of the smaller battery) and the refueling can be much faster – both are relevant for commercial transportation, from city buses to delivery trucks (Hydrogen Council, 2020). This technology can progressively integrate the market and hybrid and hydrogen car fleet can obtain a bigger share of the total in the following years

2.4.5 Replace fossil fuels as a zero-carbon feedstock in chemicals

Industrial products and fertilizers such as ammonia, which is important for farming and mining, are becoming more and more accessible and less costly, contributing to a relevant share of global GHG emissions. Only recently "green ammonia", which is a carbon neutral process, has become economically competitive – (Nayak-Luke, R. M., & Bañares-Alcántara, R., 2020) find that almost 2% of total emissions are due to ammonia production and that a sustainable production of this compound can be possible in many by 2030.
With a very high percentage of CO2 emissions, cement is also an important product to consider, as it is the most common material for construction and accounts for a considerable part of the problem. (Danish, A., Salim, M. U., & Ahmed, T., 2019) in their study present a series of measures to support "green" cement, resorting to efficient cement production, better waste management and use of sustainable raw materials.

2.4.6 Help decarbonize building heating

All these are important to any serious commitment to decarbonize. Hydrogen can be obtained through steam reforming, a high temperature process in which steam reacts with a hydrocarbon fuel to produce hydrogen, and trough electrolysis, which splits water into hydrogen and oxygen via electricity. Nowadays, steam reforming accounts for nearly all commercially produced hydrogen, generated mainly through fossils (EIA, 2021).

A regulatory framework to encourage investments on Hydrogen is crucial to its development. In a report from IRENA in 2018, some instruments can help to create a more favorable environment for a financial uplifting in the sector, such as broad financial support instruments - like capital expenditure subsidies and tax exemptions - and more specific incentives – such as take-or-pay contracts and reliefs from electricity grid charges - enabling the market to also absorb some of the infrastructure costs (IRENA, 2018). With its characteristics, incentives to a hydrogen transition also have positive repercussions to renewables' financial situation at the eyes of investors, aggregating the economic and environmental benefits of both technologies and reducing the uncertainty in long-term, by showing a clear intention to what is expected to be the future of the energy sector.

3. Geopolitical Energy Context

With various instruments such as renewable energy sources, carbon capturing, carbon pricing and green hydrogen, countries should plan their medium to long-term strategy soon, to be able to achieve international goals until 2050. The priority should be to make these alternatives as economic competitive as possible, to expand the share of neutral emissions alternatives and to implement them in an effective way. A vast portfolio of potential opportunities is one of the best referred approaches to a sustainable use of natural resources (Yousefpour, R., & Hanewinkel, M., 2016), with nations having the opportunity to decide what source of energy to use depending on the month, week or even on a daily schedule. Researchers are also increasingly interested on how the energy grid will look like in the future. The current grid has developed enough to integrate small and private energy individual producers in an open market that might be controlled closely by anyone who would like to participate in it. Being more involved in energy producing and consumption and even designing additional income sources for consumers surplus seems like an alluring idea for any politician that sees an opportunity in being in the vanguard of the energy market. (Olivares Gallardo, A., 2014)

Extreme climate weather will disrupt global food supply and consequently have bigger absolute and relative impacts in the high-income countries, rather than the low-income ones (De Winne, J., Peersman, G., 2021). This motivates economic powers to intervene, and to take the lead, to benefit from the competitive advantages of first movers. Europe and China have similar goals but quite different motivations to consider hydrogen in their energy strategies.

3.1 European Union

3.1.1 Energy Policies Overview

Europe is leading in terms of Energy transition and aims to be carbon-neutral by 2050 (European Commission, 2019). There are clear ambitions regarding the new European Green Deal (European Commission, 2021), with the main objectives being: reducing emissions, address energy poverty, reduce external energy dependance, improve health and well-being of its citizens and create work opportunities within this framework.

Harmonized energy policies between European countries became a prioritization after the Second World War, and laid ground for the modern European Union project, with the foundation of the European Coal and Steel Community (ECSC) in 1951. In despite of having some degree of economic integration, the energy policies were mostly defined on the nation level until the 1973 oil crisis (Langsdorf, S., 2011), which exposed one of the fragilities of the European continent, the lack of natural resources in comparison to other regions.

To deal with international markets' volatility, in 1974 the Council called on an increase of coordination among Member State (European Council, 1974), to diminish the susceptibility to global supply shocks. This attitude was followed by stimulus packages that aimed to address regional policies, which leveraged the growth and strengthened the stability. The need to guarantee energy security was the drive to implement measures such as the development of nuclear energy production, consider diversified and reliable external supplies and investment in research and technological development (Langsdorf, S., 2011). This baseline provided the framework in which the European Union still acts upon. The Kyoto protocol in 1997 was a significant step-forward in the climate agenda and the necessity to achieve higher goals incentivized a pursue of concrete and applicable approaches.In 2005 the European Emissions Trading System (EU ETS) was created, with the purpose of better regulate the emissions levels of its Member States and other countries, such as Switzerland, Iceland, and Norway (European Commission, 2019), being the first international cap and trade scheme. It is currently in its 4th phase (2021-2030), with adjustments and improvements being made overtime. The difference between carbon taxation and an emissions' trading system is that the first regulates price and lets the market determine the aggregate emission levels, while the cap and trade system defines the aggregate levels of emissions and allows the market to determine the price (Tietenberg, T. H., 2013). Carbon taxes are more straightforward and easier to implement, while Cap and Trade Schemes are politically more interesting, as free allowances give the chance for each company to manage their own emissions and expectations according to their situation.

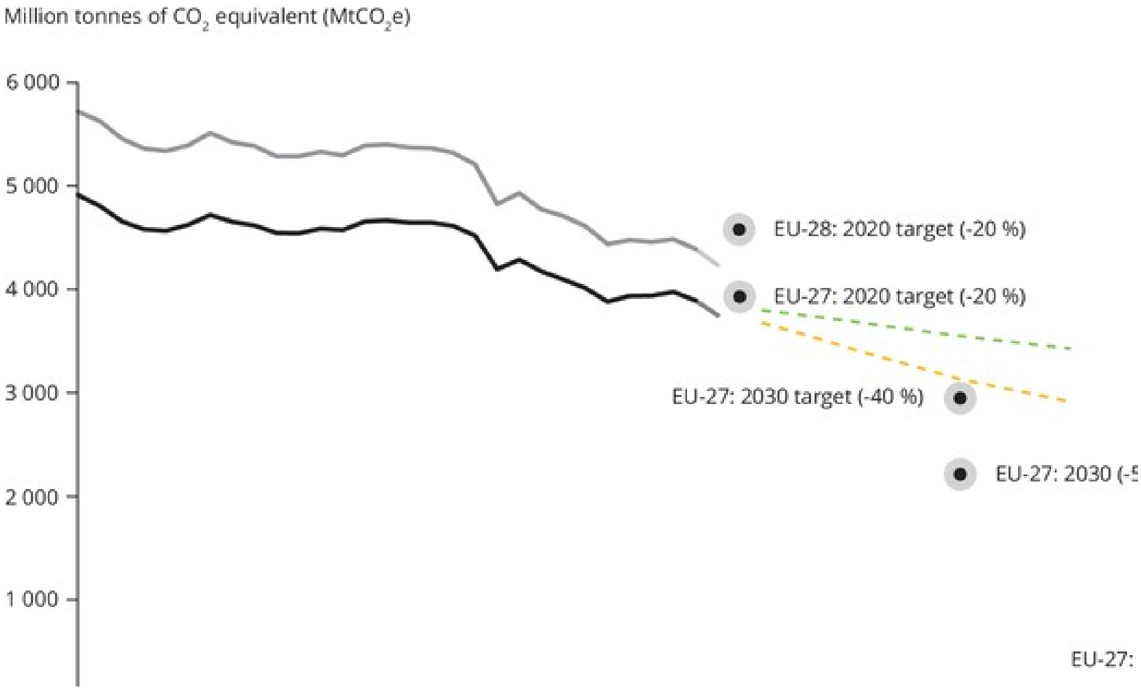

Figure 4. Greenhouse gas emission targets, trends, and Member States MMR projections in the EU, 1990-2050. (EEA)

In the Figure 4 it is possible to acknowledge the results that were already achieved, with a more considerable evolution after 2005. Reducing sensibly 1000 million tonnes of CO2 equivalent between 1990 and 2020, and with the 2030 target updated by 15 percentage points (European Commission, 2020), the European Union still has many opportunities for improvement. Although the EU ETS functions well as regulation mechanism, it still has some key points to improve as in terms of price efficiency, with some arguing that a price floor like what exists in many other GHG emissions trade systems would enhance the system design and increase the reliability of expectations (Flachsland, C., *et al.*, 2020). The Treaty of Lisbon in 2007 presented the EU "energy action plan", agreed by the EU heads of state and governments, a common energy policy unfolded, which englobed the completion of an integrated gas and electricity market, a strengthen of energy security and investment in low-carbon technologies (Langsdorf, S., 2011). Between 2007 and 2009 there was more emphasis on reducing GHG emissions, increasing energy efficiency and renewable energy share in the total production. European energy security was envisioned (which had only been the case for Member states) and in terms of energy policy, the Council would operate on more fiscal measures and nations should focus on their energy production and finding a sustainable portfolio of sources and options.

More recently, a series of proposals were adopted, including an intermediate target of an at least 55% net reduction in greenhouse gas emissions by 2030 (EC, 2021). In Europe, renewable energy annual capacity additions are forecast to increase 11% to 44 GW in 2021 and 49 GW in 2022 (IEA, 2020). With its position in the international scene, Europe is a pivotal figure in the development of research for better solutions and market prospects.

3.1.2 Europe's Clean Transition Obstacles

The Geopolitics of Energy is very dynamic (Pascual, C., & Zambetakis, E., 2010), with trading deals being made taking in account existing reserves, discoveries of new ones, political stability, and financial volatility. As previously mentioned, Europe lacks the natural resources to fully produce its own energy. This situation led to a high energy dependency, that still applies nowadays, with more than half (58,2%) of the EU's gross available energy coming from imported sources in 2018 (Eurostat, 2020b).

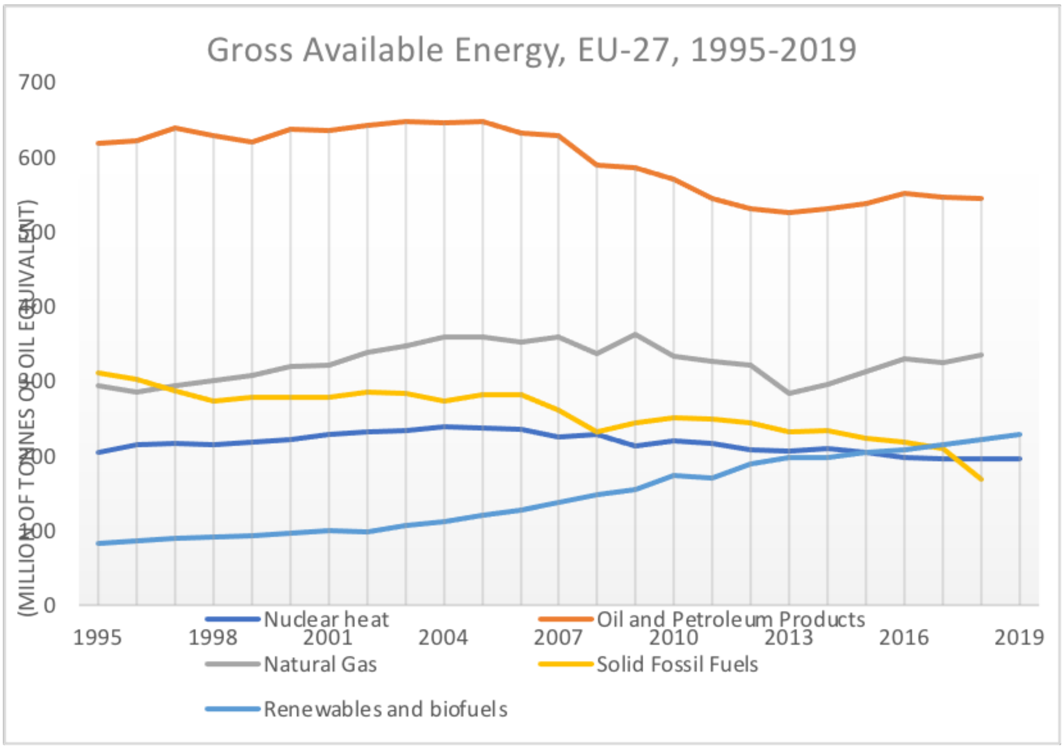

Figure 5. Gross Available Energy, EU-27 (1995-2019). Source: Eurostat (online data code: nrg_bal_c)

In the Figure 5, data presented corresponds to the gross available energy for each type of energy source in the 27-Member States European Union. By analyzing the variation of energy sources over time, it is possible to observe the hegemony of oil and petroleum products - although it suffered a backlash from the 2008 crisis and it has not yet since recovered itself to previous levels- and the spur of renewables, having recently surpassed solid fossil fuels.

Natural gas contribution to the available energy was decreasing until 2013, where its role as a transition energy source is being increasingly recognized – nevertheless (Stephenson, E., Doukas, A., & Shaw, K., 2012) argue that its function as a "bridging" fuel needs to be carefully analyzed as shale gas production, for example, is not always the best suiting option, with regional and national governments having to pay attention to how much carbon-intensive the process is. Moreover, the discussion over the natural gas production is also in the political field (Smith, K. C., 2012), where fracking turned the United States a big competitor to Russia in the last decade (IEA, 2015). Discussions regarding the geopolitical impact of natural gas and this its role in a clean transition include the carbon intensity and sustainability of production, especially by fracking, and the greenwashing of the term "transition fuel", taking in account the damage to the environment.

Europe's main suppliers of natural gas in 2020 were Russia (39.3%), Norway (19.2%) and Algeria (12.3%), while in terms of oil, the portfolio is more diverse, with Russia still being the main partner (26.4%) followed by the United States (9.2.%) (Eurostat, 2021). Although energy consumption in the European Union is increasing and natural gas should play a bigger role as a transition fuel in this next decade, (Kutcherov, V., *et al.*, 2020) suggest that Russia might maintain their natural gas export levels to Europe, but Asia should be the target for growing their energy resources exportations.

In other areas, even though the continent is the international reference in R&D and political decision towards a more sustainable society, its' territory is not homogeneous and the distribution of energy production among the Member States varies significantly, with countries like Italy and Malta having historically high energy dependency, with registered values over 80% - and others like Denmark which is an energy exporter (Chalvatzis, K. J., & Ioannidis, A., 2017). In countries that were hit by the 2008 subprime crisis – Portugal, Spain, Italy and Greece – although there is a considerable dependency of imported energy, these relative levels decreased since then - explained by a decline of total energy consumption and with an increase of investment in renewable energy sources, to diminish the energy dependency and to empower their own grids.

Europe is expected to reduce its economic relevance on the international level until 2050, with the rise of new global powershouses, such as China. With this in mind, and having to maintain its relevance in geopolitics, there is a real concern with topics like innovation, digitalization and decarbonization. These allow Europe two main positive results: a decrease in international dependency, in the energy sector, and a favorable role as the world's leader in these fields. To comply with established Climate Agendas (2030, 2050), the EU strategy EC2019 affirms that "the transition to climate neutrality will bring significant opportunities, such as potential for economic growth, for new business models and markets, for new jobs and technological development. Forward-looking research, development and innovation policies will have a key role." Green hydrogen suits this frame, being featured in all the European Commission net zero emissions scenarios for 2050 (van Rensen, 2020). It is important to investigate how the adoption of these strategies will affect the economy how it can modernize itself to accommodate the demanding climate goals.

3.2 China

3.2.1. Economic Policy Context

When the People's Republic of China came to power in 1949, and as it has been the case throughout its history, there was a high reliance on its considerable labor force relative to shortness of capital resources. The nation's economic development boomed in 1978, seeing its average growth rate and living standards increase steadily since then. This phenomenon occurred based on positive economic policy decisions made by China, which focused on pursuing economic comparative advantages (Li, L., 1998), differentiating from previously failed reforms that relied on a strictly planned economy, such as the Great Leap Forward.

In the Figure 6, it is possible to observe China's percentage growth during the last 50 years, where growth rates are constantly above the 5% value, only not achieving it on 6 occasions during this period, 2020 included (OECD, 2021). The country intends to have 70% of the income *per capita* of the United States by 2050, which will require an economy at least between two and three times larger than the American (Energy Transitions Commission, 2019). As it was the case of the Asian Tigers (Hong Kong, Taiwan, South Korea, and Singapore), which had similar patterns of state control and market interference as China in their past, the pursue of economic advantages over planned economies lead to more substantial development results (Li, L., 1998). Overcoming several obstacles, namely distortion of resources allocation between state-owned and not state-owned enterprises and macroeconomic ones such as inflation, made China take incremental gradual approaches and reforms, which furthered market liberalization (Gang, F., 1994).

The country is known to have been using five-year plans since 1953, to show the guidelines that will orient policies in a variety of domains and give citizens and investors a higher certainty for the medium and long term. Currently, the 14th Five-Year Plan (2021-2025) intends to continue the growth-promoting practices, while addressing the constraints which the economic development does not offer on its own (Stern, N., Xie, C., & Zenghelis, D., 2020). Some of the measures include strengthening the intangible economy, triple the 2020 income *per capita* while addressing the increasing income inequality amongst its citizens, promote environmental-friendly practices, and investing in innovation and technology.

China was the country that attracted more Foreign Direct Investment (FDI) in 2020 (OECD, 2021), following a trend of increasingly interest by economic agents that benefit from lower operational costs – however, if not cautious, inherent emissions from these new projects might generate potentially large-scale negative repercussions, namely in environmental terms (Ascensão, F., *et al.* 2018).

The Belt and Road Initiative (BRI) policy is the most preeminent initiative led by China. It originated after the political crisis in the early 2010's, when the new Chinese president, Xi Jinping, developed an anti-corruption reform in its government and restructured some of the country economic and bureaucratic infrastructure, aiming to position China in the center of international commercial trade and further involvement in geopolitics. A series of measures were considered and undertaken in this regard, covering areas such as improving economic development by boosting consumption and investment, increasing regional and international connectivity (which is positively correlated with bi-lateral growth), promote cultural exchanges with other Asian countries, and ultimately, it is an immense geostrategy that might impact around 4.4 billion people (Lu, H., Rohr, C., Hafner, M., & Knack, A., 2018).

However, this initiative, among other Chinese economic-growth oriented policies, does not come without some opposition. (Kang, Y. Q., Zhao, T., & Yang, Y. Y., 2016), applying a more detailed approach than the conventional environmental Kuznets curve (EKC), estimate that China sustained growth cannot rely only on economic prosperity but also needs to take in account its environmental degradation, with an example of a direct negative externality being the air pollution endangering millions of people.

Being the world's biggest polluter and with its emissions having to be decreased as soon as 2030 (Mi, Z., *et al.*, 2017), developing plan like BRI - that will further improve developing regions and countries from Asia up to Europe, the economic growth and the increased energy consumption demand, as well as the growth in heavy industry, construction, and transportation sectors – needs to be presented in a sustainable proposal, especially for poorer regions affected, which have the most potential for positive economic spillovers but are more susceptible to environmental negative externalities (Lu, H., Rohr, C., Hafner, M., & Knack, A., 2018).

China's policies, geopolitical strategies and international agreements need to be environmentally sustainable and socially responsible, taking in to account the negative impacts in its own borders and in foreign countries - continuous economic growth will only be possible if it is aligned with sustainable growth, as higher human capital and energy consumption increase environmental degradation and GHG (Sarkodie, S. A., *et al.*, 2020). The goal of carbon neutrality by 2060 is one of the biggest challenges and many conjecture about the strategies that will be adopted to achieve it. Next, an energy context of the country current situation will be presented and an overview of mechanisms that China is currently working on.

3.2.2 China's Energy Situation

The dichotomy between short-term prosperity and long-term sustainability is affecting China's development strategies for the future - the economic growth that China is experiencing over the last decades has relied heavily on fossil fuels. The increase in energy consumption is mainly explained by the potential economic development, and the inability of energy efficiency technologies to attenuate the rise in GHG emissions (Liu, X., *et al.*, 2018). As the national energy consumption increases, all energy sources having registered an increase in their absolute value on the total produced (China Energy Portal, 2021).

In 2018, the Chinese government proposed a series of measures, including financial regulatory reforms and cutting air pollution, which had repercussions on unemployment and slowed down the economic growth, which already had been affected by the trade sanctions imposed by 2017 (EIA, 2020). China needs to decarbonize their economic prosperity and to do so, it might have to concede some of its expectations towards financial oriented results.

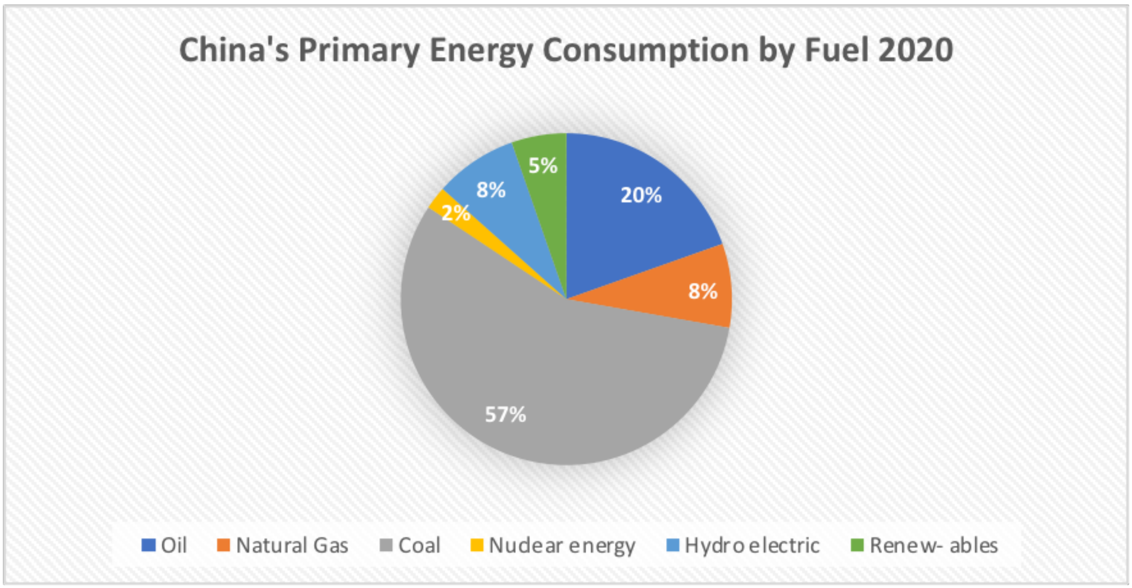

Figure 6. China's Primary Energy Consumption by Fuel 2020. Source: BP Statistical Review 2021

Figure 7 illustrates how the primary energy consumption in China was distributed by fuel type in 2020. As it can be observed, coal covered more than half of the energy consumption of the country in the last year, with around 57% of total (BP, 2021) - with almost one third of global CO2 emissions deriving from its economic activities, China was the only G20 country to increase its coal use (Ember, 2021). The large incentives to construct and built new coal power plants to sustain the energy demand led to the overcapacity of coal power plants (Ren, M., *et al*, 2019), and consequent financial infeasibility to a significant part of them. Around 18% of the power plants in the country are currently facing bad results in their performance and the authors develop some strategies to a more considerable phase out, towards 2045-2055 (Cui, R. Y., *et al.*, 2021).

Although being the one of the world's biggest petroleum and other liquids producer in the last years, China is the world's biggest oil importer (EIA, 2020), and the fuel demand is increasing, with the nation being responsible for 2/3 of the global oil demand growth in 2019. To diminish its dependency, the Chinese government requested that its National Oil Companies to increase their production, which led their investments to grow more than

20% in 2018 and 2019 (EIA, 2020). However, the Covid-19 crisis affected the oil prices and jeopardized the expectations of increasing national production – to face this problem, China is ease restrictions for foreign companies to take opportunities and develop independent projects, which contemplates a reduction of the national investment costs.
Natural gas corresponds to around 8%, virtually the same share of energy consumption as hydroelectric, and the demand for this natural resource has systematically increased over the years (IEA, 2021). Although the pandemic crisis reduced natural gas' imports in almost every region, by keeping its investments, China contributed to a global growth in demand, especially for LNG, which out weighted the decrease in pipeline gas. As gas exporting countries such as Russia plan to redirect towards Asia (Kutcherov, V., *et al.*, 2020), the demand for the applications of natural gas in various tasks, such as power generation and transportation, has been increasing and will occupy a more relevant share of China energy mix (Wang, Z., Luo, D., & Liu, L., 2018).

Regarding renewable energy, China was responsible for more than 50% of the new total installed renewable energy capacity in the world in 2020, primarily due to various projects in December that year (IEA, 2021). Hydropower is the largest contributor to China's renewable energy mix, followed by wind power and solar – although hydropower has maintained almost the same levels in the last decade (around 350 GW in 2018), photovoltaic capacity has been increasing at much higher rates, passing from only 28.1 GW in 2014, to 174 GW in 2018 (Huang, Q., 2020). If this trend continues, it is estimated that about 62% of total electricity production might be generated by non-fossil fuels already by 2030 (Hydrogen Council, 2021). However, as it happens with Europe, renewable energy production is uneven among its regions, even though this tendency has been decreasing in the previous years (Wang, Y., *et al.,* 2020).

In terms of nuclear energy, the perspective is that production and consumption will continue to grow, at least in the following years (Ding, S., *et al.*, 2021), with the need for clean energy leading to more capacity projected for this type of energy source, despite the risks associated with nuclear power in the past. (Xiao-ding, L. I., *et al.*, 2021) argue that China must invest in safety management training and adopt best practices methods to correspond to the potential role that nuclear energy might have in the future.

China must use the substantial expansion of its neutral carbon energy capacity into an energy system that can deliver the energy to the multiple sectors in the economy, and hydrogen could be the required energy vector to make this transition happen.

4. Hydrogen in Geopolitics

In this chapter, using qualitative methodology, there will be an analysis of both EU and China data and reports towards the adoption of hydrogen and especially green hydrogen, in the present and in terms of what to be expected in the following years. After the presentation of the essential guidelines, a discussion will follow, to discern opportunities for improvement, and to identify trends that might have great impact in the future, both in the energy sector and, in a broader spectrum, in the global economy.

4.1 Methodology

The goal of this dissertation is to give a more substantial answer to the question "How the European Union (EU) and China consider green hydrogen as part of their environmental strategy?". As the role that green hydrogen could have and what is the magnitude of its impacts remains widely unexplored, (Pflugmann, F., & De Blasio, N., 2020) propose that future researchers should investigate and identify the opportunities and barriers to large-scale hydrogen production, and how the geopolitical landscape might be change. To better make sense of the recent research made about it, the methodology of this dissertation consists of qualitative research, using primarily the Literature Review that is present throughout all the chapters of this dissertation. The information presented comes from three different sources:

1) Literature review, mainly on the topics of energy, sustainability, geopolitics, and economic growth, using both qualitative and quantitative research.

2) Macroeconomic reports and governmental strategic plans regarding the adoption of sustainable hydrogen in the energy mix, to better understand what is the context in which the European Union and China act upon and what to expect from each one.

3) Governmental databases and real case studies results.

The reasoning of this methodology it to have the opportunity to discuss some of the insights from the theoretical side while considering real strategies and case studies. In qualitative research there is an emphasis on understanding the context and the process, instead of focusing only on the results (Srivastava, A., & Thomson, S. B., 2009)., which benefits the analysis of political context and the identification of potential future trends.

4.2 European Union

The European Green Deal has target serious objectives to achieve, such as reducing net GHG 1990's emissions by 55% in 2030 and carbon neutrality by 2050, while creating new jobs and opportunities in a new paradigm (EC, 2020). On the 8th of July 2020, the European Commission released their "Hydrogen Strategy for a climate-neutral Europe", which will be the document scrutinized in this part. The objective is to better understand the data that supports the European plan, the coherence with the carbon-neutral goals and to give insights on what are the current strengths, and opportunities to improve.

The report gives insight about the position of the EC towards this technology, in alignment with the European Union's sustainable growth goals for 2050, which require sustainable energy sources for both electricity and, subsequently, clean hydrogen production. With its many potential end uses, the potential added value of hydrogen is very attractive for policy makers, as it offers a solution to economic growth and no aggravated climate negative externalities.

Only now, with the adoption of renewable energies being expanded at a global scale, governments and international energy economic groups have the conditions to finally consider green hydrogen production at a large-scale, in a financially viable perspective. The present hydrogen production represents a small role in the current EU energy portfolio (EC, 2020) and there is a predominancy of hydrogen production that still comes from fossil fuels, as they have a present lower cost - even with carbon storage capacities, non-renewable energy sources present a more competitive price.

Green Hydrogen capacity is increasing at a fast pace, as electrolysers projects having more than doubled their expected investments at a global scale in the first trimester of 2020, with Europe being the biggest promotor, with a share equivalent to around 57% of the total invested. From under 2% that it currently represents, it is expected that Green Hydrogen might achieve around 16% of the total final energy consumption (EC, 2021). In terms of transportation, the European Union intends to develop mass market acceptability (defined as above 1% for a segment), with buses being the first to adopt a large-scale hydrogen fleet, followed by trucks and cars in the next decade (Hydrogen Council, 2020).

By planning different stages to approach carbon-neutrality, the European Union define more concrete expectations towards the policies that should be implemented at each stage, which in turn gives more information to economic agents to invest. In the first phase (2020-2024), is where the main objectives are delineated: increasing electrolysers capacity and aim for a production of green hydrogen of 1 million tonnes by then. The infrastructure will start to develop with electrolysers and refueling stations in small scale in higher energy demand sectors, with progressive growth until the regulation and pipelines infrastructure are adequate for a further expansion.

In the second phase (2025-2030), hydrogen must become part of an integrated energy system, and the total production should reach increase by a tenfold, in comparison to the first phase target. It is important to highlight that the heavy industry and the transportation sector should start to develop and implement their hydrogen-based projects by this time - "Hydrogen Valleys" will start to be a reality, where areas that adopt this technology in a more intensive way will start to redirect some of the energy to other areas of action, such as heating for habitations and commerce, creating hubs of innovation.

Finally, in its third phase (2030-2050), CO2 neutral hydrogen use should be widespread and with this expansion, its derivative fuels and technologies, such as sustainable biogas, will emerge and further the environmental efficiency of the system. This structural transformation will require large sums of investments, with an amount between €180 and €470 billion by 2050 being required to successfully transition – as an example, from the 120 refueling stations in Europe in 2020, it expected that this number should grow to about 33 000 by 2050, an investment of nearly 27.5 billion euros (Hydrogen Council, 2020).

Part of these investments will come from various European projects, such as the European Clean Hydrogen Alliance, Next Generation EU and InvestEU. These plans are designed to stimulate both demand and supply, and to create incentives for consumers and producers to adopt the technologies as expected – some of the instruments that might be employed are direct supporting schemes, indexing the life-cycle CO2 emissions to the ETS benchmark, and establishing a standardization for carbon intensity. With the National Recovery and Resilience Programs, European countries have even more funds to support digital and sustainable solutions, in an unprecedent effort.

Serving as stabilizer for renewable energy electricity, Member States should start to benefit from the bigger share of green hydrogen penetration in the grid and with a more robust system, overproducing renewable energy in one country could be allocated to another, reducing intermittency negative results. Being a key-technology to the paradigm change in the energy sector worldwide, and with the advantages of being a first mover (Karkatsoulis, P., *et al.*, 2016), the investment in not only in European borders but also in strategic partners is essential to a long-term growth. As an example, Africa has vast potential for renewable energy production (De Angelis, P., *et al.*, 2021) and it is in the European Union interest to collaborate and finance projects in the continent, as the increased supply of green hydrogen would make it more cost-competitive.

Benchmarking euro denominated transactions in hydrogen is essential, both to avoid exchange rates shocks and to establish the position of Europe in the international stage. Hydrogen could place the European Union in a pivotal role in the energy transition, and it can be an instrument for further cooperation with other nations in case of trade agreements, research, and environmental goals.

4.3 China

China is currently the largest producer of hydrogen worldwide - however most of its production heavily relies on coal and the country is still behind in independent R&D (Meng, X., *et al.*, 2021). Carbon neutrality by 2060 is a considerable goal, especially taking in account the present GHG emissions levels that China has, and the willingness to maintain a high economic performance. Although no complete strategic roadmap was published, there are many initiatives that enhance the role of hydrogen and help delineate some of the main trends, including Five Year Plans, a Fuel Cell Vehicles (FCV) roadmap and case studies.

Hydrogen is not a new technology for the Chinese government, being already considered in the 10^{th} Five Year Plan (2001-2005), primarily aiming to create value in the transportation sector (Meidan, M., 2021). Even though not all targets regarding FCVs and refueling stations were met, the 14th Five Year Plan (2021-2025) reinforced the interest in clean development and in hydrogenation, by broadening the nation's goals and ambitions.

In 2016, China's "Hydrogen Fuell Cell Vehicle (FCV) Technology Roadmap" was published, with a strong pledge to develop hydrogen solutions for the transportation sector - until 2030 there should be 1 million FCVs in the market and over 1000 hydrogen operational refueling stations (Michal Meidan, 2021). The positive case of Electric Vehicles (EVs), where China currently dominates the market, illustrates the potential that China has in the hydrogen-based automobile production, and should be taken as a demonstration of what might happen if there are successful policies are implemented (Pflugmann, F., & De Blasio, N., 2020). The recent development of hydrogenation of the transportation sector is characterized in three ways (Meng, X., *et al.*, 2021):

1. Even though traditionally only small and medium enterprises had hydrogen projects, an increasing share of large-scale companies is embracing hydrogen, and already accounted for around 20% of the value-chain by the end of 2018.

2. There is a disproportionate number of companies across the hydrogen chain, where hydrogen production and storage (48%) and fuell cell applications (42%) have the biggest shares, leaving infrastructure design and construction only with 10% total invested – nevertheless by 2030 China should have biggest number of hydrogenation stations.

3. Significant regional differences in the endorsement of hydrogen technologies, with Guangdong, Beijing, and Hebei accounting for around 80% of the total national sales of fuel cells.

China's Hydrogen Alliance, and organization supported by the Chinese government, was established in 2018 with the goal of encouraging the development of hydrogen and increase international cooperation on both economic and innovation projects related to this technology. In the following year, China Hydrogen Energy and Fuel Cell Industry White Paper was published, where it shows the intention to adopt hydrogen as a prominent part of the national energy system in the future, and predicting that by 2050, hydrogen could represent around 10% of China's final energy, which in turn is expected to reduce CO2 emissions by 700 million tonnes and create a value-chain of 12 trillion yuan, annually (China Hydrogen Alliance, 2019).

4.4 Discussion

Although both China and the European Union have carbon neutrality as their environmental target, and green hydrogen will be pivotal technology that process, the present situation of each one is different. Historically, China has given more emphasis on the hydrogen transportation sector and still depends largely on coal to produce its electricity (BP, 2021) whereas Europe, with more advanced technology and more efficient processes, focus on R&D and investment projects, to decrease its high energy dependency and to secure its relevance in the global geopolitical context.

Considering the trade dispute that happened with the photovoltaic industry, where China surpassed both Europe and the United States as the global leader with scale and lower production costs, the risk of future challenges and trade disputes on green goods is possible (Huang, P., *et al.*, 2016). The innovation and technological advances were what used to give competitive advantages to the West, but, as China liberalized its market, and the western countries decided to start projects there, the know-how was transferred, and it was just a question of time until the country became the leader in PV production. Europe should adopt more sophisticated trade dispute settlement policies, to improve trade dialogues and avoid impediments to growth in this new opportunity (Voituriez, T., & Wang, X., 2015).

4.4.1 Barriers

Investment in the infrastructure, to lower costs and become competitive at an international scale, might result in severe financial losses if the supply and demand do not adapt to the transition at the same pace (Van de Graaf, T., *et al.*, 2020). The price of renewable energy is still the main constraint to green hydrogen production, as blue and gray hydrogen are still more market competitive, even while not considering the electrolysers costs (Campbell, L., 2021). Electrolysis is also considered somewhat inefficient, and renewable energy is more valuable if it replaces coal and other fossil fuels without energy efficiency losses.

Besides the present costs for large scale hydrogen production and considering the dimension that the coal and steel industries have in the present but also in the future, CCS and natural gas will be very important in the short and medium-term, as both brown and blue hydrogen will be more price competitive during that period (Energy Transitions Commission., 2019). This is especially true for China, as the country is “fuel-agnostic” in terms of its foreign investments (Meidan, M., 2020).

By looking at the renewable energy capacity, freshwater resources, and infrastructure potential, China has enormous renewable energy resources and capacity to create the required infrastructure, but needs to address its scarce freshwater resources with some urgency, while Europe has sufficient potential for producing hydrogen above its domestic consumption, in the long run it might be occupy a strong regional position, instead of becoming major global green hydrogen exporter (Pflugmann, F., & De Blasio, N., 2020).

While China has the larger renewable energy capacity and has more than 50% less costs with electrolysers production thanks to the lower cost of labor and the greater market power of state-owned companies (Christensen, A., 2020), the country is still behind in terms of research and innovation. One of the measures that

4.4.2. Opportunities

(Meng, X., *et al.*, 2021) propose five policy suggestions to for to successful development of green hydrogen:

1. Consider a national cohesive strategy that overviews the different aspects and applications of hydrogen, offering clearer guidelines and more certainty for economic agents in the medium and long-run.

2. Public-private partnerships are fundamental for a solid development, and there is a substantial need for an interdisciplinary body of action, between governmental organizations, academic researchers, and the private sector, not only in the energy field but also in industry and

3. Improve the standard system, to raise the quality of hydrogen-related product and to increase safety measures among the value-chain. The economic returns of carbon neutral go beyond the financial results and have positive spillover effects.

4. Support carbon neutral hydrogen production and not settle with the carbon intensive processes that currently prevail. It is more rational to develop a clean energy basis, than to continue supporting fossil fuels growth and then transition.

5. Strengthen international cooperation. While there are various organizations that directly or indirectly promote and fund the integration of hydrogen in macroeconomic strategies and energy systems, such as the Hydrogen Council, the European Clean Hydrogen Alliance, and China's Belt and Road Initiative, there are still many efforts to be made and the competition for attracting researchers and investors, to take hydrogen to the expected quantitative results by 2050 and 2060.

4.4.3 Geopolitical implications

With considerable funds and ambitious goals, both the European Union and China will benefit from the proliferation of green hydrogen in the global context (Van de Graaf, T., 2021). On one hand, European countries that are not historically self-sufficient might start to be net energy exporters, decreasing the susceptibility of energy supply shocks and to have better negotiable terms with other geopolitical powerhouses. On the other hand, China has an answer to its high GHG emissions, to improve its environmental standards and benefit from the huge renewable energy capacity that has been installing in the last decade.

Europe wants to outcompete China, in terms of hydrogen technology (Van de Graaf, T., 2021), while the ability to adapt to the new energy paradigm is essential for other nations as well. Coal and oil producing countries will need to diversify their energy portfolio, but factors such as corruption and sunk costs can be real obstacles. Moreover, Middle-East countries are investing large amounts of hydrogen as well, to maintain their relevance in the world's energy supply chain. This can lead to a production of gray hydrogen and disrupt the goal of reducing global CO2 emissions.

While the United States have competitive firms that can innovate and prosper, even though they do not have the lower costs in oil and natural gas. However, the lack of national hydrogen roadmap clearly undermines its potential to stay relevant with this technology. Russia also has a lot to do, where it might end as a raw materials exporter, rather than an energy powerhouse (Van de Graaf, T., 2021).

The geopolitical outcomes between all the involved nations are complex and cannot be precisely predicted. However, the trends suggest that the higher competition between China and the European Union is already defining the paradigm for all the other actors, and, to stay relevant in the future, all countries must consider green hydrogen and its impacts on their macroeconomic planning, the sooner the better.

5. Conclusions

This dissertation intended to evaluate the role of green hydrogen in both the European Union and China's carbon neutral agendas. As this topic is quite unexplored, official reports, databases and Literature Review were present throughout this work, to better understand the benefits and the obstacles that green hydrogen will have in the future.
There was an historical context of the energy sector, followed by an analysis of the present and future role of hydrogen as an energy vector for renewable energy, considering its energy source, production process and the various solution it can provide. Then, there was a characterization of the recent development in the countries' energy strategies and a further discussion of the main key points.

Regarding the question "How the European Union and China consider green hydrogen as part of their environmental strategy", the answer depends. The European Union has a more detailed and substantial approach, which covers various sectors of its Member States' economy. The share of green hydrogen is expected to go from under 2% to around 16%, in 30 years. To show how committed the EU is, between €180 and €470 billion are expected to be invested by 2050 in different projects, such as InvestEU and Next Generation EU, to successfully carry the transition.

China's model is more oriented towards the transportation sector and to provide storage and distribution infrastructure to all its installed renewable energy capacity. The dependency on coal has enabled the country to maintain high growth rates at low costs but the negative externalities of fossil fuels consumption is already affecting the air pollution and health of its own citizens. The opportunity to become the world's renewable energy provider is very appealing for China and, even though its technology is not at the same efficiency levels as it is in Europe, it might be a matter of time until it becomes the world's leader in green hydrogen production.

The development of hydrogen-related technologies, and the role that renewable energy will have, depends on many variables and who will lead the paradigm shift across the international level is not unequivocal. Some trends, such as the natural gas role as "bridging fuel", the investments in innovation and infrastructure, and developing financial mechanisms to promote the use of hydrogen are common amongst both strategies.

However, there is a clear distinction between the development stage at which both economic blocks are. The European Union will continue to invest in its R&D and know-how, in engineering and in regulatory terms, improving its efficiency and promoting low-carbon alternatives to achieve its Green Deal. China will continue to invest substantial amounts to its renewable capacity, but there are not hints that the pursuit of economic growth will not be at the cost of its future prosperity.

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