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# The main challenges to a Zero Carbon energy sector in the Emergent Markets - Green Hydrogen in Brazil

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## Abstract

The climate crisis is one of the most commented topics in the modern world, it is due to its importance and the global scale of its consequences. After many years of study it is possible to confirm that the environment is reaching its limit, from the point of view of resources as well as the power to be in balance after all the pollution from our society. And that's the main reason for the need of the decarbonisation of the economies, mainly one of the biggest sectors in it: the energy sector. There are multiple options on how to put this plan into action, but one that has gained more space in the last years is the implementation of Green Hydrogen as energy source. This mainly because of its characteristics and the fact that this chemical is easily found in nature in big quantities.

Once the world has especially applied themselves working to decrease the emissions of pollutants connected to the greenhouse effect. Focusing, mainly, in agreements regarding the politics involved in it and the regulation system necessary to make this happen. A hydrogen system is not something that can be applied without a plan of action, mainly because of the danger involved in the process, as well as the high cost in order to adapt the actual system to it. Decarbonisation can be a common goal for the world, but the implementation is not exactly easy. This happens because of the need for adaptation of the plans and actions for the reality of each and every country of the world. Every reality needs a whole different strategy. It is important to consider that each country adopts different strategies to achieve the same goal in the way that best works for them. This adaptation creates multiple challenges, at the same time that it can be seen as a huge opportunity for the development of the sector, as well as a chance for more renewable energies to be used in the market. And with the right strategy applied, it can be a good motivator for many other sectors of the economy as well.

In all this matter, Brazil is a huge potential reference in the production of clean energy, mainly hydrogen, because of all their natural characteristics, geographical location and the natural resources. And that's the reason why this is the topic of this thesis, especially regarding its main challenges when it comes the time to implement the green hydrogen in the country, mainly because it is seen now as disruptive in the Brazilian energy sector.

With this in mind, this project aims to make a theoretical and practical comparison between the development of the green hydrogen economy in Brazil and some other countries, showing the actual reality for this country and many efforts, challenges and characteristics that can be used in order to provide a better environment for this kind of economy to happen. Its main findings will be related to all regulatory and political challenges to include the hydrogen in the energy matrix of the country, as well as its potential not being fully used in the projects in place now. Especially focusing on all the needed adaptations not only in the energy sector, but in the country as a whole when compared to more advanced countries in this matter.

**Key-words:** green hydrogen; zero carbon; energy sector; energy transition.

## Summary

# 1. Introduction

Climate change has become one of the most current and important themes nowadays. This happened, mainly, because the world has all the indicators and evidence needed that there is no possibility that the society can continue to use the natural resources of the planet at the same rate of the present day, and there's even less of a possibility in keeping the dangerous level of emissions (Paris Agreement, 2015). That can be easily seen by the increasing level of exhaustion of resources and the limitation of the world to keep equalizing and balancing itself to attend to all the society needs. It basically means that the opposite way around, adaptation and mitigation, is the right path to follow, even though reality shows many challenges to this theoretical process (Our Common Future, 1987). Especially when we consider the global aspect of this matter and the spread from a transboundering perspective, side by side with their polarization, and also the increase in the population of the world (Noussan et al., 2020).

For all these reasons, the impacts of climate change and many other problems are now in a global and common domain. And it basically means that environmental problems are able to cross the country's borders, which brings serious consequences to the search for a solution. At the same time, the consequences are related to the relevance and pertinence to introduce a discussion related to the methodologies that each party must implement in order to avoid the worst case scenario. But the regulation of transboundary pollution represents an international public good. No government can supply itself autonomously with this kind of good except in cooperation with all other countries (Noussan et al., 2020).

Due to the constant occurrence of extreme weather events and phenomena, the world tends to awake more each day to the urgency related to the need of cooperation chasing the same objective. This is shown in more clear and direct efforts and actions chasing this objective: like agreements to decrease the emissions of greenhouse pollutants, the continuous decreasing of the extensive use of natural resources, especially, the non-renewable ones, and, of course, the search for a better use of the resources that keeps life as it is nowadays (Paris Agreement, 2015).

Nowadays, the current level of oil prices and the growing concern related to the energy security of many countries in the world present themselves as an important factor when the increasing demand of energy globally is to be met. Many countries are now facing problems with oil production or its commercialization - from problems related with prices to geopolitical issues as well (Ball et al. 2009; Hydrogen Council, 2021). And this is closely related to the development of new sources of energy and, nevertheless, some of the main characteristics associated with these new kinds of fuel are that they are simpler to handle, are easy to store and transport and it can use the existing logistic infrastructure (Ball et al., 2009).

A great opportunity in this area is presented by hydrogen, which is a disruptive and new kind of technology, which brings practically zero emission in some of its types and it is ideal for sectors where electrification is difficult (or near to impossible). Besides that, Hydrogen can be used as a vector to energy storage - which is something that nowadays with the current technology and resources involved is very hard to achieve, and expensive as well. Considering all these inherent characteristics, the hydrogen is seen as a resource that can be used in multiple fronts, like transportation, electricity, industrial production and aviation, for example (Bases para a Consolidação da Estratégia Brasileira do Hidrogênio, 2021).

In order to achieve the global goals of deduction in emissions, the world is in need of clean sources and the hydrogen will occupy a critical role, especially in sectors that the other alternative fuels have more trouble getting into. It is a critical vector and has the potential to reshape the system as it is nowadays, enabling countries to meet their net-zero target until 2050. And even though, in some sectors, hydrogen will not do all the work by itself, H2 can be a complement for many other paths. Such as in enabling a higher degree of electrification and a stronger penetration of renewable power generation to build decarbonized energy systems (Hydrogen Council, 2021).

Hydrogen's versatility enables it to store energy over long periods and provide energy system resiliency by making system balancing possible. It can facilitate the transport of clean energy over long distances via pipelines and shipping, thus unlocking previously untapped "stranded" renewables resources. Furthermore, it can reshape current chemicals, fuels, and metal production sectors and connect them with the power

industry. This systemic role of hydrogen makes possible a holistic and hence faster and more cost-effective decarbonization across sectors and regions (Hydrogen Council, 2021).

The government commitment and financial support are decisive for a deep decarbonization process. In order to prepare a country to start the use of H2, it is necessary to implement a regulatory system, as well as strategies and targets for this market. And these need to be sustained and the framework needs to be set to transform themselves in proper actions. Therefore, it is needed that the industry prepares itself too, setting up the value chain, being ready to scale up the production and attract the right talent for the job. As well as accelerate production and solution development. All this process will require a good amount of capital and the investors must be ready to act on that. And this for sure will work better in presence of partnerships and development of stakeholders relation, building an ecosystem for the new model to work on (Hydrogen Insights, 2021).

Besides that, it's also important to consider the differences between countries, studying and adapting the H2 plan to the reality of each one. On this matter, it is important to understand that every single country has its own process methodology and speed as well. And, accordingly, all their opportunities and needs will be unique. Of course, there are multiple variables to consider in this scenario as well, especially the history and also the characteristics of each country to be taken into consideration and actually that can be helpful to explain many racionalizations involved in each of these processes (Hydrogen Insights, 2021; Hydrogen Council, 2021).

It is relevant to understand that the current world may present many different realities. Especially considering that each particularity can be determinant to aspects in politics, economics, and consequently to the energy sector too. For this reason, it is more than natural that every country goes through their own opportunities and challenges, and this means that innovative solutions are a main thing to be considered to achieve the goal. A deep understanding of these different realities is fundamental to draw strategies and plans of action that can bring the best outcome for each and every country, being a facilitator for this change process to happen (Hydrogen Council, 2020).

Globally, even with the many options available to be considered for the energy transition, hydrogen is one of the most important at this point. 75 countries currently have

net zero carbon projects and goals, and inside this group, approximately 30 have plans for hydrogen, specifically. Between these governments, more than USD 70 billion were pledged to invest in new capacity and sector regulation for these initiatives (Hydrogen Insights, 2021).

As far as this is a new initiative in many countries, the production is more expensive. But, the H2 project scalonation, these costs have been dropping down and the expectation is to continue falling. When it is considered the renewable H2, the biggest driver to decrease cost would be lower financing costs for renewable resources projects as well. It is expected that in 2030 the costs must be 15% lower, and the strongest reductions are expected in locations such as Australia, Chile, North Africa and the Middle East (Hydrogen Insights, 2021).

**The emergent markets case**

The energy transition can be particularly challenging for developing countries. It is important to point out that most of the emerging economies, in fact, do not present the needed characteristics that are fundamental to the change for a greener system, in consequence of that, more non-renewable energy resources had been used throughout the years (i.e. coal and petroleum) when their market is easier to achieve (Noussan et al., 2020). These challenges are mainly connected to the fact that the energy produced from fossil fuels is yet much cheaper than the energy that comes from renewable sources. When we consider the particularities from the H2, this is even more notable. One of the main points is that the costs of carbon emission are not included in the costs associated with the final energy from fossil fuels (German National Hydrogen Strategy, 2020; Hydrogen insights, 2021).

Today, the hydrogen market appears in a strong momentum because of its benefits and opportunities, with more than 520 projects announced in 2021, many of them in emerging countries. And this will translate into a bigger scenario of clean energy supply for multiple ends. This means, mainly, an even greater investment potential in this sector by 2030. But even with all these strong characteristics associated, the implementation for this kind of energy appears with many challenges related to the theoretical and practical

use of regulations for this market to develop itself. And this is actually one of the biggest causes for the slow increase in this kind of fuel in many global economies, especially in the emergent ones (Hydrogen Council, 2021).

The perspective today shows that many of the potential projects are waiting for the right regulation framework to actually become the investments doable and the demand attractive for the development of the projects (Hydrogen Council, 2021).

Yet, it is still needed to consider the environmental perspective when we discuss this kind of change in a sector such as the energy one. Its global characteristics and consequences must go through many studies and researches in order to make it possible and to mitigate the negative effects for the way of living for the society (Hydrogen insights, 2021).

About energy sustainability and global climate stability, it is necessary to understand that the more the economy is developing itself, the more energy is needed to keep the process going. Therefore, economic development and increase in human activities are closely related to the scenario of energy use and the kind of fuel that are preferred for it (Ball et al., 2009).

When we talk about these environmental concerns connected to the energy sector, for example, the zero carbon goal is important to be completely understood and its perspective must be used to adapt the energy matrix of a country, in order to start the needed change. Mainly, when we start to consider the implementation of innovative ways to achieve the same end, even more in the scenario of technologies that, until this day, are considered as disruptive as possible to the model in use in the country currently - basically, a good take is the Green Hydrogen case in Brazil (Brazilian National Energy Report, 2021). In consequence of that, not much has been discussed or decided about the regulation and the politics involved in making this process possible and manageable. Therefore, this will be the starting point for this dissertation.

When the subject is the sustainable development and the energy transition of a society it is important to consider some of the key factors for its success: the security of the energy system, the affordability of the process implemented and the environmental concern and compatibility finding a right balance between innovation and climate action

(Hydrogen for Net Zero Report, 2021). And actually, the use of fuels that are low in carbon is a tendency for the last 20 years, the hydrogen has been considered a key player because of their natural characteristics, especially related to their capability of storage, making it one important ally to the energy transition, mainly in areas where it's difficult to implement the renewable sources directly - like Brazil, that the big commercial centers are far away from the generations of solar and wind plants (Hydrogen Insights, 2021; EPE, 2020).

Actually, looking specifically at the Brazilian reality, the country has many of the most important potentialities needed for the implementation of the hydrogen in its energetic matrix, mainly technological development, knowledge in renewable sources and their use and some viable economic factors - like the momentum after the Covid-19 pandemic, that many projects are being drawn to fasten the energy transition and to retake the economic growth (Gatto, 2010).

Since 2018, many local government institutions are announcing some policies and strategies for hydrogen (IEA, 2019b), mainly for the green H2 and its need to decrease costs in its whole process. The hydrogen provenient from renewable sources (such as solar and wind) is, generally, the most expensive route available now in the country, but we can check that when this technology is applied in the right circumstances and places, it can be very competitive when exploring specific niches (Bases para a Consolidação da Estratégia Brasileira do Hidrogênio, 2021).

Since 2005, this country has developed researches and studies regarding the H2 implementation and some of the most important conclusions were:

- The country presents some valuable technological routes that can be used as competitiveness advantage, such as the etanol, the electrolysis process coming from the hydroelectric plants of the country and the biomass from the sugar cane plantation;
- the importance and role of the natural gas system in the transaction for the green H2;
- and the possibility of acting in many fronts inside the country with lots of space to grow and develop, such as distributed generation, transportation and the need

of energy production in isolated areas of the country (Bases para a Consolidação da Estratégia Brasileira do Hidrogênio, 2021).

But, the Pre-Sal discovery in 2006 delayed this process in Brazil, and actually, that became the main investment in the energy sector for a couple of years. But now the H2 has found momentum after the world pandemic for the development of the global economy and the energy transition (IEA, 2020b).

According to the last reports about the H2 use in Brazil, this innovation presents many opportunities itself, especially related to the impacts in sustainability in the energy sector, the increase of the energetic security of the country, the development of the use of natural resources in the economy, regional development for less developed areas, the increase of the competitiveness of the industry parks and jobs generation. The green hydrogen is taken as an alternative for the production, storage and conversion for the electricity system and it can be used in the improvement of non-renewable fuels processes, making them more efficient and sustainable (Bases para a Consolidação da Estratégia Brasileira do Hidrogênio, 2021).

Therefore, in order to have a better function in this system - that will need many adaptations in the entire value chain - it’s fundamental that the regulations and politics keep up with this enhanced process. So this dissertation will start in its first part presenting an explanation about Hydrogen, its kinds and particularities, focusing mainly in presenting more the Green Hydrogen and its characteristics. After that, in the second section, it will be presented a global contextualization about this energy source in the world, as well as making details for some of the countries that show considerable influence from Hydrogen in its actual energy matrix or extensive projects in order to implement this technology. And finally, it will present the situation in Brazil, in its main characteristics, its energy transition and the presence and use of hydrogen now in the country, pointing out the biggest challenges and motivators for its implementation in the biggest country of South America. The conclusion will present a comparison from the countries previously studied and Brazil in the implementation process, concluding with the main points of development for this country to become proper for the implementation and development of the Hydrogen as an energy source.

# 2. Literature Review

## 2.1 Hydrogen: the concept

Hydrogen is the most abundant element in nature, in your natural form, there's an enormous quantity of supply, it can be generated using many different sources, renewable sources included. It is present in all growing things, and it's a non-poisonous gas. This element does not present smell, color or taste, but its products (like natural gas) have very unique characteristics (Hydrogen Tools, 2021).

As a consequence of the constant need to improve the quality of the air in the world, Hydrogen has been in focus as one of the many options to develop the meaning of fuel in the future. That's one of the main reasons that today the notoriety of this energy vector has been considered more and more each day. Besides that, this resource can also be used for storage, and being extremely useful for many industrial and transportation sectors, for example. More recently, there were two new motivators for many countries to consider even more the importance of this transaction to a greener system in the energy sector: the independence of foreign resources and the security provided by renewable energy sources. (Johnston et al., 2005).

The advantage of H2 compared to traditional fuels used nowadays is the potential non-emission of CO2 during their transformation. It means that the utility of this resource in the energy system is more fundamental than previously shown, especially considering the agreements regarding the decarbonization of the world until 2050, i.e. the Green Deal and the Paris Agreement (COM 640 Comissão Europeia, 2019; Partidário, Aguiar, Martins, Rangel, & Cabrita, 2020).

It is relevant to point out that H2 must be fractured, it is not a primary source, and actually it can be produced by several means, such as solar, gasoline, and more. One of the most important characteristics is that as a gas, this element can be stored and transported for long distances via pipelines, and it suffers the final transformation into electricity at the receiving end of the process (Hoffmann, 2002).

This element was awarded with much more space in the market after the proof of its value in the technical-economical point of view. It happened especially because of the fast and relevant decrease of energy cost remaining from sustainable sources (more than

80% since 2010) and with their constant technological evolution and the increasing of the interests related to a more sustainable world and the consequent need to lower down the emissions of greenhouse gases (Hydrogen Council, 2020). That shows that possibly, the H2 will be presented as one of the most important figures in a more efficient way to treat the resources, and obviously, more sustainable as well. Even though it is possible to find all these opportunities with H2, it is seen also as a disruptive method and full of challenges from a market and regulation perspective (EPE, 2021).

Throughout the years, the interest in H2 has been increasing potentially, this is due to a stronger climate agenda and to the increasing understanding and the spread of this matter in the world's society. It has been used as a commodity to feedstock many industrial sectors, making it possible to observe a higher use of this resource during the past few years. Even though, all the previously discussed, most of the H2 demand is supplied by fossil fuels and non-renewable sources, such as oil and coal, mainly because it is the less expensive way to produce H2 (Noussan et al., 2020).

This fuel can be generated from a broad variety of primary energy sources, but it's necessary to consider that any of these sources could be finite, and even worse than that is to understand that nowadays the processes that are used in some way to deliver the H2 are responsible for the use of some non-renewable resources (Johnston et al., 2005).

The distinction of types for the H2 definition are usually done by different colors (what means different production process). Above the discussion was about the one that is less sustainable - the gray H2. Yet, this H2 is mainly coming from the rearrangement of natural gas and it is the last renewable one. Besides that, it is the least expensive and the most used nowadays - it's very used in the industry and to refine oil. For each kilogram of this kind of H2, 10 kilograms of CO2 are released into the atmosphere - causing a big impact in the sustainable development of the world (Petrofac, 2021).

In order to comprehend more about the role that the H2 plays now in the energy sector it is necessary to understand about its production and transportation, and the most used way to do so is by the chemical process involved in its cycle, and this happens exactly because of the abundance of this element in the nature, but never in the pure form. And, of course, for that matter it is important to separate the H2 from any other elements, such as fossil fuels, biomass and water, for example. The thing is that this processes are

now outdated and the most common for many years was the process for the “Grey H2” (Newborough et al., 2020).

This first kind is widely produced from fossil fuels, mainly from techniques of steaming and oxygenating. But as a result of that method, the final result is the H2 and yet some carbon monoxide, which will be removed by eletrolisation (Hydrogen Council, 2021). This one is the most common for many reasons, but some of them are: it is less expensive and easier to use a process that is already part of the routine of this cycle, second because the chemical reactions are easy to control. In total, 6% of global natural gas production and 2% of global coal production is used to make approximately 70 Mt of H2 per annum, and this results in atmospheric emissions of about 830 Mt of carbon dioxide (Newborough et al., 2020).

But even with this significant exposure and results, in the long run, this capacity will be drastically reduced or suspended, converting themselves into renewable or low-carbon H2. And this new type promises to be the most cost-competitive in this market. And it’s valid to point out that it is expected that until 2050, H2 will be in its rightful place as the most competitive source and soon it is likely that renewable H2 is going to increase even more its capacity (Hydrogen Council, 2021).

For your time, the green H2 will account for 20% to 40% in 2050. And in this matter, this will be two to three times more than with the grey capacity for the same period. Besides that, the green H2 that it is called the renewable H2 as well, will supply more or less 60% to 80%, two times more than the usual renewable generation capacity. Both of these are seen as complementary, meaning that their paths are the same to supply in the most attractive and effective way possible to decarbonize across all sectors and regions of the world (Hydrogen Council, 2021).

Hence, the next one is the Blue H2, fabricated from a similar process that the gray one, but the big difference is the CO2 destination and management. In the blue H2 process happens what 's called Carbon Capture and Storage, meaning that the carbon monoxide produced does not go back freely to the atmosphere. But, this process faces more challenges exactly for this reason and it’s more expensive because of the storage. This option has been increasing in popularity in the last couple of years, since it is a much

more sustainable option, even though the impacts of this production are not zero either (Noussan et al., 2020).

In the last few years, there's an understanding that blue H2 could be considered as sustainable as possible, since their emissions are reduced and since it is more economically viable to be implemented. This happened especially in countries that are big oil producers and/or consumers, because it is possible to utilize the machinery and installations already existenting (Yu et al., 2021)

And, finally, the last kind is the green H2. Produced by electrolyzers supplied by renewable sources plants. This one offers the possibility of a good ecological approach and a major economic advantage as well. Besides that, the value chain of the H2 process offers huge benefits and potentials to be explored, for science and for some industries. Therefore, this is why the green H2 is seen today as a key component to a successful energy transition to a more sustainable world (German National Hydrogen Strategy, 2020). The most important difference is that this process does not fabricate carbon monoxide in any point of the production chain. Even though it is clearly the best option for the environment, unfortunately, this process faces many challenges, like heavier costs than the other two, as well as do not have any regulatory framework decided and implemented yet, what brings many issues associated with the organization and the start of its utilization in many countries (Yu et al., 2021)

The other kinds are less popular and more experimental yet, like the turquoise that is the result of a pyrolysis of a fossil fuel and generates at the end solid carbon. There’s yet the yellow H2, that is the H2 that comes from electrolyzers supplied by nuclear power plants (German National Hydrogen Strategy, 2020).

## 2.2 The Green H2

The early reference use to the Green H2 happened in NREL, in 1995, at that moment of time the term was “renewable H2”. After that, in 2006, the State of California defined green H2 as the one produced in a clear and sustainable way, especially using a renewable source. After that, the final definition of the green H2 came from the European

Parliament, and it was the first definition of this term in Europe, and it happened already in the plan for implementation of this energy (Velazquez Abad and Dodds, 2020).

Green H2 is produced from renewable energy and is the most suitable for the energy transition. The technology established is to use the water electrolysis fuelled by renewable electricity. This process is consistent with the net-zero pathway (IRENA, 2020).

Apart from that, there's actually not a standard definition for this concept, which actually makes it more difficult to include it in international trades and energy policies. For example, many authors can include the H2 from fossil, nuclear and industrial residuals as green or "clean", if the emissions associated are low enough. Yet, other studies state that green H2 requires the use of renewable sources and processes (Velazquez Abad and Dodds, 2020).

And actually the challenges with this new kind of energy start already in its concept, which brings even more issues when there's a willingness to characterize it properly. Many difficulties can be found in this matter, such as the accountability of GHG emission, the systemic boundaries of the process, trade-offs between accuracy in measurement and costs and the creation of an economically viable model. Anyhow, the definition of renewable H2 is more universal, since it defines a clear eligibility criteria for the pathways to produce this kind of energy - renewable sources, such as sun and wind, for example (Velazquez Abad and Dodds, 2020).

Even with the many standardization measures for H2, for the green especifically, this difficulty to conceptualize it made the access to a more unified interpretation on the literature for a long time (Velazquez Abad and Dodds, 2020).

But this year, in May, during a summit in Barcelona it was presented for the first time "The Green H2 Standard", a complete guide of the requirements and characteristics for the H2 to be defined as green. It establishes a global and unique definition for it as "H2 produced through the electrolysis of water with 100% or near 100% renewable energy with close to zero greenhouse gas emissions". But in order to comply with this Standard defined, the environmental, social and governance aspects are being addressed.

Meaning basically that the development and consequences of green H2 are fundamental to the definition.

This is the minimum global standard of quality and requirements needed to the process, while it keeps its flexibility and can adapt to the reality of each country. It was done in order to place and address the onus on the production side of the market, in accordance with the national laws and global best practices. The main goal of this Standard is to guarantee consistency and credibility of the process as a whole (GH2, 2022).

The most important principles of this concept are 7, that implement in a direct manner the need for compliance with the environmental, societal and governance points of view during the process. These are measures related mainly to the duties of the companies that wish to be certified as a Green H2 Project, they are:

1. Sovereignty and subsidiarity - it is the right of each project to first comply with the laws of each country, since the natural resources and energy markets are actually in the public domain of sovereign countries;
2. Proportionality - the main goal is to address the most significant issues, therefore, in face of that, some gaps in meeting a requirement must not be taken as more important as the objective of this requirement being met;
3. Harmonisation - it is advisable to follow international conventions and best practices in order to improve quality and efficiency;
4. Consultation - it is the clear evidence of consultation of every stakeholders involved in the process;
5. Transparency - it is the disclosure of information, making it comprehensible and accessible, especially considering the many different stakeholders that it needs to communicate with and adapt that information in the right form for each public;
6. Independent verification, concerns and appeals - the mandatory making of complete case in order to comply with the Standard and actually present that to the GH2;
7. Further development of the Standard - since this is a market that is constantly changing and evolving, the projects must as well understand changes in the requirements as it will evolve together with the process/technology (GH2, 2022).

One of the main goals of this Standard is to bring stability for the stakeholders, guarantee of quality and more efficiency and minimum global requirements being met in order to actually consider it as a green H2 project. It is designed in a model of lessons learned and applied as ratification of the Standard as it is now and taking into account feedback from the projects as well as the Green Hidrogen Organization members (GH2, 2022).

### 2.3 Comparison with other kinds of fuels

H2 is an element that is constantly compared with other chemical agents, this happens, especially, because it is formed by hydrocarbons, which is present in other kinds of fuels, such as natural gas, ethanol and bhutan. Compared to the other fuels, this resource is lighter, since it is formed by less carbon elements. This is also a factor to understand more about its volume and weight. These characteristics are responsible for the energy present in each unit of it (Vaz, 2021).

The fact that this element is the most usual one in the atmosphere is also a positive side of it. It is important to understand that the H2 will not be found in its pure form in nature, but it is actually present in many of the most abundant elements from nature, such as water, natural gas, seaweed, and biomass. And thanks to this, it is possible to produce its energy from different processes, such as termic, electric, biochemistry, and more (Dincer, 2012). Unlike many fuels, H2 can be obtained in many different ways of production (Vaz, 2021).

Even though fossil fuels are still the most used sources of energy, H2 presents itself as a more cost effective option. This element holds approximately three times more energy than oil and natural gas. And this fact makes it much more efficient than the internal combustion engines by fossil fuels (Vaz, 2021).

H2 has the potential to impact and facilitate the world's net zero transition, and the way that it is produced is one of the most important factors to be taken into consideration. Even though it is not the cheapest technology to be implemented, it is still one of the biggest investments in many countries for the next few years (IEA, 2019).

But this is a path once done by other renewable sources of energy, such as wind, solar panels. From 2010 to 2019, the price of solar panels decreased around 90%, this was specially due to government support and private research and investment (IEA, 2019).

So, the expectation is that green H2 will follow this same path, and with the right investment force and government subsidies this fuel will be responsible for approximately 24% of the world's energy by 2050. Being a key factor for the net zero global goal (IEA, 2019).

# 3. The Evolution

## 3.1 European Union

H2 has been coming a long way in developing its market and it is believed that this kind of fuel will gain even more space in the energy market. Its use will be increased in the next couple years in the EU (Comissao Europeia, 2020), since it is aligned with sustainable development and economic growth for the window until 2050.

Unfortunately, the contribution that H2 gives to the EU energy matrix is not so relevant at this point, especially because most of it comes from non-renewable sources. This current process results in 70 to 100 million tons of CO2 in the atmosphere. (Comissão Europeia, 2020). The main plan, according to the European Parliament is to become its matrix 100% relying on renewable sources, and it counts with the H2 for approximately 20% of this total.

The European Ecological Pact states that H2 must be a priority in this transition to a greener Europe. The delivery of this decarbonization process has a checkpoint with many goals already set to 2030. To achieve most of these goals it is necessary to consider many different sectors for the implementation of the H2 in the European economy. And, therefore, many challenges may come associated - even more than if it was only one main sector. And this Pact actually considered Ukraine as a fundamental piece for this to happen, and now, with the recent upcomings in that region, some parts of this plan will suffer with changes and delays.

According to the REPowerEU, that was a plan in order to guarantee a more affordable, secure and sustainable energy plan as a joint effort between the countries of the EU. The plan is made in order to respond to rising prices of oil, planning of how to replenish gas stocks for the winter and, as a new addition, to be independent of Russian fossil fuels before the target in 2030 - this change is due to the Ukraine invasion in March.

As a united front, most of the countries of the EU are working with the prerogative to use the H2 and to invest in strategies related to this energy source. And actually, some of them even draw some kind of National Plan, some of them are: Portugal, Germany, France, Finland, Norway and many more. And the list is growing each year, with countries like Italy and Denmark (Hydrogen Council, 2021). But for the effect of this dissertation, it will focus on the Portuguese and German plans, from Europe, and Chile as a benchmarking from South America.

### 3.1.1 Portugal

The first country to start this comparison will be Portugal, that's mainly due to the fact that this country has been implementing some exceptional regime to actually increase the active participation of renewable sources and the green H2 specially (LNEG, 2022). These actions have been taken after the "REPowerEU: Joint European action for more affordable, secure and sustainable energy" already published. This initiative has as the main goal to make the EU energy system more secure and independent, mainly from Russian sources, and after that, because of the global reality and the invasion of Ukraine, this was a topic considered even more fundamental for all the countries involved.

Portugal has set in 2016 its participation and alignment with the international effort for a decarbonized country. This means that the country was agreeing to find the balance between its GHG emissions and CO2 sequestration, meaning that one of these two actions must take place strongly, and the other one must happen for the goal to be achieved. The plan for Portugal counts with all the economy sectors participation, not only reducing its emissions, but developing their efficiency and innovation process in this matter. But, of course, the biggest player for this plan to succeed is the proper energy sector of the country, especially with the electricity process and the transportation (RNC, 2050, 2019). It is important to note that Portugal is a country that complied with Kyoto's Protocol goals and the 2020 target for decreasing emissions of GHG, energy efficiency and the use of more renewable sources (Comissao Europeia, 2020).

The first step Portugal took into this decarbonization path, according to the plan for 2030 was in 2015, when it was approved the Strategic Framework for Climate Policy. This plan was created as the main goal to actually translate into actions the Paris

Agreement. In this report the challenge was to make sure that the country was in good general condition to work towards the ambitious targets ahead for the decarbonization of the economy (RNC 2050, 2019). In the same year, it also released the National Climate Change Program, the PNAC 2020-2030. And this plan was responsible for determining the needed reduction of GHG emissions for the country: from 18% to 23% by 2020, and then 30% to 40% by 2030. This will be the main policy instrument for the next few years, and it will be responsible for setting new national targets for the emissions, the rate of renewable energies in the national matrix and measuring the energy efficiency (PNEC 2030, 2016).

The regulation and policies involved in the process of climate change is a fundamental part of the sectoral actions to reach this goal. The "Carbon Dimension" of the policies are now a priority in many areas as well as an economic factor that must be considered in the concerns of the governments and companies. In areas with major challenges many initiatives had been taken into account and implemented in the country, such as transportation, maritime and inland waterways transport starting the decarbonisation process (RNC 2050, 2019). The bright side is that Portuguese history today shows that ambitious climate policy can actually coexist with economic growth and development of society in many aspects. The Portuguese scenario now shows that the country is producing more wealth, but with less emissions, taking more into consideration the need to decarbonise the economy (República Portuguesa, 2020).

But besides that reality, the challenges are many, the first reason is the need of a supportive and extensive political framework supporting each step of this process, especially experiencing the high flow of financing needed. Many instruments can be considered for this scenario: Carbon Price limits, low emissions regulatory framework, emissions target, renewable energy regulation (RNC 2050, 2019).

Even with these many challenges for the implementation of the green H2, Portugal has already some initiatives to contribute to the goals for the environmental development regarding the decrease of emissions and compliance with regulatory measures for decarbonization. One of them is related to installing a system for green H2 production, which objectively will cover the gap between the H2 price and natural gas. The second is to actually come up with the complete regulatory framework for the H2, with the goal to provide licenses to H2 to get access to the natural gas installation (Plano Nacional de

Hidrogenio, 2020; REN, 2021).

Some of the biggest challenges for the implementation of a low carbon system in Portugal are: the transportation sector and its adaptation to the H2, decarbonization of the chemical industry which are today one of the main sources of emissions, the use of residual water for the electrolysis process for the H2 and to implement the tech related to the H2 with the adequate regulation and politics (Plano Nacional de Hidrogenio, 2020).

Even though there's a couple of issues ahead, Portugal has determined that until 2030, approximately 10% to 15% of green H2 will be present in the natural gas network. And by 2050, 75% to 80%. Some of the most important sectors to achieve these goals are the industry and transportation (Plano Nacional de Hidrogenio, 2020).

According to the scenarios proposed in the RNC 2050: first, the scenario maintaining the climate policies in force, with a considerable decarbonisation path. In this case, the economy would grow and the emissions would decrease, but motivated by more efficient or less emitting technology, not related to the implementation of new options. The second scenario is an evaluation of the emissions in a carbon neutral economy, leading to a decrease of 60% by 2030 and 90% compared to 2005.

Although, the increase of the circular economy and improvement on efficiency would be responsible for "making more with less resources", besides the reinforcement of carbon sinks to directly impact the reduction of the concentration of CO2 in the atmosphere and to be dealt with by the regulations in place. And in order for this to happen, a regulatory framework needs to be defined, which would be able to guarantee the commitment from the main public and private stakeholders, to actually implement the actions and measures to reach the objectives drawn, and this would also be the provide the stability for the sector that the investors would appreciate (RNC 2050, 2019).

Therefore, the actual strategy in place for Portuguese society is based on a combination of plans, policies and measures, besides the investment in cost-effective tech options. The development of these new technologies will require a big enforcement in innovation and research, as well, this process must be followed closely from the regulatory point of view, since the development of the technology until the end of the cycle. But in order for this to happen, Portugal will rely on the national and European support framework for every step on this procedure, with the main goal to get into the

stage of the behavioral change that will allow the increase in the decarbonisation rate (RNC 2050, 2019).

### 3.1.2 Germany

Germany is today one of the biggest references in the EU to apply the H2 technology in its energy sector. And has become one of the pioneers in investments in this matter, inside and outside of itself, and this country actually started some of its investments in South America. The main motivator was to decrease the GHG emissions, mainly targeting the transportation sector (Mitsui & Co., 2020). According to the Germany National H2 Strategy, to become GHG-neutral and meet the goals set to the decarbonisation process, the Federal Government considers only the green H2 as adequate to that in the long term, especially in the terms of the Paris Agreement. Being one of the most influential countries in the energy sector for the EU, the German government seeks to promote and strengthen the market and establish the green H2 market.

After the global coronavirus pandemic, and all the consequences for the economy of the countries, the H2 would bring a new potential for the industrial policy and to deal with these consequences, planning to open up to new economic opportunities (The National Hydrogen Strategy, 2020). One of the main goal of this country is to actually present itself as a pioneer and reference in the implementation of green H2 (Mitsui & Co., 2020). To reach this goal, many projects are under development, political and regulatory plans as well as many research projects about this matter. Besides that, H2 will be the main character in some sectors, such as energy source and storage, it will be the substitute to the green H2 used today, it will connect some sectors of the economy and it will be used as a way to capture CO2 and apply it in an economic and more sustainable manner (The Federal Ministry for Economic Affairs and Energy, 2020) .

Since 2006, the German government has been aware of the potential attached to H2 technology. Until 2026, more than a billion euros will be used to research and develop this technology in the country. Especifically between 2020 and 2023, there is the injection of 310 million euros under the Energy and Climate Fund, and another 200 million are

being studied to be provided to this project too. And as part of the decarbonisation program, the investments are focused on large scale industrial facilities which will be using H2 in their manufacturing process. And as one of the biggest steps towards this goal, in 2020, the Coalition Committee started the “package for the future”. which are an amount of incentives to speed up the market process of the H2 tech and more money available for investing in international partnerships and projects (The National Hydrogen Strategy, 2020).

But even with all this action towards this objective, the improvement of the national policy and addressing the ongoing matters and developments in this area will be an ongoing job. This will need to be constantly reviewed and the strategy will be adequate to the needs and challenges up front (The National Hydrogen Strategy, 2020). The German National Strategy were actually published in 2020, and its main goals were to increase the competitiveness of the h2, create a proper and structured market for this resource, establish the h2 as one of its alternatives energy fuels, turn this process the most renewable and sustainable as possible, investments in research and implement the transportation system for it and to develop structures and researches for h2 technology, and lastly to help establish and maintain an international market based on mutual cooperation for this natural resource.

Actually, the reality in Germany is much more advanced than in other countries of the EU. After the publication of RePower EU, because of the Ukrainian invasion, the incentives in order for this to happen are even bigger. With this reality, it became one of the main goals for the EU to actually have a more secure energy system, and not be as dependent, especially from the Russian gas, for example. And due to this, many actions are in place and in the development stage, to guarantee that Germany will be one of the first countries involved to succeed in this project, some of these actions are:

1. a governance structure to monitor and implement the main strategy for the H2 - and to develop it further as well - bringing a State Secretaries’ Committee on H2 to actually follow the National Strategy;
2. Implementation of corrective acts in coordination with the Federal Cabinet, adapting the plan to new requirements;

3. Programs to assure that the National Strategy is in line with the market development and its deliverables are accordingly with the targets;
4. The Federal Government will create a National H2 Council, formed by the top 26 experts in this field, from various sectors, to assure the diversity of ideas and perspectives. These experts must have expertise in production, research and innovation, decarbonisation of industry, transport and urbanization, infrastructure, international partnerships, sustainability and climate changes. The main task of the National H2 Council is to support the new Committee through proposals in implementing and enhancing the H2 Strategy (The National Hydrogen Strategy, 2020).

Besides these actions from a Federal perspective, the German Government has also planned to implement their H2 measures at the state level, forming a strong cooperation with the federal level of it. This is made in order to achieve the creation of a proper H2 economy for the country and involve the German companies in the process too. This is in order to achieve a coordinated effort and activities, use the synergy and avoid dependencies. Besides, in this double action it is possible to share experiences and define further steps and actions as a whole unit (The National Hydrogen Strategy, 2020).

### 3.1.3 Chile

Taking the comparison for a more similar ground from the Brazilian experience, this project will present the Chilean experience regarding the green H2 and the decarbonisation process of its economy. Chile is also a country that is very privileged when it comes to renewable sources. And besides that reality, it shows potential to be one of the biggest producers and exporters of H2 in the world (Vásquez, Salinas y Sociedad Alemana para la Cooperación Internacional (GIZ), 2019). This potential will take the prices to a continuous decrease, making the Chilean green H2 as one of the most competitive in the world (International Energy Agency, 2020).

The planning for this will attend around 94 thousand jobs until 2050, expecting that the use of this fuel will enter the mobility sector, residential, industry and energy,

meaning some of the biggest and more challengings sectors now for the sustainable development of a country (Fichtnet GmbH & Co.KG, 2020).

Chile already has multiple projects for the implementation and development of H2 technology, nationally, they are present in many sectors and in different stages of maturation. Besides that, the country is interested in understanding the reality and development of this energy sources in the countries of South America in order to plan together the best way to enter this technology in the continent, as well as create a strong collaboration and regulatory measures for the whole continent (Centro de Energía UC, 2020).

As far as 2020, none of the biggest countries from the continent had any kind of National regulatory plan of action, and this presents itself as an opportunity to form strategic alliances in this market, from human capital to the commercial exchange of goods and technologies. And even more than that would be the willingness to create an integrated market sharing experiences and adapting the process to better fit and attend the needs of all the countries involved (Vásquez, Salinas y Sociedad Alemana para la Cooperación Internacional (GIZ), 2019).

Part of the main step to adapt the use of the H2 in the economy is to input this technology in the system already in use by natural gas (Fichtnet GmbH & Co.KG, 2020). But the reality now in Chile is a continuous investment in the technological part, but this can't be all that matters, especially in the scenario of the need for the implementation of a proper market, well structured, for this new technology. It is fundamental to have a whole framework prepared to insert and adapt to the new system in place, as well as political and regulatory norms carefully planned. And in this point of view, in Chile there's no concrete plan for the regulation of H2, and neither any update of the regular norms in place to be according to the international standards of regulation in this front (Centro de Energía UC, 2020).

In Chile there're previously only the regulation and norms to the use of H2 as an industrial material, inflammable and considered as dangerous. Hence, the need to guarantee a set of regulations and rules for all the other economic sectors that this fuel will act in some way. For that reason, it is mandatory that the regulation established the minimum security standard and what exactly are the duties and rights for the companies

that are involved in this process and dealing with the H2, this is needed to make sure that no harm will be brought to the people and the environment around (Vásquez, Salinas y Sociedad Alemana para la Cooperación Internacional (GIZ), 2019).

Besides that, it is still important to submit these regulations to the evaluation in an optic more related to a sustainable development, considering all the reach that a project of this size would have in the environment and make sure that everything is aligned with the regulatory dispositions for the renewable resources and its uses (Vásquez, Salinas y Sociedad Alemana para la Cooperación Internacional (GIZ), 2019).

Regarding the upgrade needed in the regulatory aspect of the H2 implementation, the National Government started to process each part of the life cycle of the H2 to understand its formation and the potential breaches related to them. This includes the regulation for dangerous substances, the norms for work security in risky professions and each and all regulations behind the public services that could potentially affect the H2 system function (Centro de Energía UC, 2020).

The second step would be to take all the regulations and norms related to this matter and compare it with the international requirements and regulations. This is due mainly to the fact that most of the internal regulations of Chile are from at least 10 years ago, making them not adequate to the current reality and development suffered in the H2 technology and market and very superficial when dealing with a whole new substance and in many different applications (Centro de Energía UC, 2020).

The current regulation covers the storage process, and aspects related to the distribution, transportation and the use of H2, but much less than it is actually needed in order to create a H2 economy for the country. Furthermore, regarding the environment and its regulations, even though it is not specifically designed to this fuel process, its knowledge base can be considered, since this will be dealing with a source of energy that has its own value chain defined and the current rules can be applied in order to guide how to proceed in the environmental impact front (Centro de Energía UC, 2020).

According to the “Informe Final de la Proposición de Estrategia Regulatoria del Hidrógeno para Chile”, there would still be different breaches in the regulation existent that actually need to be addressed in order to have a system that it functional, safe and

efficient to the country and the companies involved in this sector of business and processes. This country was able to draw 20 topics of regulation that were a priority and needed to be addressed specifically for the implementation of a proper market for the H2, it would involve the creation of 12 regulations, 2 guides, 2 recommendations and the change and updating of 4 regulations of two different ministries of the government:

| Nº | Nombre |
|---|---|
| 1 | Reglamento general de instalaciones de hidrógeno combustible |
| 2 | Reglamento de transporte de hidrógeno combustible por vía pública |
| 3 | Reglamento de sistema de hidrógeno combustible en maquinaria y vehículos industriales |
| 4 | Reglamento de almacenamiento de sustancias peligrosas (DTO 43) |
| 5 | Reglamento sobre condiciones sanitarias y ambientales en los lugares de trabajo (DTO 594) |
| 6 | Reglamento de transporte de cargas peligrosas por calles y caminos (DTO 298) |
| 7 | Reglamento de transporte y distribución de hidrógeno por cañerías |
| 8 | Reglamento de artefactos domésticos a combustión de hidrógeno |
| 9 | Reglamento de generadores eléctricos a hidrógeno y duales |
| 10 | Reglamento para las estaciones de dispensado público de hidrógeno |
| 11 | Reglamento de requisitos técnicos, constructivos y de seguridad para los vehículos a hidrógeno gaseoso |
| 12 | Manual de revisión técnica de vehículos a hidrógeno gaseoso |
| 13 | Reglamento de sistemas de hidrógeno para minería subterránea. |
| 14 | Reglamento de seguridad para tanques y contenedores para hidrógeno combustible |
| 15 | Recomendaciones de seguridad para las emergencias de vehículos a hidrógeno |
| 16 | Reglamento de seguridad para talleres de reparación y mantención de vehículos a hidrógeno |
| 17 | Recomendaciones de seguridad para garajes de estacionamiento de vehículos a hidrógeno |
| 18 | Reglamento de manipulación y almacenamiento de cargas peligrosas en recintos portuarios (Res. 96, 1997) |
| 19 | Reglamento de requisitos técnicos, constructivos y de seguridad para los vehículos a hidrógeno líquido |
| 20 | Manual de revisión técnica de vehículos a hidrógeno líquido |

**Figure 1. The most important changes needed in order to evolve and implement a hydrogen market in Chile.**

Fonte: Vásquez, R., & Salinas, F. (2019). Tecnologías del hidrógeno y perspectivas para Chile. Santiago, Chile: GIZ GmbH

Even with all this plan already drawn by the Chilean Government, it is possible to predict around two more years to fully develop the regulatory framework for the country - counting on all the sectoral regulations as well. Because of that, the country will

share a “Technical Guide”for the new projects to follow. Being the main source of knowledge regarding the instructions and a step-by-step guide on how to proceed. Once the main objective of the H2 implementation is the decarbonisation of the Chilean energetic matrix, the Government intends to study all the sources today utilized by the country and giving the preference for the ones that are actually from renewable sources. This part of the project will be especially done in order to sinalize what is the use of Green H2 inside the matrix, certifying and recognizing it. Meaning that this would cause the scenario where the use of Green H2 is less expensive than the use of electric energy, it would be a reward for the use of renewable sources mainly (Centro de Energía UC, 2020).

# 4. The Brazilian Case

There are many studies stating that the demand for energy tends to grow strongly for the next few years in the whole world, and more than 90% of this increase comes from developing countries (GEI, 2014). Especifically for Brazil, until 2030, it is expected to triple the energy demand due to many reasons, some related to the growth of the population, its aging process, leading to an older population who have different and more expandable patterns related to energy consumption - mainly because of the adaptation of the family threshold, the comfort level needed for older people and the habits acquired with the aging - and the increase in the GDP of the country (EPE, 2015).

But besides considering the need to increase and answer to this growing demand, it is fundamental to consider the scenarios with the lowest environmental impact, and to understand how every kind of energy generated affects the transition to a more sustainable energy system for the country (EPE, 2015). In Brazil, renewable energy accounts for approximately 48% of total primary energy supply and almost 85% of the power sector production too, and the potential for the renewable sources in the country is not yet fully operational (EPE, 2020).

For this reason, the research on H2 production is growing more each day, mainly because of the developments and innovations in the technology for storage and

conversion of it. And even the academic database for research, articles and publications have been increasing constantly (Lellis et al., 2010)

According to the Brazilian National H2 Plan, this market will achieve its momentum after the Covid-19 pandemic. Mainly because of the collective movement of most of the countries to make their energetic matrixes as sustainable as possible until the mark of 2030, that it is already close. That's why there are now many initiatives focused on recovering the national economies, at the same time that it is increasing the speed in promoting the energy transition, especially when we discuss renewable methods to do so. And the H2 is considered important mainly because of its possibility to enter difficult sectors, like aviation, transportation, siderurgy and many others that are big players needed in the decarbonization progress.

### 4.1 Historical and current situation

The idea of using H2 as an energy system is not something new in history, it actually began in the 60's. Previously, H2 was used in order to warm the houses, preparation of food and for public illumination. The first big motivator for this kind of energy was the oil crisis around 1970 (Cruz, 2010).

Brazil as well had their transition process began, foremostly, through the energy insecurity that came from the Oil Crisis in 1973, that caused the prices to increase a lot at that time showing how fragile the system was and it was a free presentation to the government and private sector that it was very risky to just rely on this only option (Moreira, 2005).

Even though this was the first push towards the transition, it was only in the 90's that the process really took some form and started in fact, just like it happened in the rest of the world. These changes, especially behavioristic, were based on the sustainable development in need, that it was actually a concept just brought into light in the world, and it was a new worry for the energy sector, focusing on the supply stability of this sector and its prices as well (Castro et al., 2021).

In 1987, the Brundtland Report defined the concept of sustainable development for the first time, bringing this topic into the spotlight and becoming one of the main

topics in discussion (Matos, 2009). According to the Brazilian National H2 Plan, because of its nature of security for the system and the decrease in environmental impacts, the H2 became one of the most important options in order to achieve the goal of a greener energy system for the country.

In order to fulfill the goal of decarbonisation and preservation of the environment, the reduction of pollutant gasses, mainly the CO2, came into perspective. And this is mainly the reason why the H2 appeared as an option, since its process could be more sustainable as possible (Rohrich, 2008).

The Brazilian matrix has developed itself mainly using oil and gas as fuels and the hydroelectric power plants to generate the electricity needed. In January 2021, Brazil had 12.7 billion barrels of proved oil reserves, the second-largest oil reserves in South America, as well with the discovery of the Pre-Salt (oil reserve in the southeast region of the country) increased in almost 1.6 million barrels/day the potential of the country production between 2012 and 2019 (EIA, 2020).

From the perspective of electrical production, the main character is hydroelectricity, being responsible for 615 billion kilowatt hours (kWh) of the power generation supply for Brazil in 2019. The country is the second largest producer of this kind of energy in the world, being just after China. It is the dominant source in Brazil, accounting for approximately 64% of the total electric generation in the country (EIA, 2020).

It is important to understand that despite the Brazilian matrix being today mostly created with large hydroelectric power plants, and these have been considered as clean energy with low emissions rate, it is important to point out that its building process and maintenance are harmful for the environment in many other ways (WWF-Brasil, 2012). The renewable sources as its configuration accounts for more or less 42% of total primary energy supply of the country (EIA, 2020).

And this reality brings the need of greener approaches for the energy system in Brazil, mainly because there is still more sustainable ways to produce energy and make the process the less harmful to the environment as possible, considering not only the main

outcome, but also the life cycle of the energy source in question (Climate Transparency Policy Paper, 2020).

For this context and its inner properties as a chemical substance, H2 has become a good option and is seen as the "fuel of the future", and a key tool to pursue the objectives of emissions neutrality by 2050, as stated in the Paris Agreement (McKinsey, 2021). And as discussed previously, there are many possibilities to obtain H2, some of them are renewable and some not. Now, in the whole world, almost 96% of the H2 produced are from fossil fuels origin, meaning that this is not sustainable. Natural gas is the main source and electrolysis has a participation of only 4%, being the most available source but the least used one (Cruz, 2010).

Considering all this context, nowadays the Green H2 is presented as a viable option that would solve the biggest part of these problems. But the main issue is that the H2 is still facing many challenges, the main 3 bottlenecks to its implementation are:

1. Costs associated with the process - especially related to the tech development that are needed to emergent economies, taking into consideration the prices of these innovations. Meaning that this kind of energy is yet much less competitive in these markets, and Brazil is one of them (Bases para a Consolidação da Estratégia Brasileira do Hidrogênio, 2021);
2. Storage and Transportation process - because of its nature of inflammable and hard to compress gas, to scale this process many challenges surface, especially causing more costs to the production as well (Hydrogen Council, 2020);
3. Regulation - Brazil does not have a proper regulation and norms to the production, storage and transportation of H2, even though in 2021 it was approved the National H2 Program, this would be seen more as guidelines, in a more technical way than the need of actual legislation for this market and its function.

At this point, Brazil can't be considered as a productor of Green H2, but there is an increasing number of projects borning from this potential identified in the country to be a global protagonist, as an emergent market. The most important step in this process started in the state of Ceara in February 2021, it launched the first HUB project for this subject in the country (McKinsey, 2021).

This project is a collaboration between the state government and the defertion of industries of Ceara (FIEC). The main goal is to attract investors, count with the federal university for the technological development of the project and use the Port Complex of Pecem as the house of this HUB. This project has evolved since then and already 12 memoranda were signed with companies from many different countries that are interested in building and participating in the construction of the first electrolysis plants to produce green H2 in the country for exportation (McKinsey, 2021).

Even though this project is enormous and will be a great development in this area in the country, there will still be the regulation challenge not yet addressed in Brazil to get in the way of the evident progress that this energy source can bring to the country. While more than 30 countries are already implementing a Strategic Plan to use H2, Brazil is late in the process as the number of projects grows (Hydrogen Council, 2020).

The regulation will present itself as a decisive point to be taken into consideration in the implementation of H2 plants in the country. Part of the reason is related to the security it will give to investors, which can create the conditions to scale this process to the rest of the country. But, now, the government has used the regulation to the renewable sources and electrolysis norms to hold the process in motion and keep the licensing of companies to it (McKinsey, 2021).

### 4.2. The energy transition and the main challenges in Brazil

Furthermore all the development needed in the finance and efficiency of the energy market, one of the main points is the substantial decrease in the environmental damage, including the emissions and the mitigation of the situation that the world is already facing. This way, there's a fundamental question and primary possibility of increasing the national energy security in Brazil, and even the more isolated areas in the country could be actually affected by the "new system" relying on the H2 process, since it presents a minor need of complex logistics when compared to the actual system in place (WWF-Brasil, 2012).

Besides that, this innovation would bring more stability to the grid all year long, even in times of droughts, mainly because the H2 production is not at all related to the

time of the year and its rain rates, besides being one of the more abundant gasses on the planet. Therefore, this option presents itself like a real and good possibility as a source of energy - reliable and presenting minor impact (WWF-Brasil, 2012).

According to Kelman et. Al, 2020, Brazil presents a series of attributes that corroborate to the internal market development for the H2 and it is also quoted to be one of the most important potential exporters to Europe. This could happen for many reason, but mainly:

1. This is a resource that is not that expensive and once it becomes competitive into the brazilian market, it would present as a substitute to the non-renewable sources used today in many important positions in the country economy;
2. The geopolitical stability of Brazil, as well as a stable political regime are competitive advantages to other countries where the H2 could be processed too, like the Middle East and North and East Africa;
3. The existence of a integrated and flexible grid make it possible to the energy be generated elsewhere, not as close from the consumers;
4. The good diplomatic relation between Germany and Brazil - since this country is one of the leaders in the H2 development and implementation. Besides, most of the companies from Germany that are influential in the H2 Council in Germany present subsidiaries in the country, therefore, it is possible to have cooperation between the countries.

Because of that, the H2 use is considered for its high potential to become more competitive in Brazil, if the right conditions are applied. But this is something that will depend on many variables of region, its specifics and the end applications for it. These will all be fundamental things when considering the application of H2: price to be, the availability of other renewable sources and their competitiveness, besides their characteristics for sustainable development, Co2 emission and their possibility of capturing it during the process. Even though all these variables exist, the common ground is that the acceleration for the entrance of this technology and process into the brazilian grid depends a lot of governmental actions, coordinated with multiple stakeholders in this network, besides the need of a unique regulation to eliminate the entrance barriers in this market - that nowadays are pretty high. It is necessary to consider institutional

padronizations, incentives and subsidies, besides the discussion about investments in infrastructure (EPE, 2021).

The production and industrial uses for the H2 in Brazil find themselves close to being consolidated. But, besides that, the wider use of it for energetic projects will demand a continuous investment in research, development and innovation, this way the country would be a relevant agent in the long term. The implementation of new technologies, the development of a structure for the production, storage, transportation and distribution of the H2 insert themselves as main topics to be addressed and treated (CÉSAR et al., 2019).

Besides that standardization of security conditions and the structure and regulation of the market, the main challenge found today is the development of the energetic use of the H2 to achieve the levels of competitiveness against other sources of energy, this needs to happen from a decrease in costs associated together with the market projections for the next years (EPE, 2021).

Even considering these projections, it is clear the importance of a alignment with the governmental acts, meaning, the development of national strategies, partnerships, coordinations with the stakeholders involved and the promotion of a efficient regulation and that propose to decrease all the challenges and barriers to entry this market, a change and standard procedure as well as a increase of money flow and incentives to actually consolidate the H2 in the energy sector (EPE, 2021).

The reality involved in this market in Brazil today is having a good amount of resources to explore alternative sources, including green H2. But in order for this to happen and work, it is needed to invest even more in R&D projects to develop the technology that is available today in the country. The more expressive gains that would be shown is the improve in the cost effective for production of the energy in Brazil, the increase of jobs for the society in this sector and, this would bring as consequence, an improvement in the supply of energy in many other sectors of the economy, causing a decrease in the general prices, what would be a necessary and fundamental step for this innovation to finally consolidate in the market (WWF-Brasil, 2012).

Consequently, it has become more clear the importance and urgency of putting the energy transition as priority, as it is considered the size and inherent characteristics of Brazil. But in order for this to happen it is more than necessary a conjunct of synchronized actions to make the adoption of Green H2 a reality in the country (EPE,2021).

# 5. Conclusion

As it was possible to notice from the last chapter, Brazil has yet a long way to go in order to develop its H2 economy and a proper market. And more than that, to adapt its current energy system to receive this innovation. First regarding the technology needed to implement the H2 in the country and to make sure that the actual system (like the natural gas pipelines, for example) will be able to receive and handle such unstable chemicals.

The second main point to be considered is the need for proper regulation, laws and rules for the market to work under. Now, the country presents its regulation for many other matters, such as renewable sources, H2 as a dangerous chemical, the energy regulation for the system now and much more. But none of them is actually covering all the needs of the H2 market and its implementation. Besides that, it is important to notice the nonexistence of a regulator and it remains the question of what government body would be responsible for that as well.

In a comparative mode with Portugal, Brazil does have projects as well, but no advance in the regulatory front was made so far. In the meantime, the "brother" country it's already trying to figure this out. At the same time it is possible to appreciate many qualities present on that country that Brazil does not present for the adaptation of the market to receive the H2 tech, such as: support from a body like the European union, and the fact that most of the countries are focusing to reach for the same goal regarding the implementation of renewable sources and search for more energy security. Besides, the fact of the "Carbon Dimension" is seen as a priority in the new climate change framework is a huge motivator in order to adopt the H2 as source of energy in this continent.

Germany is actually one of the biggest influences and presences nowadays in the H2 front. This country has been leading the way, and it is actually already in a stage of

making investments in other countries in order to provide the right environment for them to adopt the H2. This is due to the interest that the country has in being a huge piece importing this H2 from emergent countries with more adequate characteristics to apply this new tech inside their borders. The path for Brazil to actually meet the development in this sector like Germany is long. But some good lessons can be learned from the experience, especially considering the conjunct effort of Federal and State policies to improve this market and develop in a much more efficient way.

And finally, when compared to Chile, a country from the same continent and that faces some of the same challenges of being emergent and a latin country, Brazil presents itself as a beginner in the process. This is due mainly because of the good structure of regulations and norms that Chile has to deal with the H2 (there are 20, to be exact). This has made this process a little less tricky for the country, since not a lot of changes are necessary on this front. And regarding the technology improvement, Chile is one of the countries receiving the investments coming from Germany in order to organize and evolve as much as possible - and faster - the internal H2 market. This would be, actually, a very similar strategy that the Brazilian government is trying to apply in Ceara, with many projects together with different countries in order to develop as much as possible the technology and the HUB for the H2 in the country.

Even with all of this comparison and the long way that the country has until become a proper market for the H2, Brazil is still considered one of the most promising countries to develop this Green H2 Market and to be one of the big references for import of this source in the future. All the challenges that are still a reality for Brazil to implement and become a relevant actor in the H2 market, the Bloomberg New Energy Finance in 2020 projected large decreases in costs for these innovations and the production of H2 blue and green for the next years to come. And this report also proposes a competitive advantage above the non-renewable sources until 2050. Together with this, the H2 Council predicts a decrease of almost 60% in the costs associated with the Green H2 until 2030, taking into the next level of competitiveness needed to face other kinds of energy. So, basically, that with many other conditions pointed during all this project it is clear that the H2 is one of the goals for the future as an energy source and fuel and the countries that are able to adapt its system earlier will be in front of this change in becoming a reference in decarbonisation and implementation of green energy.

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