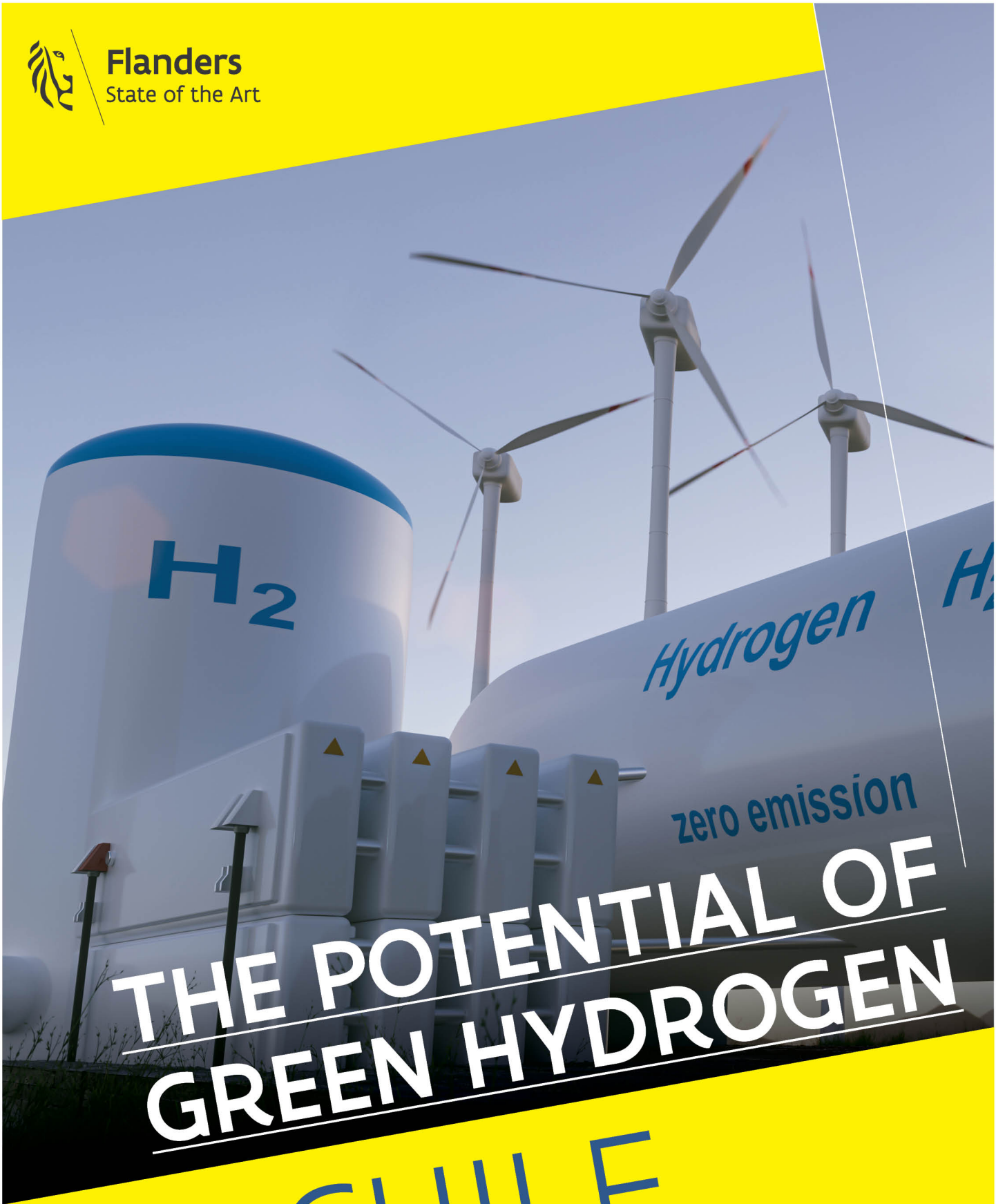
Flanders
State of the Art



THE POTENTIAL OF GREEN HYDROGEN IN CHILE

FLANDERS INVESTMENT & TRADE MARKET SURVEY

THE POTENTIAL OF GREEN HYDROGEN IN CHILE

Based on its evolution of renewable energy

1/07/2022

Flanders Investment & Trade Santiago
Piet Morisse – Flemish Economic Representative
Maria Elena Duarte Vilches – Assistent
Axelle Vandaele - Intern

TABLE OF CONTENT

INTRODUCTION

Chile is the country of copper and ranks first among global copper producers. The production of green hydrogen in the country is expected to be second in the future.

The info in this sector study is first of all based on desk research on the evolution of the largest renewable energy sources in Chile, wind and solar energy. It is explained separately how the energy is generated and what the current data are.

Then Chile's potential for green hydrogen production is explored through field research, consisting of a qualitative study of eight interviews of people with experience in the subject (Chilean Ministry of Energy, the Port of Antwerp and companies such as SOLCOR, GNL Quintero and Engie). The methodology used was qualitative research, as it allows to gather in-depth insights and generate new ideas.

It became clear that Chile is one of the best countries in the world to produce green hydrogen in the cheapest and most ecological way. Chile has the largest source of solar and wind energy. In the future, there will be a huge production of hydrogen, and they would like to export the surplus worldwide.

This report shows how Chile currently stands in the field of renewable energy, what the future holds, what opportunities there are and which potential the future overproduction of green hydrogen will offer to the market, to potential buyers. It also covers the transport possibilities, the future vision and hydrogen projects in Chile.

It can be concluded that renewable energy has increased over the years and will continue to do so, especially solar and wind energy. Hydropower is currently decreasing due to the large droughts that occur. Green hydrogen is not yet produced, but Chile's large source of renewable energy would place the country in the top three countries for making hydrogen cheaply and sustainably.

1. THE RENEWABLE ENERGY SITUATION IN CHILE

In recent years, non-conventional renewable energy sources (NCRE) in Chile have grown strongly. NCRE-projects involve the use of renewable energy sources for power generation and the minimalization of social and environmental impacts. Examples of NCRE-projects are power plants based on organic waste, hydropower, wind power, solar power, biomass cogeneration and geothermal heat. See the graph with the evolution of NCRE in Chile since 2012 below.

"Currently, a process of the energy transition is underway, in which the gradual closure of thermoelectric plants is taking place and there has been a constant contraction in the contribution of hydroelectric generation (due to the sustained drought of the last 15 years), which has been compensated by a permanent increase in renewable generation in recent years, mainly from solar photovoltaic and wind technologies." (F. Gallardo, personal interview, May 3, 2022)

Photovoltaic cell (PV), Concentrated Solar Power (CSP) and wind energy (see yellow and orange in the figure below) have registered significant growth in Chile, outpacing other NCRE such as hydro, biomass and geothermal. (Moraga-Contreras et al., 2021)

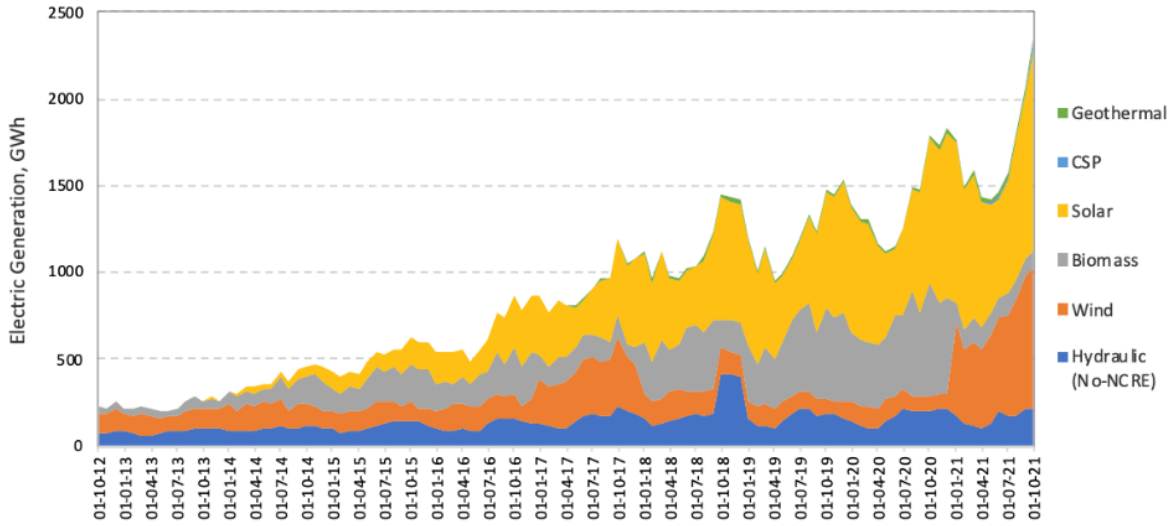


Figure 1: Electric Generation Chile (Moraga-Contreras et al., 2021)

After all the investments that have been made and the evolution that has taken place, there is still room for improvement. Chile is known as the country with leadership in renewable energy and as the country of renewable energy sources. It has the highest solar radiation in the world, strong North and South winds, oceanic energy on the coast and geothermal energy in the mountains. (Ministerio de Energía, 2022)

Chile is doing well in terms of renewable energy, but on the other hand they are stuck with a high burning of fossil fuels. As the country does not have enough to be self-sufficient, it is forced to import it. As a result, the cost of living is high for Chileans. Because it has a high price tag and is not good for the climate, Chile is forced to reduce greenhouse gas and carbon dioxide emissions, planning, and promoting energy efficiency in the country. (Ministerio de Energía, 2022)

The year 2021 ended with 166 projects under construction for non-conventional renewable energy (NRCE) according to data from the National Energy Commission (CNE). Additionally, commissioning of new projects is expected to occur between December 2020 and December 2023. Together, the

projects would produce a total of 4.473 MW, which is 51.4% of the total renewable energy produced today, 8.695 MW of which almost 99.7% is connected to Chile's National Electricity System. (Comisión national de Energía, 2022)

Finally, in December, the Environmental Assessment Agency received 7 new NCRE project initiatives for evaluation, representing a total of 722 MW and an investment of 645.2 million USD. (Comisión national de Energía, 2022)

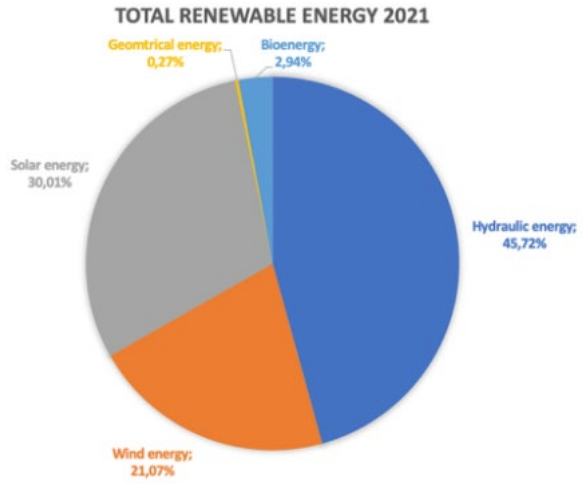


Figure 2: Total renewable energy matrix 2021 (IRENA, 2022)

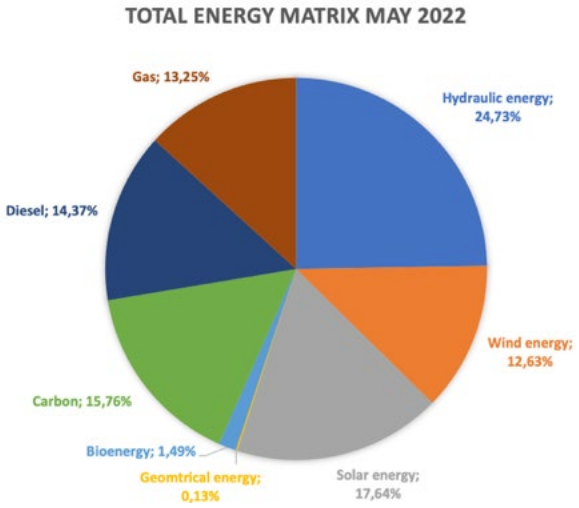


Figure 3: Total energy matrix May 2022 (Energia Abierta, 2022)

Chile had an installed capacity of 28,011 MW in February 2022, of which the generated capacity was 11,215 MW. If you look at the figures above for the total renewable energy in 2021, it is clear that hydraulic energy, solar energy, and wind energy are the leaders. (IRENA, 2022)

It is also important to note that Chile is a country that operates without government subsidies, and this also applies to renewable energy projects such as green hydrogen projects. Only a government agency CORFO has raised money through fundraising to invest in some hydrogen projects. These are not subsidies but offer help in the form of investments. The thinking behind this is that Chile is

doing extremely well in terms of renewable energy at a good price, so there is no need for government subsidies for these projects. Sometimes, however, people can be subsidised by the government to install solar panels, for example, by taking part in competitions in which people can earn 20,000 euros for installing them. Sometimes poorer communities or remote regions can apply for subsidies, but this is a very small market. (A. Decock, personal interview, May 11, 2022)

1.1 MINISTRY OF ENERGY

The ministry of energy is responsible for preparing and coordinating, in a transparent and participatory manner, the different plans, policies and standards for the development of the country's energy sector, thus ensuring that all Chileans can access energy safely and at reasonable prices. (Ministerio de Energía, n.d.)

Since March 11, 2022, the commercial engineer named Claudio Huepe Minoletti is in charge of the ministry of energy in Chile. Julio Maturana França, the state secretary of energy, works under him. Together they work under the new government of President Gabriel Boric who was elected on March 11, 2022. Gabriel Boric is 36 years old, making him the youngest state sufferer in the world. He succeeds Sebastián Piñera and his political party is Social Convergence, a left-wing political party in Chile.

1.2 EVOLUTION

In the year 2005, only 285 MW of renewable electricity was produced. In 2012, only 5% of electricity was generated from renewable energy. This extremely low figure was caused by various factors, such as an interruption to gas supplies from Argentina, prolonged droughts, difficulty in obtaining environmental permits, citizens' opposition to large power plant projects and scarce investments in the infrastructure for electricity generation and transmission. (Ritzek, 2018)

In 2016, 11.4% of renewable energy was generated from renewable sources, amounting to a production of 2,135 MW. This increase is mainly due to a huge source of wind and solar energy. (Coordinador eléctrico national, 2016) In 2018, this figure increased more than threefold, to 18%. This means that even more electricity was generated from renewable energy. The 18% figure or 4134 MW was composed of 8% electricity generated from solar panels, 6% from onshore wind, 2% from biomass and 2% from small hydroelectric plants of up to 20 MW. (Ritzek, 2018)

In 2021, a high value was reached, more than 2,400 GW per hour of renewable energy was produced. Compared to the same month last year, the production of renewable energy increased by almost 39%. (Statista, 2022)

Since the start of the Pandemic in Chile on February 8, 2020, energy projects from renewable and non-renewable sources have monopolized the procurement market. That is, according to data from the Ágora system. The energy industry has been the industry with the largest volume of transactions, and mobilized many operational resources, up to 14.7 billion USD. Of this, 81.5% was related to acquisitions of companies in renewable energy, namely wind, thermoelectric and solar photovoltaic companies. (Munguía, 2021)

On November 13, 2020, the transaction with the highest economic value in terms of green energy projects was closed. This was achieved through the acquisition by State Grid International Development (SGID) of Naturgy's share in the Chilean subsidiary Compañía General de Electricidad (CGE). The acquisition amounted to three million USD. (Munguía, 2021)

"In 2020, Chile was the 28th largest producer of hydroelectric power in the world, with 6.9 GW installed capacity, the 29th largest producer of wind power in the world, with 2.1 GW installed capacity, the 24th largest producer of solar power in the world, with 3.2 GW installed capacity, and the 33rd largest producer of energy through biomass, with 0.4 GW installed capacity. " (IRENA, 2022)

On February 13, 2021, Chile published a new law on energy efficiency (CEE). This law would provide noticeable monetary savings and a reduction in greenhouse gas emissions. In addition, it would reduce energy intensity by 10% at the national level.

Now Chile ranks second in terms of investment in renewable energy to combat climate change in the Latin American and Caribbean region. This was awarded in the latest version of the New Energy Finance Climatescope. (Ministerio de Energía, 2021) They evaluate countries based on: the investments made globally along with the ability to attract capital for low-carbon technologies and at the same time a greener economy, considering energy transition. This is mainly because Chile invested more than double in 2015 compared to 2014 in projects for NCRE (non-conventional renewable energy). In 2014 this amounted to 1.3 billion USD, whereas in 2015 a record investment of 3.2 billion USD took place. Since December 2009, Chile is part of the OECD countries, characterized by developed markets with economic progress and stimulation of global trade. (Climatescope, 2021)

In addition to the advances Chile has made in renewable energy, Chile also took measures in the field of fossil fuels. A total of five coal-fired power plants have already been closed, with four more to follow in 2022. But going forward, they should all be shut down to be completely carbon neutral. (Moore, 2022)

However, this is not going to be so easy. The water shortage and the huge ongoing drought make this process much more difficult. For example, in the middle of 2021, there was almost a power cut, which quickly turned into a crisis in which they almost considered reopening a closed coal plant in the Valparaíso region. In the end, they decided not to, but such situations should be avoided in the future. (Moore, 2022)

1.3 FUTURE GOALS

Chile is considered as a highly vulnerable country to climate change according to the UNFCCC (United Nations Framework Convention on Climate Change) because it has seven of the nine characteristics defined by this organisation. These include low-lying coastal areas, arid and semi-arid areas, areas with forest cover, areas exposed to forest degradation, areas prone to socio-natural disasters, areas exposed to drought and desertification, and areas with high levels of urban air pollution and areas with fragile ecosystems, including mountainous ecosystems. According to the Climate Treats Explorer, a continuation of the temperature increase is expected in the period 2035-2065, with increases of 1.15°C to 2°C compared to the historical period 1980-2010. It is, therefore, crucial to pay attention to climate change in Chile. (Ministerio del medio ambiente, 2021)

The Ministry of Energy in Chile predicts that by 2050 more than 90% of electricity production will come from renewable energy sources, considering the major development of solar photovoltaic technology, solar CSP, wind and storage systems. (Ministerio de Energía, 2022)

Chile has set a lot of goals for the future in the field of energy. Therefore, it wants to ensure that more renewable energy is produced, fossil fuels disappear, and climate change is slowed down. The central goal that the country wants to achieve is to be carbon neutral by 2050, but this still requires a lot of effort. (Ministerio de Energía, 2022)

1.3.1 Low carbon strategy

Despite the evolution and progress in renewable energy, Chile is still very dependent on fossil fuels. These account for 57% of final energy consumption. (Palma-Behnke et al., 2021) To achieve the central goal of the Paris Agreement in which Chile participates, greenhouse gas emissions must be reduced by 45% by 2030 and become carbon-neutral by 2050. The ambitious change in emissions by 2050 is to reduce emissions from 130 million tonnes of CO to 65 million tonnes. To achieve this, Chile aims to phase out half of its coal-fired power plants by 2025 and close all 28 by 2040. This is written in the updated version of the Nationally Determined Contributions (NDCs) submitted by Chile on 9 April 2020. It sets out intermediate targets towards the central goal of carbon neutrality and resilience by 2050 at the latest. For greenhouse gas emitting sectors, peak emissions will be reached in the year 2025 at the latest. Between 2020 and 2030, they will reach a maximum emission of 95 tonnes of CO2eq. (Ministerio del medio ambiente, 2021)

Chile submitted its updated version of the NDC to the UNFCCC where all the countries of the world have agreed to prevent the global average temperature from rising by more than 2°C compared with pre-industrial conditions and even to make efforts to ensure that it does not rise by more than 1.5°C. As a result, the quality of life of people living in the world would be adversely affected, it would improve people's quality of life. However, to achieve this goal, adjustments are needed. Due to the severe and persistent drought in the country, it is necessary to build reservoirs to collect enough water, from which energy can be extracted afterwards. This guarantees constant energy production in Chile. (Moore, 2022)

The involvement of the Ministry of Finance and sectoral ministries will be crucial to determine the cost of these measures and their impact on the economy, in addition to aligning the NDC with Chile's green growth strategy before the OECD and the Agenda 2030 with the Sustainable Development Goals. Finally, the existence of two preparatory bills on climate change, one by the executive branch and the other by Congress, will allow us to bring all these goals into a discussion with citizens and in Congress to achieve national regulation. (Mussa, 2021)

During its COP25 presidency, Chile was a strong supporter of the Paris Agreement at the international level, using science as the basis for decision-making. (Ministerio del medio ambiente, 2021) The chair of COP25 was Carolina Schmidt, Chile's environment minister at the time. Among other things, her role was to steer international climate agendas and call on all countries to present ambitious NDCs and ECLPs, as stipulated in the Paris Agreement. (COP25, 2022)

Following the negotiations at the United Nations Framework Convention on Climate Change (UNFCCC), the COP26 (Conference of Parties) was concluded on 13 November 2021, agreeing the Glasgow Climate Pact in Scotland. There, Alok Sharma, a British politician, was elected chairman. The theme of the new climate treaty is 'Alarm and Concern', for all the damage done to the planet as well as the necessary attention to the urgent reduction of polluting gases. The latter must have a 40% reduction by 2030 compared to 2010 and achieve zero emissions by 2050 to meet the main objective. (COP25, 2022)

1.3.2 Energy policy

The Ministry of Energy launched a National Energy Efficiency Plan on 24 November 2021, to be updated every five years. (Solcor Chile, 2021) This can be used as a strategic framework against the high energy consumption that the country presents compared to other OECD (Organisation for Economic Co-operation and Development) member countries. The aim is to discuss the methods by

which the country can continue to grow economically, but with much lower energy consumption. Therefore, the highest consumers can use energy more responsibly and efficiently, thus trying to reduce the negative effects of climate change. The end uses in Chile are in three sectors: industry and mining (38%), transport (36%) and consumption, public and commercial (22%), which together generate emissions of approximately 303,153 tons of CO2, which is a huge amount. (Ministerio de Energía, 2022)

The Ministry of Energy has the largest participation in the topic and is implementing mitigation measures to achieve carbon neutrality. New efforts are continually being made to innovate and integrate new technologies, creating laws, strategies, programs, and projects that contribute substantially to the direct reduction of greenhouse gas emissions. . (Ministerio de Energía, 2022)

Chile had set a goal of generating at least 20% of its electricity from renewable sources by 2025. Given the dynamics and enormous potential in its development, this was achieved ahead of schedule. Thus, by 2020, Chile was already generating 25% of its electricity from renewable energy sources, of which 17% was from wind and solar power. (Ministerio de Energía, 2022)

Their second goal is to achieve energy efficiency for decarbonization, among other things. To be carbon neutral by 2050, sustainable and non-polluting transport is essential. The Ministry of Energy recently launched the National Electromobility Strategy, which states that only emission-free light vehicles will be sold in Chile by 2035. In addition, the Energy Efficiency Law was promulgated, which specifies light, medium and heavy-duty vehicles. (Ministerio de Energía, 2022)

A third goal is to increase the use of low emission technologies and energy sources such as the use of green hydrogen in all sectors. By 2035, Chile wants the sale of new agricultural vehicles in the light and medium category or with zero emissions, and the sale of public transport vehicles with zero emissions. By 2030, it wants to achieve 15% of zero-emission fuels in non-electric end-use energy. For example, green hydrogen. They want to extend this to 2040 so that urban transport is with 100% emission-free vehicles. Then, by 2045, they want to sell only zero-emission trucks and buses. By 2050 they want to achieve at least 70% emission-free fuels in the non-electric end-use of energy. (Ministerio del medio ambiente, 2021)

2. ELECTRICITY MARKET

The Chilean electricity market consists of three independent systems.

First is the Sistema Eléctrico Nacional (**SEN**). This system consists of the old Interconnected Central (SIC) and Interconnected Norte Grande (SING) systems. In recent years, it has seen a significant increase in renewable energy generation, reaching 44.8% of renewable generation by 2021. (Generación eléctrica en Chile, n.d.)

In addition, Chile has the Sistema de Aysén (**SEA**). This system produces electricity to supply the Aysén region of General Carlos Ibañez del Campo. As of January 2022, it will have a net installed capacity of 66 MW.

The country also has the Sistema de Magallanes (**SEM**). This system produces electricity to supply only the Magallanes and the Chilean Antarctic regions. (Generación eléctrica en Chile, n.d.)

In Chile, a total of 8,695 MW of net installed capacity was generated based on NCRE technologies in 2021. In the table below, you have an overview of the installed capacity per energy system and its breakdown per energy source.

- Of the total net installed capacity in Chile, the SEN system generated 8,667 MW of renewable energy, mainly by the sun (50%) and wind (36%), so representing 86% of the energy.
- Only 0.3% or 26 MW of renewable energy was generated in the SEA area, only by two sources; 88% came from water/ocean and 12% from wind.
- Finally, only 0.03% or 3 MW of energy was generated in the SEM area, only by the wind. (Comisión national de Energía, 2022)

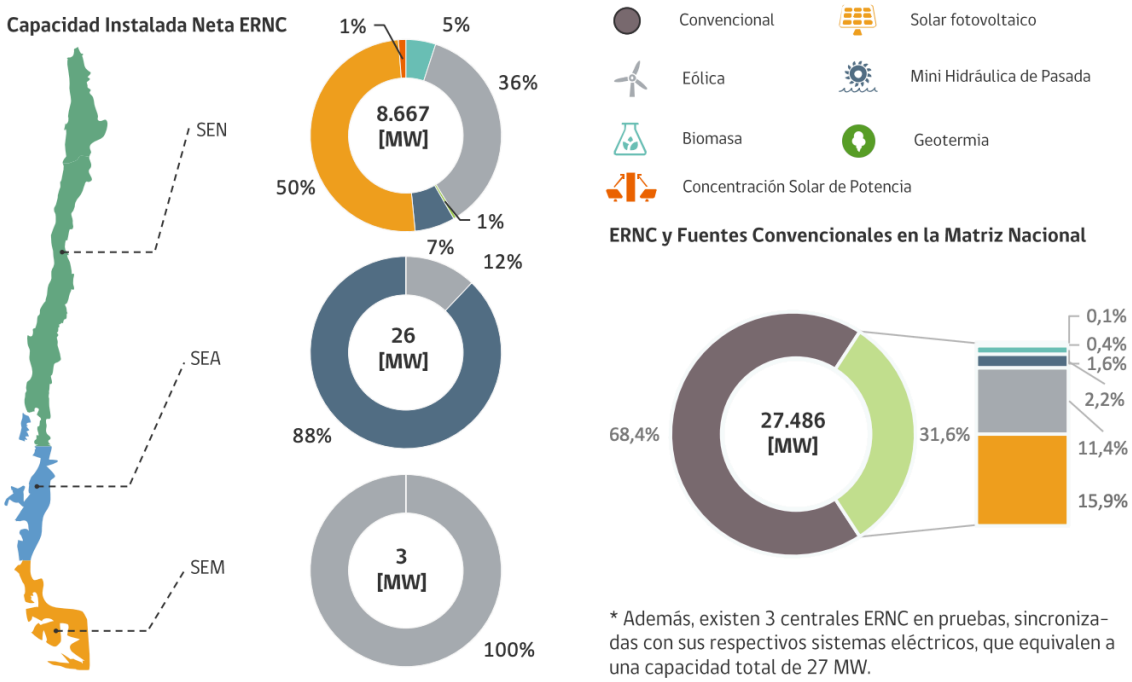


Figure 4: Installed capacity Neta January (Comisión national de Energía, 2022)

Due to the large production of non-conventional renewable energy, the country has surpluses. Law 20.571, also known as Netbilling or Net metering, describes that users have the right to sell their surplus unconventional renewable energy directly to electricity distributors at a regulated price. However, this must be published on the website of each distribution company. Any electricity generation system that wants to benefit from this law must be declared to the Superintendencia de Electricidad y Combustible (SEC). (Comisión national de Energía, 2022)

In the most recent ACERA report verifying renewable energy in Chile in January 2022, we can conclude that in 2021, 27% of renewable electricity generated came from non-conventional renewable energy sources. (Acera 2022)

3. EVOLUTION OF RENEWABLE ENERGY IN CHILE

3.1 SOLAR ENERGY

The highest, most powerful, and direct solar radiation in the world takes place in the north of Chile, the Atacama desert. This makes Chile the best place in the world for generating solar energy. The potential of the Atacama desert is so great that Chile could generate all of its electricity with about 4% of the desert's surface area. This desert has namely one of the best conditions for the installation and development of solar technologies in the world. There is almost no chance of survival for organisms such as vegetation due to the intense solar radiation, the constant dry air, and the lack of water molecules in the air. (Miroff, 2017)

Making even more use of the advantages of solar energy would be very beneficial for the goals they want to achieve in terms of renewable energy. Since solar producers have a much lower cost for generating electricity, this results in the effect that several coal-fired power stations can be closed for the benefit of the climate. Moreover, solar energy helps sustainable development since the sun is a non-polluting renewable source and is available everywhere on earth. For every 100 kW of solar power installed, 75,000 kg of CO2 is avoided every year. This also contributes to the creation of jobs in the areas where it is implanted. (Enel X Chile, n.d.)

The only problem is that the photovoltaic solar panels cannot produce electricity when it is dark. However, a solution has been found for this: the solar thermal system. This involves rotating mirrors, each with a surface area of 140 square metres and a weight of three tonnes, being placed in a circle around a central tower. This ensures that the sun's rays are concentrated on top of a huge receiver filled with molten salts. In this receiver, the molten salts circulate at a temperature of at least 560 to 1000 degrees Celsius. When the superheated salts sink into the boiler, this creates long-lasting steam that can also provide energy at night. Due to the global focus on cheap solar energy, the prices of photovoltaic solar panels are falling sharply. These can be found mainly in the deserts of Chile, on farmland and on rooftops to convert solar energy into electricity. (Miroff, 2017)

In July 2019, Enel Green Power submitted the environmental impact statement for the 404 MW Sierra Gorda solar photovoltaic project to the Chilean Environmental Assessment Service (SEA). This makes Enel Green Power the largest solar photovoltaic power plant in Chile. Over the years, solar power generation increased enormously (see the chart below). In 2020, Chile generated 3,205 MW of solar energy. By using better technologies such as solar thermal installation, this will increase even more.

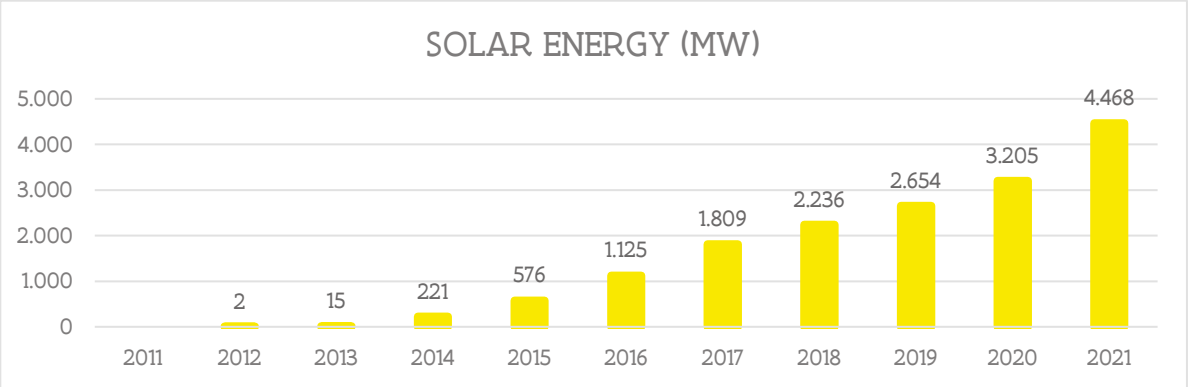


Figure 5: Solar energy (IRENA, 2022)

During the 2021 Asia-Pacific Economic Cooperation (APEC), Chile's former president, Sebastián Piñera, announced the new Antípodas project. This project aims to share clean solar energy with Asian countries so that they can also meet their electricity demand at night. It involves the transmission of 200-600 gigawatts of electricity via long-distance undersea cables, which would avoid annual global emissions of up to 4.5% CO2, equivalent to 1.6 billion tonnes annually. (Gob.cl, 2021)

3.2 WIND ENERGY

Wind energy is one of the fastest-growing renewable energy sources in the world and in Chile. It is an abundant, renewable, and clean resource that also helps to reduce greenhouse gas emissions by replacing the energy produced by fossil fuel thermal power plants. (Mainstream renewable power, 2022)

Due to its geographical location, extensive coastline and anti-cyclone climate in the Pacific, Chile is exposed to constant winds from the southwest. These are ideal conditions for generating electricity from wind power. Moreover, wind farms are easy to install unlike other technologies and last up to 25 years; they have a small footprint, are compatible with other activities such as agriculture, livestock, and forestry, and are easy to restore. (Ministerio de Energía, 2022)

Currently, there are no offshore wind farms established in Chile because the investment costs are too high and there is sufficient capacity to generate wind on land, which makes it more advantageous to install wind farms on land since wind farms at sea are much more expensive than wind farms on land. (Electricidad, 2017)

In 2001, the first wind farm was commissioned, which consisted of three wind turbines with a nominal installed capacity of 2 MW. This could provide electricity for 42,600 families in the area. Since then, Chile's energy matrix has shown a continued increase in generation from renewable sources and a simultaneous decrease in the volume of energy produced from conventional sources, such as charcoal. Wind technology had evolved tremendously in 2018. At that time, Chile generated an installed capacity of 1,524 MW, generated by 650 wind turbines. This means that 4.7% of all energy in Chile, was produced by wind turbines. The evolution was made possible by the larger rotating diameter of the blades and by the higher towers that were developed to capture the wind with greater energy content. In 2021, the installed capacity was about 3.137 MW, equivalent to almost 10% of the country's total electricity generation capacity. (Ministerio de Energía, 2022)

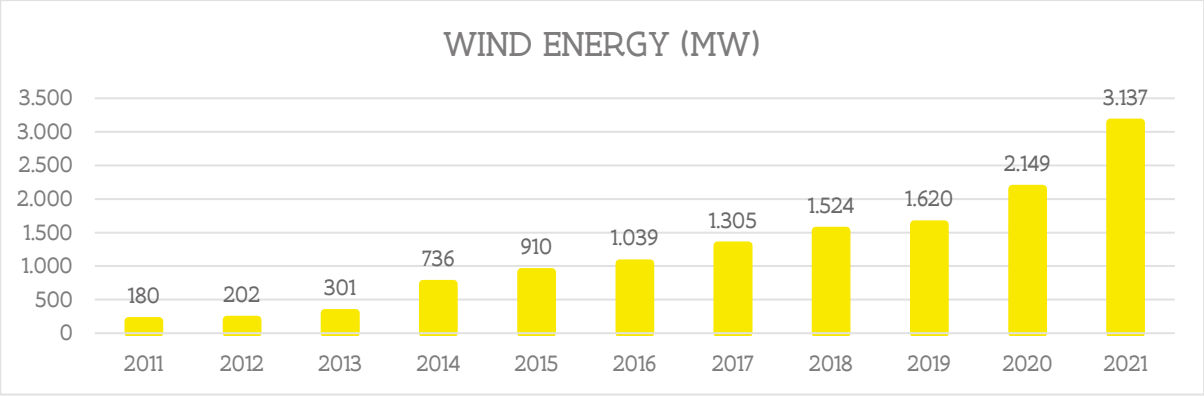


Figure 6: Wind energy (IRENA, 2021)

In recent years, the technical efficiency of the equipment has improved, and, at the same time, the costs of the plants have fallen. This is having a positive impact on the development of ever-larger projects. (Generadoras de Chile, n.d.) Chile currently ranks 29th in terms of installed wind power capacity worldwide and fourth in South America. Brazil, Mexico, and Argentina are the leaders. (Statista, 2021)

The largest wind complex in Chile is Cabo Leones in Freirina. It consists of three wind farms (Cabo Leones I, II and III) located in the Atacama Desert, in the north of Chile. The wind farms generate a combined installed capacity of 613 MW, which will provide clean energy to 521,000 Chilean homes and prevent the emission of 956,000 tonnes of CO2 into the atmosphere per year. Freirina is a municipality with a 100% renewable matrix, based entirely on wind energy. (Ministerio de Energía, 2022)

Colbun will start up a new project called "Horizonte" in Taltal (https://www.colbun.cl/en/home), located in the Antofagasta region, in the fourth quarter of 2023. Horizonte would be the largest wind farm in Chile and South America, where 140 wind turbines would generate 2,400 GWh of electricity per year. This is equivalent to the consumption of over 700 thousand homes. It will prevent the emission of 1.2 million tonnes of CO2 per year. (Colbun, n.d.)

3.3 HYDRAULIC ENERGY

Hydroelectricity is the most widely used renewable energy in the world. Hydroelectricity comes from flowing water that is converted into energy by local hydroelectric plants.

In 2021 Chile's hydropower accounted for 45.72% of the energy matrix in 2021 (as showed in figure 2 "Total renewable energy matrix 2021" on page 5). This is equivalent to 6,807 MW. (See graph below) So hydraulic energy is still the leader in renewable energy.

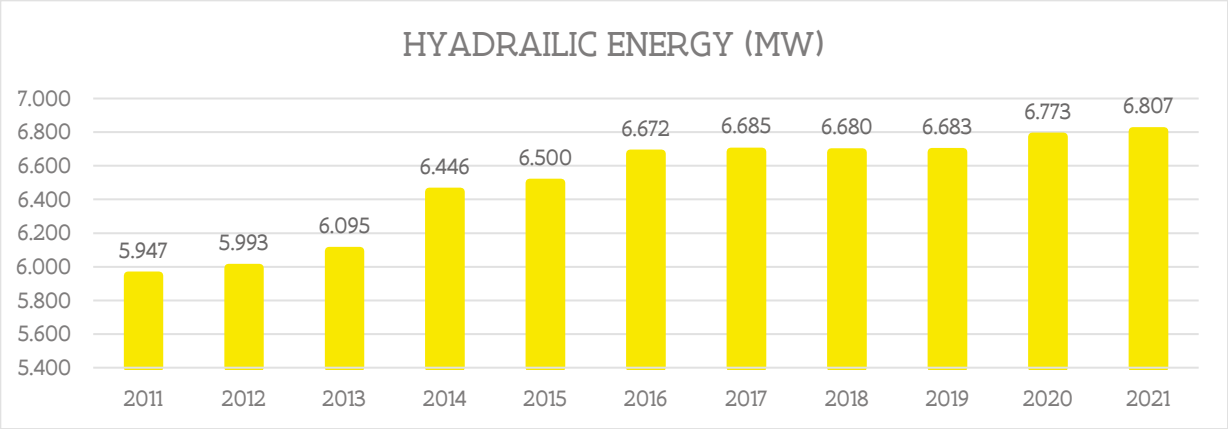


Figure 7: Hydropower (IRENA, 2022)

However, hydraulic energy fell to an all-time low in 2021 due to the prolonged drought in the country. In the month of April 2021, hydropower production was barely 13% of the total energy matrix mainly due to a lack of rain and an increase in production costs. This was the lowest figure seen in decades.

About 20 years ago, an emergency was declared in Chile due to a lack of electricity, which resulted in power cuts. The cause of this was the electricity system, which relied mainly on water as an energy source for electricity. The water reservoir plants were running out of water and other technologies were not able to meet the electricity demand due to the decrease in hydroelectric production. However, the droughts then were not comparable to those that the country is experiencing now. This has meant that systems have had to change and become less dependent on water as a renewable energy source. (La Tercera, 2021)

"With current progress on hydropower, the global energy plan towards net zero emissions will not be realised" - IHA President Roger Gill. (Guía Chile energía, 2021)

With the sustainable development of wind and solar energy at an annual growth rate of 1.5 to 2%, the installed capacity will not be able to double to achieve zero emissions by 2050. To combat dangerous global warming, the size of the hydropower sector will have to be doubled. (Guía Chile energía, 2021)

4. GREEN HYDROGEN

4.1 DESCRIPTION

Hydrogen (H2) is a worldwide topic today due to it is clean image and it can be used for many different purposes. Blue and green hydrogen are expected to be the future of various industries, but the green one is the most environmentally friendly. (Schamphelaere, 2021) Green hydrogen is considered the "fuel of the future" because the fuel in an engine emits only water vapour, unlike the carbon emitted when using fossil fuels. Consequently, it is a highly combustible gas that would not only play an important role in decarbonizing industry and produce a sustainable fuel for transport, but also provide heating to buildings, store excess renewable energy, etc. It would even be able to produce fuels such as methanol, ammonia, and propane in a low-carbon way. (Schamphelaere, 2021)

The energy system of green hydrogen is based on three main aspects: firstly, it must be produced without emissions of growth gases or pollutants; secondly, its production must be maintained if renewable sources are available, and thirdly it must apply to all energy-consuming sectors. (Osorio, 2021)

A positive aspect of green hydrogen is that it is an environmentally friendly product. It can be applied in various sectors and has infinite potential because renewable energy sources cannot be exhausted. A negative aspect of green hydrogen is that the production and transport costs are still too high to eliminate fossil fuels. (Schamphelaere, 2021)

Chile has enormous potential to produce one of the most efficient and competitive green hydrogen products in the world, as the country has the largest solar irradiation in the world and generates a large amount of wind energy. As a result, the cost of producing green hydrogen would be much lower in Chile compared to other countries. (Schamphelaere, 2021)

4.2 PRODUCTION TECHNOLOGIES

Historically, hydrogen has been obtained from fossil fuels. It is possible to produce hydrogen by different methods from various sources such as electricity, natural gas, or biomass, but the most environmentally friendly production uses renewable energy sources such as solar and wind power. No matter how it is produced, it always ends up with the same carbon-free molecule, except that the methods are very diverse and include different greenhouse gas emissions such as carbon dioxide (CO2) and methane (CH4).

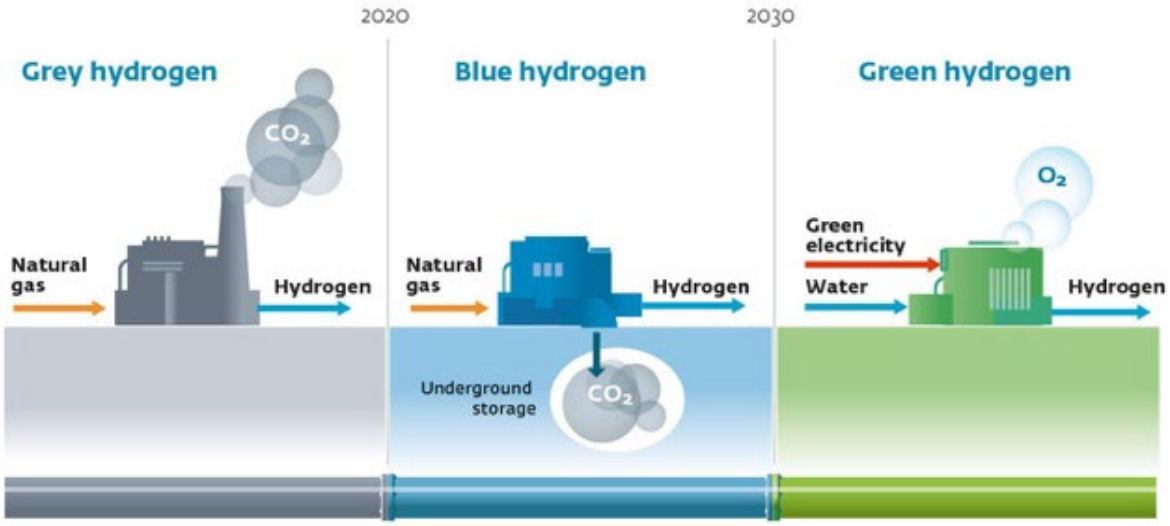


Figure 8: Indications of hydrogen (Gasunie, n.d.)

Blue hydrogen is hydrogen generated from renewable sources of energy, but which still captures, stores, or utilizes CO2 emissions. Green hydrogen comes from solar and wind energy and does not generate CO2 emissions. (Schamphelaere, 2021) Besides blue and green hydrogen, there is also the grey variant, which uses fossil fuels such as coal, natural gas and petroleum in its production, emitting CO2. This makes grey hydrogen the least environmentally friendly. (Nguyen, 2022)

Green hydrogen is the champagne of energy carriers: it's a fantastic tool, but very expensive. Only for special occasions.' Thijs Van de Graaf, a researcher at Ghent University and consultant at the International Renewable Energy Agency.

The main commercial electrolysis method for making green hydrogen is the Alkaline method. The alkaline method is via an electrolysis device with two electrodes, electrical voltage is applied to a salt solution, usually potassium hydroxide (KOH). When this is added, hydrogen is released at the cathode and oxygen at the anode. During this process, the salt solution is separated by a diaphragm that allows hydroxyl ions (OH-) to pass through it to prevent oxygen from mixing with the resulting hydrogen (Generadoras de Chile, n.d.). In addition, the diaphragm is non-conductive to electrons, which reduces the distance between electrodes by avoiding electrical short circuits between electrodes. The alkaline method is the most evolved, it contains the cheapest technology, and it has high durability.

Producing green hydrogen requires some major investments. It starts with an electrolysis infrastructure that must consider the price of green electricity and water. Its production is currently very expensive, but it is expected that the price will decrease when larger volumes are produced. The biggest challenge is to lower the cost of electrolysis, which would have to be reduced at least threefold in the next 10 years to make green hydrogen competitive. The production of one kilogram of hydrogen requires about 50 kWh and the result would have an energy value of 35 kWh, giving an efficiency of 70%. (HydrogenNet, n.d.)

4.3 STORAGE

Green hydrogen is very interesting for seasonal storage and is necessary to develop a hydrogen economy. This is especially useful during periods when there is a lack of solar, wind or other renewable energy. This makes hydrogen storage very important to provide an energy buffer. This

ensures that hydrogen is not dependent on demand but can be stored anywhere near the consumers. (Generadoras de Chile, n.d.)

4.3.1 Liquid

Hydrogen is a very low-density gas and can be stored in different ways in tanks, both liquid and compressed, but it can also be processed in materials. At normal temperature and pressure, approximately 800 litres of gaseous hydrogen can be converted into one litre of liquid substance, which is an enormous difference in volume. The only disadvantage of this process is that there is a 10% loss of energy by reaching the pressure of 200 bar. This evolves progressively as more pressure is added. For example, there is an energy loss of 15.5 bar to achieve a pressure of 800 bar and a loss of 40% to achieve a liquid state. (Hydroville, n.d.)

The liquid way is only achievable by cooling the gas until the temperature falls below the boiling point to less than -252 °C in a cryogenically cooled tank, thus causing condensation. In addition, the tank must be well insulated, and the liquid kept cool to prevent evaporation. This process brings a higher cost of about 1 USD per kilogram of hydrogen, but this way, almost twice as much liquid hydrogen can be stored in the same volume as gaseous hydrogen. The downside is that 10% to 15% energy is lost in making this, depending on the desired pressure, unlike in the gaseous form. (Jiménez Sáez, 2020)

4.3.2 Gas

The process of storing hydrogen in a gaseous state is the cheapest and simplest way. Unlike the liquid storage method, the gaseous storage method has lower consumption of energy to compress it. As a result, high-pressure vessels can achieve pressures of at least 300 to 700 bar. On the other hand, hydrogen can only be stored in a gaseous state in a smaller quantity, which due to its very low density requires larger and heavier tanks, resulting in heavier and more transport to store the same quantity as the liquid state. (Generadoras de Chile, n.d.) If large-scale hydrogen production is to take place, it will be necessary to provide storage alternatives. Such as underground in caverns and cavities in the ground like depleted oil and grass fields, salt caves or saltwater reservoirs. (Generadoras de Chile, n.d.)

4.3.3 Chemical bonding

The third option to store hydrogen is in materials either through chemical bonds, which are created when there is a chemical reaction between gaseous hydrogen and certain substances called carriers or bonds. The chemical reaction is possible using natural gas, nitrogen, metal hydrides, organic molecules, etc. They can be divided into three types: surface hydride, intermetallic hydride and complex hydride. This chemical reaction must be reversible to recover hydrogen if necessary. (Jiménez Sáez, 2020)

Surface withdrawal occurs when the hydrogen molecule is attached to the surface of the material. Intermittent hydride is when hydrogen atoms are absorbed into a solid structure by the splitting of hydrogen molecules. Finally, complex hydride occurs when hydrogen is strongly bound in the molecular structure when the chemical components contain hydrogen. (Jiménez Sáez, 2020)

4.4 TRANSPORTATION

Hydrogen can be delivered in a gaseous, cryogenic, solid, or liquid state. The current transport possibilities of liquids and gases in Chile are rail and road networks via tanks, pipelines, and shipping via containers. In the future, ocean transport by tanker would be a solution to enable global exports. (Jiménez Sáez, 2020)

The complexity of transporting hydrogen is its low mass density, which would not move sufficient volumes with traditional transport. Therefore, it is necessary to find alternatives or adapt existing means of transport to combine them with the storage methods already described (see chapter 4.3).

4.4.1 Rail and road network

Transport by road and rail in Chile can be carried out via high-pressure cylinder trailers that contain a pressure of 180 to 250 bar when transported in a gaseous state. When these are installed on a truck, they are called tube trailers. Liquid hydrogen can also be transported in these with a volume of 20,000 to 50,000 litres, where the pressure is low from 6 to 10 bar with a temperature of at least -253°C. If the gaseous hydrogen is transported in this way, about 200 to 300 kg can be carried in each truck. (Jiménez Sáez, 2020)

4.4.2 Pipelines

Pipelines are cheap ways to transport large quantities of hydrogen. Only minor modifications to existing gas pipelines are necessary and only a small amount of energy is lost during transportation. These modifications should be made at the injection and withdrawal points where the gases are to be separated. (Jiménez Sáez, 2020)

The pipelines in Chile are used for domestic distribution, but in the future, the existing pipelines from Chile to Argentina could also contribute to hydrogen transport. (F. Bernardelli, personal interview, April 27, 2022).

Pipelines that already exist in Chile are limited and based on natural gas technology. The simplest and most effective way to export hydrogen globally is to add a certain amount of hydrogen to the natural gas transport networks established worldwide. (Jiménez Sáez, 2020)

The main difficulty with this method of transport is the material from which some pipelines are made. If they are made of steel or alloys of that metal, embrittlement can occur, resulting in possible hydrogen leaks. There is a solution to this, whereby new pipelines are constructed solely for the transport of hydrogen. These pipelines would be larger in diameter, better able to withstand higher pressures and made of different materials to prevent embrittlement, but the cost of making and installing this is enormous. (Jiménez Sáez, 2020)

4.4.3 Shipping

International shipping is also possible to transport hydrogen worldwide from Chile. To make this more efficient, it is possible to first convert hydrogen into ammonia (NH3) by adding nitrogen at high pressure and temperature, which can then be converted back into hydrogen after transport. (Jiménez Sáez, 2020)

Federico Bernardelli is convinced that hydrogen will be transported to Europe by maritime shipping because there are not enough existing pipelines leaving Chile. (F. Bernardelli, personal interview, April 27, 2022).

4.5 FUTURE VISION

Chile's first national goal is to implement green hydrogen in the Chilean mining industry in order to avoid emitting 5 million tonnes of CO2 per year, which would help decarbonise the country by 2050. It would also be used to electrify public transport and heat homes. (Pascual, 2021)

The National Green Hydrogen Strategy (Ministry of Energy, 2021) launched by the Ministry of Energy in late 2021 has three main goals.

- It predicts that by 2025 Chile will have the first operational production plants that would develop up to 5 GW of electrolysis capacity.
- By 2030, Chile is expected to produce the cheapest hydrogen in the world at a price below 1.5 USD per kilogram (Mikus, 2021) to a price of 80 cents in 2050.
- Finally, due to the cheap cost of green hydrogen, they estimate that the country will be among the three largest exporters of hydrogen and its derivatives worldwide by 2040. Chile certainly has great potential to export green hydrogen internationally if it manages to produce it at a low price, as the country has, among other things, free trade and tax agreements with countries that generate 80% of the world's GDP. (Gobierno de Chile, 2020b)

Many jobs are expected to be lost due to the closure of carbon power plants, but the production of green hydrogen would create an estimated 22,000 new jobs by 2030 and 91,000 by 2050. (Generadoras de Chile, n.d.)

4.5.1 Strategy: the three distinct waves

The applications of green hydrogen in Chile is foreseen to be spread over three different "waves".

The first wave covers the period 2020 to 2025 and concerns the high demand for energy or hydrogen in domestic use and the stimulation of production. In the short term, it is possible to replace imported ammonia with locally produced green ammonia. In addition, the use of hydrogen would also be applied for heavy and long-distance traffic for means of transport and machines operating in concentrated areas such as mining. Finally, they would inject it into the gas network up to 20%. (Ministry of Energy, 2021)

The second wave would be about the export activities and local applications between 2025 and 2030. This requires good local knowledge, scale, and infrastructure. In the medium term, there is an opportunity for the export of green ammonia and the first hydrogen production. (Ministry of Energy, 2021)

The third wave is long term, towards 2030, where new export markets will emerge worldwide, enabling mass production. Many countries are investing in green hydrogen as a more 'democratic' fuel, as it would help to combat climate change by reducing dependence on the carbon industry (oil and gas producing regimes). Its use would play an important role for countries that have signed the Paris Agreement, including Chile, which aims to become climate-neutral by 2050 (IRENA, 2021). The

production of this fuel from green hydrogen will be decisive for the decarbonisation and sustainability of transport such as shipping and aviation on national and international routes. (Ministry of Energy, 2021)

In addition, it would be very effective in eliminating CO2 emissions from non-electrified sectors, but for that to happen, the production of renewable energy plants must first be intensified so that they permanently replace fossil fuels. For example, support in the electricity grid would account for 40% of the world's hydrogen demand by 2050. (Ministry of Energy, 2021)

The latter would not only be important in terms of climate change but also in terms of economic sustainability. It would create more jobs, increase current prosperity, and preserve various industries.

4.6 ONGOING PROJECTS

In Chile, there are currently around 60 mini projects producing green hydrogen. The Chilean government agency CORFO has raised money through fundraising to help develop six green hydrogen production plants. It is estimated that these should come on stream by December 2025 at the latest. The company has raised 50 million USD for this. (CORFO, 2021) This amount was invested in 6 selected proposals that will produce 45,000 tonnes of green hydrogen per year, reducing more than 600,000 tonnes of CO2 per year. (Marca Chile, 2022)

The first project selected is "Proyecto Faro del Sur", by the company Enel Green Power Chile, which is a subsidiary of the Italian energy company Enel. It is the largest project that has received almost 16.90 million USD and is located in the Magallanes region and would produce 25,000 metric tonnes per year. (Enel, 2021) Proyecto Faro del Sur will install electrolysers of 240 MW powered by wind energy from a nearby wind farm. This produced green hydrogen is expected to be resold to HIF (High Innovative Fuels). A Chilean company that will produce 350 tonnes of ethanol and 250 tonnes of CO2-neutral engine per year from green hydrogen and captured CO2 from the atmosphere, to be exported to Europe. (Osorio, 2021)

The next project is "HyPro Aconcagua". This is a design by the German chemical company Linde GmbH that is expected to produce 3,000 metric tonnes per year of green hydrogen with a capacity of 20 MW at the Aconcagua oil refinery in the Valparaiso region, owned by ENAP (Empresa Nacional del Petróleos). This project would replace part of their current production of grey hydrogen with green hydrogen (Adler, 2022)

Another project is "HyEx-Green Hydrogen Production" by France's Engie SA. This would be good for the production of 3,200 metric tonnes of green hydrogen per year, in an industrial plant located in the Antofagasta region. The electrolysis plant will have an arrangement of electrolysers with a total installed capacity of about 26 MW. To ensure that green hydrogen can be produced and supplied 24 hours a day, the project envisages a hydrogen compression and storage system, so that production can take place day and night, without the need for a continuous electrolysis process. The Chilean mining company Enaex, which will be located on land adjacent to the project, will buy up their green hydrogen to use as feedstock for the production of green ammonia for export (Adler, 2022). So far, this is the only project that has been approved (April 2022) by Environmental Impact Assessment System (SEIA) whose investment amounts to 47 million USD. (Gobierno de Chile, n.d.)

The project "Antofagasta Mining Energy Renewable" (AMER) is led by Air Liquide, the French industrial gas producer. This project takes place in the Antofagasta region and involves the production of 60,000 metric tonnes of e-methanol from renewable energy, green hydrogen and CO2 captured from a solid source. (Adler, 2022)

"Hydrogen Green Bahia Quintero" is a project led by GNL Quintero SA. It involves the development, construction, and operation of the first large-scale green hydrogen plant located in the Valparaíso region. The project is expected to generate 430 tonnes of green hydrogen per year with an installed electrolysis capacity of 10 MW of new power. (Adler, 2022) The aim of GNL Quintero is to provide production, storage and loading in tankers with green hydrogen. This project was submitted to SEIA in May 2022 with an investment amount of 30 million USD and it is expected to be approved soon (Gobierno de Chile, n.d.). Recently, the American investment group EIG Partners and the Belgian energy infrastructure group Fluxys bought a joint-equity stake of 80% in this project. (Business Wire, 2022)

Finally, CAP SA, a Chilean mining and steel company, is developing "H2V-CAP" in the Biobío region. The green hydrogen plant will produce 1,550 metric tonnes per year of green hydrogen with an electrolysis capacity of 20 MW of renewable energy. This would avoid more than 161,000 tonnes of CO2 emissions per year. (Adler, 2022)

The first green hydrogen project was announced on 24 August 2021 by President Sebastián Piñera. The first molecule was produced during an event in the Colina district, at the industrial facilities of the Anglo-American mining company. There, for the first time, a filling station containing green hydrogen was opened, where the presentation was demonstrated using a front-loading LHD, a mining vehicle. (Pascual, 2021)

4.7 EXPORT FROM CHILE TO BELGIUM

Belgium, Antwerp, Ghent, and Ostend are developing projects to produce hydrogen locally. (A. Decock, personal interview, May 11, 2022) The Belgian government knows that the country lacks the capacity to generate sufficient renewable energy, such as solar and wind energy, to produce green hydrogen in large volumes. This makes it necessary to import it from abroad. The Hydrogen Import Coalition ("H2IC") with partners DEME, ENGIE, Exmar, Fluxys, Port of Antwerp, Port of Zeebrugge and HydrogenNet, conducted a study published on January 2021 analysing the supply chain for the transport of renewable energy to Belgium/Europe. Chile emerged as one of the best producers due to the very low cost of electricity, the large amounts of wind and solar available and the space to install these capacities. (G. Decan, personal interview, May 16, 2022) On 4 November 2021, a bilateral trade agreement was signed between Chile, Antwerp's port, and Zeebrugge's port regarding cooperation on the green hydrogen power.

The Federal Planning Bureau calculated that Belgium would need 117 terawatt-hours (TWh) of green electricity by 2050 if they were to produce green hydrogen locally. In the total electricity consumption of Belgium, only about 18% was generated from renewable energy sources such as solar and wind energy, which is equivalent to 15 TWh. The government estimates that Belgium will be able to import 3 to 6 terawatt-hours (TWh) of renewable molecules for its use by 2030, according to a study by Deloitte consultants and the Federal Public Service Economy. This corresponds to 1.5% to 3% of current imports of fossil gas. With the port of Antwerp being Europe's main port for exporting petroleum, Belgium could become a central hub for transporting hydrogen to the rest of

Europe, just as it already does with natural gas. By 2050, Belgium aims to import 100-165 TWh of hydrogen for its use and double that for exports to neighbouring countries. (Steel, 2021)

As explained in 'The three distinct waves', Chile would only be able to realise international trade of green hydrogen in the second- third wave. The second wave is mainly about the international export of green ammonia production and from the third wave onwards the export of green hydrogen including its derivatives can take place.

However, there is an enormous distance between Chile and Belgium, which makes export of hydrogen challenging. Green hydrogen would initially be exported from Chile in the form of ammonia. From 2030 onwards, maritime transport of green hydrogen would become a reality. (Pohu, 2021) Transportation of hydrogen or its derivatives such as ammonia, methanol or e-methane would be done via pipelines and maritime transport. (Steel, 2021) Maritime transport could be achieved through the use of cylinders. This would take 25-30 days before the product could be delivered, under very high pressure between 300 and 700 bar. (Pohu, 2021) Existing (natural) gas pipelines could transport green hydrogen provided that the compressors and seals between the valves are adapted. (Pohu, 2021) It is estimated that by 2026 there will be a network of hydrogen pipelines of 100 to 160 km between the industrial clusters.

Figure 9: Estimated market size for Chilean exports (Ministry of Energy,

There are a few challenges to exporting green hydrogen worldwide.

- First of all, the transport costs if it is a long-distance trip. The product is still a competitive product, regardless of the different costs.

- The second thing to consider is the greenhouse gas emissions from transporting green hydrogen across the oceans on ships. This is contrary to the various climate pacts, including the Paris Agreement. The solution is to use ships that use green hydrogen as fuel, but this requires a large investment.

- Another problem is storing green hydrogen once it is delivered, as this is more difficult than storing natural gas. It can be stored underground in a gaseous or liquid state, but the burning and storage of green hydrogen is different from natural gas. Green hydrogen burns three times faster and takes up four times more volume to store than, say, one litre of petrol. (Pohu, 2021)

In the 1960s, the company Air Liquid laid 900 km of underground pipelines in Flanders to transport hydrogen, making this the largest hydrogen pipeline network in the world. This network is used to supply hydrogen to the industries that need it. These pipelines run through Belgium, France, and the Netherlands, allowing for further distribution abroad. (WaterstofNet & Hinicio, 2018)

Figure 10: Pipelines Flanders (WaterstofNet & Hinicio, 2018)

4.7.1 MoU: Memorandum of Understanding

On 4 November 2021, representatives of the port of Antwerp and Zeebrugge, the Minister of Energy in Chile, Juan Carlos Jobet, together with the Minister of Energy in Belgium, Tine Van der Straeten, signed the official MoU during Energy Day at the COP26 climate conference in Glasgow. This MoU was negotiated in advance in July 2021 when Minister Jobet came to Antwerp. With this agreement they commit to working together to make green hydrogen flows between Chile and Western Europe a reality. They will collaborate on a regular basis in order to exchange knowledge, information and experience to further explore the possibilities of the cooperation.

Besides the port of Antwerp-Bruges, a MoU has been signed between Chile and Rotterdam (Netherlands), Singapore, Korea (Japan), and almost Hamburg (Germany). It can be concluded that Europe and Asia will be Chile's biggest markets in the field of green hydrogen. (F. Bernardelli, personal interview, April 27, 2022)

4.8 POTENTIAL HYDROGEN MARKETS IN BELGIUM

In 2019, Belgium emitted 115.6 million tons of CO2, of which the steel producer ArcelorMittal was responsible for emitting 9.7 million tons per year. Consequently, the 10 most polluting companies in Belgium are responsible for 68% of the total registered national CO2 emissions. (Klimaat.be, n.d.) In the figure below you can see that Belgium has a decreasing evolution in the annual share of CO2 emissions worldwide, but to ensure that the climate objective for CO2 emissions will be achieved by 2050, the import of green hydrogen will be necessary. Belgium's first target is to reduce CO2 emissions by 40% by 2030. For this, a strategic elaboration is needed to see which markets will first need a transformation to guarantee that this objective is achieved.

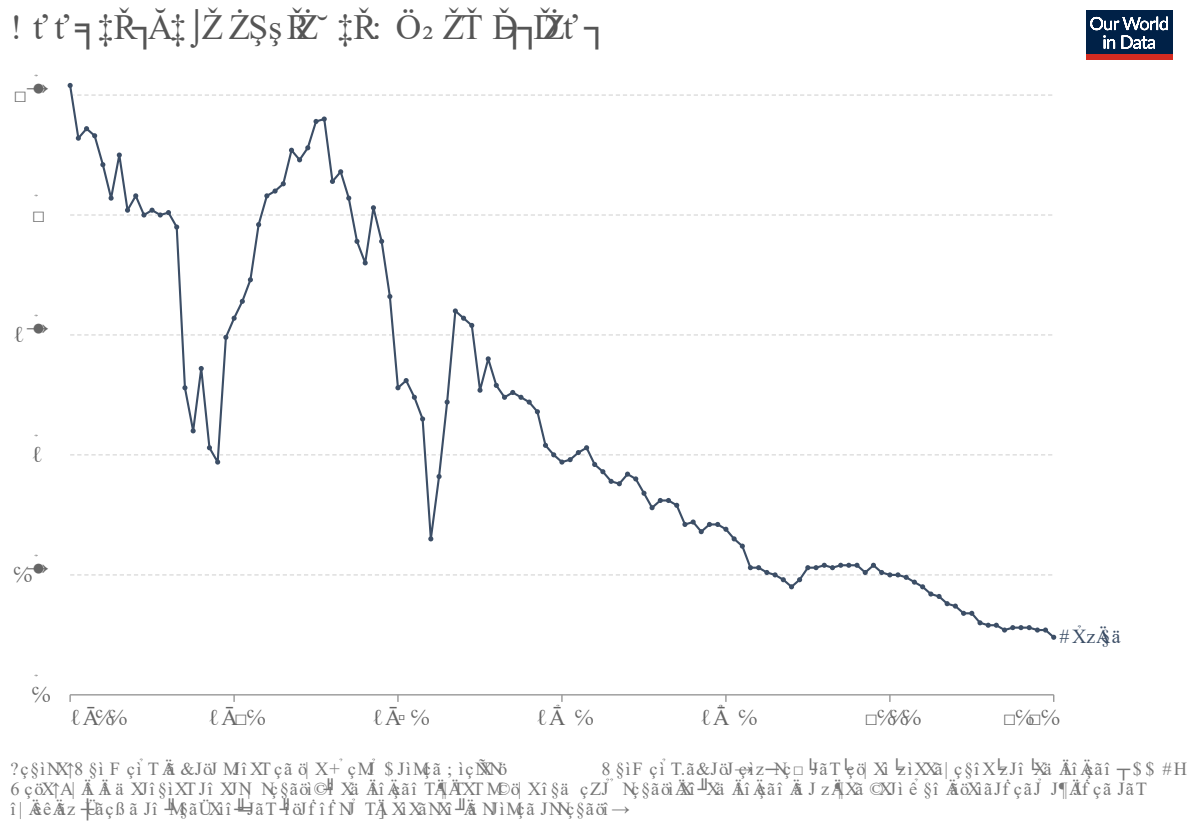


Figure 11: Annual share of global CO2 emissions (Ritchie, 2020)

"Hydrogen will play a decisive role in the energy transition and in making our industry sustainable", says Alexander De Croo, Prime Minister of Belgium. (World Energy Trade, 2021)

The first thing that will be tackled is to convert the existing heavy industry to energy based on green hydrogen. (World Energy Trade, 2021) In Belgium, the most polluting sectors are the steel industry, the petrochemical industry, the energy producers, and the cement industry. There is an urgent need to change this in order to divert the industry away from fossil fuels. Leading company ArcelorMittal has already confirmed its support for the development of the regional infrastructure needed to enable sustainable production of steel, ammonia, ethylene, and fuel. Steel production in Belgium aims to produce 10% with green hydrogen by 2050. After the application of renewable energy in heavy industry in Belgium, this will be transferred to several industries. (Roca, 2021)

To ensure positive climate change worldwide, it is necessary to export green hydrogen in a sustainable way. Therefore, priority is also given to converting heavy means of transport such as maritime shipping, trucks, aircraft, etc. to fuel on a green hydrogen basis. Afterwards, the import of green hydrogen vehicles will also become an essential part of the climate pact. If means of transport are to use green hydrogen as a fuel, it will therefore be necessary to convert filling stations to make them compatible with the sustainable fuel. (World Energy Trade, 2021)

The potential of hydrogen for transport in 2050 is:

- Passenger cars: one million cars with +30,000 km/year
- Public transport: 900 intercity buses with +90.000 km/year
- Trucks: 12,500 rigids with over 18 tons and +40,000 km/year
- Rubbish trucks: 850 rubbish trucks
- Tractor-trailer: 20,000 tractors with more than 18 tons and +100,000 km/year
- Inland navigation: 50% of the fleet
- Rail: 50% of existing diesel trains (World Energy Trade, 2021)

Green hydrogen can also fulfil electricity and/or heat demands. It can serve as a replacement for natural gas when heat needs to be generated. High temperatures can be reached with green hydrogen. On the other hand, it can also satisfy a large electricity demand by means of turbines, engines, or fuel cells. (World Energy Trade, 2021)

5. RELEVANT INSTITUTIONS

In order to provide you with an overview of the main players in the energy market in Chile, below is a list with the contact details and a word of explanation of the most relevant institutions. Those are important for identifying new opportunities in the market.

Ministry of Energy
Minister: Claudio Huepe Minoletti
Contact person: Federico Bernardelli
M: fbernardelli@minenergia.cl
Address: Av. Alameda Libertador B. O'Higgins 1449, Edificio Downtown 11, piso 13 y 14, Santiago
T: (56-2) 365 6800
http://www.energia.gob.cl/

Ministry of Finance
Minister: Mario Marcel
Address: Teatinos 120, Santiago, Región Metropolitana
https://www.mercadopublico.cl/Home

National Energy Commission (CNE)
CNE is a technical committee responsible for analysing tariffs and drafts technical standards that companies must comply with (ranging from production, and transmission to distribution).
Address: Avenida Libertador Bernardo Ohiggins 1449, Santiago, Región Metropolitana
T: (56-2) 797 2600
https://www.cne.cl/

Energía Abierta
Energía Abierta is a CNE innovative platform for sharing information on the energy market. It provides monthly regional reports on the evolution and potential of renewable energy.
http://energiaabierta.cl/

Servicio de Evaluación Ambiental (SEA)
This agency is in charge of the environmental assessment of energy installations. It can also be used to look up specific projects.
Address: Miraflores 222, piso 7, 19 y 20, Santiago
T: (56-2) 616 4000
http://www.sea.gob.cl/

Superintendencia de electricidad y combustibles (SEC)
The main supervisory body for the energy market.
Address: Avenida Libertador Bernardo O'Higgins, torre 3 1465, local 10, Santiago, Región Metropolitana
T: (56-2) 600 0732
https://www.sec.cl/

InvestChile
InvestChile is a government organisation that represents Chile to foreign investors. It aims to position Chile as an attractive destination for foreign investment.
Address: Av Libertador Bernardo O'Higgins Nº 1449, Piso 10, Santiago, Región Metropolitana
T: (56-2) 698 4254
https://investchile.gob.cl/

CORFO
CORFO is the local Chilean investment agency, supporting the economic development of Chile. It does this through an active credit policy and capital injections. They also have programmes such as Start-up Chile, where you can win start-up capital. CORFO is mainly focused on stimulating innovation and entrepreneurship, so (foreign) projects that meet these requirements can count on support from this institution.
Address: Valuta 921, Santiago
T: (56-2) 631 8820
https://www.corfo.cl/

Start-Up Chile
Start-Up Chile is part of CORFO. It offers financial support as well as training, a network, and assistance in starting a business in Chile. Two of the companies consulted in this study, Turbulent and Solcor, used Start-Up Chile and were very satisfied with it.

Comisión Nacional de Investigación Científica y Tecnológica (CONICYT)
CONICYT is dedicated to the promotion of science and technology, including renewable energy. It has several programmes whereby (financial) support is given to innovative projects
Address: Moneda 1375, Santiago
http://www.conicyt.cl/

Asociación de Empresas Eléctricas
Association of electricity producing and distributing companies. Useful contact details of all members can also be found on the website.
Address: Av. Nueva Tajamar 555, piso 5 - Torre Costanera, World Trade Center - Vitacura Santiago
T: (56-2) 203 64 27
http://www.electricas.cl/

Agencia Chilena de Eficiencia Energética (ACEE)
ACEE is a non-profit organisation whose main objective is to promote and strengthen efficient use of energy through bringing together the relevant stakeholders, both nationally and internationally; as well as implementing initiatives in various energy sectors with the aim of contributing to the sustainable development of the country.
Address: Monseñor Nuncio Sotero Sanz de Villalba 221, Santiago, Providencia, Región Metropolitana
T: (56-2) 571 2200
https://www.acee.cl/

Asociación Chilena de Energía Geotérmica
Interest group in charge of the development of geothermal energy in Chile
Address: Vitacura 2939, piso 10, Las Condes, Santiago
T: (56-2) 431 5356
http://www.achegeo.cl/

Asociación Chilena de Energías Renovables (Acera)
Acera is an interest group dedicated to the promotion of 'Energías Renovables No Convencionales (ERNC), in order to make them compete under the same conditions as traditional energy sources.
Address: Av. Providencia 1760, Office 601 - Providencia, Santiago, Chile
T: +56 2 2236 3348
http://www.acera.cl/

Asociación Chilena de Energía solar (Acesol)

Acesol's main focus is to promote the sustainable development of the solar energy industry, and groups the main players in this sector.
Address: Napoleon 3233, Las Condes, Santiago - Chile
T: +562 2631 4119
https://www.acesol.cl/

5.1 BELGIUM – CHILE

Embassy of Belgium in Chile

Embajado de Bélgica - Edificio Forum
Avenida Providencia 2653, Oficina 1103
Providencia - Santiago, Chile
T: +56 2 2232 1070 and +56 2 2232 1071 | F: +56 2 2232 1073
E: santiago@diplobel.fed.be

Embassy of Chile in Belgium

Aduatukersstraat 106, B - 1040 BRUSSELS
T: +32 2 743 36 60 | F: +32 2 736 49 94
E: echilebelgica@minrel.gov.cl

Belgian-Luxembourg-Chilean Chamber of Commerce

President: Laurent De Meester
Rue Aduatukers 106
1040 Brussels
T +32 2 743 36 60
E contact@chileanchamber.be
www.chileanchamber.be

BELGOLUX - Cámara Chileno-Belgium-Luxembourguesa de Comercio

Chairman: Alain Kaczorowski
Contact Person: Lieselotte de Ly
Embajado de Bélgica - Edificio Forum
Avenida Providencia 2653, Oficina 1103
Providencia - Santiago, Chile
T +56 9 69197663
E contacto@camarabelgolux.cl
www.camarabelgolux.cl

Flanders Investment & Trade Santiago

Commissioner: Piet Morisse
Representación Económica de Flandes
c/o Embajada de Bélgica
Av. Providencia 2653 - Of. 1104
Santiago de Chile
Contact person: Piet Morisse, Maria-Elena Duarte
T: +56 2 2 334 35 65
E: santiago@fitagency.com

RECOMMENDATIONS

Chile's large amount of renewable energy sources, especially wind and solar power, make it an ideal country for the production of green hydrogen. Production is expected to start by 2025 and the first large volumes will be produced by 2030. After meeting Chile's own needs, the surplus will be exported internationally from 2050 onwards. The export to Belgium will be by sea and then transported by pipeline or road to large and small Belgian companies. The difficulty and uncertainty are the cost of production and transport, as many different aspects must be considered. It is estimated that 1 litre will cost USD 1 for large-scale production, but this could change, when it will effectively be produced.

The largest markets in Belgium that will import green hydrogen first are the heavy polluting (existing) markets. These consist of steel-, petrochemical-, and cement industries. Next in line is the transport industry, which needs to operate on the basis of green hydrogen. The third is the electricity and heating industry.

Given this, it is highly recommended to:

- Follow up on the status of the projects discussed. On the website Servicio de Evaluación Ambiental (SEA)' there is a clear overview of which projects are in operation, under assessment and accepted. Both for renewable energy and green hydrogen projects.

  On the SEA website, at the top, you will find 'Buscar y revisar proyectos". In the field Nombre del Proyecto you can fill out for example hidrógena or energía to obtain the list concerning hydrogen or energy projects. For energy projects you can also do the search by sector. This list is much longer then searching through Nombre del Proyecto.

  Renewable energy projects:
  https://seia.sea.gob.cl/busqueda/buscarProyectoAction.php

  Hydrogen projects:
  https://seia.sea.gob.cl/busqueda/buscarProyectoAction.php

  The website of 'Acera' visually shows where the projects related to renewable energy are located. By using the filters you can visualise as desired. There is also a link to the project on the SEIA website (part of SEA).

- Check constantly the FIT website for news or possible actions. For instance, Flemish companies interested in a trade mission on renewable energy can participate in the Cleantech mission organised by Flanders Investment & Trade (Chile and Argentina). The mission is suitable for companies within the CleanTech sector. This concerns: water - soil - air - renewable energy - energy efficiency - circular economy - waste management – sustainable materials. It will take place from Sunday 20 November to Friday 25 November 2022, the first 3 days in Chile and then 3 days in Argentina. The registrations can be done until 16/09/2022. More information and registrations can be found via this link:

  https://www.flandersinvestmentandtrade.com/export/acties-events/cleantech-chili-argentini%C3%AB

- Review a number of interesting trade fairs about energy:

Exhibición Internacional de Tecnologías e Innovaciones para la Industria Minera y Energética. • Last edition: 13-16 June 2022 • Exponor • https://www.exponor.cl/exhibicion/
International Exhibition on Electromobility, Renewable Energy and Sustainability • 20-23 October 2022 • Espacio Riesco Convention Centre • https://www.experienciae.cl/
Expo Energía 2022 • 9 November 2022 • Club hípico • https://www.expoenergia.cl/

CONCLUSION

The renewable energy market in Chile is very large, with still many potential capacities in the future. Over the years, Chile has already built up a huge lead in the field of renewable energy. Currently, 27% of the electricity matrix is generated from renewable energy sources. It will increase in the future, due to the huge potential of solar and wind energy in particular and will be crucial for avoiding dependence on fossil fuels, which are currently generated and imported into the country in large quantities. This is very important, since it greatly decreases national dependency on national fuel imports, costs which are often highly variable, with a high degree of uncertainty associated with upward trends, strengthening the country's economy and economic independence, without ruling out the possibility of even becoming an energy exporter. Given this, Chile has set a target to close all 28 carbon power plants by 2040; eight of them have already been closed. All of the above would represent important progress for Chile in economic, environmental and even geopolitical terms, which would allow for the advancement of many other projects at the national level.

Chile is the country with the highest solar radiation in the world. Solar power generated accounted for 30.01% in the energy matrix of all renewable energy generated in 2021. In first place was hydropower with 45.72%, but this is expected to decline due to the drought prevailing in the country. In third place was wind energy with a share of 21.07%.

Thanks to the ideal conditions and the high source of renewable energy such as solar and wind power, Chile is in the top three countries for producing green hydrogen in a cheap and ecological way. Currently, no green hydrogen is produced in the country, but there are already 60 projects under development in the country, 6 of which have received investments from CORFO, 50 million USD in total. The subsidised projects set ambitious targets to start producing green hydrogen by 2025 and export the surpluses worldwide by 2050, mainly to Europe and Asia. The price will depend heavily on transport costs and the cost of generating the necessary renewable energy, which has not yet been clearly established.

Due to its open economy and numerous trade agreements, there are many opportunities in Chile to trade their generated renewable energy, among others. For example, Belgium, more specifically the port of Antwerp-Bruges, signed a MoU with Chile this year. Besides Belgium, Chile has several MOUs with other countries. This is not a commercial agreement, but a long-term relationship in which information, know-how and advice are exchanged to stimulate the production and export of hydrogen. On the other hand, in the case of Belgium, it is important to implement green hydrogen first in the heavily polluting industry, transport, and heating. In this way, the CO2 emissions in Belgium can be quickly reduced, which currently amount to 115.6 million tons per year.

To export green hydrogen, it can be transported to neighbouring countries by pipeline at a pressure of 300-700 bar, or by sea transport in the form of ammonia, fuel, gas or in liquid form. To this end, the Belgian company Fluxys has confirmed that it intends to invest in the construction of the natural gas network in Belgium and to transform the existing natural gas network to make it possible to transport and export green hydrogen abroad, among other things. On the other hand, Fluxys and EIG have acquired a joint 80% stake in the 'GNL Quintero' green hydrogen project in Chile.

Finally, as mentioned above, the expected price of green H2 in the coming years is very low and allows foreseeing a great opportunity to replace the use of traditional fuels, especially in industrial applications or use in high energy demanding processes. Both the increase in renewable energy

generation and the start of green hydrogen production in Chile will contribute to the Paris Agreement, which includes targets to combat global warming. By doing so, Chile would make a huge contribution not only to its own country but also worldwide to other countries by importing their green hydrogen when those do not have the capacity and resources to generate it on a large scale.

"Green hydrogen is key to achieve the global energy transition".

(ENGIE, personal interview, May 17, 2022).

BIBLIOGRAPHY

- https://acera.cl/2022-comienza-en-chile-con-la-fotovoltaica-generando-el-20-de-la-electricidad/
- https://cleanenergynews.ihsmarkit.com/research-analysis/chile-awards-six-new-green-hydrogen-projects.html
- https://www.businesswire.com/news/home/20220327005107/nl/
- https://www.cega-uchile.cl/en/noticias/las-trabas-legales-de-la-geotermia-en-chile/
- https://horizonte.colbun.cl/
- https://www.cne.cl/wp-content/uploads/2022/01/RMensual_ERNC_v202201.pdf
- https://www.cne.cl/wp-content/uploads/2022/02/RMensual_ERNC_v202202.pdf
- https://www.conicyt.cl/fondef/lineas-de-programa/instrumentos-pasados/bioenergia/
- https://www.coordinador.cl/wp-content/uploads/2017/05/Reporte-Anual-2016.pdf
- https://cop25.mma.gob.cl/en/home/
- https://www.corfo.cl/sites/cpp/hidrogeno-verde-chile
- https://www.tijd.be/ondernemen/milieu-energie/tegen-2030-importeren-we-zon-en-wind-uit-oman-en-chili/10280119.html
- https://www.ebpchile.cl/es/pdf/generate/node/1510
- http://www.revistaei.cl/reportajes/aun-no-se-hacen-parques-eolicos-offshore-chile/
- https://www.enel.cl/en/meet-enel/media/press-enel-green-power-chile/d202112-egp-awarded-us-forgreen-hydrogen-proyect-with-hif-in-magallanes.html
- https://www.enelx.com/cl/es/historias/porque-la-energia-solar-promete-un-buen-futuro
- http://generadoras.cl/generacion-electrica-en-chile
- http://energiaabierta.cl/visualizaciones/capacidad-instalada/
- http://generadoras.cl/tipos-energia/energia-solar
- https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Chile%20First/Chile%27s_NDC_2020_english.pdf
- https://www.gob.cl/en/news/chilean-government-presents-national-strategy-convert-chile-global-leader-green-hydrogen/
- https://seia.sea.gob.cl/busqueda/buscarProyectoAction.php
- https://www.gob.cl/en/news/president-pinera-presents-proyecto-antipodas-at-apec-2021-it-will-allow-us-to-share-chiles-clean-solar-energy-in-order-to-meet-other-countries-nighttime-electricity-demand/
- https://www.guiachileenergia.cl/el-informe-de-estado-de-la-energia-hidroelectrica-de-2021-subraya-la-necesidad-de-un-crecimiento-rapido-para-lograr-el-cero-neto/
- http://hydroville.be/waterstof/hoe-sla-je-waterstof-op/
- https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2022.pdf
- https://repositorio.uchile.cl/bitstream/handle/2250/175586/Evaluaci%C3%B3n-t%C3%A9cnica-y-econ%C3%B3mica-del-uso-de-hidr%C3%B3geno-verde-en-aplicaciones-para-la-industria.pdf?sequence=1
- https://klimaat.be/in-belgie/klimaat-en-uitstoot/uitstoot-van-broeikasgassen/uitstoot-per-sector
- https://www.latercera.com/earlyaccess/noticia/produccion-hidroelectrica-cae-a-minimos-historicos-ante-prolongada-sequia/NNNPMGTYTRFWBCYP44KH6KIRUU/
- http://mainstreamrp.cl/tecnologia/energia-eolica/
- https://marcachile.cl/innovacion-emprendimiento/los-6-proyectos-que-marcaran-el-despegue-del-hidrogeno-verde-en-chile/#:%7E:text=Hidr%C3%B3geno%20Verde%20Bah%C3%ADa%20Quintero%3A%20liderado,de%20hidr%C3%B3geno%20verde%20al%20a%C3%B1o
- https://www.erneuerbare-energien-hamburg.de/de/blog/details/to-ramp-up-green-hydrogen-a-focus-on-strategic-sectors-as-early-adopters-at-large-scale-is-required.html

- https://energia.gob.cl/noticias/nacional/se-publica-nuevo-estandar-de-eficiencia-energetica-para-vehiculos-livianos
- https://www.energia.gob.cl/sites/default/files/energia_2050_-_politica_energetica_de_chile.pdf
- https://energia.gob.cl/sobre-el-ministerio
- https://www.bcn.cl/leychile/navegar?idNorma=150669
- https://cambioclimatico.mma.gob.cl/wp-content/uploads/2021/11/ECLP-LIVIANO.pdf
- https://energia.gob.cl/sites/default/files/national_green_hydrogen_strategy_-_chile.pdf
- https://www.washingtonpost.com/sf/world/2017/03/31/while-trump-promotes-coal-other-countries-are-turning-to-cheap-sun-power/
- https://dialogochino.net/en/climate-energy/chiles-energy-transition-renewables/
- https://doi.org/10.3390/en15020551
- https://www.ciperchile.cl/2021/12/24/a-40-dias-del-cierre-de-la-cop-26-algunos-conceptos-discutidos-en-glasgow-que-chile-podria-incluir-en-la-nueva-constitucion/
- https://newenergyevents.com/50mw-geothermal-project-in-chile-expected-in-2024/
- https://energyfactor.exxonmobil.eu/nl/science-technology/blauw-groene-waterstof/?gclid=Cj0KCQjwyMiTBhDKARIsAAJ-9VvH1vjXXgA8BCQIajuOb2TzpNkzpuTX5NBU42DcRy8953rH0JGhcbwaAlsXEALw_wcB
- https://laboratorio.latercera.com/tiempo-de-actuar/noticia/energia-geotermica-lo-traba-desarrollo-gran-potencial-chile/994739/
- https://www.ciperchile.cl/2021/05/29/hidrogeno-verde-en-chile-la-gran-oportunidad-para-crear-un-modelo-de-desarrollo-ejemplar/
- https://comitecientifico.minciencia.gob.cl/wp-content/uploads/2021/11/The_Chilean_Potential_for_Exporting_Renewable_Energy_web.pdf
- https://es.euronews.com/2021/08/24/chile-estrena-su-primera-estacion-de-hidrogeno-verde-y-apuesta-por-abaratar-su-produccion
- https://businessam.be/haven-van-antwerpen-slaat-de-handen-in-elkaar-met-chili-om-waterstof-in-te-voeren-goed-idee-in-theorie-maar-in-de-praktijk/
- https://newsroom.portofantwerpbruges.com/port-of-antwerp-port-of-zeebrugge-and-chile-join-forces-to-foster-hydrogen-production
- https://elperiodicodelaenergia.com/orsted-desarrollara-una-de-las-mayores-plantas-de-hidrogeno-verde-del-mundo-para-cubrir-la-demanda-industrial-de-holanda-y-belgica/
- https://www.solcorchile.com/plan-nacional-de-eficiencia-energetica/
- https://es.statista.com/estadisticas/1237334/capacidad-instalada-energia-eolica-america-latina-caribe/
- https://www.tijd.be/politiek-economie/belgie/federaal/regering-gaat-voor-grootschalige-import-van-waterstof/10342883.html
- https://unric.org/nl/cop26-teleurstelling-in-glasgow-ondanks-belangrijke-vooruitgang
- https://www.waterstofnet.eu/nl/waterstof/hoe-wordt-het-gemaakt
- https://www.energiesparen.be/sites/default/files/atoms/files/Rapport-Vlaams-potentieel-groene-waterstof.pdf
- https://www.worldenergytrade.com/energias-alternativas/gas/un-nuevo-estudio-confirma-el-potencial-de-la-economia-del-hidrogeno-en-belgica