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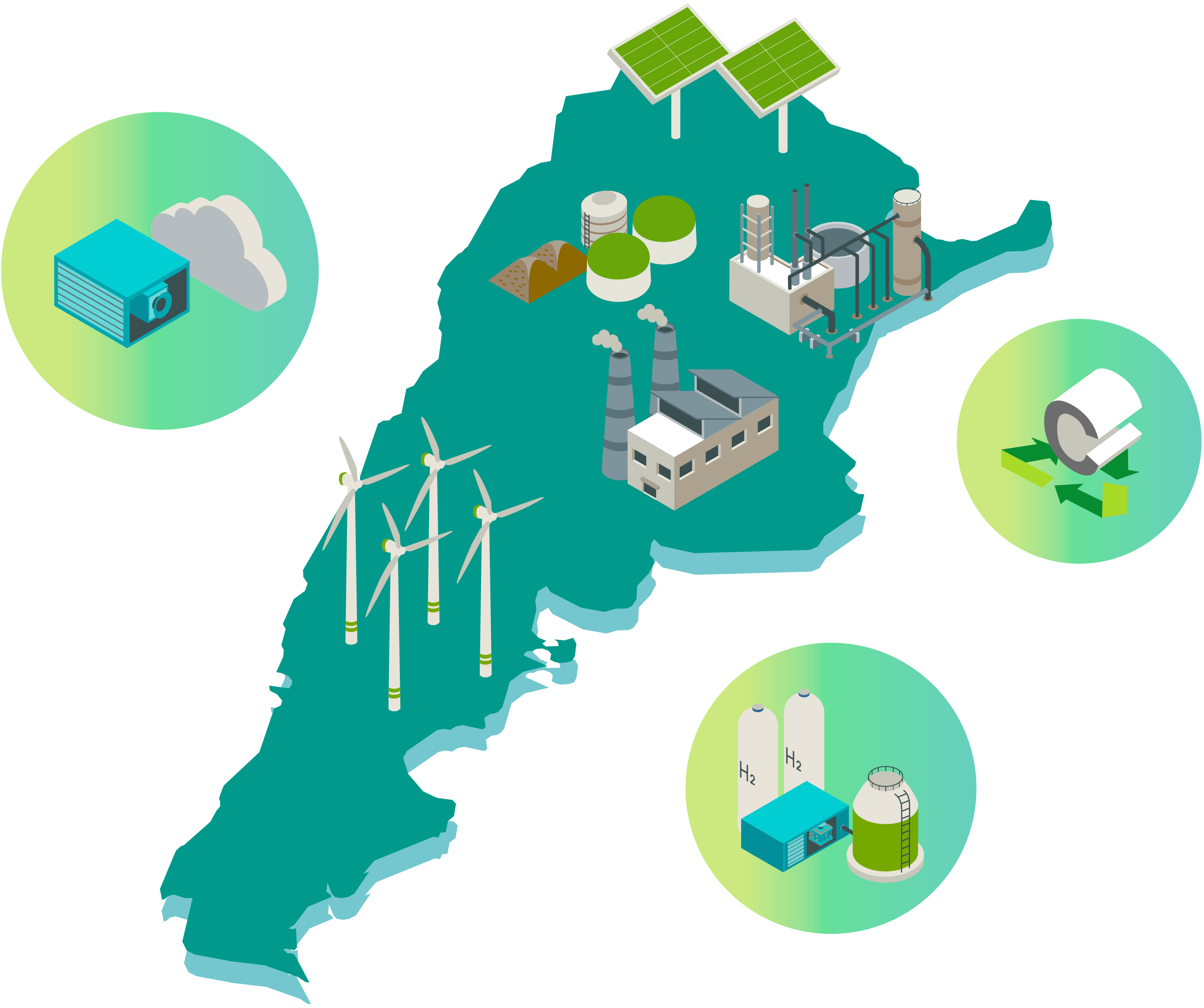
CO_2 SOURCES FOR PTX PRODUCTION IN ARGENTINA



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The present study focuses on the analysis of CO_2 availability and potential demand for PtX in Argentina. It has been developed in the framework of the International PtX Hub, implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Affairs and Climate Action (BMWK). The study was conducted by the project partners GIZ Argentina, DECHEMA e. V., CEARE and Fundación Torcuato Di Tella.

Within the framework of the International PtX Hub, a report titled "Carbon for Power to X – Suitable CO_2 Sources and Integration in PtX Value Chains" was published by the German Organization DECHEMA e. V., which serves as an introduction and technical support for the present study. It gives some insights about different CO_2 point sources and analyses the characteristics of different capture technologies, along with an overview of the transport and (temporal) storage of CO_2. The report can be accessed through this **link** (https://ptx-hub.org/publication/carbon-for-power-to-x-suitable-co2-sources-and-integration-in-ptx-value-chains/).

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ABBREVIATIONS AND ACRONYMS

AER	Alberta Energy Regulator
AFCP	Association of Portland Cement Manufacturers
AFOLU	Agriculture, forestry, and other land use
ASME	American Society of Mechanical Engineers
BOF	Basic Oxygen Furnace
CAA	Argentine Chamber of Steel
CAMMESA	Wholesale Electricity Market Management Company
CCU	Carbon Capture and Utilization
CCUS	Carbon Capture Utilization and Storage
CCS	Carbon Capture and Storage
CO2	Carbon Dioxide
DAC	Direct Air Capture
DESNZ	Department for Energy Security & Net Zero
DOE	Department of Energy
DPA	Dispatchable Power Agreement
EAF	Electric Arc Furnace
ENARGAS	Natural Gas Regulatory Agency
EOR	Enhanced Oil Recovery
EU	European Union
FAO	Food and agricultural organization
GHG	Greenhouse gas
GHS	Globally Harmonized System
GSP	Government Support Package
HVO	Hydrogenated vegetable oil
ICC	Industrial Carbon Capture
IIJA	Infrastructure Investment and Jobs Law
INGEI	National Greenhouse Gas Inventory
IPA	Argentine Petrochemical Institute
IPPU	Industrial processes and product use
IRA	Inflation Reduction Act
LNG	Liquefied natural gas
NOA	Northwest Argentina
NOPSEMA	National Offshore Petroleum Safety and Environmental Mgment Authority
OIIP	Provincial Petroleum Infrastructure Investment Program
PHMSA	Pipeline and Hazardous Materials Safety Administration
PtX	Power to X
RDF	Running ductile fractures
RED	Renewable Energy Directive
RFNBOs	Renewable fuels of non-biological origin
SADI	Argentine Electric Interconnected System
SAE	Secretariat of Strategic Affairs
SAF	Sustainable Aviation Fuel
SCA	Supplementary Compensation Agreement
TGN	Northern Gas Transport
TGS	Southern Gas Transport

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EXECUTIVE SUMMARY

Green hydrogen is currently being positioned as a crucial contribution to a sustainable energy system. In some cases, hydrogen needs to be converted into more complex molecules, either to facilitate transport or because they are required in different applications.

Some examples of these molecules are synthetic kerosene for aviation; methanol and ammonia for maritime transport and the production of chemicals and fertilizers. They represent an opportunity for the defossilisation of hard to abate industries and sectors. A large proportion of these molecules are carbon-based and for their production, apart from renewable hydrogen, a carbon source will be needed. In this framework, the role of carbon sources must be highlighted in a Power-to-X (PtX) economy.

At the same time, producing carbon-neutral renewable synthetic fuels and feedstocks based on green hydrogen and captured carbon could contribute to a reduction of CO_2 emissions in the final use, due to the fact that it replaces fossil products.

CO_2 is a suitable carbon source and can be obtained from different sources, such as industrial and biogenic point sources or from the atmospheric air. However, there are only few CO_2 sources which offer a closed carbon cycle [1], including direct air capture (DAC) (operated with renewable energy), and biogenic sources (as long as sustainability criteria are compiled).

With the aim of GHG reduction, CO_2 sources from closed carbon cycles are preferable. Nevertheless, these sources often imply a higher cost in comparison to other CO_2 sources.

Also, the global availability of biomass is limited and unevenly distributed. However, according to recent EU regulations, in the short- and mid-term, various industrial CO_2 sources will be accepted for PtX production, according to the Delegated Acts [1].

Development of carbon capture and utilization (CCU) technologies may face some challenges, but as there have been CCU projects in place for decades, the technological obstacles may be considered as solvable.

Argentina is a very extensive country, which has an immense variety of resources, and excellent conditions for the production of low-cost green hydrogen. Additionally, its large industrial sector and biogenic industries can provide a suitable carbon source for PtX applications.

The requirements to implement a PtX project (renewable energy, carbon sources, water and infrastructure, etc.) are not distributed uniformly throughout the country, and therefore, their location must be carefully studied in order to optimize the project location.

The aim of this study is to evaluate the different options for utilizing CO_2 as a feedstock in PtX production and to analyze the potential, locations and challenges of these carbon point sources in the context of Argentina.

Through this study, a characterization of the different carbon sources from various sectors available in Argentina is conducted, with a focus on their geographical distribution. It was estimated that approximately 74.5 Mt of CO_2 are emitted annually as point sources across the country, with 1.9 Mt originated from biogenic sources. While many factors influence the selection of suitable locations for PtX plants, regions, where abundant renewable resources do not coexist with the availability of carbon sources will face challenges. This may require either transporting CO_2 to areas suitable for renewable energy generation or transporting electricity from regions with high wind speed and/or solar irradiation to locations with carbon sources for hydrogen and PtX production. Moreover, production areas situated far from consumption centers or ports will also face challenges which must be considered given the country's vast size.

As part of this study, a web map has been elaborated, which shows the identified CO_2 point sources in the country (section A2.5), indicating their location, type of source and size. It is important to note that the availability of carbon point sources is unequally distributed throughout the country. Identifying these sources will help to prioritize pathways for producing PtX products and identify potential infrastructure needs, such as transporting CO_2 to areas with high potential for hydrogen production.

The transport of CO_2 in Argentina is currently carried out only in small scales by truck. For larger scales in the future, service pipelines will play an important role, and operation licenses and safety monitoring will be necessary. Retrofitting existing natural gas pipelines for the transport of CO_2 would not be feasible in the country, due to technical limitations and the future national plans of natural gas usage.

In addition to availability, sustainability criteria applicable to different CO_2 sources must be taken into account and are included in chapter A4.1. In the long term, the production of renewable PtX will have to ensure that CO_2 comes from truly sustainable and renewable sources. Nevertheless, these options are currently either not mature enough, not available in the required quantities or present still extremely high costs. Therefore, it is expected that industrial emissions (e.g., cement production) will continue to be considered in the short term.

To facilitate the development of hydrogen derivatives containing carbon, it will be necessary to implement public policies for the development of carbon sources and CCU(S) technologies, establish regulations regarding standards for the reduction of CO_2 emissions, and establish an authorization regime for the supply of carbon transport and storage services.

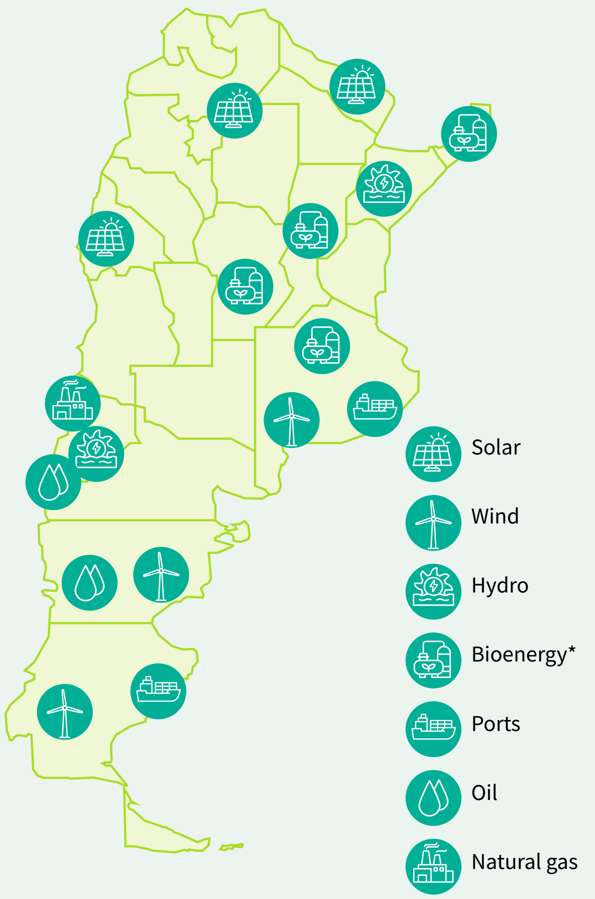
[1] A carbon cycle is described as closed when the amount of carbon emitted through the process was beforehand extracted from the atmosphere or separated from the process flow and sequestrated, and therefore the carbon balance is zero.

1 INTRODUCTION

In recent years, renewable hydrogen has been gaining importance worldwide as a key to abate emissions in sectors, that are difficult to defossilise and achieve climate neutrality. Argentina's renewable energy conditions are optimal for renewable hydrogen generation. For example, values of full-load hours of renewable energy plants result in a weighted average of the capacity factor for wind power of 47% in 2021 and 29% for solar PV in the same year [2].

As shown in Figure 1., the best wind resources, key for the production of low-cost green hydrogen, are located in the south of the country, especially in the Patagonia region. Mapping the distribution of these energy resources, as well as the carbon sources, industrial facilities and available port infrastructures is essential for identifying potential project locations and hubs for green hydrogen and PtX production.

Figure 1: Map of the distribution of natural and energy resources among the provinces



Source: Agora Energiewende, Agora Industry and Fundación Torcuato Di Tella (2023) [3]

In September 2023, the national Secretariat of Strategic Affairs (SAE) launched the National Low-Emission Hydrogen Strategy [4], upon its validation through consultations coordinated at a multi-stakeholder roundtable.

The National Hydrogen Strategy defines goals and actions for the following eleven areas: costs; export markets; internal market; industrial development; science, technology and innovation; employment and training; certifications; infrastructure; investments; environmental policy and international and regional cooperation. Among the most significant goals, Argentina sets the objective of achieving domestic low-emission hydrogen production of at least 1 Mt/year in 2030 and 5 Mt/year by 2050 (1 Mt for the local market and 4 Mt for exports) [4]. To achieve the production goal by 2050, the Strategy estimates that it will be necessary to install at least 30 GW of electrolysis capacity and 55 GW of renewable electricity generation. Projected hydrogen domestic uses include methanol, synthetic fuels such as sustainable aviation fuel (SAF) and hydrogenated vegetable oil (HVO) to decarbonise the shipping and aviation sector. To a lesser extent, the application of low-emission hydrogen is planned for the steel industry and fuel cells in heavy vehicles. The creation of a voluntary market for blending with natural gas is also included.

In this way, Argentina could become a net exporter of renewable hydrogen and its derivatives to countries which will depend on imports to defossilise their energy and industry matrix.

In order to develop a Power-to-X (PtX) value chain in the country, in addition to renewable hydrogen, carbon sources will be needed to produce hydrocarbons such as methanol or synthetic fuels through PtX processes. Carbon dioxide (CO_2) is a suitable carbon source for PtX products, as it is a waste product of combustion processes or chemical reactions in many industries. This CO_2 can be sourced from various points, such as industrial and biogenic sources. As these point sources currently release the gas into the atmosphere, there exists potential to capture and utilize it as a feedstock for PtX. However, it is important to differentiate between these different sources, as some of them may have disadvantages given their fossil origin and the risk of creating a lock-in effect.

Another important source of CO_2 is the atmospheric air, where the concentration of CO_2 has been steadily increasing since the industrial revolution, reaching a current value of 419 ppm [5]. However, current technologies to capture CO_2 from the atmosphere are still very expensive and not entirely mature.

The aim of this study is to evaluate the different options for utilizing CO_2 as a feedstock in PtX production and to analyze the potential, locations and challenges of these carbon point sources in the context of Argentina.

To achieve this objective, this study analyzes various economic sectors of the country to identify possible industrial and biogenic carbon sources. The study attempts to comprehensively assess the availability of all carbon sources in the country without considering further implications related to their use. However, when developing a new project, it is relevant to focus on the sustainability and acceptance of the different carbon sources. Chapter 4.1 includes a section on sustainability criteria applicable to different CO_2 sources to address this issue. As explained in this section, in the long term, the production of renewable PtX will have to ensure that CO_2 comes from truly sustainable and renewable sources and therefore industrial carbon point sources are discouraged in the mid- and long-term.

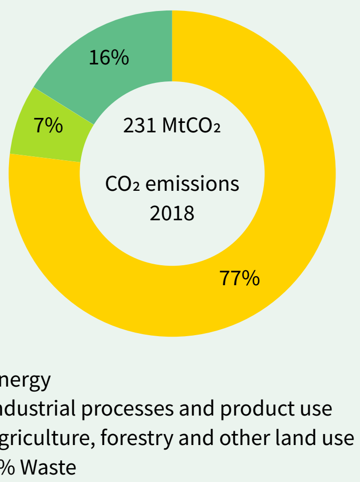
Nevertheless, in the short term, industrial emissions are expected to persist, particularly in hard to abate sectors such the cement industry. At the same time, there is an expectation that the costs of Direct Air Capture (DAC) technology, which are currently practically prohibitive high for PtX development, will significantly decrease. Therefore, it coheres to leverage industrial sources with lower costs as a transitional source towards truly sustainable sources like DAC. The challenge lies in effectively utilizing these specific sources, minimizing carbon lock-in effects, and ensuring that the respective industries continue to have sufficient incentives to reduce their emissions.

As part of this study, a **map** has been elaborated, and is presented in section 2.5 The aim of the map is to identify and visualize carbon sources in the form of CO_2 in Argentina to collaborate in the search for opportunities to develop PtX projects in the country. To do this, the map shows the main point sources of CO_2 in Argentina, indicating their location, type of source and size. It is relevant to highlight that the availability of carbon point sources is unequally distributed throughout the country and identifying these carbon sources will help to prioritize the pathways to produce PtX products as well as to determine potential infrastructure needs, such as transporting CO_2 to areas with high potential for hydrogen production.

2 SUPPLY OF CO_2 AS CARBON SOURCE IN ARGENTINA

Argentina's total Greenhouse gas (GHG) emissions amounted to 366 Mt_{CO2e} in 2018, from which 63% corresponded to CO_2. The energy sector was the largest contributor with more than three quarters (77%) of Argentina's total CO_2 emissions (see Figure 2). Most of the emissions from the energy sector are primarily related to the combustion of fossil fuels. The second largest contributors to Argentina's CO_2 emissions were agriculture, forestry, and other land use (AFOLU) with a share of 16%, followed by industrial processes and product use (IPPU) (7%) and waste (0.01%) [6].

Figure 2: Sectoral distribution of CO_2 emissions in 2018 [6]



CO_2 for utilization in PtX production can be captured from energy generation, industrial and biogenic point sources and from atmospheric air.

Argentina has a significant industrial development, such as in the cement and steel sectors, and has also created a relevant industry derived from bioenergies. Consequently, the existing industry can serve as an important source of carbon to produce PtX products. Likewise, the future expansion of the bioenergy industry could contribute to further development of the PtX industries by providing valuable carbon inputs.

CO_2 direct emissions from the industrial sector can be divided in two categories: process and energy emissions.

- Energy related emissions mainly arise by the combustion of fossil fuels to supply the required process heat. These emissions could be reduced with efficiency improvements of the process and avoided by replacing fossil fuels with renewable alternatives.
- Process emissions are generated directly as a byproduct of certain reactions, such as in the calcination of feedstock in the cement production. Some of these emissions are unavoidable, as the corresponding processes lack alternative materials and production routes.

Apart from point sources, CO_2 can be obtained from atmospheric air through direct air capture (DAC). This carbon source is physically available at any location. However, separating CO_2 from the air is an energy-intensive process and not cost-competitive yet. Currently, there are no DAC plants in Argentina and therefore this technology is not further described as a current source in the following chapters. However, DAC is expected to play an important role in PtX production in the long

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term. More information about this technology can be found in the general report "Carbon for Power to X – Suitable CO_2 Sources and Integration in PtX Value Chains" under this link.

The following sections provide context about point sources from different sectors in Argentina and their CO_2 emissions, as potential feedstock for PtX.

2.1 Energy emissions

Fuel combustion in Argentina generated 172 Mt_{CO_2} in 2018 which corresponded to 97% of total energy CO_2 emissions in the country. The contribution of different industries to these emissions are shown in Figure 3. The energy industry accounts for 34% of combustion emissions and include electricity and heat production, oil refining, solid fuels production and other energy industries. Additionally, the manufacturing and construction industry's share of combustion emissions amounts to 19%, which arise from fuel combustion to manufacture products such as iron and steel, chemicals and paper. Emissions from transportation and other sectors are not further discussed as they are not considered point sources and therefore cannot be used for PtX production.

Figure 4 shows the national electric power supply in 2021. The Argentine electricity matrix is dominated by thermal generation which accounted for 63.5% in 2021. The main fuel used for electricity production in 2021 was natural gas (82%) followed by, diesel (10%), fuel oil (4%) and coal (3%). Renewable energy sources, including hydroelectric <50MW, wind and solar power accounted for 12,3% while hydroelectric >= 50MW contributed 17% and and nuclear energy 12.3%, of total electricity production. Renewable electricity[2] production is expected to increase to 20% until 2025 according to the target set by Law N° 27.191 [7].

Annual CO_2 emissions from electric power plants are presented in Figure 5. According to the Wholesale Electricity Market Management Company CAMMESA, CO_2 emissions from electricity generation totalised 42 million tons CO_2 in 2021, most of them arising from the use of natural gas.

[2] Not including large hydropower.

Figure 3: CO_2 emissions from fuel combustion in 2018 [6]

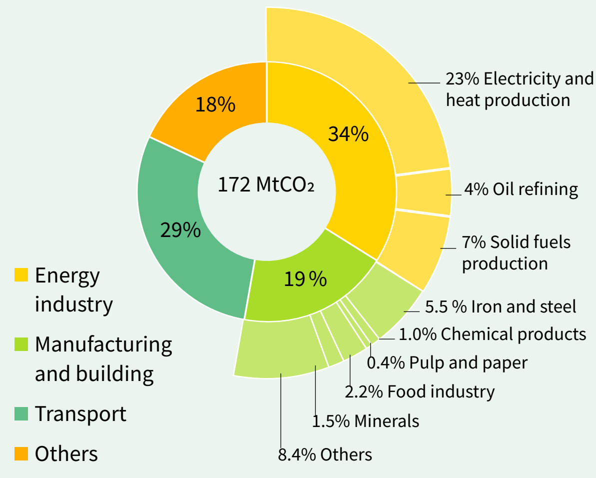
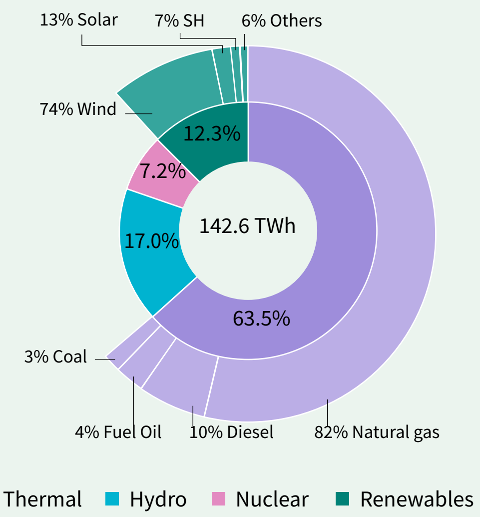
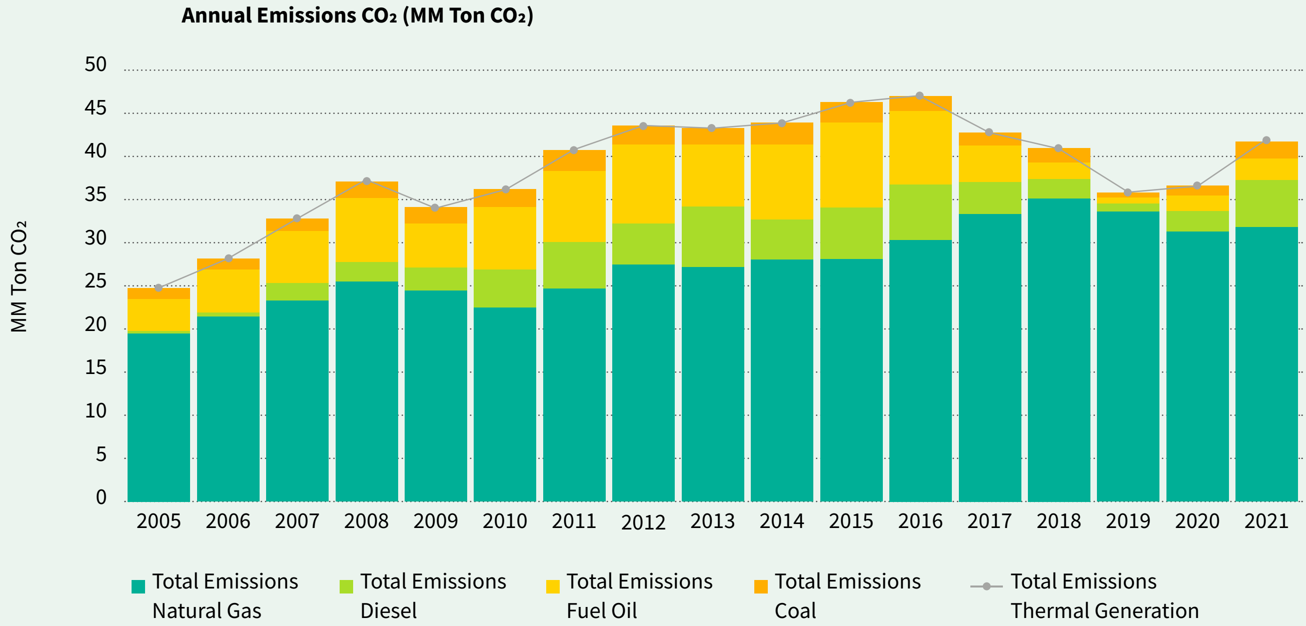


Figure 4: National electric power supply, 2021



Source: Own elaboration based on CAMMESA data [8]

Figure 5: Annual CO_2 emissions from electric power plants in Argentina



Source: CAMMESA 2021 [9]

In Argentina, electricity has a very wide coverage, reaching 98% of households. In contrast, the natural gas network reaches 71% of households [6].

Due to the location of energy resources and the concentration of consumption points, Argentina has an extensive interconnected transmission network with a closed-loop configuration and local distribution networks. The network spans more than 28 thousand km of lines (from 500 kV to 33 kV) and is operated by 11 companies. However, due to its vast extent, the network incurs significant losses (approximately16%) resulting in economic implications and increase in emission per unit of generation. The average emission factor of the national interconnected network in 2018 was 0.30 t_{CO_2}/MWh [6].

Although the oil refining sector represents a relatively low percentage of emissions, these are highly concentrated in a few refineries. While several facilities process liquid fuels to some extent, only seven refineries that centralize production, with four of them considered to be of high complexity, collectively accounting for over 80% of fuel production.

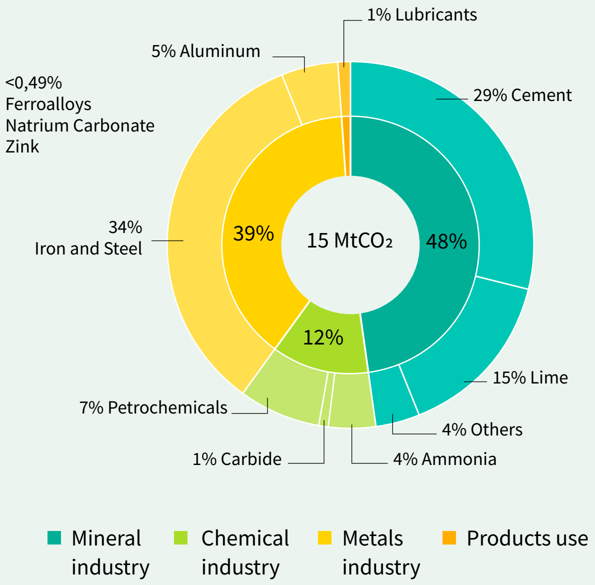
Refineries require a significant energy consumption in the form of heat and electricity to fractionate the crude oil and convert it into finished fuels and chemicals such as naphtha, fuel oil, diesel, gasoline, aviation fuel, and liquefied gas. In 2018, refining activity consumed 332 ktep of liquid fuels and 2,418 ktep of gaseous fuels, emitting approximately 6,792 kt of CO_2 [6].

2.2 Process emissions

In Argentina, the industrial sector is characterized by a great diversity of activities, companies and scales. The main sectors are the production of food and beverages with 27% of the gross value of the sector's production, followed by the construction sector with 14% and the manufacturing of chemical substances and products with 12%. In 2018, the industrial sector was the second-largest consumer of natural gas, after power plants. Contrary to the trend in the residential sector, gas consumption in the industrial sector is not seasonal. Construction is one of the most relevant items due to the number of companies and the large number of inputs it demands, particularly cement [6].

In 2018 the industrial sector in Argentina emitted 15 Mt_{CO_2} related to process emissions. Figure 6 shows the emission shares of the different subsectors. The mineral industry was responsible for 48% of the sector's emissions, while the chemical industry represented 12%. For its part, the metals industry was responsible for 39% and the products usage contributed for 1% to sectoral emissions. 93% of CO_2 emissions of the minerals industry arise from the production of cement and lime. In the chemical industry, most emissions are generated in the production of ammonia and petrochemicals (including methanol and ethylene). Iron, steel and aluminum production are the main emitters of CO_2 in the metals industry.

Figure 6: Process CO_2 emissions from the industrial process sector and product uses 2018 [6]



2.3 Industrial emissions

This section describes different industrial sectors in Argentina, as they offer possible carbon sources for PtX products. The emissions presented in this chapter which are subsequently shown in the map (see section 2.5), include both process and energy CO_2 emissions. The list of industries presented in this chapter is not exhaustive, focusing on the main industrial emitters in the country. Some other point sources not described here include the food and beverage industries and the glass industry.

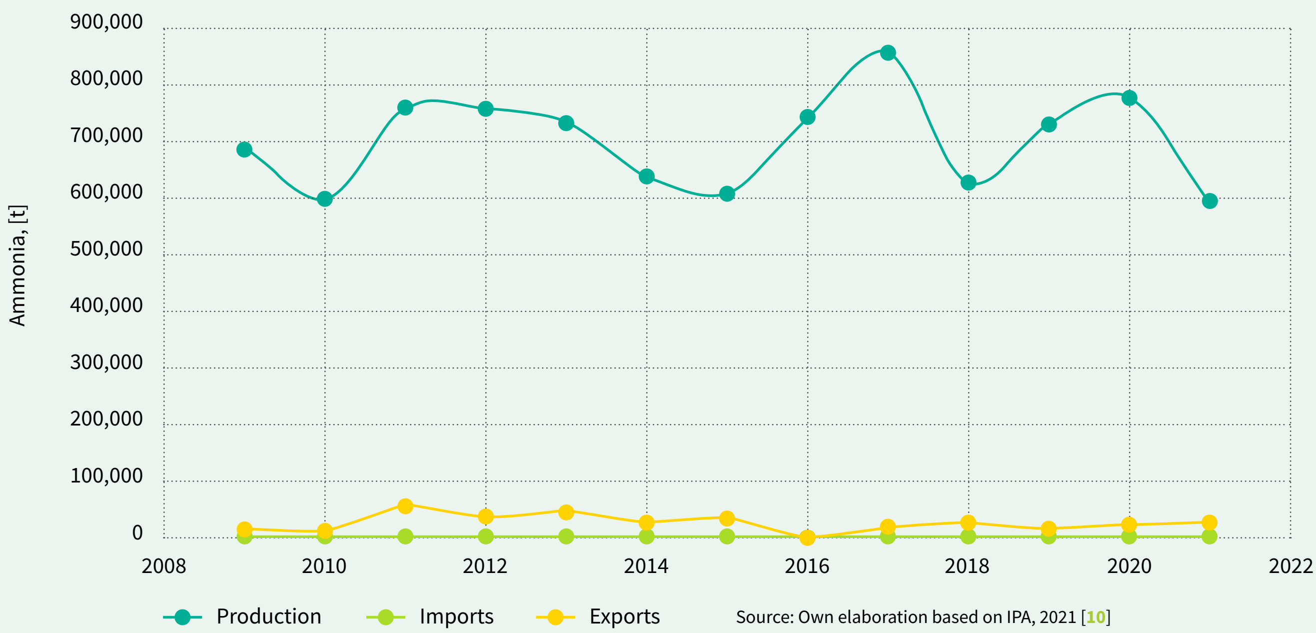
2.3.1 Ammonia production

In the ammonia production, as it is the case of other basic chemical industries, CO_2 is generated both by the combustion of fossil fuels for energy transformation and as a byproduct in the steam methane reforming process for hydrogen production. Currently, this CO_2 is captured by the companies Profertil and Austin Powder, and in the case of Profertil, further converted into urea.

According to the Argentine Ministry of Environment and Sustainable Development, the Argentine ammonia industry emitted 575 kt of process CO_2 emissions in 2018 [6]. In the inventory, energy emissions are listed only for the chemical sector but not specifically for ammonia.

The annual production of ammonia in Argentina based on the 2021 yearbook of the Argentine Petrochemical Institute (IPA) is shown in Figure 7. Accordingly, the country's ammonia production peaked in 2017 of 856 kt and the value of 2021 corresponded to 593.4 kt. According to IPA, 98% of ammonia production in 2021 was used to produce urea.

Figure 7: Ammonia production, imports and exports in Argentina



Source: Own elaboration based on IPA, 2021 [10]

In Argentina, there are three ammonia plants operated by the companies Bunge Argentina S.A., Profertil S.A. and Austin Powder Argentina S.A. Table 1 provides general information about these three plants, which use natural gas as feedstock. It is noteworthy that the ammonia plant from Austin Powder is new, with its commissioning taking place in June 2021.

Table 1: Ammonia production plants

Company	Location	Installed capacity [t/year]	Process	Feedstock
Bunge Argentina S.A	Campana (Buenos Aires)	29.700	N-Ren	Natural Gas
Profertil S.A.	Bahia Blanca (Buenos Aires)	790.000	Haldor Topsoe	Natural Gas
Austin Powder	El Galpón (Salta)	60.000	Girdler Corp.	Natural Gas

Source: Yearbook IPA 2021 [10]

Profertil holds about 90% of total ammonia installed capacity in the country and according to its sustainability report, the company implements controls and processes that allow efficient use of natural gas, both for combustion and for processing and transformation into fertilizer. Thus, they adopt the use of off-gas as fuel, which contributed to reducing the consumption of 5.2 million tonnes of natural gas in 2021 and in this way, 10.2 kt CO_2 were avoided in the same year [11]. In 2021, the company consumed 223.4 GWh of electrical energy, 64% of which was produced from renewable energy after the commissioning of the Los Teros wind farm [11].

2.3.2 Cement industry

In cement production, CO_2 emissions are generated from the combustion of fossil fuels (energy related emissions) and from the calcination of the feedstock, which produces lime and CO_2 as a byproduct.

The cement industry was responsible for 4,535 kt of process CO_2 emissions in 2018 in Argentina [6]. Energy emissions in this sector are not specifically listed.

Due to a long process of acquisitions and mergers, cement production in the country concentrates in only four companies.

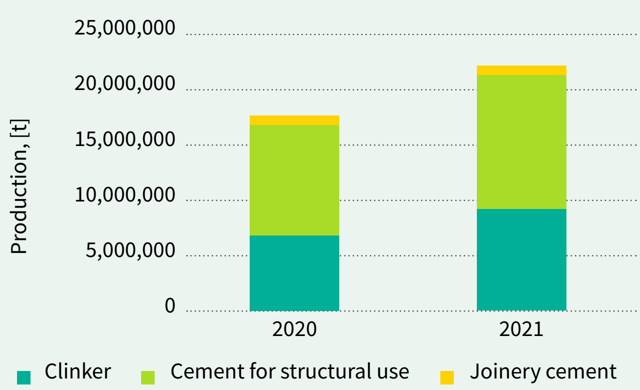
The Association of Portland Cement Manufacturers (AFCP) integrates the four cement companies that operate in the Argentine territory: Loma Negra CIASA, Holcim (Argentina) SA, Cementos Avellaneda SA and PCR S.A.

As of December 2021, the Argentine cement industry had 16 cement manufacturing and grinding plants, distributed in different regions of the country. In 2020, as a whole, they had an operating annual installed capacity of 18,468,000 tonnes of cement [12].

In Argentina, cement for general use, masonry cements and cements for use in concrete for the construction of pavements with high-performance technology (TAR) are produced.

Figure 8 shows the production amounts of cement goods in Argentina in 2020 and 2021 [12], being clinker and cement for structural uses the predominant products. Cement production in 2021 in Argentina equaled 12.1 million tonnes, from which 114 kt were exported and 12.0 million tonnes were consumed internally.

Figure 8: Production of cement in Argentina in 2020 and 2021



Source: AFCP 2022 [12]

In 2021, the specific energy consumption of the cement industry in Argentina was 3.46 GJ per tonne of clinker and 2.36 GJ per tonne of cement with a share of alternative fuels and biomass of 8.7% and an emission factor of 61.9 kg CO_2/GJ. In the same year, 519 kg_{CO_2} per tonne of cement were released into the atmosphere.

2.3.3 Iron and Steel industry

In steel manufacturing CO_2 emissions are generated from burning fossil fuels to obtain high temperatures needed for the different processes, from the reduction of iron oxide with a reductant agent like CO, and from the use of power and steam for the steelworks.

In 2018, iron and steel manufacturing was responsible for 5,279 kt of process CO_2 emissions and 9,537 kt energy CO_2 emissions in Argentina [6].

The steel sector in Argentina is highly concentrated, comprising 11 companies, three of which produce 97% of crude steel and 88% of finished products. The three most important companies are integrated companies, that means, that they obtain their steel products from iron ore. The production process in this type of company comprises four stages: reduction, steel making, hot rolling and cold rolling. The companies that make up this segment are Ternium-Siderar, Acindar and Tenaris-Siderca. The annual production capacity of these companies is about 7 million tonnes of crude steel.

The production capacity in the basic stage of iron casting or reduction of primary iron (pig iron and/or sponge iron) is mainly concentrated in Ternium-Siderar, which holds 56.6% of the total capacity, while Acindar (24.6 %) and Tenaris-Siderca (18.9%) produce the rest.

Ternium-Siderar is the only company that has a blast furnace (Basic Oxygen Furnace or BOF), while Acindar and Tenaris-Siderca produce through direct reduction – electric furnace (Electric Arc Furnace or EAF).

The next phase of production (steel making) is also concentrated in few suppliers, including two additional: AcerBrag and Aceros Zapla, which reach 6.1% of the installed capacity and increase the number of companies to five, the three leaders account for 93.9% of the crude steel operable capacity.

The Argentine GHG Inventory for 2018 indicates that 87% of the emissions related to the metals industry are mainly due to the production of iron and steel and 12% to the production of aluminum. The remaining 1% consists of emissions from the production of ferroalloys and zinc [6].

According to the Argentine Chamber of Steel (CAA), the Argentine steel sector has maintained a production level of around 5 million t/year of steel for several years. In Argentina, of the 5 million tonnes of steel produced annually, between 1.5 and 1.7 million come from steel made from ferrous scrap. CAA indicates that the environmental footprint of the use of ferrous scrap for the manufacture of steel is highly beneficial for the country. For every tonne of scrap recycled in steel furnaces, 1.5 tonnes of CO2[3] are avoided, 1.4 tonnes of iron ore are saved, and the specific energy consumption in manufacturing processes is reduced by 13 GJ/t. Steel production in Argentina has three process routes, and all of them consume ferrous scrap as raw material in different proportions: 1) the Blast Furnace-Oxygen Converter route (flat products) uses between 15 and 20% ferrous scrap as raw material; 2) the Direct Reduction-Electric Arc Furnace route (long products, including seamless tubes) consumes between 40 and 60% ferrous scrap; and 3) the 100% scrap Electric Furnace route (long) requires only ferrous scrap as feedstock to produce steel [13].

[3] This value corresponds to the calculation of emissions using the methodology of the World Steel Association. In the case of the National Inventory, the emission intensity indicator for the steel sector is 1.17 tons of CO_2 equivalent per tonne of steel produced, since those emissions associated with the consumption of purchased energy are not taken into account and it is based on the consumption of agents carbon-containing reducers.

2.3.4 Aluminum industry

Global CO_2 emissions from the aluminum industry can be classified into three different types: (i) The majority of the emissions (around 60%) are indirect and come from the use of electricity, which could be mitigated through the use of renewable energy, (ii) direct process emissions result from the consumption of carbon anodes during aluminum smelting (around 15%), while (iii) direct energy emissions arise from the combustion of fossil fuels to achieve the requited high temperatures (around 15%) [14].

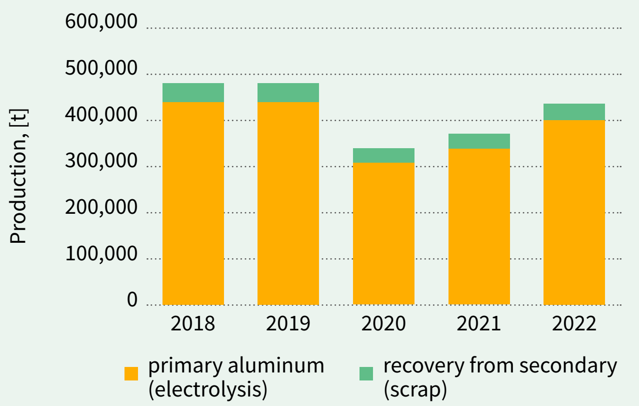
Aluminum production emitted 703 kt CO_2 process emissions in 2018 [6]. Energy emissions are not specifically listed for this sector.

Aluar Aluminio Argentino is the only Argentine company producing primary aluminum in the country, and it holds the highest share of aluminum production (427 kt/year in 2019 [15]). The production of primary aluminum of this company is located in Puerto Madryn, Chubut and its product portfolio includes both liquid aluminum and processed products for various industries.

Other companies involved in the aluminum industry in Argentina include Alcemar, ALKE, Alpros, ISHI and EXAL Aluminio [16].

Figure 9 shows the domestic production of aluminum in Argentina, with approximately 9% of production sourced from recycled aluminum scrap.

Figure 9: Domestic production of aluminum [17]



A significant portion of the alumina needed for aluminum production in Argentina is currently imported, primarily due to the country's low reserves of bauxite and the high electricity costs associated with alumina production [16].

The economic segments with the highest consumption of aluminum in Argentina in 2022 were containers (27.3%), civil construction (24.1%), transportation (16.2%) and the electric industry (12.1%) [17].

2.3.5 Pulp and paper industry

Pulp mills are among the largest consumers of wooden biomass globally, resulting in significant emissions of bio-based CO_2. In part, the composition of emissions in the pulp and paper industry depends on the origin of the fuels used for the drying process which is an energy intensive step of this industry. If biomass is used as fuel for this drying process, the CO_2 emissions of this industry are primary biogenic. Additionally, there are other process emissions that are also biogenic, generated in the recovery cycle of the white liquor that stem from the wood raw material.

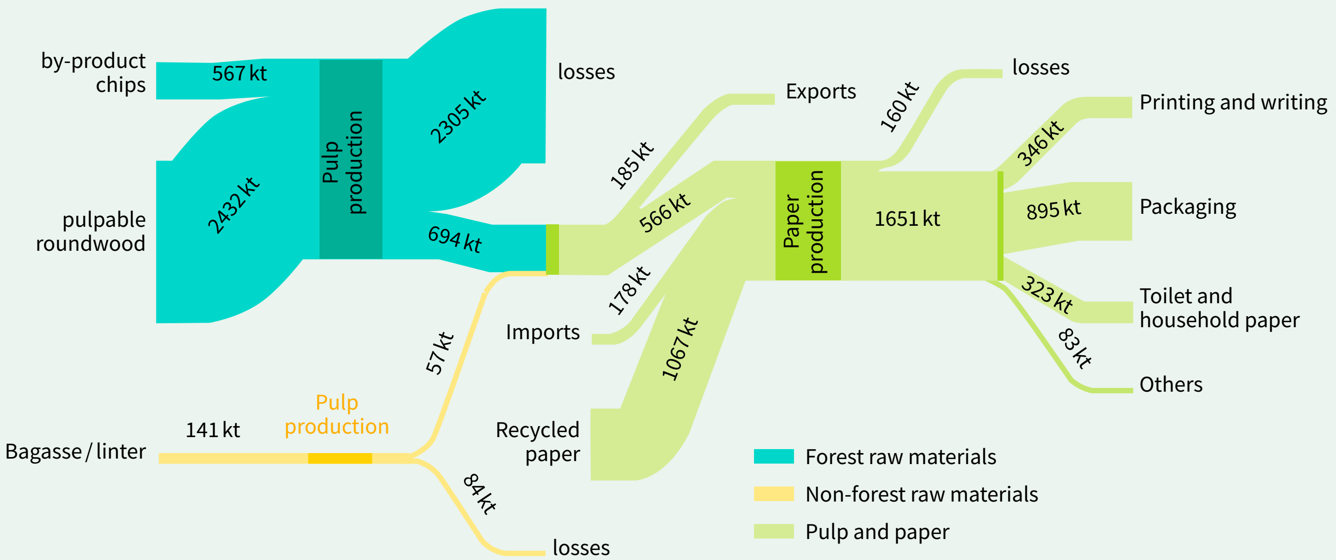
Pulp and paper industry in Argentina was responsible of 659 kt of CO_2 energy emissions in 2018 [6]. Process emissions are not mentioned in the inventory.

Figure 10 shows the mass balance of the pulp and paper production in Argentina. Forest raw materials, comprised of by-product chips and pulpable roundwood, represent 95% of the total feedstock for pulp production. The remaining 5% consists of bagasse and linter.

Paper production uses 59% of recycled paper, 31% national manufactured pulp and 10% imports. Packaging paper is the most produced type of paper (54%), which together with printing paper (21%) and sanitary and domestic paper (20%), represent 95% of the total paper produced in Argentina. Regarding the location of paper production, 79.7% is located in the Pampas region, 10.7% in the Northwest, 6.4% in the Mesopotamian region, and 3.2% in Cuyo and Patagonia, while cellulose pulp production is mainly located in the provinces of Misiones (50%), Buenos Aires (18.4%) and Santa Fe (18.2%).

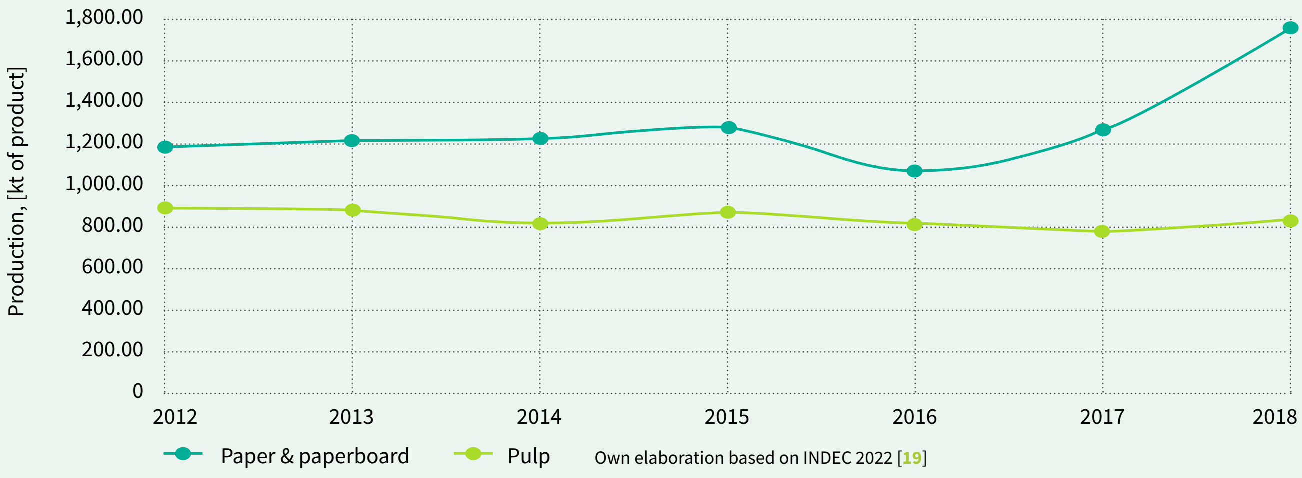
Pulp production has remained relatively stable during the last decades in Argentina at around 800 kt/year, while paper production increased considerably from around 1050 kt/year in 2016 to 1750 kt/year in 2018 (see Figure 12),with a focus on the domestic market.

Figure 10: Pulp and paper industry mass balance



Own elaboration based on MAGyP 2022 [18]

Figure 11: Production of pulp and paper in Argentina



Own elaboration based on INDEC 2022 [19]

Arauco is the only company in the country that produces market pulp. Additionally, there are 6 integrated companies that manufacture pulp as an intermediate product for the subsequent manufacturing of paper and/or cardboard [18]. Other companies only manufacture paper and/or cardboard, buying pulp from third parties and recycled paper in the domestic and imported markets.

The set of integrated companies, for the most part, use raw material derived from pulpable logs from implanted forests, and wood chips (industry by-products), while other companies use other fibers, such as sugar cane bagasse or linters of cotton. The integrated companies use 100% of their pulp production, but they buy a smaller proportion of other raw materials, in order to later manufacture paper and/or cardboard.

As mentioned before, the majority of the pulp used as a feedstock for paper production comes from planted forests.

In this regard it is worth to note that the Argentine forest area is made up of 50 million hectares of native forest and approximately 1.3 million hectares of implanted forest. Approximately 12% of the country's total land area consists of forest areas. According to data from the Ministry of Agriculture and Livestock, there are more than 42 thousand hectares destined for forest-based production.

Wood raw materials in paper production are also used for energy generation, whose combustion can be considered CO_2 neutral, provided a sustainable forest management. In 2020, a total of 6.5 million m³ of forest residues were generated from Argentine forest-based industrial production, of which 43% (2.8 million tons) were used as biomass for energy production [18].

Table 2 shows the list of pulp producing companies, together with their location, the level and use of their installed capacity, and the type of pulp they produce.

Table 2: Cellulose pulp companies

Company name	Location	Installed capacity (Air Dry metric tonne)	Use of Installed Capacity	Type of cellulose
Arauco Argentina S.A.	Misiones	350,000	87%	Sulfate chemistry (Kraft) and fluff paste
Celulosa Argentina	Santa Fe	166,560	92%	Sulfate chemistry (Kraft)
Papel Prensa S.A.I.C.F.	Buenos Aires	168,705	66%	Semi chemistry
Papel Misionero	Misiones	108,885	90%	Sulfate chemistry (Kraft)
Papelera del NOA S.A.	Jujuy	34,170	84%	Semi chemistry
Fábrica de Papel Ledesma	Jujuy	84,900	67%	non-forest fibers
Fana Química S.A.	Entre Ríos	1,600	41%	non-forest fibers

Source: Survey of the pulp and paper industry 2020 [18].

2.4 Biogenic point sources

2.4.1 Bioethanol

Bioethanol is produced from the fermentation of different raw materials. Currently, bioethanol production in Argentina is made from molasses (a by-product of sugar manufacturing) and direct sugar cane juice and cereals (mainly corn).

CO_2 is produced in the fermentation process of bioethanol production (around 0.95 tonnes of CO_2 per tonne of bioethanol). CO_2 capture from bioethanol production is already applied in some production sites in the country. Due to the availability of concentrated carbon streams, the costs of carbon capture from the fermentation process used in bioethanol production are among the lowest of all carbon point sources.

Since the implementation of Law N° 26.093 (2006) and 26.334 (2007), the production of bioethanol was significantly expanded in Argentina, in addition to the emergence of projects aimed at obtaining ethanol from corn with modern technologies.

The sugar industry is concentrated in northwestern Argentina, with Tucumán, Jujuy and Salta being the main producing provinces, and, to a lesser extent, the provinces of Santa Fe and Misiones. Consequently, the highest concentration of bioethanol producing plants from sugar cane occurs mainly in northwestern Argentina (NOA) while those bioethanol plants from corn are located in the center of the country.

Figure 12 summarizes the country's bioethanol production scheme. In 2018, 19 plants were installed and produced 880 kt of bioethanol, of which 72% used sugar cane as feedstock and the remaining corn.

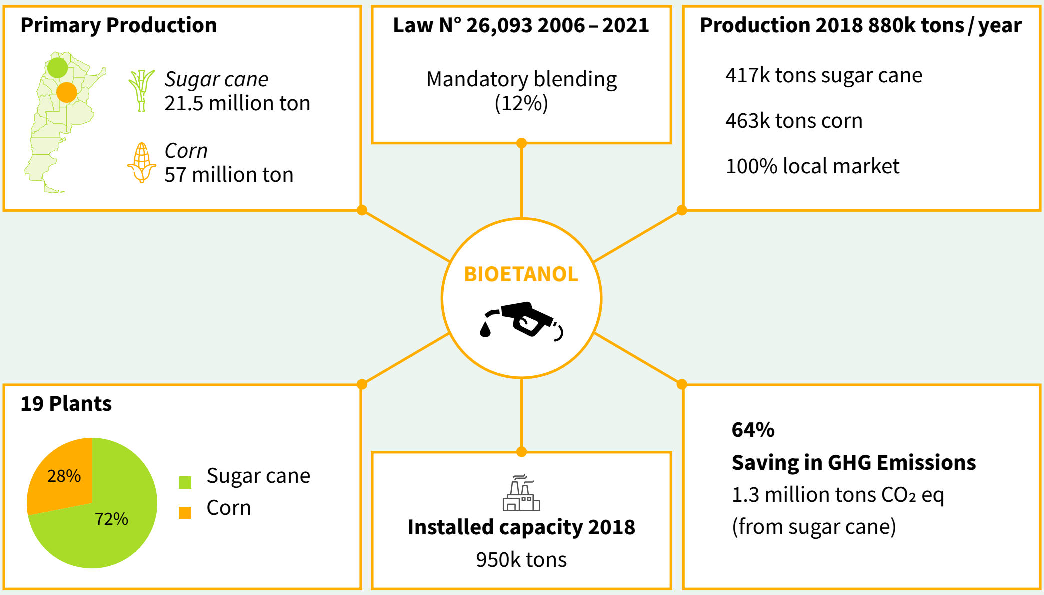
Table 3 presents bioethanol producing companies in Argentina classified by feedstock used.

Table 3: Bioethanol producing companies

Sugar Cane	Corn
Alconoa S.R.L.	Aca Bio Cooperativa Ltda.
Bioenergía La Corona S.A.	Bioetanol Rio Cuarto S.A.
BIOENERGÍASAGROPECUARIAS S.A.	Diaser S.A.
Bioenergía Santa Rosa S.A.	MAÍZ ENERGÍA S.A.
Bio Ledesma S.A.	Promaíz S.A.
Bio San Isidro S.A.	Vicentin S.A.I.C.
Biotrinidad S.A.	
Compañia Bioenergética La Florida S.A.	
Energias Ecologicas del Tucuman	
Fronterita Energía S.A.	
Rio Grande Energía S.A.	

Source: Secretary of Energy, 2022 [21]

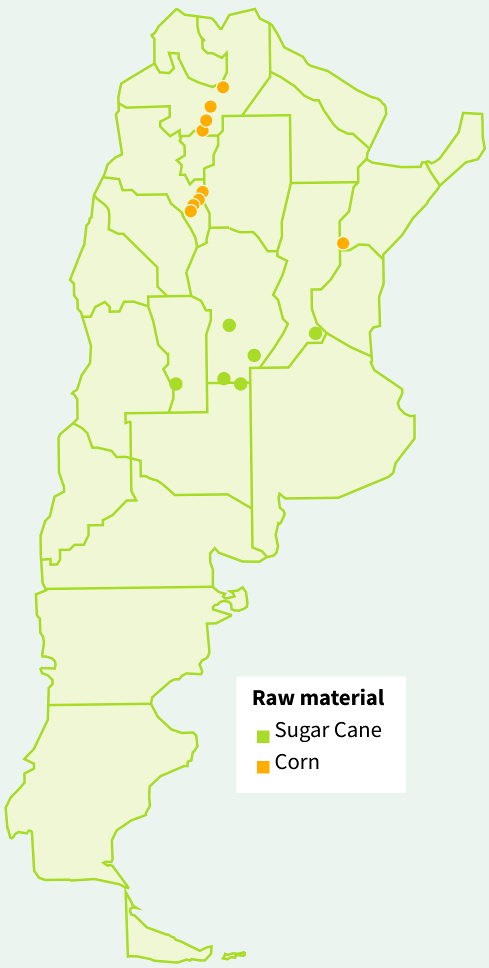
Figure 12: Synthesis of the ethanol production and market scheme



Source: Ministry of Agriculture, Livestock and Fisheries (2018) [20]

Figure 13 offers an overview of the location of bioethanol plants in the country.

Figure 13: Location of bioethanol plants by input used



Source: own elaboration based on SAGyP, 2022 [22]. On template from the National Geographic Institute of the Argentine Republic.

2.4.2 Biogas

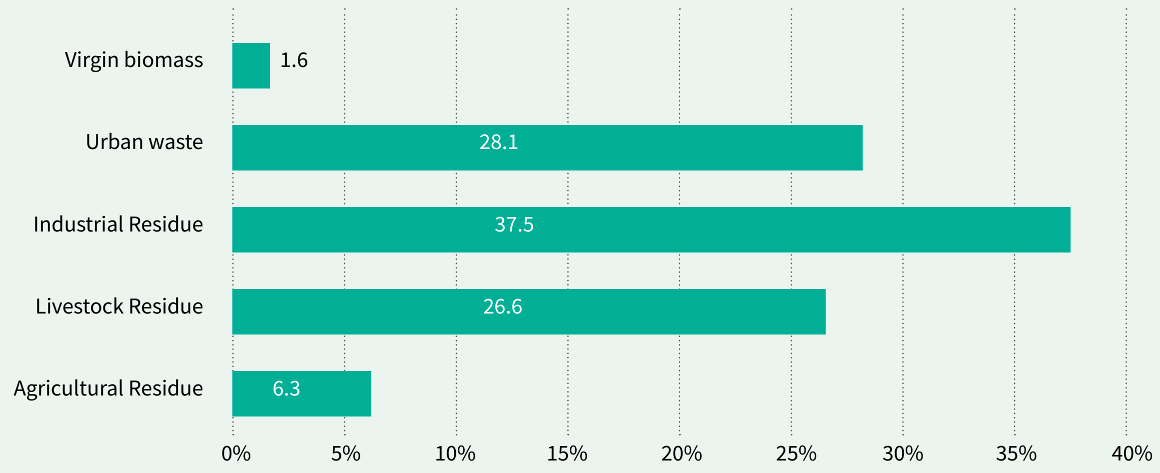
Biogas is produced during the anaerobic digestion of organic matter. Its main component is methane, and the remaining component is CO_2 which is a byproduct in the digestion process and can be obtained highly concentrated after the biogas upgrading. As a result, biogenic CO_2 from biogas can be obtained through this upgrading process and/or by utilizing it as fuel or feedstock in different processes.

There is a large number of small biogas production plants, which are distributed across the country. One of the most recent national diagnosis about the situation of anaerobic biodigestion in the country was made in 2015, in which the existence of 105 biogas production plants were identified [23]. In this context, a survey of 61 plants was carried out, located in 11 Argentine provinces, the majority in Santa Fe (27%), Buenos Aires (18%) and Córdoba (10%).

The plants were classified, according to their scale (biodigester volume in m^3), into large (more than 1,000 m^3), medium (between 100 and 1,000 m^3) and small (less than 100 m^3). More than 40% of the surveyed plants qualified as large (65% within the private sector and 20% within the public sector). The cooperatives operated medium plants and the NGOs only small plants. 52% of the plants corresponded to rural areas, 41% to urban areas and 6% to industrial parks. However, a low percentage of the installations surveyed (all from the private sector) had purely energy purposes. In the public sector (municipalities), biogas plants are principally used for waste treatment (treatment of sewage effluents and recovery of the organic fraction of urban solid waste). These plants produce biogas from solid urban waste, waste from the poultry and pig industry, corn vinasse, cereals and oilseeds, etc.

The substrates used to feed the biodigesters were also analyzed and are shown in Figure 14. The substrates were classified into five large groups: agricultural waste, livestock waste, industrial waste, urban waste and virgin biomass. The most used substrates are waste from industry, followed by urban solid waste and livestock waste (see Figure 14).

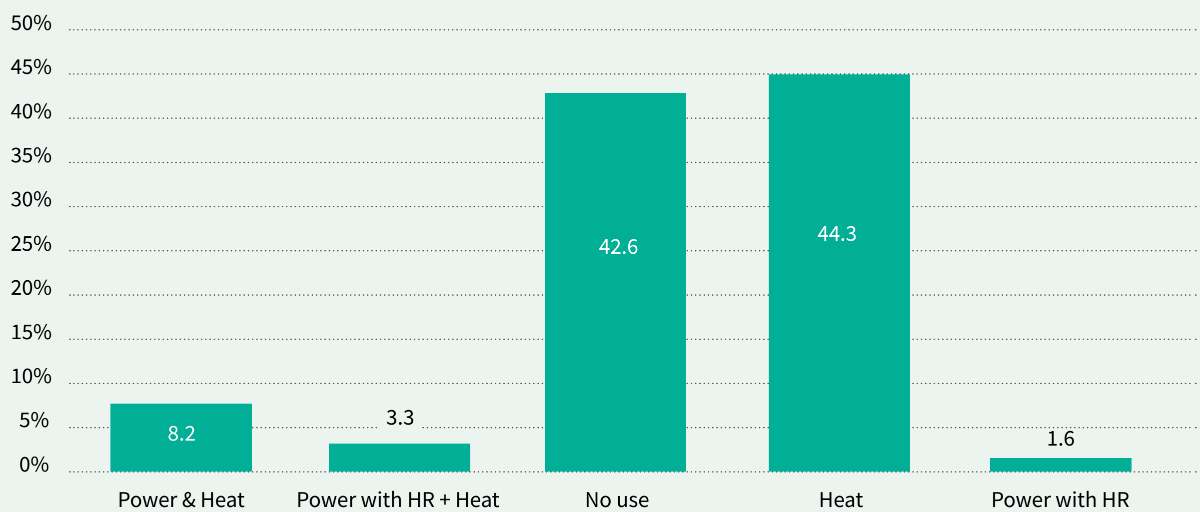
Figure 14: Classification and level of use of the different substrates in the surveyed anaerobic biogas plants



Source: FAO, 2019. [23]

When analyzing the use of biogas as an energy source as shown in Figure 15, an outstanding fact is that 42.6% of the surveyed plants burn or vent the produced biogas without further use; 44.3% of the plants use biogas for thermal purposes only and the remaining 12% utilizes it to produce electrical and thermal energy. Of the total number of biogas plants surveyed, less than 5% sell the transformed energy in form of electricity [23].

Figure 15: Use of biogas of the surveyed plants[4]



Power & Heat: Power and heat generation
Heat: Heat generation
Power with HR: Power generation with heat recovery
Power with HR & Heat: Power generation with heat recovery and heat generation
No use: The gas is vented or burned without use

Source: FAO, 2019. [23][4]

[4] **No use:** biogas burning or venting; **Thermal:** production of thermal energy only; **Electrical+thermal:** production of electrical and thermal energy (electrical energy without recovery of electrical energy); **Electric TR:** Production of electrical energy with recovery of thermal energy; **Electric TR+thermal:** production of electrical energy with recovery of thermal energy from the combustion engine, plus production of thermal energy.

In 2021, INTA (Instituto Nacional de Tecnología Agropecuaria) and the Ministry of Agriculture, Livestock and Fisheries carried out a new survey report on biogas production in Argentina [24]. It was based on the survey carried out by INTI-PROBIOMASA [23] and the biogas plants that provide electricity to the electricity grid were also taken into consideration. Through a survey, 20 biogas plants were surveyed, out of a total of 27 registered as operational and with volumes of reactor greater than 1000 m³. 90% of the surveyed plants belong to the private sector and their main purposes are electricity production (55%), waste treatment (40%) and energy generation for self-consumption (5%). The main substrate used in the surveyed plants comes from agricultural-livestock activity (62.5%), with pig slurry and corn silage being the predominant biomasses, and the rest from agro-industrial activities.

Around 70% of the plants carry out co-digestion processes (mixture of substrate with co-substrate). Corn silage and cattle manure are the predominant co-substrates.

The degree of knowledge of the quality of the biogas generated was evaluated, because it is one of the main parameters that allows indicating the efficiency of the process. 82% of the biogas plants declared knowing and analyzing the composition and quality of the biogas generated, while 18% did not analyze its composition. In relation to the composition of biogas, the plants reported adequate concentrations of CH_4 and CO_2 and low traces of hydrogen sulfide, suggesting optimal efficiency of the process and its potential use for electrical energy generation. In this sense, regarding the uses of biogas, 95% of these plants carry out cogeneration.

Biogas for electricity generation

In 2015, the Argentine Republic enacted Law 27.191, which modified Law 26.190, with the aim of promoting the participation of renewable sources until they reach 20% of the national electricity consumption in 2025. To facilitate this goal, the Government launched a bidding program called "RenovAr". In recent years, the generation of biogas has increased due to this program.

CAMMESA is the company that administrates the wholesale electricity market and has the registry of all the electric energy plants that are connected to the Argentine Electric Interconnected System (SADI). According to its monthly report, as of September 2022 there was a total installed capacity of biogas plants of 72.6 MWel. Most of these plants were developed within the framework of the “RenovAr Program” and had a commissioning date between 2017 and 2021.

Table 4 shows the current installed capacity of biogas generation in Argentina, by region and province.

Table 4: Biogas power plants, September 2022

Agent	Region	Province	Installed Capacity [MWel]
BIOGAS CT AVELLANEDA SECCO	LITORAL	SANTA FE	6.3
CENTRAL BIOELECTRICA R.CUARTO1	CENTRO	CORDOBA	2
C.BIOELECT.R.CUARTO1 REN2	CENTRO	CORDOBA	1.56
C.BIOELECT.R.CUARTO2 REN1	CENTRO	CORDOBA	1.2
C.BIOELECT.R.CUARTO2 REN2	CENTRO	CORDOBA	1.2
BIOGAS CTBG CITRUSVIL-ALCOVIL	NOROESTE	TUCUMAN	3
BIOGAS RS CT ENSENADA SECCO	GRAN BS.AS.	BUENOS AIRES	5.3
CTBG GENERAL ALVEAR	BUENOS AIRES	BUENOS AIRES	1
BIOGAS CTBG GIGENA I	CENTRO	CORDOBA	1.2
BIOGAS CTBG JUSTO DARACT	CENTRO	SAN LUIS	1
BIOGAS CTBG PACUCA BIO ENERGÍA	BUENOS AIRES	BUENOS AIRES	1
BIOGAS CTBG PERGAMINO	BUENOS AIRES	BUENOS AIRES	2.4
C.T.SAN MARTIN NORTE 3A	GRAN BS.AS.	BUENOS AIRES	5.1
CT SAN MIGUEL NORTE III-ENARSA	GRAN BS.AS.	BUENOS AIRES	11.5
ENERGIA AGRO S.A.U	LITORAL	SANTA FE	1.415
BIOGAS CTBG TIGONBU	CENTRO	SAN LUIS	2
BIOGAS CTBG VILLA DEL ROS. CGY	CENTRO	CORDOBA	1

BIOGAS CTBG VENADO TUERTO	LITORAL	SANTA FE	2.1
BIO ENERGÍA YANQUETRUZ S.A.	CENTRO	SAN LUIS	1.5
BIOGAS CTBG ENRECO	CENTRO	CORDOBA	2
CTBG BIO ENERGÍA YANQUETRUZ II	CENTRO	SAN LUIS	0.8
CTBG BIO. SANTA CATALINA	CENTRO	CORDOBA	2
BIOGAS CTBG AB ENERGÍA	COMAHUE	LA PAMPA	2
CT BIOMASA MM BIOENERGÍA	NORESTE	MISIONES	3
CTBRS SAN MARTÍN NORTE III-D	GRAN BS.AS.	BUENOS AIRES	5.1
BIOGAS CTBG ARRE BEEF SA	BUENOS AIRES	BUENOS AIRES	1.5
BIOGAS CT RESENER SA	BUENOS AIRES	BUENOS AIRES	0.8
CTBG POLLOS SAN MATEO	CENTRO	CORDOBA	2.4
CTBG GENERAL VILLEGAS Ren 2	BUENOS AIRES	BUENOS AIRES	1.22
Total Biogas (MW)			**72.6**

Source: Own elaboration based on CAMMESA data [8]

It was estimated that biogas power plants in the country emit approximately 480,000 tonnes of CO_2 annually. This value considers only the 29 plants which are used for electricity generation and are interconnected to the Argentine Electric Interconnected System, because there is information available about their location and capacity of production. Although, as mentioned before, there are about 105 biogas production plants distributed across the country, which were not considered for the estimation because there is no information available and updated.

2.4.3 Biomass

Biomass is renewable organic material that comes from plants and animals and can be burned directly for heat and electricity generation or converted to renewable liquid and gaseous fuels through various processes.

Some regions in Argentina such as Corrientes, Misiones and Entre Ríos have a strong forestry activity and generate a large amount of waste, which could serve for the generation of renewable energy and at the same time could be used as an important carbon source for PtX production.

According to information from CAMMESA, the biomass power plants interconnected to the Electric System (SADI) came into operation in 2019 and are presented in Table 5.

Table 5: Biomass power plants, September 2022

Agent	Region	Province	Installed power [MW]
CT BIOMASA GARRUCHOS	Northeastern	CORRIENTES	36
CTBM. GENERACIÓN LAS JUNTURAS	Central	CORDOBA	0.6
CTBM INGENIO LEALES	Northwestern	TUCUMAN	2
CT BIOMASA SANTA ROSA CORRIENT	Northeastern	CORRIENTES	15
CT BIOMASA LA ESCONDIDA -CHACO	Northeastern	CHACO	10
CTBM.BIOMASA UNITAN SEISMEGA	Northeastern	CHACO	6.7
Total Biomass (MW)			**70.3**

Source: Own elaboration based on data from CAMMESA [8]

2.5 Location of CO_2 sources in Argentina

Figure 16 and Figure 17 show the availability of CO_2 by province, considering all beforementioned CO_2 sources, in a map and a bar chart. Buenos Aires province is the region with the highest availability of this feedstock with 37.9 Mt_{CO2} per year, followed by Santa Fé, Mendoza, Neuquén and Córdoba with yearly CO_2 values of 6.7 Mt_{CO2}, 6.6 Mt_{CO2}, 5.7 Mt_{CO2} and 4.7 Mt_{CO2}, respectively.

In the Southern regions, which have a good potential for green hydrogen production, only limited quantities of CO_2 are available. Consequently, the production of carbon-containing PtX products in these regions may require the installation of DAC plants, the transport of CO_2 from the emission point source to the green hydrogen production facility or the transport of green hydrogen to the emission point source. In any case, although the existence of fewer alternative carbon sources in the Patagonia region is a challenge, for the purposes of the development of specific PtX projects, it is relevant to highlight that there are specific point carbon sources of quality and scale that could offer a suitable carbon source for these projects.

Figure 16: Map of availability of CO_2 by province

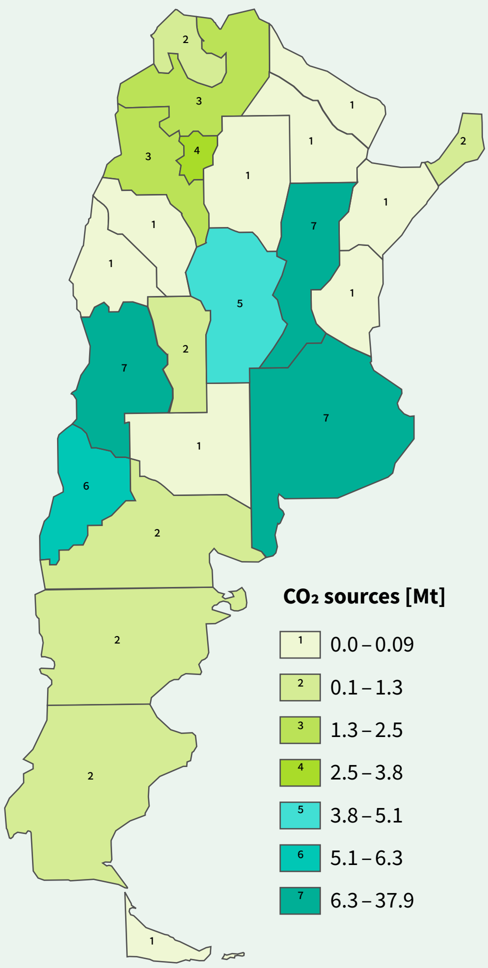


Figure 17: Availability of CO_2 sources by province

Additionally, Figure 18 and Figure 19 give an overview of the availability of biogenic CO_2 sources by province. As it can be seen in the Figures, these sources are more concentrated in the north-eastern region of the country, being Córdoba the province with the highest availability of these kind of sources. It should be noticed that the scale of Figure 17 and Figure 19 is different, due to the lower amount of biogenic sources.

Figure 18: Map of availability of biogenic CO_2 sources by province

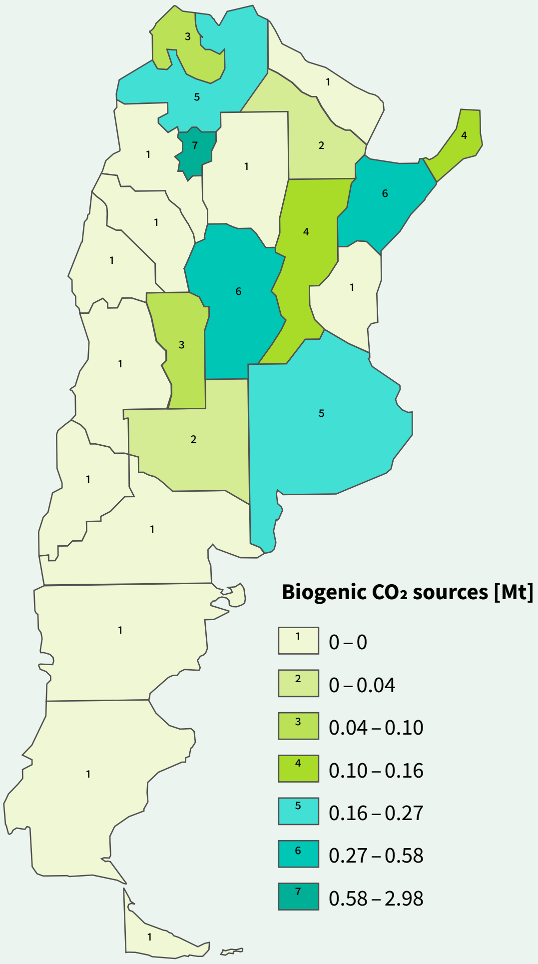


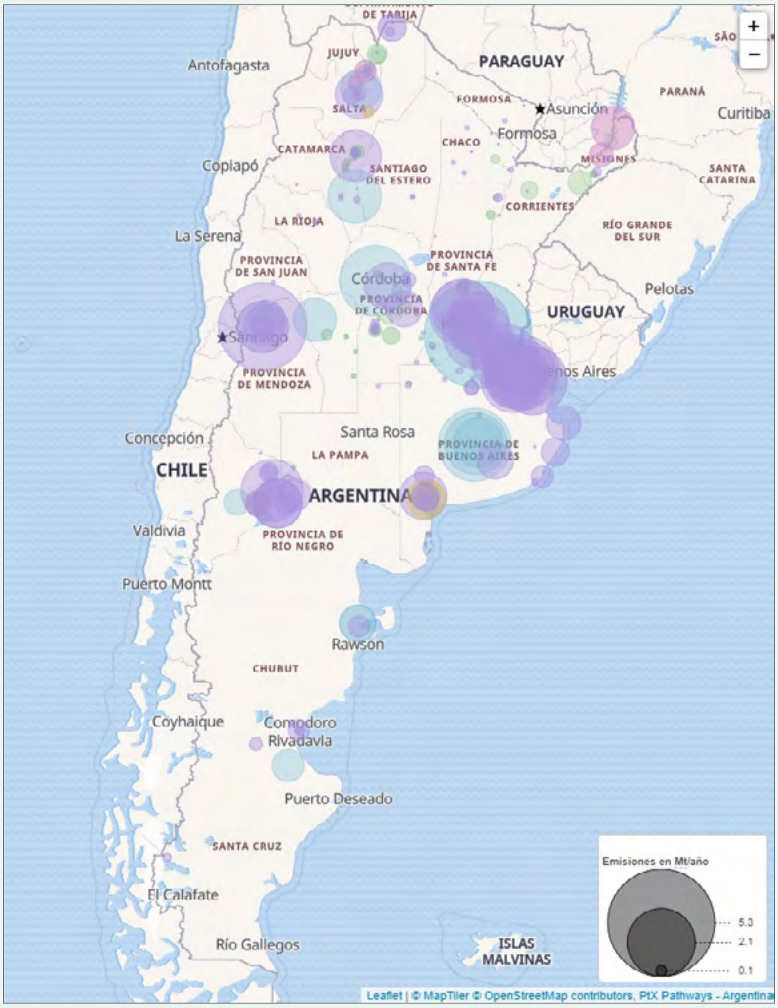
Figure 19: Availability of biogenic CO_2 sources by province

A detailed map with all point sources and their respective emission values and locations was developed by the International PtX Hub Argentina (GIZ) and DECHEMA and published under **www.ptx-hub.org/carbon-sources-map-argentina**. This interactive map allows the user to choose between industrial/energetic and biogenic sources as well as between different sectors. A screenshot of this map is shown in Figure 20.

This map aims to identify carbon sources in the form of CO_2 in Argentina, based on the industries and biogenic sources described in the previous sections, and uses as a basis public and industry specific information sources, information acquired from consultations with associations and in some cases, estimations based on real production capacity.

The interactive map provides specific details of the sources of information used for each industry as well as the methodology used for the estimations (see "Data and Sources" tab in the **web map**).

Figure 20: Screenshot of the interactive web map of carbon point sources in Argentina



2.5.1 Analysis of location of different point sources in the country

The main focus of this study was to estimate CO_2 emissions from different point sources in Argentina. This chapter summarizes and analyses the identified emissions by sector and region.

Biogenic Point Sources

Biogenic emissions by province and category are shown in Table 6. Out of a total of 74.5 Mt of CO_2 point source emissions identified and estimated in the study, only 1.9 Mt come from biogenic sources, such as bioethanol, biomass, or biogas. The province of Córdoba has the highest biogenic carbon emissions, followed by Tucumán, Buenos Aires, and Santa Fe. The largest sources of biogenic carbon are the bioethanol plants, one individual plant can emit up to 165 kt of CO_2. It is relevant to highlight that from all the 105 biogas plants mentioned in section 2.4.2, the map only identifies the 29 plants that are used for electricity generation and are interconnected to the Argentine Electric Interconnected System because there is information available about their location and capacity of production.

In Patagonia, which is the most promising region for hydrogen and Power-to-X (PtX) development due to its high wind speeds, no biogenic sources have been identified.

Table 6: Biogenic emissions by province

Province	Biogenic Point Sources (kt/year)			
	Bioethanol	Biogas Power Plant	Biomass Power Plant	Total
	1.012	477	394	1.882
Buenos Aires	-	229	0	229
Santa Fe	99	64	-	163
Córdoba	336	96	145	577
San Luis	62	35	-	96
La Pampa	-	13	-	13
Tucumán	261	20	29	310
Salta	174	-	99	273
Jujuy	80	-	-	80
Misiones	-	20	121	141

Pulp and Paper Industry

The pulp and paper industry is categorized separately because these plants typically have both, biogenic and fossil-based emissions, and the proportion of biogenic emissions can vary significantly from one plant to another. A specific analysis is required for each plant to understand the quantity and quality of emissions. It is estimated that the total CO_2 emissions from these plants could reach 2.3 Mt/year. Most of these plants are located in Misiones, Buenos Aires, Santa Fe, and Jujuy, as seen in Table 7.

Table 7: Pulp and paper emissions by province

Province	Pulp and Paper (kt/year)
	2.287
Buenos Aires	422
Santa Fe	416
Jujuy	298
Misiones	1.147
Entre Ríos	4

Industrial Point Sources

Table 8 shows industrial emissions by province and category. When examining industry sources, Buenos Aires emerges as the most industrialized province by far, accounting for more than half of the country's total industrial CO_2 emissions. This is largely due to the steel industry in the northern part of the province, the cement industry in the central region, and the petrochemical activity in the south, specifically in the city of Bahía Blanca.

Table 8: Industrial emissions by province

Province	Industry Point Sources (kt/year)						
	Cement	Steel	Aluminum	Ammonia	Ethylene	Methanol	Total
	12.059	7.054	612	821	611	309	21.466
Buenos Aires	5.419	5.936	-	747	585	-	**12.687**
Santa Fe	-	1.118	-	-	26	34	**1.152**
Mendoza	534	-	-	-	-	-	**534**
Córdoba	2.366	-	-	-	-	-	**2.366**
San Luis	840	-	-	-	-	-	**840**
Neuquén	305	-	-	-	-	275	**581**
Chubut	-	-	612	-	-	-	**612**
Santa Cruz	458	-	-	-	-	-	**458**
Salta	-	-	-	74	-	-	**74**
Catamarca	1.374	-	-	-	-	-	**1.374**
Jujuy	763	-	-	-	-	-	**763**

Energy Sector Point Sources

The power generation sector, that burns natural gas in combined cycles, open cycles, and vapour turbines, emits approximately 42 Mt of CO_2, according to CAMMESA [9]. Additionally, this activity is well distributed among the provinces. The only province without a natural gas power plant connected to the mainland grid is Tierra del Fuego. However, it has two mid-sized power generation plants that supply power to the island and are disconnected from the Argentine electrical transmission system.

The actual CO_2 emissions from each plant varies proportionally to its capacity and capacity factor, which is different every year and depends on the overall performance of the country's power generation system.

Furthermore, in the global energy transition, a rapid decline in fossil-based power generation is anticipated, in line with the expansion of renewable power. Therefore, using energy sector point sources for PtX production presents a dual risk: firstly, the availability of CO_2 emissions from these sources is expected to decrease in the medium term; and secondly, fossil-based power may become an unacceptable CO_2 source for Power-to-X (PtX) products in importing countries, such as European countries.

The oil refining sector also plays a significant role in Argentina's CO_2 point source emissions, accounting for approximately 6.8 Mt of CO_2. However, as described above, a marked decline in fossil fuels is anticipated in the medium to long term, aligning with the defossilisation pathways necessary to achieve the net zero target by 2050. In addition, international product certification can also be a challenge given the risk of causing a carbon lock-in effect. Chapter 4.1 provides further detail in this context. On the other hand, if certification issues are resolved, oil refineries could utilize their current facilities to co-process synthetic crude oil. Furthermore, in the long term, a conventional oil refinery could even be transformed into a synthetic oil refinery.

In Argentina, there are seven medium or large-scale refineries. Three of these are located within an 80 li radius of Buenos Aires City, one in Bahía Blanca (also Buenos Aires Province), and the other three in Mendoza, Neuquén and Salta.

Table 9: Energy emissions by province

Province	Energy Sector (kt/year)		
	Refinery	Fossil Thermal Power Plant	Total
	6.792	41.732	48.524
Buenos Aires	4.918	23.162	28.080
Santa Fe	-	4.905	4.905
Mendoza	1.230	1.403	2.633
Córdoba	-	1.944	1.944
La Pampa	-	7	7
San Juan	-	6	6
Neuquén	293	4.871	5.164
Chubut	-	489	489
Santa Cruz	-	111	111
Río Negro	-	532	532
Tucumán	-	2.701	2.701
Salta	351	1.252	1.603
Catamarca	-	30	30
Jujuy	-	73	73
La Rioja	-	48	48
Chaco	-	37	37
Santiago del Estero	-	44	44
Formosa	-	23	23
Misiones	-	71	71
Corrientes	-	17	17
Entre Ríos	-	9	9

2.5.2 Overlapping of CO_2 sources and Renewable Energy Potential

Hydrogen and PtX project locations should be critically evaluated following a comprehensive and multisectoral geographic analysis. This analysis should consider different aspects, including renewable energy resources, water access, existing infrastructure, industry development and possible local demand. Additionally, if the final product is a hydrocarbon, it requires a carbon source as well (as in the case of methanol or synthetic fuels). As a consequence, the carbon source location can be as critical as the renewable power potential for the economic and technical assessment.

CO_2 Sources in Patagonia

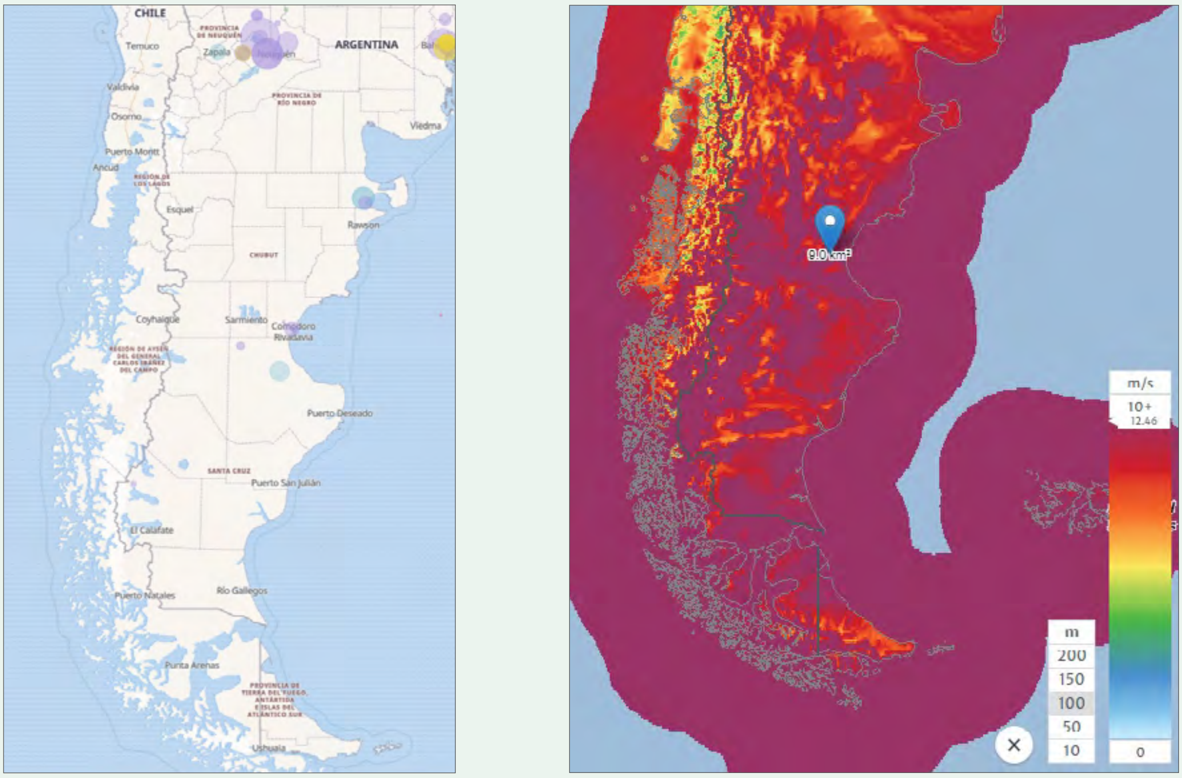
The Patagonian region shows an extraordinary wind power potential characterized by wind speeds up to 12 m/s. An additional advantage of this region is its availability of large and lightly populated areas. To understand the potential of the region, there already are wind power farms operating with capacity factors above 60%.

In terms of CO_2 availability, several point sources have been identified in the region, including two cement plants, one primary aluminum plant, one methanol plant and twenty-three natural gas power plants.

Figure 21 shows a comparison of carbon point sources and wind resources in the Patagonia region.

Excluding the natural gas power plants from the analysis, the opportunities for developing PtX projects using local CO_2 are limited. Nevertheless, these few sources could support a few large-scale projects. For example, with the cement plant located in Santa Cruz, a methanol plant with a nominal capacity of approximately 288 kt/year could be installed[5]; alternatively, using the CO_2 from the aluminum plant, a methanol plant with a nominal capacity of 385 kt/year could be developed. The scales of these examples are compatible with export sizes, yet the main challenge lies in engaging the companies responsible of these activities in the development of these projects.

Figure 21: Comparison of carbon point sources with wind resources in the Patagonia region [25]



[5] With the assumption that 1.59 t of CO2 are required for each t of methanol.

A clarification is needed in this section, fossil fuels upstream and midstream activities have not been included during the identification of CO_2 point sources due to the lack of public information. Despite this exclusion, it is known that there already are operative CO_2 capture plants located in Oil & Gas production areas, as the Patagonia region. The objective of these plants is to remove the CO_2 from the natural gas that comes from production wells, to meet the quality specifications required by Argentinian normative and the technical requirements for natural gas transportation. In these plants, the CO_2 stream is a by-product with normally a low economic value. This could consequently represent a low-cost CO_2 source for a PtX project. However, despite the cost opportunity, there are some risks that need to be addressed:

- the acceptance of this type of sources for an international PtX product certification is currently not clear, and even if it is accepted, this can be modified in the short-term.
- the usage of these sources introduces risks of carbon lock-in effects. For this reason, from a climate change mitigation perspective, this source is not the most suitable option for PtX production.
- the availability of CO_2 from this type of sources will be reduced if fossil fuel demand decreases or if the CO_2 content in gas production decreases (situation expected with non-conventional gas production).

Center and South of Buenos Aires Province

The center and southern areas of the Buenos Aires province have a good wind power potential and, as it can be seen in Figure 22, there are CO_2 sources available: cement plants, chemical and petrochemicals plants, an oil refinery, and several natural gas power plants. The port city of Bahia Blanca stands out for its chemical and petrochemical activities, including a refinery and an ammonia production and export plant, these characteristics position the city as a potential H_2 and PtX hub.

Figure 22: Comparison of carbon point sources with wind resources in the Buenos Aires Province[25]

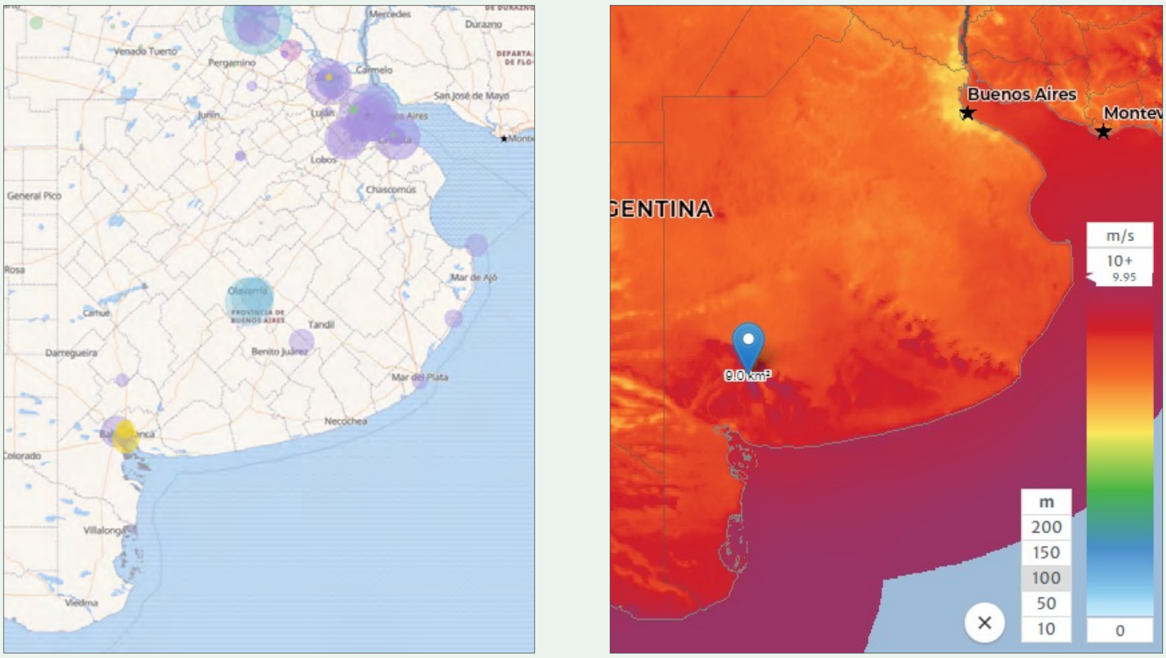
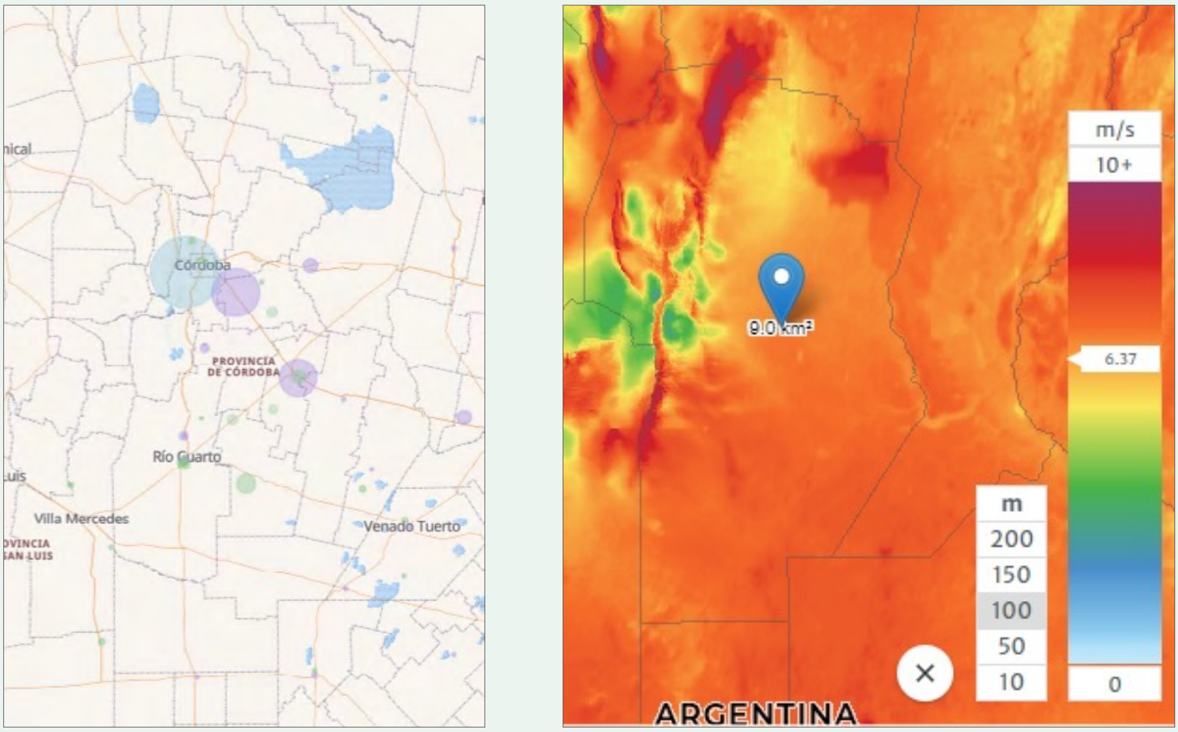


Figure 23: Comparison of carbon point sources with wind resources in the central region of the country [25]



Biogenic Sources in the Central Region of the Country

Figure 28 shows a comparison of carbon point sources and wind resources in the central region of the country.

As mentioned before, the province that ranks first in biogenic CO_2 sources availability is Córdoba, located in the central region of the country. The bioethanol activity explains the large amount of biogenic CO_2 emissions. The biogenic CO_2 from bioethanol production can create a closed carbon cycle. The mitigation potential is greater in this case, because in a closed cycle, every carbon molecule that is emitted in the air is sequestered back into the earth. The smaller the cycle, the less time carbon stays in the atmosphere. Also, with the correct sustainability practices during operation, product certification should be simpler than in projects using CO_2 from industrial sources.

Despite the biogenic CO_2 sources, neither wind speed nor solar irradiation are particularly remarkable in the province, renewable energy costs need to be studied to analyse if competitive hydrogen costs can be achieved.

Alternatively, the biogenic CO_2 from Córdoba could be combined with the renewable energy from the southern region of the country. To achieve this, two alternatives can be analysed:

1. Transport CO_2 from a biogenic CO_2 source to regions with high wind speeds in the south, preferably near the coast, where sea water can be desalinated and the hydrogen and PtX plant can be located near the port. This would require a CO_2 liquefaction plant and more than 800km of CO_2 pipelines with pumping stations.
2. Transport electricity from the region with high wind speed to the location of the plant with the biogenic CO_2 source and produce the hydrogen and PtX in Córdoba. High voltage power transmission lines seem to be more convenient than CO_2 pipelines in terms of costs. However, other challenges can appear in this case regarding water supply and logistic costs of the final product, especially when it is intended for export.

A techno-economic assessment must be carried out to understand the feasibility and competitiveness of these alternatives.

Solar Irradiation and CO_2 Sources in the North

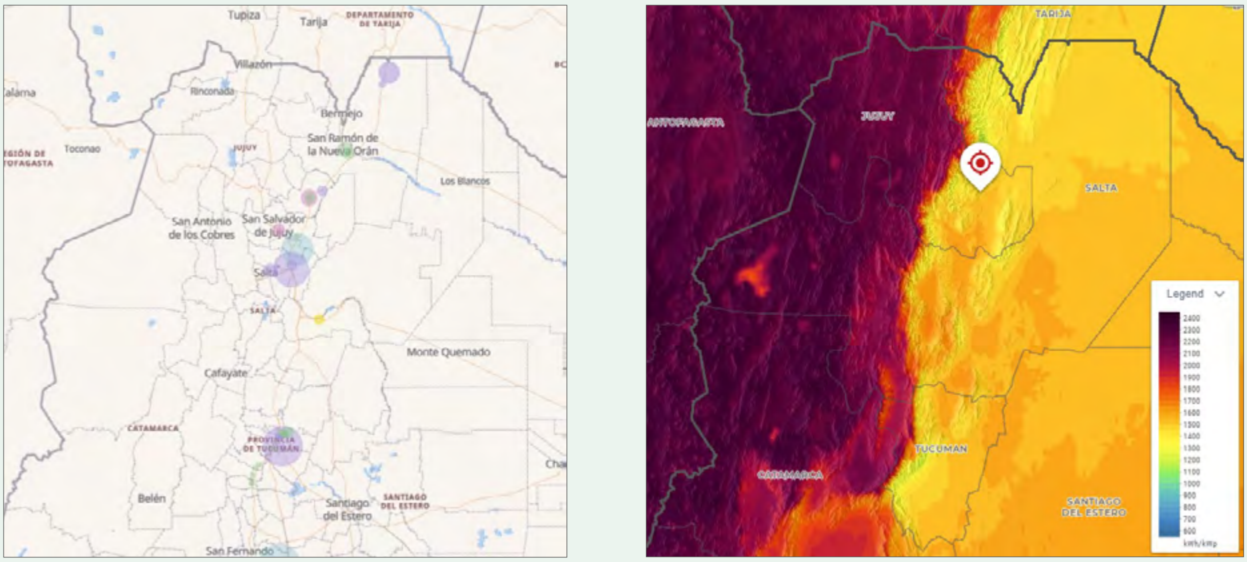
Figure 29 shows a comparison of point sources with solar resources in the northern region of the country.

In the north-western region of the country, also known as NOA (Noroeste Argentino), several sources like bioethanol, pulp and paper and natural gas power plants have been identified, accounting for approximately 7.4 Mt of CO_2 (with more than 0.5 Mt of biogenic CO_2). This region counts with an excellent solar irradiation, comparable with the northern region of Chile and other regions with the best solar potential around the world. This explains the capacity factors above 30% of some solar farms that are already in operation.

On the other hand, some of the main challenges to develop PtX projects in the region can be related to the following aspects:

- Solar power profiles demand greater process operation flexibility compared with Argentinian wind power profiles. If the process operation is inflexible, huge amounts of hydrogen storage would be required or additional transmission capacity for electricity transportation would be necessary.
- Access to water could be a challenge in this region. From a sustainability perspective water usage should not contribute to or cause water stress or any other water use conflict. The water supply strategy can be a critical factor concerning the acquisition of the social license in this region.
- Final product logistics may result in extra costs due to the distance from the local demand zones and ports unless the consumption takes place in the same region.

Figure 24: Comparison of carbon point sources with solar resources in the northern region of the country [26]



2.6 Study cases

To be able to estimate the order of magnitude that can be expected when capturing and utilizing CO_2 from a point source, the estimated emissions from four specific plants were evaluated. Hereby, the subsequent possible methanol production and the required amount of green hydrogen were estimated. These four study cases are shown in Table 10.

As an example, an ammonia plant producing 710 kt of CO_2 yearly, could supply the necessary carbon to produce 447 kt of methanol and for this, 103 kt of green hydrogen would be needed. For this specific case, it should be considered that currently, many ammonia facilities capture and utilize the CO_2 emissions for the subsequent urea production. For this reason, these emissions could not be available for the further production of PtX.

A cement plant emitting 1,370 kt CO_2 per year, could deliver the carbon to produce 862 kt of methanol, which would also require 199 kt of green hydrogen.

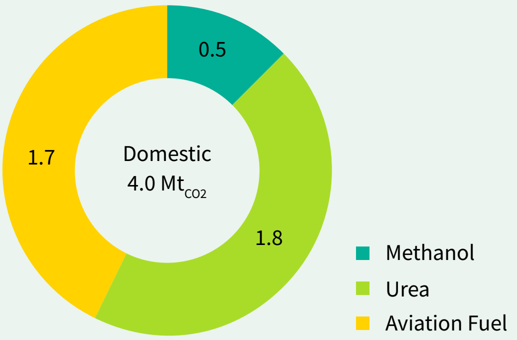
The bioethanol and biogas plants could provide enough carbon to produce 113 kt and 25 kt of methanol per year, respectively.

For comparison, the largest methanol plant in Argentina has a production capacity of 411 kt of methanol per year [10].

Table 10: Order of magnitude of CO_2 offer in four study cases

Plant	Location	Emissions [t_{CO2}]	Possible production of methanol [t_{MeOH}]	Green hydrogen needed [t_{H2}]
Ammonia plant	Bahía Blanca, Buenos Aires	710,000	446,822	103,126
Cement plant	El Alto, Catamarca	1,370,000	862,177	198,991
Bioethanol plant	Orán, Salta	180,000	113,279	26,145
Biogas plant	Santa Fé	40,000	25,173	5,810

Figure 25: Domestic demand of CO_2 (scenario: complete replacement of apparent consumption in 2021 of methanol, urea and aviation fuels by PtX products)



2.7 Demand of CO_2 for the production of PtX

To estimate the future CO_2 demand for PtX in Argentina, both the domestic usage and the potential exports of carbon containing PtX products should be considered.

For the local domestic use of hydrocarbons, no future scenarios were found. With the purpose of providing an approximation, the apparent consumption of methanol, urea and jet fuel in 2021 in Argentina was considered (285 kt, 2,470 kt and 613 kt, respectively). In a hypothetical scenario in which these products are completely replaced by PtX synthetic products, around 4 Mt of CO_2 would be needed: 0.5 Mt for methanol, 1.8 Mt for urea and 1.7 Mt for aviation fuels (see Figure 25).

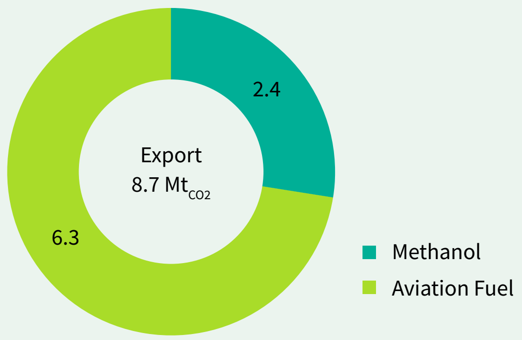
It must be mentioned that the future demand for urea is uncertain, since its current production process relies on the CO_2 produced in ammonia manufacturing. With the current goals of decarbonising different sectors, including ammonia production, there is the possibility that urea may be replaced by other nitrogenous fertilizers which do not contain carbon in their molecules.

For the production of hydrocarbons dedicated for export, the Argentine National Hydrogen Strategy was considered, which plans to produce and exports 4 Mt of low-carbon hydrogen yearly in 2050, aiming to supply 5% of the global market [4]. The Strategy does not specify in which form the hydrogen will be exported (e.g., liquid hydrogen, ammonia, methanol, synthetic fuels). Deloitte presents estimations about the composition of green hydrogen and its derivatives for global trade in 2050. It assumes that 7% and 33% of the green hydrogen market will be traded via methanol and sustainable aviation fuels (SAF), respectively [27]. The remaining 61% will be traded in the form of pure hydrogen and ammonia, both of which do not require a carbon feedstock.

Applying these values to the goals presented in the National Hydrogen Strategy of Argentina results, it is assumed that out of the 4 Mt of hydrogen dedicated for export, 0.3 Mt will be converted to methanol and 1.3 to aviation fuels. This would translate to a requirement of 2.4 Mt and 6.3 Mt of CO_2, respectively (see Figure 26).

According to the data collected throughout this study, biogenic CO_2 emissions in Argentina amount to 1.9 Mt_{CO2}/year, which are not sufficient to meet the presented demand. The remaining amount should be consequently covered by either DAC, which is currently not yet economically viable, or other point sources such as pulp and paper (2.3 Mt_{CO2}/year) or cement (12.1 Mt_{CO2}/year).

Figure 26: Assumed demand of CO_2 in Argentina required for export of PtX products



3

INFRASTRUCTURE

The infrastructure to transport and temporarily store CO_2 is not well developed in Argentina, as is the case in most of the countries. Although small amounts of CO_2 from the bioethanol production are used in the food industry, they are not comparable with the amounts required for a future PtX industry.

The natural gas infrastructure is well-developed throughout the entire country and plays a central role in Argentina's energy system. The most important hydrocarbon basin is the Neuquina Basin, where almost 69% of the total natural gas is produced, followed by the Austral Basin with 20%.

3.1 Description of gas transport infrastructure in Argentina

To supply the natural gas public service, there are two transportation companies that hold the concession on the transportation of natural gas in their area: Transportadora de Gas del Norte (TGN), and Transportadora de Gas del Sur (TGS).

TGS system is the most important in the country and the most extensive in Latin America. It connects the gas reserves of the south and west of Argentina, crossing seven provinces to supply natural gas to the City of Buenos Aires, Greater Buenos Aires, the center and south of the country. TGS carries approximately 60% of the gas consumed in the country, with a system of 9,232 km of total extension.

TGN system and its related pipelines extend over 10,971 kilometers, 21 compressor plants with an installed power of 391,000 HP. This system transports 40% of the natural gas injected in all the trunk pipelines, connecting to the Neuquina Basin (Gasoducto Centro-Oeste), and to the Northwest region (NOA) and the Bolivian transportation system (Gasoducto Norte).

The TGN system is 6,806 kilometers long in the Central-West Gas Pipeline and the Northern Gas Pipeline.

3.2 Requirements for CO_2 transport infrastructure in Argentina

Argentina has an extensive Natural Gas transportation system, and retrofitting the system to transport CO_2 could be seen as a way to avoid stranded asset. However, considering the requirements for CO_2 transportation and the high level of capacity utilization of the existing infrastructure, it could be assumed that this retrofit does not seem to be a viable option.

The safety requirements for CO_2 are very different, even if CO_2 and natural gas are both gases at standard conditions of pressure and temperature, because the CO_2 is transported in liquid form.

Factors such as compositions, phase of transportation, original pipeline specifications, and pipeline route require major studies prior to allowing its re-use.

One of the main differences is the operating pressure needed in the pipeline. To prevent phase changes, higher pressure levels would need to be adopted in CO_2 pipelines. Liquid CO_2 pipelines must operate above the critical point pressure of 1,070 psig (73.8 bar). Below this pressure the CO_2 evaporates, leading to a pressure spike and may lead to ruptures. Many natural gas pipelines are not capable of operating under these CO_2 pressure requirements [28].

In addition, existing natural gas pipelines typically have a maximum pressure of 1,480 psig, whereas CO_2 pipelines usually operate at 2,200 psig. As a consequence, retrofitting a natural gas pipeline for CO_2 transport would require installing more pump stations along the route, compared to a new CO_2 pipeline. For this reason, the use of an existing natural gas pipeline for CO_2 transport is not a practical option for large flow rates (from 19 Mtpa) or over long distances (longer than 100 miles) [28].

Another critical difference is the need to dehydrate the CO_2 stream to avoid corrosion of the pipeline. CO_2 can react with water to form highly corrosive carbonic acid, which can corrode carbon steel at rates of more than 10mm/year in wet pure CO_2. Consequently, it is necessary either to dry the product prior to transportation or specify a more corrosion-resistant material [29]. In this sense, a liquid CO_2 pipeline made from a insufficiently tough steel will be susceptible to running ductile fractures (RDF), which may be the case of existing natural gas pipelines [28]. Therefore, it is vital to understand the weaknesses of the existing natural gas pipelines before converting them to CO_2 service.

Moreover, liquid CO_2 is an excellent solvent, which may dissolve non-metallic pipeline components (e.g., seals, gaskets, valves and lubricants), resulting in leaks, ruptures, and damage to pipeline equipment [28].

In this sense, according to UK regulation, the pipeline operator must determine the design, construction, operation and maintenance history of the pipeline. If this information is unavailable, appropriate testing must be conducted to determine the condition of the pipeline and verify if it could be safely operated for the intended purpose. It may also be necessary to verify the design pressure of the pipeline [29].

A report from the National Petroleum Council (USA) concludes that repurposing natural gas pipelines would not help develop and extend the CO_2 pipeline network in the United States. If the goal is to transport large volumes of CO_2 over large distances (100 miles or more), then the lower pressure rating of existing natural gas pipelines makes it impractical to repurpose them for CO_2 use. However, natural gas pipelines could be repurposed if their diameters are large enough and throughput volumes are optimized for a tighter operating range. In the USA, each pipeline's potential should be studied based on the project-specific conditions being evaluated and verified that the conversion of the line from natural gas service to CO_2 services complies with the requirements determined by the Pipeline and Hazardous Materials Safety Administration (PHMSA).

In conclusion, repurposing a natural gas pipeline for CO_2 use depends on several factors:

- Pressure required does not exceed the pressure of design along the pipeline
- Pipeline material has adequate toughness
- Coating materials and any non-metallic materials are suitable for CO_2 transportation
- Design, construction, operation and maintenance history of the pipeline or appropriate testing, must be conducted to determine its condition for retrofitting
- Monitoring technologies and emergency protocols are in place to proactively address pipeline integrity challenges
- Tools, metering, and intermodal designs to enable multimodal transport of CO_2

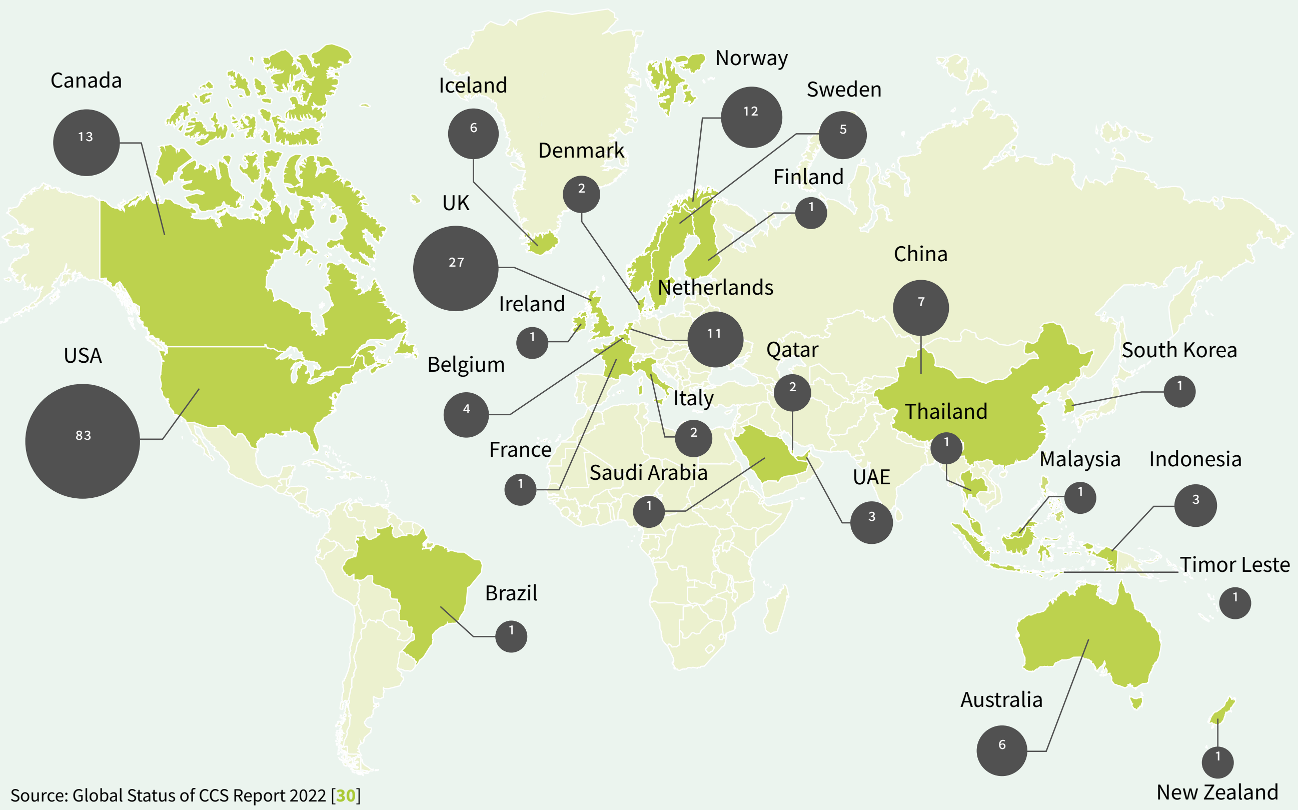
Status of global CO_2 transportation infrastructure

The Global CCS (Carbon Capture and Storage) Institute's database of CCS projects (including CO_2 transportation) provides insights into worldwide development.

In the Global Status of CCS Report 2022, a list of 196 projects in 25 countries is provided (see Figure 27). The data included for each project are: Status, Operational Date, Facility Industry, Facility Storage and Capture Capacity.

Only 6 projects that could become hubs (sites where CO_2 from different sources are received) are identified, and none of them are currently in operation. It could be concluded that currently the CO_2 transportation pipelines (at least for CCS projects) are directly connecting CO_2 producer with the sequestration facility. In particular, only one project is under development in Latin America (Brazil) and no CCS projects are registered in Argentina.

Figure 27: Number of CCS projects in selected countries



Source: Global Status of CCS Report 2022 [30]

3.3 Possibilities of retrofitting current infrastructure

Considering the specific circumstances of natural gas usage in Argentina, and the technical (and consequently economical) challenges related to retrofitting the natural gas transportation infrastructure, it could be concluded that implementing a retrofit plan would not be feasible for a relevant share of the transportation system. The specific circumstances are:

- Natural gas is a very relevant fuel in Argentina's energy matrix (56% of Total Supply of Primary Energy).
- Argentina has important reserves of natural gas, and expanding the transportation system would be necessary, not only to ensure domestic supply, but also to replace imports (Bolivia, LNG) and export to regional markets or LNG to international markets.

However, feasibility assessments could be conducted for very specific parts of the system that could connect potential CO_2 source facilities to potential locations of synthetic fuel production sites.

Additionally, a national regulatory framework for the CO_2 transportation would need to be developed. Considering, that there will generally be a direct relationship between the CO_2 producer and the consumer or the storage site, the framework should focus on the standards for the design, operation, siting, and maintenance of the CO_2 pipelines, based on frameworks that have already been developed all over the world. Chapter 4 provide additional information on the regulatory framework.

4 CO_2 LEGAL ASPECTS: SUSTAINABILITY CRITERIA AND REGULATIONS FOR CCUS

Legal aspects regarding CO_2 in relationship to the production of PtX involve (i) any binding sustainability criteria whereby certain sources of CO_2 are acceptable and others are not; and (ii) regulation and incentives applicable to the carbon capture, utilization and storage (CCUS) technologies. Argentina has not developed regulations on either of these two aspects. However, in the following sections, some criteria and regulations adopted by other countries are addressed.

In the case of sustainability criteria, EU regulations will be specifically addressed, as it is assumed that Argentina would be interested in participating with its PtX exports in the supply of the European market. Therefore, the sustainability criteria defined within the EU Renewable Energy Directives (RED) should be considered as a reference.

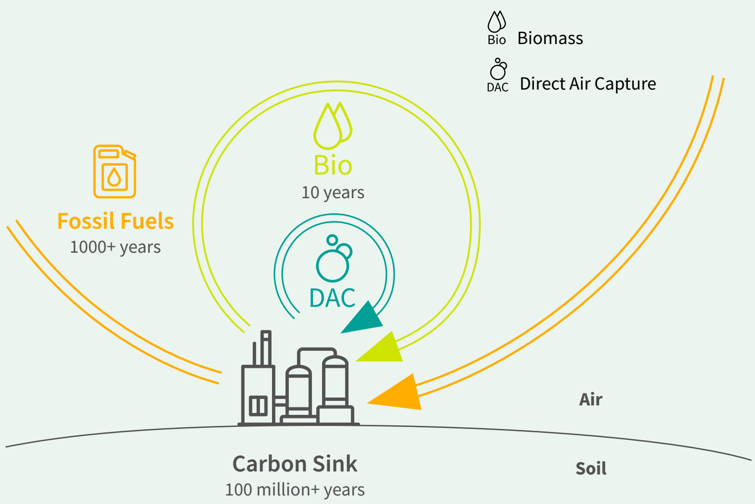
Regarding regulations and incentives applicable to CCUS technologies, different countries have been reviewed (United Kingdom, United States, Canada, Australia) as the identified mechanisms could be adopted in Argentina.

4.1 Sustainability criteria applicable to the different CO_2 sources

In a global scenario with increasingly ambitious sustainability criteria, in the long term, the production of renewable PtX will have to ensure that CO_2 comes from truly sustainable and renewable sources: CO_2 will have to be obtained from sources with a short or closed carbon cycle.

Figure 28 shows different kinds of carbon cycles for PtX products. A carbon cycle describes the process by which carbon molecules are exchanged from the atmosphere to the earth and then back into the atmosphere. The figure shows how long carbon stays in the atmosphere depending on the origin of the carbon source. In a closed cycle, every carbon molecule that is emitted in the air is sequestrated back into the earth. The shorter the cycle (DAC, then biomass), the fewer CO_2 molecules remain in the atmosphere. Fossil fuels cycles last over 1,000 years.

Figure 28: Carbon cycle



Source: International PtX Hub (2022) [31]

4.1.1 Direct air capture (DAC)

From a long-term perspective, DAC would be the best option in terms of sustainability as it has a closed, immediate carbon cycle. DAC can be applied in sufficient amounts at every potential production site. However, DAC technologies have not yet reached the level of technology readiness needed for them to dominate carbon sources for PtX production in the short-term. They are likely to remain expensive for quite some time [32].

4.1.2 Biomass

Biomass can also be considered a sustainable CO_2 source, provided specific sustainability criteria established by the Renewable Energy Directive I (RED I) as applicable to the biomass value chain are also met.

In turn, the Renewable Energy Directive II (RED II) defines a series of sustainability and GHG emission criteria that bioliquids used in transport must comply with to be counted towards the overall 14% renewables' target and to be eligible for financial support by public authorities.[6] The sustainability criteria for bioliquids were extended to solid biomass fuel used for electricity and heating, and to gaseous biomass fuel used for electricity and transport. Default GHG emission values and calculation rules are provided in Annex V (for liquid biofuels) and Annex VI (for solid and gaseous biomass for power and heat production) of the RED II. The European Commission can revise and update the default values of GHG emissions when technological developments make it necessary [33].

The economic operators (in most European countries identified as the companies that pay fuel tax) are responsible for showing that the sustainability criteria have been fulfilled. Economic operators have the option to either use default GHG intensity values provided in Annexes V and VI of the RED II or to calculate actual values for their pathway. They are obliged to have a control system that keeps track of the different batches of biofuels, where the raw material is taken from, and the sustainability properties of each batch. Independent auditors inspect and approve the quality of the control systems.

By-products from the production process of the biofuel can share the GHG emissions in relation to their energy content. Several negative emissions can reduce the total GHG emission value, including improved agricultural management methods allowing more carbon to be bound in soil, excess electricity produced in the biofuel plant, CO_2 that is separated and geologically stored, and CO_2 that is separated and replaced. There is also a GHG bonus if raw material is cultivated on severely degraded land. One example of a feedstock that gives negative CO_2 emissions is manure [34]

To avoid indirect land use change (ILUC)[7] (which may cause the release of CO_2 stored in trees and soil negating the GHG savings that result from increased biofuels), there is a limit on high ILUC-risk biofuels, bioliquids and biomass fuels with a significant expansion in land with high carbon stock. Member states can still use (and import) fuels covered by these limits, but they cannot include these volumes when calculating the extent to which they have fulfilled their renewable targets.[8]

4.1.3 Industrial point sources

The use of CO_2 from industrial point sources (i.e. electric power generation, chemical industry, cement, paper, iron, glass) is discouraged in the mid- and long-term.

As stated in Chapter 2, industrial points generally produce two kinds of emissions: (i) energy related emissions (resulting from the combustion of fossil fuels where geological carbon is touched); such emissions should be avoided using climate neutral fuels; and (ii) unavoidable process related emissions (e.g. in the case of cement production, the calcination of the feedstock which produces lime and CO_2 as a waste product) which for the next years will still be considered an acceptable CO_2 source for renewable PtX production. However, using CO_2 from unavoidable emissions of industrial point sources is only recommended in the short and medium term, as these sources are subject to phase-out trajectories. There is a significant risk of lock-in effect for CO_2-intensive technologies and industrial processes [PtX Hub Berlin 2021].

The above criteria have been confirmed in June 2023 by the European Commission, when it formally published the two Delegated Acts outlining detailed rules on the EU definition of renewable H_2 and renewable PtX products. The first Delegated Act defines under which conditions hydrogen-based fuels or other energy carriers can be considered as renewable fuels of non-biological origin (RFNBOs). The second act provides a methodology for calculating life-cycle GHG emissions for RFNBOs [35].

According to the latter – the Delegated Regulation (EU) 2023/1185 – in the short term the origin of carbon used to produce PtX is not relevant for determining emission savings of such fuels as currently many carbon sources are available and can be captured while making progress on decarbonisation. However, "in an economy on a trajectory towards climate neutrality by 2050, sources of carbon that can be captured should become scarce in the medium- to long-term, increasingly restricted to CO_2 emissions that are hardest to abate". The Delegated Act emphasizes that continued use of PtX products that contain carbon from non-sustainable fuel is not compatible with a trajectory towards climate neutrality by 2050 as it would entail the continued use of non-sustainable fuels and

[6] Under the Renewable Energy Directive I (RED I) EU countries are obliged to ensure that the share of renewable energy in the final consumption of energy in transport is at least 14% by 2030, including a minimum share of 3.5% of advanced biofuels. RED I established sustainability criteria for biofuels and bioliquids. Since its recast in 2018 (RED II), the sustainability criteria were extended to solid biomass fuel used for electricity and heating, and to gaseous biomass fuel used for electricity and transport.

[7] Biofuel production typically takes place on cropland that was previously used for other agriculture such as growing food or feed. This may lead to the extension of agriculture land into non-cropland, possibly including areas with high carbon stock such as forests, wetlands and peatlands. This process is known as indirect land use change (ILUC).

[8] Delegated Regulation (EU) 2019/807 sets out specific criteria both for (i) determining the high ILUC-risk feedstock for which a significant expansion of the production area into land with high carbon stock is observed; and (ii) certifying low ILUC-risk biofuels, bioliquids and biomass fuels.

their related emissions. Consequently, CO_2 captured from the combustion of fossil fuels for electricity production should be phased out by 2035, while CO_2 from other uses of non-sustainable fuels would be acceptable up to 2040. These dates will be subject to review.

4.2 GHG Calculations: GHG savings thresholds in RED II

In terms of GHG savings, the current RED framework sets different GHG savings thresholds, depending on the starting dates of installations. For plants starting operations after January 2021, GHG saving thresholds for transport biofuels have been set in 65% and for RFNBO in 70%. In other words, according to the current RED framework, RFNBO to be considered as "low emission", the GHG savings need to be of at least 70% compared to conventional fuels.

The methodology for GHG calculations applicable to RFNBO is established in the Annex to the Delegated Regulation (EU) 2023/1185. Section 10 of the Annex refers to the GHG emissions stemming from the carbon that has been captured from the atmosphere and imbedded in the PtX product. The CO_2 sources must comply with the following criteria:

(a) CO_2 captured from the combustion of fuels for electricity generation will be accepted until 2036, while CO_2 obtained from other industrial sources listed under Annex I of Directive 2003/87/EC (cement, steel, glass, paper, among others) might be used until 2041;
(b) CO_2 captured from the air has no restrictions;
(c) CO_2 stemming from the production or the combustion of biofuels, bioliquids or biomass fuels must comply with applicable sustainability and GHG saving criteria (as described above);
(d) CO_2 stemming from a geological source of CO_2 only qualify if the CO_2 was previously released naturally;
(e) CO_2 stemming from a fuel that is deliberately combusted for the specific purpose of producing the CO_2 is not accepted.

4.3 Carbon capture regulations and incentives

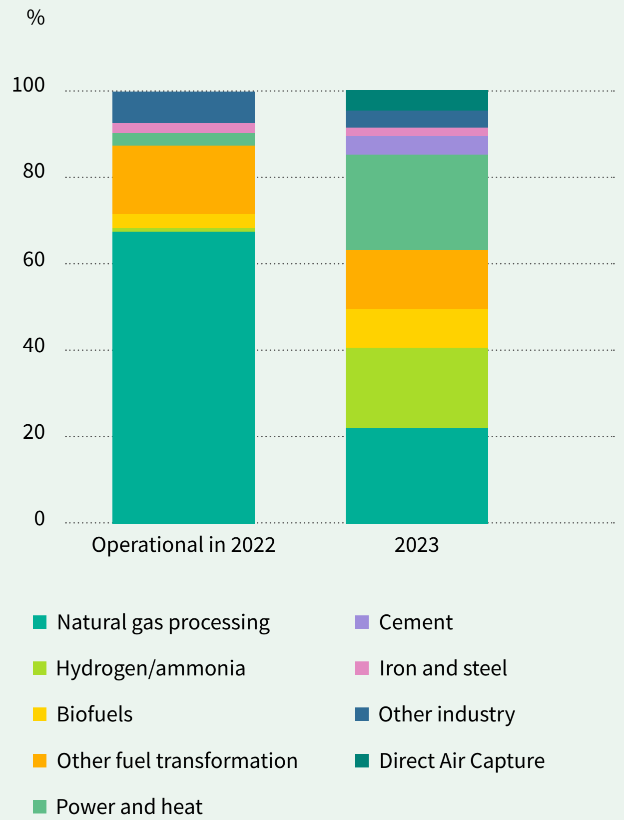
The development of carbon capture technologies has a broader spectrum, as carbon capture may be developed by industries with high GHG emissions (e.g. natural gas processing) with the objective to just store the CO_2 and avoid the emissions into the atmosphere. In such cases, the CO_2 is not further marketed nor used, but the relevant industry can reduce its net emissions. Such operations imply the storage and transport of CO_2 in large volumes and for long timespans.

Around 230 Mt of CO_2 are currently used each year, mainly in direct use pathways in the fertilizer industry for urea manufacturing (~130 Mt) and for enhanced oil recovery (~80 Mt).

The current project pipeline related to new utilization pathways shows that around 10 Mt of CO_2 per year could be captured for these new uses by 2030, including around 7 Mt_{CO2} in synthetic fuel production [36].

Figure 29 illustrates operational and planned carbon capture capacity by sector. Globally, natural gas processing represented in 2022 more than 65% of existing carbon capacity. By 2030 this share is expected to decrease to a 20% and a similar share would correspond to the hydrogen and ammonia sector [37].

Figure 29: Operational and planned carbon capture capacity by sector



Source: IEA 2024 [37]

Accordingly, some countries are developing new regulations and incentives for carbon capture, transport and storage technologies, which include the decarbonisation of conventional fossil-based industries. In the context of a just transition, in the short- and medium term, such regulations and incentives (basically designed for the fossil-based sector) could represent some advantages in terms of the availability of the CO_2 sources needed for the production of PtX (or other CO_2 uses).

Argentina has no regulations for CCUS technologies yet. In the following sections, some highlights of the CCUS regulations and incentives mechanisms in the United Kingdom, the United States, Australia and Canada, have been summarized. Following this, the Argentine carbon transport regulations are outlined, leading to a conclusion on regulations and incentives that could be adopted by Argentina.

4.3.1 International CCUS regulations and incentives

Carbon capture and utilization (CCU) of CO_2 for PtX production shares part of the carbon capture and storage (CCS) value chain, particularly the capture and transportation of CO_2. Given that CCS has been developed for a longer time, this chapter describes regulations for both CCU and CCS.

United Kingdom

In April 2020, the United Kingdom (UK) published the Carbon Sequestration Investor Roadmap. The roadmap aims at meeting the target of capturing 20-30 Mt_{CO2} per year by 2030, which includes 6 Mt_{CO2} per year of carbon captured in the industrial sector. Therefore, the government will support the establishment of at least two CCUS clusters by 2025 and another two by 2030.

Incentives for industry include the development of an Industrial Carbon Capture (ICC) model that will provide long-term compensation for industries that want to achieve deep decarbonisation, including waste CCUS projects. It will be a kind of carbon contracts for the difference.

For transport and storage businesses, it is proposed to grant licenses with regulated tariffs. The Energy Bill (in clauses 7–12 and 16 and Schedule 1) proposes to give powers to the Department for Energy Security & Net Zero (DESNZ) to grant licenses to CO_2 transportation and storage companies, during an initial interim period, the duration of which will be determined by DESNZ. Responsibility for granting licenses will thereafter be taken over by the economic regulator (although not yet formally appointed, this is expected to be Ofgem), which will also have general responsibility for administering licenses.

The draft law establishing an economic regulatory framework for CO_2 transport and storage is currently open for consultation and aims at creating the regulatory framework and support needed to attract private financing and remove investment market barriers, as well as providing long-term revenue security for the deployment of the first carbon transport and storage network.

The licenses will be granted to CO_2 transportation and storage companies to design, build, own and operate the transportation and storage network. It will be made up of three sections in line with the structure for other regulated networks: the Standard Conditions, Special Conditions and Schedules of the license. CO_2 companies will be granted the license and will also enter into:

(i) the Government Support Package (GSP), including the Supplementary Compensation Agreement (SCA)[9] and Discontinuation Agreement with DESNZ;
(ii) the RSA with the RSA Counterparty; and
(iii) any funding arrangements agreed under the CCS Infrastructure Fund (CIF) [38].

United States

The United States (US) continues to increase CO_2 storage capacity with a near doubling in new announcements in 2022 compared to 2021. Worldwide there are currently around 9 500 km of CO_2 pipelines in operation, the vast majority of which (92%) are in the US [39].

In the US, CCUS projects under development are subject to federal and state laws and regulations at the source of CO_2, during transportation to the injection site, and at the injection site for Enhanced Oil Recovery (EOR) or long-term storage of CO_2. Various federal and state laws and regulations (such as the National Environmental Policy Act, the Clean Water Act, the Clean Air Act, and statewide oil and gas regulations) may affect carbon sequestration projects and identifying the US CCUS regulatory framework becomes challenging.

The US presents the largest financial incentives to support CCUS development. In 2022, the Inflation Reduction Act (IRA) added impetus to CCUS by expanding and extending the 45Q tax credit, nearly doubling the credit for CO_2 captured by industries and power plants, and nearly tripling the credit for CO_2 obtained by DAC. In the case of EOR and other industrial uses, this means up to USD 85 per tonne of CO_2 for permanent storage and up to USD 60 per tonne of CO_2 for uses where CO_2 emissions reductions can be clearly demonstrated. The amount of the credit increases significantly for DAC projects (USD 180 per tonne of permanently stored CO_2 and USD 130 per tonne of CO_2 used). Also, a 2022 amendment reduced capacity requirements for eligible projects: 18,750 tons per year for power plants (provided at least 75% of CO_2 is captured), 12,000 tons per year for other facilities and 1,000 tons per year for DAC installations. Finally, the deadline to qualify for the tax credit was extended by 7 years, which means that projects have time until January 2033 to begin their construction.

To sum up, the 45Q tax credit expanded and extended to CCUS projects approved by the US Congress in early 2018. It is the most significant specific incentive for carbon capture available, globally [40].

Australia

Likewise, the legal framework governing CCUS in Australia is shared by the Commonwealth with the states and territories. Commonwealth laws only apply to projects located in offshore areas (between 3 and 200 nautical miles – 270 km – from the

[9] The SCA is a contract under which DESNZ will make payments to T&SCo with respect to certain losses arising in particular CO_2 leakage scenarios in circumstances where commercial insurance is unavailable or insufficient. The objective of the SCA is to ensure T&SCos are able to return their assets to a reasonable and sustainable level of operational readiness. While the SCA will be available to manage the risk of leakage of CO_2, it is not designed to assist with stranded asset risk.

coastline) and state/territory laws apply to onshore and offshore areas within their respective jurisdictions. The development of specific state/territory CCUS regulations varies significantly across the country.

The federal legislation provides a framework for licensing, regulatory oversight, and applicable environmental standards for CCS projects in Commonwealth waters. Commonwealth laws regulating CCUS projects include the 2006 Offshore Greenhouse Gas and Oil Storage Act and the 1999 Environmental Protection and Biodiversity Conservation Act.

In September 2020, the Commonwealth published its First Low Emission Technology Statement, in which it gives CCS a leading role in reducing GHG emissions [41]. The statement emphasizes the importance of CCS in sequestering GHG emissions generated in natural gas processing and in hard-to-decarbonise industries such as steel and aluminum manufacturing. It aims at reducing the combined cost of compression, transport and storage (this does not include capture processes) to A$20 per tonne of CO_2 equivalent. It also commits the government to provide A$50 million for research and amend legislation to ensure CCS is eligible for support from three other existing funds: the i) Emissions Reduction Fund, ii) the Australian Renewable Energy Agency, and (iii) the Clean Energy Finance Corporation [42].

In that framework, the Carbon Capture, Use and Storage Development Fund provided businesses with grants of up $25 million for pilot projects or pre-commercial projects aimed at reducing emissions. The main objectives of the Fund are (i) to foster existing, pilot or pre-commercial CCUS facilities that could connect into a regional CCS hub in the future and bring together a network of multiple GHG emitters enabling reductions in costs and risks for CCUS projects and large-scale abatement; and (ii) support the Australian Government's priority technology stretch goal to compress, transport and store CO_2 for less than $20 per tonne [43].

Table 11 lists the grants awarded by the Australian Government trough the CCUS Development Fund.

In 2021 Australia confirmed those incentives when presenting its Long-Term Emissions Reduction Plan [44] in which CCUS technology appears as one of the options to mitigate CO_2 emissions in many industrial processes, including: natural gas processing, cement production, steel, fertilizers, power generation, hydrogen production from fossil raw materials.

Canada

Canada has been regulating CCS for many years. Carbon storage is subject to local regulations. When CCS involves seabed management, national borders, international relations or transnational financing, central government steps in. The transport of CO_2 is also regulated at provincial level, provided it does not cross more than one province.

The province of Alberta introduced amendments to the Mining and Minerals Law, and the Energy Resources Conservation Law in order to include guidelines for CCS regulation. The ownership of the subsoil and pore space always remains in the domain of the provincial state. The Alberta Energy Regulator (AER) is the regulatory authority for the CCS chain. CO_2 capture is considered a sour gas removal in the oil industry, requiring environmental assessment and approval from the Ministry of Environment and Parks. In addition, the permitting process is carried out under the supervision of the Minister of Energy. Exploration permits do not grant exclusivity. The operator's period of responsibility lasts 10 years counted as from the injection of CO_2 into the storage. The operator must pay a charge per tonne (which is determined for each project) to finance the fund that will be applied for monitoring costs after closing.

Table 11: Grants awarded by the Australian CCUS Development Fund (2021)

State (Project Location)	Applicant	Project	Grant Amount
SA	Santos Limited	Moomba Carbon Capture and Storage (CCS) Project	$15,000,000
QLD	Energy Developments Pty Limited	Landfill Gas Carbon Capture and Use Project (the Project	$9,000,000
NSW, ACT	Mineral Carbonation Internation Pty Limited	Australian CCU Flagship: Demonstrating decarbonisation for heavy industry	$14,600,000
NSW	Boral Limited	Turning mineral waste to carbon sink – a low cost carbon storage technology	$2,400,000
SA	Corporate Carbon Group Pty Ltd	Pilot Direct Air Carbon Capture, Use & Storage: off-site abatement & ACCUs	$4,000,000
QLD	Carbon Transport and Storage Corporation (CTSCo) Pty Limited	CTSCo Surat Basin CCUS Project	$5,000,000

Within the Incentive and Promotion Mechanisms, Canada has an Energy Innovation Program that included a Call for ID&D for CCUS [45]. The aim is to support the investment and development of next-generation CO_2 capture technologies and processes, which have the potential to significantly reduce the capital and operational costs of capturing CO_2 and increase applicability to different CO_2 emission sources, sizes and concentrations compared to CO_2 capture technologies.

From 2022 to 2030, the tax credit rates will be: 60% for investment in CO_2 capture equipment in direct air capture projects; 50% for investment in CO_2 capture equipment in the rest of CCUS projects; and 37.5% for investment in transport, storage and use equipment. From 2031 to 2040, tax credit rates will fall to 30%, 25% and 18.75%, respectively. The tax credit may be claimed by businesses that, as of January 1, 2022, incur in eligible expenses related to the purchase and installation of equipment used in a new CCS project. Companies can claim the tax credit only if they agree to comply with a validation and verification process to prove that the project meets CO_2 storage requirements.

There are also incentives at provincial level. In November 2021, the province of Saskatchewan announced the eligibility of pipelines carrying CO_2, either for CCUS or Enhanced Oil Recovery (EOR), for the provincial Petroleum Infrastructure Investment Program (OIIP).

The province of Alberta has committed C$1240 million[10] through 2025 for two commercial-scale CCUS projects. Both projects will help reducing CO_2 emissions from the tar sands and fertilizer sectors and reduce GHG emissions by up to 2.76 million tons per year. Both projects are required to submit annual reports to the knowledge-sharing program to ensure public access to technical information and learnings from the project.

4.3.2 Carbon transport regulations in Argentina

In Argentina, CO_2 is supplied as compressed gas and liquid, in a variety of purities and concentrations. For beverages and food, the concentration is 99.9% and 99.8%, respectively [46]. CO_2 is being transported by truck. Resolution No 1957/1997 of the Secretariat of Transport included CO_2 among hazardous materials, belonging to Risk Class: “Gas under pressure” and “Toxicity”. The Secretariat of Transport is the national governing body that regulates and supervises the transport of hazardous materials and/or waste by road and railway. Resolution 64/2022 adopted the Regulation for Hazardous Materials approved by MERCOSUR.

Other regulations applicable to the transport of CO_2 in Argentina include:

- Law No 20,284 on Air Pollution
- IRAM 3797 standard on risks and handling symbols for the transportation and storage of materials.
- Resolution N° 801/2015 related to Labor Risks adopts the Globally Harmonized System (GHS) for the classification and labeling of chemical products, with express requirements on labels and safety sheets.
- Law No 24,557 aims to reduce workplace accidents through the prevention of risks.
- Resolution 295/2003 deals with health and safety requirements in workplaces. Its Annex IV introduces chemical substances and sets thresholds for time-weighted maximum permissible concentration for substances that are suspended in the air.

In the future, CO_2 is expected to be transported by pipelines. Regarding the business model, two regulatory situations are likely to occur:

(i) For dedicated upstream CO_2 pipelines, owned and operated by the same owner / operator of the industrial infrastructure where CO_2 is captured and used, only safety (not economic nor commercial) regulations would apply.
(ii) If the CO_2 pipeline transport expands and becomes a service provided to third parties, operation licenses should be granted by national or provincial authorities and a regulatory agency would be monitoring safety requirements and assuring that there is no monopolistic use of the infrastructure. Such agency could be the National Natural Gas Regulatory Agency, provided that Law 24.076 is amended to extend ENARGAS’ jurisdiction to carbon dioxide as well as to hydrogen and other green or synthetic gases to be transported by pipelines.

In all cases, applicable technical codes and standards should be in place, to cover the following aspects, so that the transport of CO_2 is safe:

- Technical specifications of the infrastructure associated with CO_2 transportation
- Specifications on the purity and pressure at which CO_2 must be transported
- Assignment of responsibility in case of damages derived from emissions of CO_2
- Accounting for fugitive emissions in the emissions inventory of a project

Technical regulations for CO_2 pipeline transport could be based on existing regulations for safety and environmental protection in the operation of liquid hydrocarbon transportation systems through pipelines: Resolution E 120/2017 of the former Secretariat of Hydrocarbons, Ministry of Energy and Mining. This Resolution establishes conditions for the design, construction, inspection, operation, maintenance, integrity management and corrosion control of systems transportation of liquid hydrocarbons through pipelines and is based on international standards and the best practices of the industry, establishing the minimum technical requirements that operators of liquid hydrocarbon transportation systems must comply with respect to pipes and ancillary facilities. In this sense, a principal regulatory standard is the ASME Code B31.4 —Piped Transportation Systems for Liquids and Residual Sludge‖, 2016 edition, from the American Society of Mechanical Engineers (ASME)[47].

[10] Around 913 million USD.

4.3.3 Conclusions on CCUS technologies' regulations and incentives

Hydrocarbon producing countries are giving significant incentives for the development of CCUS technologies (US, UK, Canada, Australia). The EU has also committed 38 billion euros through the EU Innovation Fund for CCUS. Accordingly, regulations are being approved for CO_2 transport and storage, including the granting of licenses which involve rights and obligations for the authorized licensees to act as CO_2 transport and storage suppliers.

In Argentina, private companies operating in the hydrocarbons and industrial sectors are starting to implement technologies for CCS and for methane leakage reduction as part of their sustainability programs. The Secretariat of Energy and the natural gas regulatory agency (ENARGAS) are likely to approve standards and conditions for the progressive reduction of CO_2 and methane emissions. However, like in Brazil and Mexico, in Argentina the development of CCS technologies remains basically related to EOR as an additional income is needed to make it economically viable.

Therefore, and having in mind the beforementioned aspects on sustainability, it should be noted that in the short- and medium-term there could be synergies between the carbon capture technologies to be implemented by the hydrocarbon and industrial sectors and the use of carbon for the production of PtX. Such synergies could operate as a commercial incentive for both parts: the industrial sector would have a buyer for the captured carbon reducing the overall cost of the CCS procedure and the PtX sector would account for a carbon source that will be accepted globally in the short- and medium term.

In this sense, the National Hydrogen Strategy anticipates the need of infrastructure for CO_2 transport and storage. It aims at promoting R&D in CCUS technologies, based on technology transfer and innovation.

To sum up, public policies regarding renewable H_2 and its derivatives should include highlights on the development of CCUS technologies in line with the global sustainability criteria described above. Even if it were not possible to provide public financial support for CCUS technologies, some regulations regarding standards for the reduction of CO_2 emissions and an authorization regime for the supply of carbon transport and storage services when third parties are involved (e.g. potential buyers of the CO_2 or even the general public in connection with safety and environmental issues) will be necessary to assure an enabling environment for investments in these sectors.

Currently, CO_2 is transported by truck and regulations on transport of hazardous materials -under the supervision of the Secretariat of Transport- apply. In the future, pipeline transport of CO_2 will be governed by safety and technical codes and standards, similar to those currently applicable to the operation of liquid hydrocarbon transportation systems through pipelines as approved by Resolution E 120/2017. Regarding the business model, if the CO_2 transport becomes a service to be provided to third parties, operation licenses should be granted by national or provincial authorities (depending on the jurisdictions crossed by the pipeline) and a regulatory agency would be in charge of monitoring safety requirements and assuring that there is no abuse of the monopolistic condition of certain infrastructures.

5 CONCLUSIONS

To develop a PtX value chain in the country, in addition to renewable hydrogen, a carbon source will be needed to produce hydrocarbons such as methanol or synthetic fuels through PtX technologies. CO_2 is a suitable carbon source for PtX because it is produced in many industries as a waste product from combustion processes or chemical reactions. Even though highly diluted, CO_2 is also present in the atmospheric air.

Therefore, identifying suitable locations for hydrogen and PtX projects is a crucial aspect that should be faced following a comprehensive and multisectoral geographic analysis, including the identification of carbon source locations.

Throughout this study, a characterization of the different carbon point sources available in Argentina has been carried out, focusing on their geographical distribution. It was estimated that around 74.5 Mt of CO_2 are emitted yearly as point sources across the country, with 1.9 Mt originating from biogenic sources. Those regions where remarkable renewable resources do not coexist with availability of carbon sources will face challenges in either transporting CO_2 to areas suitability for renewable electricity generation or transporting electricity from high wind speed/solar irradiation regions to the location of the carbon source for hydrogen and PtX production.

From the analysis per region, it is possible to conclude that:

- The Patagonian region shows an extraordinary wind power potential characterized by wind speeds up to 12 m/s and wind farms operating with capacity factors above 60%. Although no biogenic CO_2 sources have been identified in the Patagonian region, several industrial point sources exist, including two cement plants, a primary aluminum plant, a methanol plant and nearly twenty-three of natural gas power plants. Despite limited opportunities for developing PtX projects using local CO_2, these identified sources could support large-scale projects compatible with export dimensions.
- The center and south of Buenos Aires Province have good wind power potential and there are CO_2 sources available, such as cement plants, chemical and petrochemicals plants, an oil refinery, and several natural gas power plants. The port city of Bahia Blanca stands out for its chemical and petrochemical activities, including a refinery and an ammonia production and export plant. These characteristics position the city as a potential H_2 and PtX hub.
- In the central region of the country despite the availability of biogenic CO_2 sources, neither wind speed nor solar irradiation are particularly remarkable. Further study of renewable energy costs is necessary to analyze if competitive hydrogen costs can be achieved.
- The northwest region has excellent solar irradiation conditions and there are several carbon sources available such as bioethanol, pulp and paper and natural gas power plants. However, challenges in this region include critical water supply strategies to avoid competition with other water uses, obtaining social license for projects, and final logistics costs due to the distance from local demand zones and ports unless the consumption occurs within the same region.

Future demand for CO_2 for PtX can be divided into local use and export. It was estimated that approximately 4.0 Mt of CO_2 would be necessary to replace current demand of methanol, urea and aviation fuels by PtX products. By 2050, 8.7 Mt of CO_2 would be required for the export of methanol and aviation fuels. However, these estimates should be treated as reference scales, as it includes many uncertainties.

Currently, transport of CO_2 in Argentina is carried out only on small scales by truck and is regulated under the supervision of the Secretariat of Transport for hazardous materials. In the future, pipeline transport of CO_2 will be governed by safety and technical codes and standards, similar to those currently applicable to liquid hydrocarbon transportation systems through pipelines as approved by Resolution E 120/2017. Regarding the business model, if the CO_2 transport becomes a service to be provided for third parties, operation licenses should be granted by national or provincial authorities (depending on the jurisdictions crossed by the pipeline) with a regulatory agency would be responsible for monitoring safety requirements and assuring that there is no abuse of the monopolistic condition of certain infrastructures. For dedicated upstream, CO_2 pipelines, owned and operated by the same owner / operator of the industrial infrastructure where CO_2 is captured and used, only safety regulations would apply, not economic nor commercial.

Regarding retrofitting current infrastructure for transporting CO_2, it is worth noting that considering the specific circumstances of natural gas usage in Argentina, and the technical challenges related to retrofitting natural gas transportation infrastructure, implementing a retrofit plan may not be feasible for a relevant share of the transportation system. However, it would be possible to assess feasibility for very specific parts of the system that could connect potential CO_2 source facilities to potential locations of synthetic fuel production sites.

Since Europe will be a target country for PtX product export, EU regulations were considered in the study. According to them, in the short- and mid-term, the origin of CO_2 used for PtX production is not relevant for determining emission savings of these fuels as currently many carbon sources are available and can be captured. However, in the long term, renewable PtX production will have to ensure that CO_2 comes from truly sustainable and renewable sources. For such fuels to have any chance of complying with the 70% GHG savings thresholds, it is necessary that the emissions are avoided by capturing CO_2, and thus can be subtracted from the total GHG emissions of the production process. And this will be the case only if the CO_2 captured complies with the following requirements:

- in the long term, only direct air capture will be accepted, if the energy used for its operation comes from renewable sources;
- biomass sources are accepted only if the sustainability and GHG saving criteria are fulfilled;
- emissions from electric power generation will be accepted until 2036;
- emissions from other industrial point sources will be accepted until 2041;
- in the case of geological CO_2, it must have been released naturally.

These regulations shall be binding and directly applicable in all EU Member States; therefore, the same criteria shall be relevant for PtX production in countries that plan to export PtX to the EU.

In addition to the fact that fossil carbon sources are not the best option from a GHG mitigation perspective, sustainability requirements for fossil carbon sources and advancements towards energy transition pose challenges for industrial point sources:

- a rapid decline in fossil-based energy generation is expected, and therefore the availability of CO_2 emissions is expected to decrease in the medium term
- the acceptance of this type of sources for an international PtX product certification is currently not clear. Even if they are accepted up to date, this can be modified in the short-term
- fossil-based power and other industrial point sources may soon become an unacceptable CO_2 source for PtX products in importing countries, e.g. in Europe
- the usage of these sources introduces risks of carbon lock-in effects

In the short- and medium-term there could be synergies between the carbon capture technologies to be implemented by the hydrocarbon and industrial sectors and the use of carbon for the PtX technologies.

Public policies regarding renewable hydrogen and its derivatives should include highlights on the development of CCU(S) technologies in line with the global sustainability criteria. In the same way, regulations regarding standards for the reduction of CO_2 emissions and an authorization regime for the supply of carbon transport and storage services when third parties are involved will be necessary to assure an enabling environment for investments in these sectors.

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