NOVA SCHOOL OF SCIENCE & TECHNOLOGY

DEPARTAMENTO DE QUÍMICA

MARIA MENDES ESTEVES

Licenciada em Ciências de Engenharia Química e Bioquímica

Air Liquide impact in Environment improvement – Fuels emissions and measurement

Dissertação para obtenção do Grau de Mestre em

Engenharia Química e Bioquímica

MESTRADO EM ENGENHARIA QUÍMICA E BIOQUÍMICA

Universidade NOVA de Lisboa
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*"Let us remember the past with gratitude,
live the present with enthusiasm, and look
forward to the future with confidence."
(Pope John Paul II)*

ABSTRACT

The present study has the objective to provide a vision about how energy transition, in the topic of fuels, will impact the Oil & Gas market in the SWE cluster. In addition, it is intended to evaluate Air Liquide's (AL) performance in this sector and provide a vision of how it can grow in the R&A market (Research & Analysis).

This market study provided a knowledge of the available projects in the Horizon 2020 and LIFE programmes and, with a respective analysis, a new lead of potential customers. By analysing 994 projects, it was possible to classify them and get 324 gas potential users and 83 of them that focus on the sector of fuels analysis. For France, it was discovered that 57% of the companies aren't AL customers, 70% for Spain, 82% for Portugal and 66% for Italy.

The Oil & Gas market is divided into submarkets, R&A04C, M&P02, and M&P03. Furthermore, to facilitate the forecast, they were divided into sectors of study: refinery, natural gas, biomethane and crackers.

A forecast was done for study sectors based on the BP and International Energy Agency (IEA) Outlooks. The timeline defined was until 2040. The results to the refinery sector were of growth of 0,2%, and for natural of 1% until 2040, these sectors from the outside are in crisis due to restrictions. Still, this market is compensated by increasing analysis demand due to environmental control and for a new upcoming energy source, biomethane, that has predicted growth of 15%. Therefore, the results are positive, with an average growth of 1,5% within the SWE territory.

Globally, Air Liquide has a reasonable penetration rate and market share. However, it is highlighted the French and Portuguese markets. France is the bigger market of the cluster, and Portugal has a less competitive nature and more exclusive consumers face to the other countries.

Finally, a competition analysis was performed to look at the Air Liquide's position inside the market. The main conclusion is that the company lacks accreditation for Oil & Gas products, having a fragile stand on the market compared to the main competitors.

Keywords: Air Liquide market, Oil & Gas, Refinery, Biomethane, Forecast, Penetration rate, Market share, Analysis.

RESUMO

O presente estudo tem como objetivo fornecer uma visão sobre o impacto da transição energética, no tópico dos combustíveis, no mercado do *Oil & Gas* no cluster *SWE*. Destina-se avaliar o desempenho da Air Liquide (AL) entre este setor e fornecer uma visão de como pode crescer no mercado R&A (*Research & Analysis*).

O estudo de mercado providencia um conhecimento dos projetos disponíveis dos programas *Horizon* 2020 e *LIFE* e com a respetiva análise, uma pista de potenciais clientes. Ao analisar 994 projetos, foi possível classificá-los, e obter 324 potenciais usuários de gás, 83 dos quais com o foco no setor de análise dos combustíveis. Para França foi descoberto que 57% das empresas não são clientes AL, 70% para Espanha, 82% para Portugal e 66% para Itália.

O mercado *Oil & Gas* encontra-se dividido em submercados, R&A04C - laboratórios de *Oil & Gas*, M&P02 - refinação e petróleo, transporte de carvão e LNG, e M&P03 - petroquímica. De modo a facilitar a previsão, estes foram divididos em setores de estudo: refinação, gás natural, biometano e *crackers*.

Baseado no BP e na Agência Internacional de Energia (IEA) *Outlooks* foi realizado uma previsão futura para os setores em estudo. O cronograma definido foi até 2040. Os resultados para o setor de refinação foram de um crescimento de 0,2% e para o gás natural de 1% até 2040. Estes, estão em crise devido a restrições, mas este mercado na AL é compensado pela procura crescente em análises de controlo ambiental e por uma nova fonte de energia, o biometano, que tem um crescimento previsto de 15%. Portanto, os resultados são positivos, com um crescimento médio de 1,5% do mercado no cluster *SWE*.

Globalmente, a Air Liquide tem uma taxa de penetração e quota de mercado razoáveis. No entanto, destacam-se o mercado francês e português. A França é o maior mercado do cluster, e Portugal apresenta um carácter menos competitivo e consumidores mais exclusivos face aos restantes países.

Finalmente, foi realizado uma análise da competição para observar a posição da Air Liquide dentro deste mercado. A principal conclusão é que a empresa tem uma falta de produtos acreditados no *Oil & Gas*, resultando numa posição frágil no mercado, em comparação com os principais competidores.

Palavras-chave: Mercado Air Liquide, Oil & Gas, Refinação, Biometano, Previsão, Taxa de penetração, Quota de mercado, Análise.

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GLOSSARY

AL - Air Liquide

ASTR - American Society of Testing Materials

CAGR - Compound Annual Growth Rate

CHP - Combined heat and power

EAP - Environment Action Plan

ECE - Economic Commission for Europe

ENAC -Entidade Nacional de Acreditação

EPA - Environmental Protection Agency

EU - European Union

FP - Framework Programme

GC - Gas Chromatography

GHG - Greenhouse Gas

GWP - Global Warming Potential

HTA - Hydrocarbon Type Analysis

IEA - International Energy Agency

IM - Industrial Merchant

INECP - Integrated National Energy Climate Plan

IPAC - Instituto Português de Acreditação

LI - Large Industries

LPG - Liquified Petroleum Gas

M&P - Manufacturing & Process

PEM - Proton Exchange Membrane

R&A - Research & Analysis

R&D - Research & Development

R&I - Research & Innovation

SG - Speciality Gas

SGDs - Sustainable Development Goals

SPAL - Sociedade Portuguesa do Ar Líquido

TRL - Technology Readiness Level

UN - United Nations

WBCSD - World Business Council for Sustainable Development

WRI - World Resources Institute

1.

FRAMEWORK AND MOTIVATION

The history of industrial gases links to the rapid pace of industrialisation that marked the nineteenth century and is a constantly growing market. The discovery of oxygen and carbon dioxide elements marked the end of the XVIII century. The discovery of some elements such as sulphur dioxide, HCL (hydrochloric acid), ammonia and carbon monoxide belong to Priestly in the IXX century. Helium and argon were also found in the late IXX century. It is in this period, in 1895, the industrial-scale production of acetylene started, initially was mainly used for lighting purposes due to its bright flame. At this time, an important step was taken, the liquefaction of air by Carl von Linde, marking the birth of an entirely new industry. There was a robust competition between C. v. Linde and G. Claude during this period, further developing air separation technology and significant improvements. Both founded companies with an essential presence in the gas industry, Linde and Air Liquide [1, 2].

Air Liquide was born in 1902, due to innovation and with the encounter between George Claude, inventor of an industrial process to produce oxygen from liquid air, and Paul Delorme, a visionary entrepreneur and rapidly developed to an international presence, in Europe (1906) and overseas to the United States (1916). During the XX century, Air Liquid developed and innovated the gas industry with pipeline network strategy, space industry, ASUs (Air Separation Units), electronics market, hydrogen and steam offer and development of a healthcare market. Air Liquide presents as "A world leader in gases, technologies and services for Industry and Health", and it is present in 80 countries and serves more than 3.8 million customers [3].

The industrial gas market is consolidated. Some significant players include Air Liquide, Air Products, Linde, and Messer. They enrol a vital part in the market in different applications like industry, medicine, research, and electronics.

This study focuses on the environmental improvement in the segment of fuels, which is essential in the early days because it is one of the most responsible segments for greenhouse gas (GHG) emissions. At Air Liquide, one goal is to limit the company's environmental footprint and its customers. Therefore, there are goals for innovation to invest more in sustainable solutions, taking ambitious actions to reduce the carbon intensity of their activities by 30% by 2025 [4]. To reach the target, the company has Climate Objectives: Taking actions on the assets

- Committing to reduce the impact of production, distribution, and service activities; Acting with customers - Innovate to minimise the customers' greenhouse gas emissions, and work for cleaner industry, and acting for ecosystems - Contribute to the growth of a low-carbon society by developing energy transition solutions to fight climate change.

Since the past decades, the European Union's environmental policies have delivered substantial benefits for people and the planet. The EU formulates and implements procedures and strategies on climate change, taking a leading role in international negotiations on climate. For example, the 8th Environment Action Plan (EAP), European Green Deal - started in December 2019 - and the Paris Agreement - started in December 2015; in this regard, the EU countries have agreed to meet various targets in the years to come.

In Europe, Air Liquide subdivides into four business areas: Large Industries- LI, Industrial Merchant- IM, Healthcare and Electronics. The Industrial Merchant sector, in 2019, presented a growth of 3,4% in Europe, making up 44% of the company revenue. This sector divides the activity into four markets: Entrepreneurs & Professionals- E&P, Food and Pharma- F&P, Manufacturing & Process- M&P and Research & Analysis- R&A [5].

This study is focused on the R&A market, more specifically on Oil & Gas. Therefore, it includes the sub-market of R&A04C (Oil & Gas Labs), M&P02 SG Sales (Refining & Oil, Coal and LNG Transportation), and M&P03 SG Sales (Petrochemicals).

Since there is an urgency in the energy transition, companies must follow policies and regulations to meet the environmental goals targeted. It is expected, and the forecasts presented by other companies prove it, that sectors that have non-renewable products, like refinery and natural gas, will decrease their demand and consumption of products over the years. Renewable products like hydrogen and biomethane will overtake these.

This study aims to identify the tendencies of the Air Liquide's market in the energy transition. The main activity of the Oil & Gas market inside the R&A is the measurement and quality control of products. With the help of gas chromatography technology, there is a need to control the specification in this market, with gas usage for measurement and calibration. Therefore, although these sectors will decrease their products, the measure will increase since the specifications and quality control tend to tighten over the years.

Some sectors will emerge with the regulations. It is the example of biomethane, which will have a demand and consumption, more in the following years on the injection inside the natural gas site, because its usage doesn't emit greenhouse gases to the atmosphere, reaching more than 15% in the scope of 20 years.

Given the importance of the energy transition topic, there's a need for a deep study of the possible future regulations, how this will impact the gas market, the identification of the main stakeholders, and their needs, analysing the company's performance in this area.

1.1. Objectives

The study to be developed have the main objectives:

- ✓ Identify European regulations and programmes until 2030.
  - o Study their strategy, funding, and objectives
- ✓ Identify the appropriate EU regulation and local for the SWE cluster
  - o Inside the Oil & Gas market
- ✓ Study the tendencies of this market
- ✓ Make a forecast for the Oil & Gas market based on the energy transition topic
- ✓ The study of a new potential market
- ✓ Identify stakeholders
  - o Size of the market that uses pure gases, calibration gases, equipment, and services
- ✓ Study the performance of Air Liquide through the market share, penetration rate, CAGR, and market forecast.
- ✓ Study the competitors in this market and the position of Air Liquide inside the marketplace
  - o SWOT Analysis

2. INTRODUCTION

The present chapter has the objective of developing and deepening concepts necessary for this study. Therefore, the best techniques are presented that will be able to obtain the best results sustained by theories and methods over the years.

2.1. Characterization and history of fuels

This section has presented an overview of the history and characteristics (chemical and physical) of fuels studied: coal, liquid fuel (petroleum/crude oil) and gaseous fuel (natural gas, biogas and biomethane).

Coal is mainly composed of organic and inorganic matter. The organic material comprises macerals, discrete minerals consisting of carbon, hydrogen, oxygen, and small amounts of sulphur and nitrogen; the inorganic components contain a wide selection of ash-forming compounds [6].

The geochemical process and its effect on the composition, coalification, is the transformation of the debris plant into coal, and It Is expressed by:

Peat → Lignite → Subbituminous Coal → Bituminous Coal → Anthracite

One method to measure the quality of the coal is by grading it - it refers to the amount of mineral matter that is present in the coal. Another way to class the coal is to measure the sulfur content, ash fusion temperatures – measurement of the behaviour of ash at high temperatures – and quantity of trace elements.

There are two classification systems to grade coal: the ASTM (American Society of Testing Materials) system in America and an international ECE (Economic Commission for Europe) Codification system developed in Europe. The categorization systems used commercially are primarily based on volatile matter, found in Appendix A [6].

Throughout history, for over more than two centuries, the coal sector has undergone a massive change. These changes have vastly altered the size and composition of coal use and changed its production and use location. There are several reasons for this to happen, but the principal determinant has been the increase of massive supplies of two fuels: petroleum and natural gas; They have numerous advantages over coal in usage, conversion, and transportation [7].

During this transition, the public-policy evaluation of coal has reversed focus. In the 1970s, coal was regarded as the potential saviour of oil- and natural gas depleted world. Several countries, mainly in Europe, wasted away billions, hoping that domestic coal would be an essential component of the rescue from depletion. The threat of rapid depletion has vanished. Oil and gas were so much more available than feared and easier to employ than coal. This reality has now sunk mainly in [7].

In the environment, the pollution externalities come from the mining, transformation, and use of coal. Concerns have intensified over time. The initial problem was the evident ash emission but then turned to the health effects of the ash and sulfur held in the coal and released during burning. The acid rain effects on steams and forests were a new matter since it came from the coal's sulfur and the nitrogen oxides produced by any combustion process. Another issue that emerged was the trace amounts emitted from coal. It came from the 1990 Clean Air Amendments, which included a long list of toxic chemicals, including mercury, whose pollution effects were considered severe enough to warrant regulation. Over time, mercury emerged as a prime concern. Table 2.1 represents all the emissions made by coal as a fuel [7].

Table 2.1- Coal use emissions, methods of measurement and SG usage: adapted from [7]

Emissions of interest by coal	Analytical Methods	Speciality Gases Requirement
NO_x	IR	Yes
PIC-CO; VOCs	PID	No
SO_2 / SO_3	IPA/DPM	No
Mercury	ICP-MS	No
PM-ash	--	--
CO_2	GC-MS	Yes
Acid gases-HCl[d]	IR	Yes

[d]Hydrogen chloride.

Note: IR (infrared spectrometry), PID (photoionization detector), DPM (dewpoint meter), IPA (absorption in an isopropyl alcohol solution), ICP-MS (Inductively Coupled Plasma Mass Spectrometry), GC-MS (gas chromatography-mass spectrometer)

Petroleum is characterized as a flammable liquid, a heavy mixture of hydrocarbons in a specific rock stratum derived from the decomposition and transformation of animals and plants.

Operationally, a blend of liquids, condensates, and gases upon production is what petroleum is referred to. The primary source of the material is the source of theories from the origin of oil. They are divided into two groups according to their point of view if either is organic or inorganic. Initial approaches tended towards inorganic; nevertheless, the theory most accepted was that the petroleum's primary source was organic. Three reasons justify this acceptance; First, in earth's sediments, most organic matter and hydrocarbons are found. Second, almost all crude oils contain nitrogen, and many have been found to carry out molecular forms – porphyrins – biomarkers. Third, petroleum is optically active, so it contains constituents that can rotate polarized light, which is a characteristic only seen in nature for compounds that arise from living organisms [6].

The primary concerns about oil and security date back to World War I. In 1913, Winston Churchill decided to change the British Navy from employing coal to bunker oil, which, back then, was a cleaner and more efficient fuel. In addition, the growth of tanks and other motorized military vehicles emphasized oil's important new role as a tactical commodity [6].

Following World War I, the importance of oil continued to grow, which led to a series of events such as crises, conflicts and advantages.

Even though the usability and importance of oil in the world economy have weakened since the 1970s, oil remains one of the largest sources of primary energy in industrial countries [6].

For decades, transportation has been one of the most essential and fastest-growing sectors for oil used by European countries. Air pollution and greenhouse gases responsible for global climate change are results of the utilization of oil in transportation. Low-level ozone is the most crucial air pollution challenge because it is formed in the atmosphere by complex photochemical reactions involving VOCs and nitrogen oxide in the presence of sunlight. In 1970, a criterion was made by EPA, the Clean Air Act, to limit pollutants. This criterion was amended several times.

Another problem that produces and emits NOx is that although engines are cleaner now than in the past, vehicle miles continually increase as more cars are purchased. Even more efficient engines today tend to produce NOx [8]. The emissions made by liquid fuels, more specifically Fuel oil, is represented in table 2.2 [7].

Table 2.2- Oil use emissions, methods of measurement and SG usage: adapted from [7]

Emissions of interest by coal	Analytical Methods	Speciality Gases Requirement
NO_x	IR	Yes
PIC-CO; VOCs	PID	No
SO_2 / SO_3	IPA/DPM	No
Mercury	ICP-MS	No
PM-ash	--	--
CO_2	GC-MS	Yes
Acid gases-HCl[d]	IR	Yes

[d]Hydrogen chloride.

Note: IR (infrared spectrometry), PID (photoionization detector), DPM (dewpoint meter), IPA (absorption in an isopropyl alcohol solution), ICP-MS (Inductively Coupled Plasma Mass Spectrometry), GC-MS (gas chromatography-mass spectrometer)

Crude oil can variate in elemental composition. The worldwide analysis shows that it can variate its composition range by:

- 82-87% C
- 12-15% H_2
- balance being O_2, N_2, and S.

Nevertheless, individual compounds present in these crude oils contain hundreds of unique combinations. These fall into various classes of hydrocarbons: alkanes (alkanes are also called paraffins), which can be straight-chained (standard or n-alkanes with the stoichiometry of CnH2n12), branched-chain (also called isoparaffins with the stoichiometry of CnH2n12), or cyclic (also called cycloalkanes, cycloparaffins, or naphthene's with ring structures covering 5, 6, or 7 carbons with the universal stoichiometry of CnH2n); and aromatics (compounds that contain at least one benzene ring (C6H6)) [6].

Crude oil is refined to create valuable products. An oil refinery entails several processes designed to build physical and chemical changes in the crude oil to transform it into products, including fuels.

To separate into fractions, purify the products, the crude oil is passed through several operations. One central process in the refinery is distillation, which is a crucial process in refining. Distillation takes benefit of the boiling point ranges of the various elements to separate the crude oil into fractions or cuts. Figure 2.1 is a generalized schematic diagram of an atmospheric crude fractionator showing the produced significant fractions. Table 2.3 represents examples of petroleum fractions produced by distillation of crude oil [6].

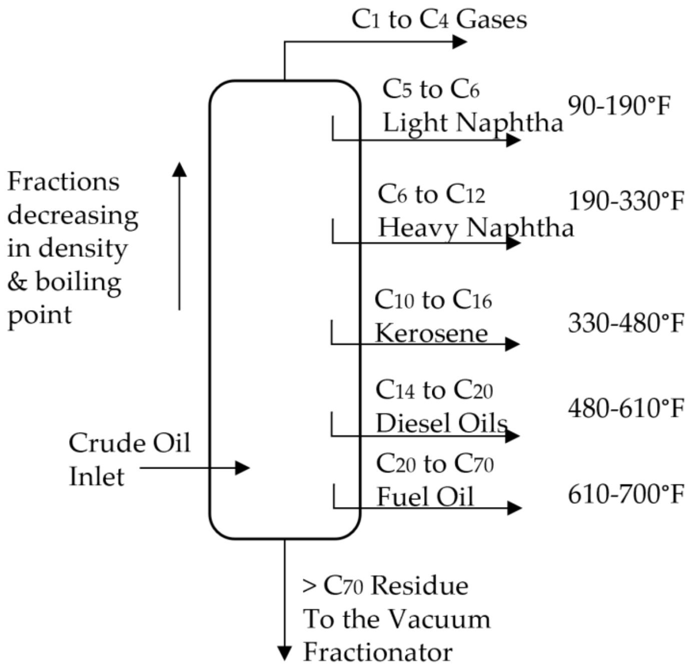


Figure 2.1- Crude oil distillation column by fractions produced: adapted from [6]

Table 2.3- Petroleum fractions produced by distillation of crude oil: adapted from [6]

Petroleum Fraction	Number of carbon atoms	Typical usage	Boiling point, °C
Fuel Gas	$C_1 - C_2$	Fuel Gas	< 29,4 °C
LPG	$C_3 - C_4$	Fuel Gas	< 29,4 °C
Light naphtha	$C_5 - C_6$	Gasoline	29,4 - 85 °C
Heavy naphtha	$C_6 - C_{12}$	Gasoline / jet fuel	85 - 177 °C
Kerosene	$C_{10} - C_{16}$	Jet fuel / kerosene	177 - 249 °C
Light gas oil	$C_{14} - C_{20}$	Heating fuel, diesel fuel	249 - 321 °C
Heavy gas oil	$C_{20} - C_{70}$	Fuel oil, feed to cracking units	321 - 427 °C
Reside	> C_{70}	Heavy fuel oil, as-phalt	> 566 °C

Gaseous fuels include natural gas and other gases obtained during the manufacture of natural gas. Natural gas is generally defined as a mixture of hydrocarbons with quantities of nonhydrocarbons. It is composed of predominantly methane (CH4) and ethane (C2H6) with other hydrocarbons such as carbon dioxide, hydrogen, nitrogen, argon, helium, and hydrogen sulfide.

Methane is formed in two general ways: diagenesis of accumulated organic matter and catagenesis of kerogen via hydrogen abstraction; or hydrogen capping methyl radicals produced in thermal cracking.

The capacity to condense hydrocarbons other than methane from natural gas provides a classification of the gas as dry gas, which, by definition, contains less than 0.013 L/m3 condensable hydrocarbons and wet gas which have greater than 0.040 L/m3 of the condensable hydrocarbons [9].

Table 2.4- Natural gas use emissions, methods of measurement and SG usage: adapted from [7]

Emissions of interest by Natural Gas	Analytical Methods	Speciality Gases Requirement
NO_x	IR	Yes
PIC-CO[a]; VOCs[b]	PID	No
SO_2 / SO_3	IPA/ DPM	No
PM[c]	--	--
CO_2	GC-MS	Yes

[a]Products of incomplete combustion
[b]Carbon monoxide; Volatile organic compounds
[c]Particulate matter
Note: IR (infrared spectrometry), PID (photoionization detector), DPM (dewpoint meter), IPA (absorption in isopropyl alcohol solution), GC-MS (gas chromatography-mass spectrometer).

Another gaseous fuel is biogas, and it is produced in biogas plants. This fuel is produced naturally from the biogenic matter if under anaerobic conditions, all forms of biomass. One of the leading players in global warming, methane (CH4), is released into the atmosphere during this process. Methane has become one of the most employed fuels for heating, power generation, and transportation over the last century. Today, most of the methane used comes from natural gas.

There are three categories of biomass:

- A substrate of farm origins such as liquid fertilizer, feed waste, yield excess and energy crops.
- Waste from households and cities, such as separately collected organic waste (in organic waste tanks).
- Industrial by-products such as glycerine, by-products of food processing or waste from fat separators. The methane content of the biogas adjusts between 50% and 75%, depending on the substrate digest in the biogas plant.

With a share between 25% and 50%, the second principal component of biogas is carbon dioxide (CO_2). The other parts are water (H_2O), oxygen (O_2), traces of sulfur (S_2) and hydrogen sulfide (H_2S).

For many years, biogas has been used in household and farm-scale sectors. Biogas production has been a standard process since the 1930s for the stabilization of sewage sludge. Over the last 40 years, what changed is that biogas production has been on a more industrial level, with better efficiency, level of complexity and specification [10].

Since the twenty-first century, policymakers have recognized that biogas production can simultaneously answer several challenges. For example, it can reduce emissions of greenhouse gases (GHGs) such as methane, provide a renewable source of energy, and lead to decreasing impacts of pollution by waste disposal. Equally important, the process upgrades the waste into a product and makes it a valuable organic fertilizer, thus closing the cycle from soil to crop, development, waste, and back to the ground [10].

A primary objective of the biogas industry is the reduction of fossil fuel consumption, with the final goal of mitigating global warming. However, anaerobic digestion is associated with the production of several greenhouse gases. Therefore, dedicated measures should be taken to reduce these emissions. According to several authors [11, 12], the main criteria to improve the reduction of global warming potential of biogas sites are to use a flare to avoid methane discharge, to conceal tanks, to improve the efficiency of combined heat and power (CHP) units, to improve the electric power utilization strategy, to exploit as much thermal energy as possible, to avoid leakages. Also, other conclusions were that the biomethane chain exceeds the minimum value of GHG saving (35%) mainly due to the open storage of digestate; usual practices to improve GHG reduction (up to 68.9%) include using heat and electricity produced by the biogas CHP plant and covering digestate storage tanks [13].

Table 2.5- Biogas use emissions, methods of measurement and SG usage: adapted from [13]

Emissions of interest by Biogas	Analytical Methods	Speciality Gases Requirement
NO_x	IR	Yes
CO	GC-MS/ IR	Yes
SO_2	IPA/ DPM	No
NMVOC[a]	--	--
CH_2O[b]	HPLC	No

[a]Non-methane volatile organic compounds

[b]Formaldehyde

Note: IR (infrared spectrometry), DPM (dewpoint meter), IPA (absorption in isopropyl alcohol solution), GC-MS (gas chromatography-mass spectrometer), HPLC (high performance liquide chromatography).

Biomethane is a gas resulting from a process that increases the quality of biogas by reducing its levels of carbon dioxide, hydrogen sulphide, moisture, and other gases. As a result, biogas upgraded to biomethane has a higher percentage of pure methane. Presently, the biomethane composition differs since its production can depend on several aspects like exact temperature, location, biogas composition, and more [10].

Biomethane offers many advantages, such as being a renewable energy source; when burned, it emits less pollution than diesel or gasoline. The emissions from these fuels are compared in Table 2.7. In table 2.6, is represented the emissions, analytical methods to measure and SG usage of biomethane.

Table 2.6- Biogas use emissions, methods of measurement and SG usage: adapted from [13]

Emissions of interest by Biomethane	Analytical Methods	Speciality Gases Requirement
NO_x	IR	Yes
CO	GC-MS/ IR	Yes
SO_2	IPA/ DPM	No
NMVOC[a]	--	--
CH_2O[b]	HPLC	No

Biomethane can be produced from locally made biogas. It eliminates the need to transport the gas over long distances as natural gas. Processing waste into biomethane reduces aquatic pollution; an increased share within a country's borders makes a nation's natural gas supply more reliable. Biomethane is economically attractive in lowering the costs of importing fuel and rising local production; rural areas significantly profit from biomethane production because a considerable part of the revenue along the value chain is generated there [10].

Table 2.7- Emissions from certain transportation fuels: adapted from [10]

Components	Emission Unit	Gasoline	Diesel	CNG (CBG)*
CO	g/km	10.9	0.662	6.54
NOx	mg/km	559	507	504
SO_2	mg/km	3.5	21.6	3.5
VOC	mg/km	662	166	146
TPM	mg/km	15.8	68.3	3.2
PM_{10}	mg/km	15.5	68.2	3.2
$PM_{2.5}$	mg/km	7.1	55.6	1.4

*CBG- Compressed Biomethane Gas

In table 2.8, is represented the different compositions and standards for the other gaseous fuels. When this kind of fuel is analysed, the gas quality and energy quantity must be determined, and the accuracy of these values must be verified using gas chromatography [14].

Table 2.8- Gaseous fuels compositions and standards: adapted from [14]

Parameters	Biogas	Biomethane	Natural Gas
Measurements			
CH4	60,15	97,20	95,41
C2H6	-	0	1,93
C3H8	-	0	0,15
C4H10	-	0	0,02
CO2	35,50	1,80	0,65
H2S	2,876	1	4
Total Sulfur	2,730	-	-
O2	0,95	0,20	0
H2	0,005	0	0
H2O	Saturated	5,40	21,50
Derived valued			
N2 O2 CO2	39,85	2,80	2,47
Calorific Value	22,68	36,64	37,89
Wobbe Index*	23,70	48,30	50,38

*Measure of the energy content of gas measured based on its calorific value per unit volume at standard pressure and temperature

Hydrogen has been the most abundant element of the Universe, and it has a lot of different sources to be produced. This element was first discovered in 1671 by British scientist Robert Boyle while experimenting with ions and acids. But the first written paper about this element was made by Henry Cavendish in 1766.

Hydrogen is not thought of as a primary energy source but is an energy carrier transformed from other energy sources. It has a low environmental impact at the point of usage, and there can be some problems about impact in its production and distribution [15]. When consumed in a fuel cell, it is a clean fuel that produces only water (figure 2.2). Natural gas, nuclear power, biomass, and renewable power are examples of the various domestic resources' hydrogen can be created, in table 2.9 is represented the hydrogen production methods and the respective environmental and scaling factors. Nowadays, several ways can make hydrogen fuel; the more common are natural gas reforming and electrolysis [16].

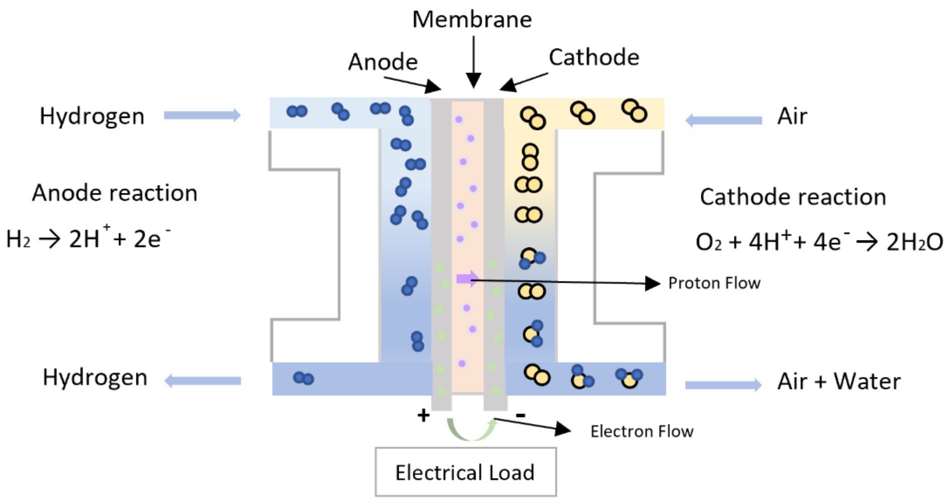


Figure 2.2- PEM Fuel Cell: adapted from [16]

Table 2.9- Hydrogen production methods: environmental and scale potential: adapted from [17]

Method	Renewable	Scaling potential
Natural gas reforming	No	Good
Coal gasification	No	Good
Biomass gasification	Yes	Moderate
On-shore wind	Yes	Moderate
Off-shore wind	Yes	Moderate
Thermal solar/electrolysis	Yes	Good
Solar PV/electrolysis	Yes	Moderate
Nuclear electrolysis	No	Good

There are several codes for the categorization of hydrogen by colour. The European Union used them, and it depends on the feedstock, energy utilization, and more.

- Black: Hydrogen created from fossil fuels by gasification of coal with high emission of greenhouse gases.
- Grey: Hydrogen created from fossil fuels by SMR (Steam Methane Reforming), use of methane with high greenhouse gas emissions.
- Blue: Hydrogen produced from fossil fuels with CO2 capture (carbon-free hydrogen). CO2 is usually stored geologically in old empty oil or gas pockets. A technique called CCS (Carbon Capture and Storage).
- Turquoise: Pyrolysis (including hydrogen plasma produced via methane, depending on the source of electricity used)
- Yellow: produced by water electrolysis and nuclear electricity.

- Green: hydrogen created by electrolysis of water with electricity exclusively from renewable sources (solar, wind, or hydroelectric installations).

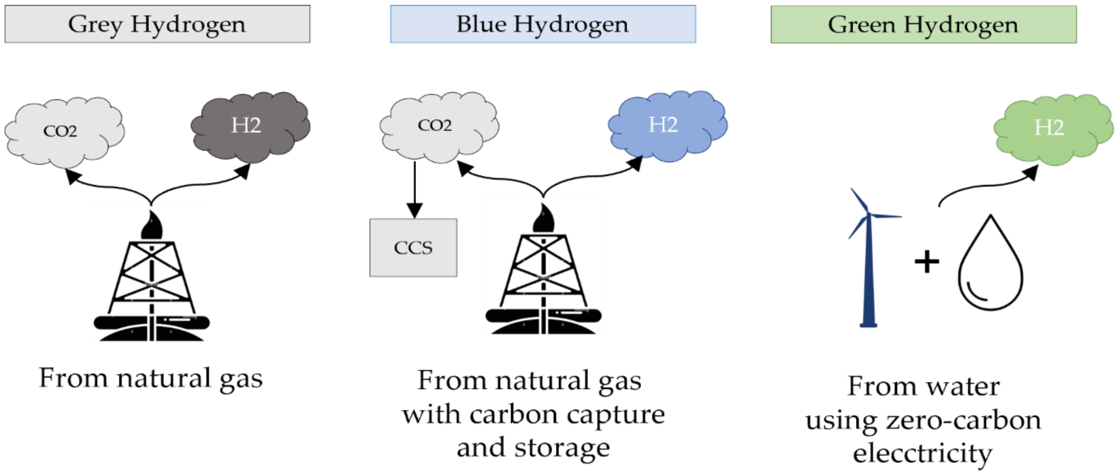


Figure 2.3- Difference between hydrogen based on its production: adapted from an inside source

The more common hydrogen production is grey, blue, and green. In figure 2.3, it is possible to understand the main difference in its utilization and production.

The chain involves using renewable electricity to electrolyze water for hydrogen, used as an energy carrier or energy vector to various conversion devices. Finally, it is transformed back into helpful electricity for the end-user applications.

Automobiles generate the most significant demand for fossil fuels worldwide, and this drives the most problematic emissions. Hence, the transport sector is likely to be decisive in these arguments and lead to a hydrogen cycle-based infrastructure, as shown in Fig. 3.6. Thus, hydrogen and fuel cells are the only reasonable options to prevent direct economic and climatic consequences. Moreover, it is helpful for the gases market since hydrogen needs to be measured and analysed [17].

To have hydrogen in fuel cells, this must be measured to ensure that it has the specifications of this technology. In table 2.10, is represented the analytical sampling and measurement of contaminants at H_2 fuelling stations in Japan.

With the growing H2 stations and hydrogen as a fuel, the AL market has a good perspective since gas chromatography uses gases for measurement and calibration.

Table 2.10- Hydrogen as a fuel specification: adapted from [18]

Impurities	Analytical methods	SG Requirements	Detection limit	Determination limit	Threshold limit in ISO
H_2O	DPM	No	0,5	1,7	5
THC	GC-FID	Yes	0,1	1	2
O_2	O_2 meter	No	0,01	0,03	5
He	GC-TCD	Yes	3	9	300
N_2, Ar	GC-TCD	Yes	1	3	100
CO2	GC-MS	Yes	0,01	0,03	2
CO	GC-FID / IR	Yes	0,01 / <0,05	0,03 / 0,05	0,2
Total S	IC	No	0,001	0,004	0,004
HCHO	DNPH/HPLC	No	0,002	0,006	0,01
HCOOH	IC	No	0,002	0,005	0,2
NH_3	IC	No	0,01	0,04	0,1
Total halogenate	IC	No	0,05	0,17	0,05
PM size	--	--	--	--	10
PM conc	--	--	--	--	1

Note: DPM (dewpoint meter), GC-FID (gas chromatography-flame ionization detector), GC-TCD (gas chromatography-thermal conductivity detector), GC-MS (gas chromatography-mass spectrometer), IR (infrared spectrometry), IC (ion chromatography), DNPH/HPLC (dintrophenylhydrazine-high-performance liquid chromatography).

Figure 2.4 makes it possible to analyse how the research for hydrogen fuel has evolved over the years. Over the last ten years has been developed over 15 000 scientific articles used for investigation in this field. It is a reason to the point that this is a growing market, and to measure this compound, it has gases utilization, even for scientific purposes, which is a good insight for Air Liquide's market.

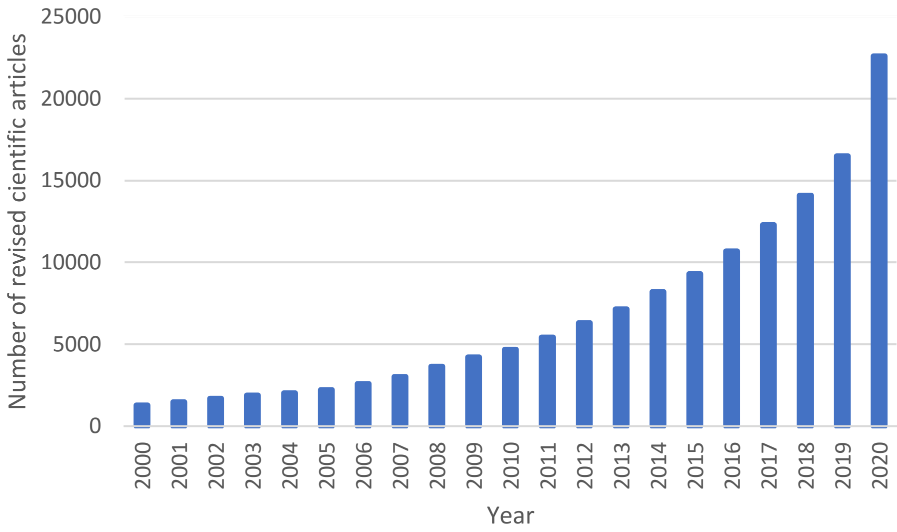


Figure 2.4- Evolution of scientific articles about hydrogen as a fuel (Google Academic; hydrogen as a fuel)

2.2. Technology Readiness Level (TRL)

In 1974, Stan Sadin developed a system of the current NASA because of the need for a "technology-independent scale" called the technology readiness level (TRL), which contained seven levels. In 1990, the system was adapted to incorporate nine levels. Five years later, John Mankins codified the nine-level TRL system in a white paper that offered a limited description of each level and its criteria. Then, in 2000, Brown and McCleskey proposed a new TRL containing a level 10, which indicated "flight-certificated maturity" that is a resource for space technology. NASA developed and created this system for aerospace applications, and the scale was also adapted for non-aerospace [19].

TRL is a method for assessing the maturity of technologies. The usage of this method allows for a uniform and consistent discussion of technical maturity in different types of technology. They are based on a scale from 1 to 9, with nine being the most mature.

Between 1 to 2 represents a basic technology, still in the research phase. 2 to 3 means that the technology is still in the research phase to prove its viability. From 3 to 5, the technology is already being developed. From 5 to 6, the technology is being demonstrated. From 6 to 8, it is already in systems development; it is defining, designing, testing, and implementing a new program. Finally, from 8 to 9, the technology is already mature and already in operation.

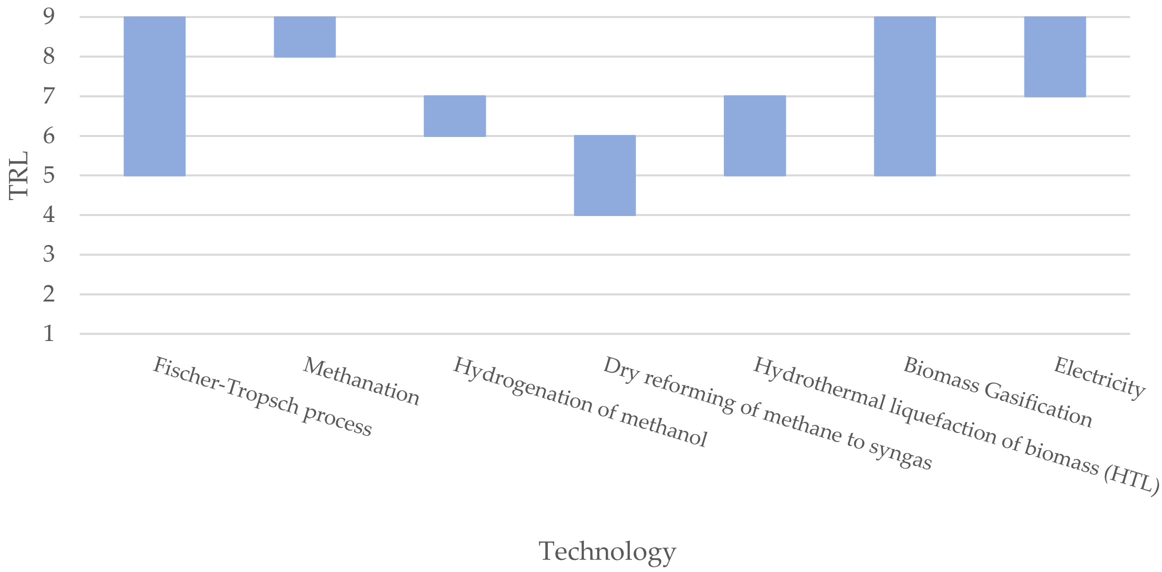


Figure 2.5- TRL's of fuels production [84, 85]

There are several technologies to produce fuels, in figure 2.5 is an example of some technologies with the respective TRL to analyse how advanced they are and the upcoming ones.

In figure 2.5, it is possible to verify the reach of the TRL of the respective technologies. Overall, fuel conversion technologies are mature and up-to-date technologies. However, newer technologies with lower TRL are part of the renewable path, such as dry reforming.

2.3. History of fuels emissions

Without considering the consequences of the financial decisions, everyone retracts benefits from activities that pollute the earth, and energy generation is the most considerable. When pollution is not considered, fossil fuel consumption is the cheapest form of energy and has been for the last centuries.

Climate change and the increase of atmospheric carbon dioxide associated with energy and industrial production are a growing concern since they can come from various fuel types. Moreover, the impact of these resources has changed considerably over time, and today still reveal significant variations by region.

Figure 2.6 shows the contribution of CO2 emissions by source, distinguished between coal, gas, oil, flaring, and cement manufacture through time between 1990 and 2019.

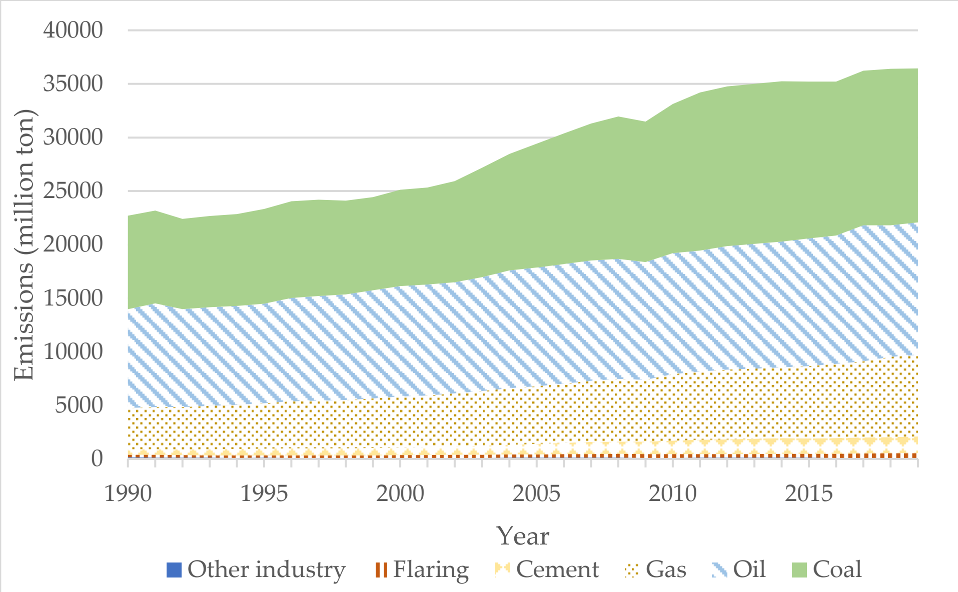


Figure 2.6- CO2 emissions by type of fuel: adapted from [20]

Globally, it is seen that early industrialization was ruled by using solid fuel. Coal-fired power at an industrial scale was the first to emerge in Europe and North America during the 1700s. Nevertheless, it was not until the late 1800s that it began to grow in oil and gas production emissions. Emissions from flaring and cement production began after one century.

Today, solid and liquid fuels stand out, although contributions from gas production are also noteworthy. The tendencies vary substantially by region. Overall, the patterns across Europe and North America are alike: initial industrialization began with solid fuel consumption. Still, through time this energy mix has diversified. Today, CO_2 emissions are distributed evenly between coal, oil, and gas. It can be related to the consumption of speciality gases in the research and analysis area. These sectors over the years have been growing, and with an increase of environmental concern, there's more analysis demand, so more SG consumption.

Coal production was predominant all over Europe and America during the 19th and 20th centuries. However, the energy transition has become more relevant in these regions, explaining the decline in recent decades. Besides, there has been a rapid rise in coal emissions from economies suffering from industrialization in recent decades, such as China, South Africa, and India [20].

2.4. Analytical Methods - Fuels

2.4.1. Analytical methods - evolution

Today, analytical chemistry is known to be encircling any investigation of chemical material with the target of delivering information concerning its elements:

- *character* – form, quality, or pattern of chemical bonding

- *distribution* – homogeneity, but also concerning internal and external boundary surfaces
- *structure* – spatial arrangement of atoms or molecules.

This goal is followed using an appropriate combination of chemical, physical, and biological methods. Since the eighteenth century, the term "analysis" was practically implicit, and it was allied to the practice of the alchemists. In Lavoisier's era, Chemistry emerged and became an individual science, and the term "analysis" appears explicitly. Our understanding of matter has been responsible for the contribution of analytical chemistry. Many of the most significant discoveries in chemistry were typical examples of successful analysis, including discovering oxygen, halogens, and several other elements [21].

Through the years, the methods of modern analysis evolved. Figure 2.7 highlights the rapid rate of advancements in analytical chemistry during the 20th century [21].

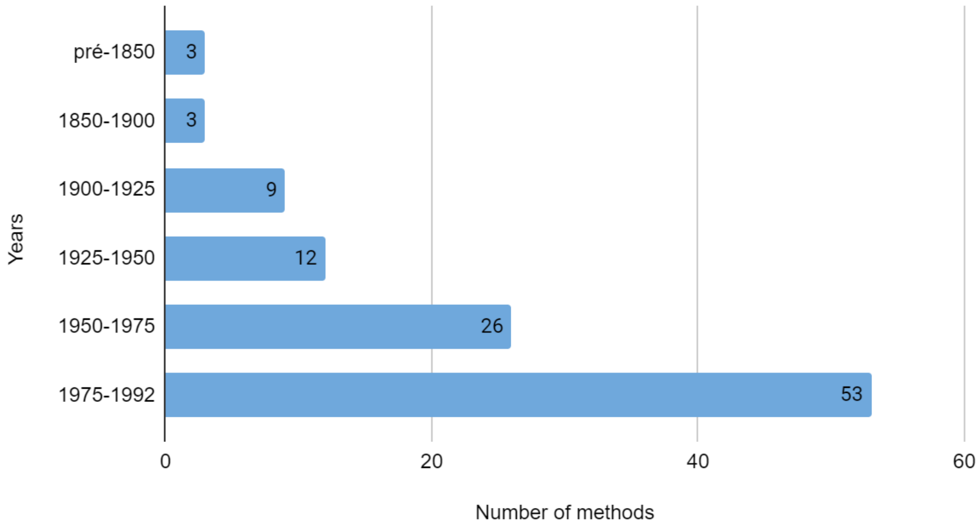


Figure 2.7- Evolution of experimental methods for analytical chemistry: adapted from [21]

It is to be noticed that the analytical techniques operated by gas have become more critical over the years, increasing their use.

There are two types of reactions in analytical chemistry: selective and specific. A particular response or test occurs with other elements. Still, it displays a level of preference for the essence of interest, and a particular test or reaction occurs only with the element of interest. Only a few analyses are detailed, but many can achieve selectivity through several strategies, for example [22]:

- Sample preparation (extraction, precipitation)
- Instrumentation (selective detectors)
- Target analyte derivatization (derivatize specific functional groups)
- Chromatography, which separates the sample elements

Table 2.11 represents a comparison between some different analytical methods.

Table 2.11- Comparison between analytical methods: adapted from [22]

Method	Aprox Range (mol/L)	Aprox Precision (%)	Selectivity	Speed	Cost	Principal Uses
Gravimetry	10^{-1} - 10^{-2}	0.1	Poor – moderate	Slow	Low	Inorg.
Titrimetry	10^{-1} - 10^{-4}	0.1 – 1	Poor – moderate	Moderate	Low	Inorg., org.
Potentiometry	10^{-1} - 10^{-6}	2	Good	Fast	Low	Inorg.
Electrogravimetry, coulemetry	10^{-1} - 10^{-4}	0.01 – 2	Moderate	Slow – moderate	Moderate	Inorg., org.
Voltammetry	10^{-3} - 10^{-10}	2 – 5	Good	Moderate	Moderate	Inorg., org.
Spectrophotometry	10^{-3} - 10^{-6}	2	Good – moderate	Fast – moderate	Low – Moderate	Inorg., org.
Fluorometry	10^{-6} - 10^{-9}	2 – 5	Moderate	Moderate	Moderate	Org.
Atomic Spsctros-copy	10^{-3} - 10^{-9}	2 – 10	Good	Fast	Moderate – High	Inorg., multi-element
Chromotography-Mass Spectrometry	10^{-4} - 10^{-9}	2 – 5	Good	Fast – moderate	Moderate – High	Org., multi-component
Kinetics methods	10^{-2} - 10^{-10}	2 – 10	Good – moderate	Fast – moderate	Moderate	Inorg., org. en-zymes

2.4.2. Chromatography - Evolution and characterization

Inside analytical chemistry, chromatography is the single most popular and cost-effective separation technique available. Its applicability ranges from analysing permanent gases and natural gas to heavy petroleum products, oligosaccharides, lipids, and more. For this reason, it is relevant to study it in more detail since its discovery. Moreover, chromatography is one of the more straightforward techniques to implement with modest samples and perform divisions on an analytical level [23].

Chromatography history is long, and several scientists have given to creating and improving this technique. At the beginning of the twentieth century, the method was created and first developed by a Russian scientist, Tsweet, but he could not succeed because of that early stage of high technology. Nevertheless, some Germans took his work and succeeded in using chromatography to extract and purify plant pigments. Then, in cooperation with other scientists, Archer John Porter Martin (A.J.P Martin) created gas-liquid chromatography [23].

Chromatography techniques require a diphasic system, in which a mobile phase penetrates all through a stationary phase, causing a rapid mass transformation. The requirement is two phases in relative movement and an excellent connection between them so that the concentration in the stationary phase is constantly close to the equilibrium value. Since the mobile step is fluid, the primary selection standards are excellent solubility for the analytes and low-down viscosity. Therefore, the chosen fluids that dominate the chromatography techniques are gas, gas-dense (supercritical-fluid) and liquids.

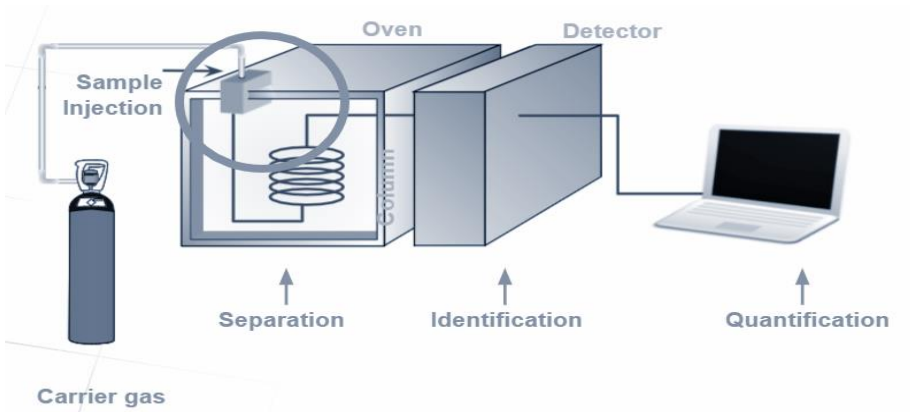


Figure 2.8- Gas Chromatography: adapted from Air Liquide's source

In gas chromatography, in the mobile phase are valuable quasi-ideal inert gases such as Helium, Hydrogen and Nitrogen; Their role is entirely mechanical; they provide transport for solutes down the column axis. The remaining time of solutes is impacted only by their vapour pressure, depending on the temperature and the intermolecular interaction between the solutes and the stationary phase.

When choosing the carrier gas, there are some aspects to consider, such as the column and the detector used and the required speed of analysis and detectability. The distinctions between the gases are apparent when comparing their Van Deemter curves; in figure 2.9, it is analysed, for the three gases (Helium, Hydrogen and Nitrogen), the relation between the speed of analysis and the column height [24].

Compared to helium and hydrogen, nitrogen has a high density, making the longitudinal diffusion spread slightly; but the resistance to mass transfer in the mobile phase improves. Since the other two gases have low density, the contrary happens.

The resistance to mass transfer in the stationary phase can be overlooked for columns with small quantities of stationary phases.

The optimum speed of analysis for each gas is:

$$u_{opt}(N_2) = 10\ cm/s$$

$$u_{opt}(H_2) = 40\ cm/s$$

$$u_{opt}(He) = 25\ cm/s$$

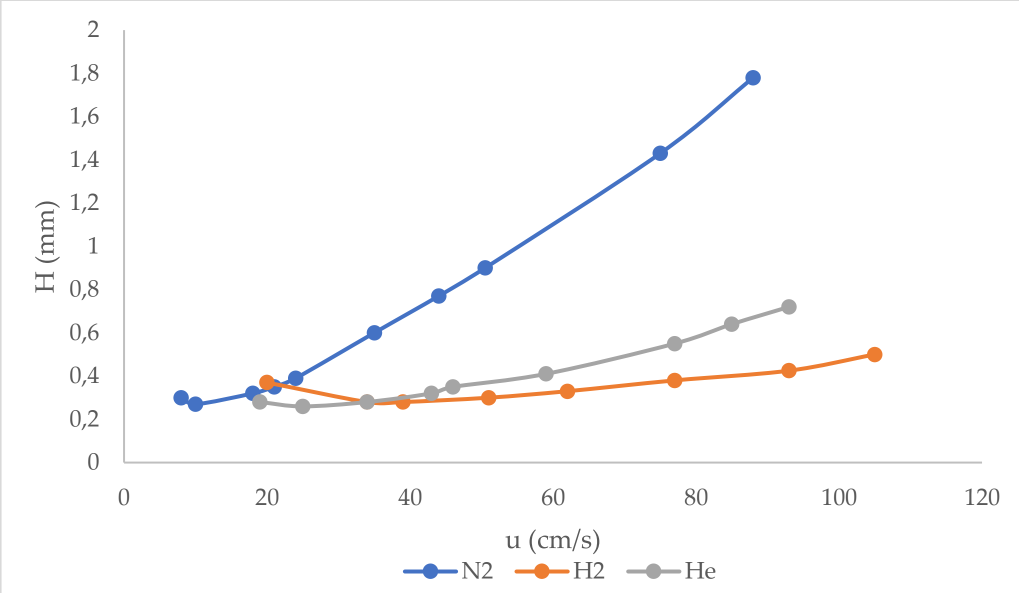


Figure 2.9- Van Deemter curves for N2, H2 and He: adapted from [24]

In thin-layer columns, hydrogen is the most excellent option because the analysis time is lowered by a factor of 4 compared to nitrogen. However, most of the time is rejected as a carrier gas because of the safety measures in the laboratories, taking into consideration other possibilities. The next gas with better performance is helium; nonetheless, it is a more expensive gas. In conclusion, nitrogen gas happens to be more selected, namely in GC columns with the low stationary phase (thin-film columns), where mass transfer resistance can be despised, and its cost is considerably lower than helium. However, in a stationary phase (thick-layer column) column, the choice remains between hydrogen and helium since mass transfer resistance plays an essential role in a quicker analysis [24].

2.4.3. Chromatography - Fuel measurement

Fossil fuels and oils are complex combinations of hydrocarbons and associated compounds; the composition of a particular hydrocarbon in each outcome depends on the type of fuel and its resource. For the characterization of petroleum products, several chromatographic techniques are applied to evaluate and determine compounds. Since most fossil fuels and oils have chemical groups instead of individual molecules, hydrocarbon type analysis (HTA) is used by chromatography; this has been the most common and popular characterization method to determine the quality of the fuel.

Petroleum and coal products are often submitted through chromatography techniques to measure boiling point distributions. However, fractionated results fall into three classifications depending on their boiling point range:

- light distillates (gasoline and naphtha)
- middle distillates (diesel, jet fuel and kerosene)
- heavy distillates (distillation cuts from vacuum gas oils).

Therefore, to fill the requirements for an ideal chromatography method for the determination of specific compounds, HTA or boiling point distribution, the process should [22]:

- robust and reproducible
- fast and measurable
- suitable for quality control
- relevant to the entire sample without demanding prefractionation

Most of these criteria are acceptable for light and middle distillates. Nevertheless, for heavy distillates or samples covering a broad boiling point as well as polarity range, they often have some limitations due to insufficient resolving power, little volatility, the low solubility of components in the chromatographic mobile phase, strong adsorption of sample components on the stationary phase, or low sensitivity [22].

A) Gas Chromatography

To meet environmental regulations, gas chromatography has long been an essential technique for petrochemical analysis. Its role ranges from monitoring process streams and characterization of feeds, intermediates, and products in refinery operations to providing analytical data. In addition, this technology can operate over a large variety of temperatures (-50ºC to 430ºC), granting these methods to be appropriate for samples varying from gas to high boiling residuum [25].

Table 2.12 represents a list of some GC techniques approved by the American Society for Testing and Materials (ASTM). It reveals the large selection of GC applications for petroleum-related materials and the usage of gases in this technology [26].

Table 2.12- GC methods for fuel analysis: adapted from [26]

Method no.	Application area	Description
D 2163	Liq. petroleum gas (LPG)	LPG analysis and propene concentration by GC
D 2268	n-Heptane and i-octane	Great purity n-Heptane and i-Octane analysis by capillary GC
D 2427	Gasoline	C2 - C5 hydrocarbons gasoline by GC
D 3710	Gasoline	Simulated distillation of gasoline and gasoline fractions by GC
D 4420	Gasoline	Aromatics in completed gasoline by GC
D 4815	Gasoline	Oxygenates (ethers and alcohols) in gasoline by GC
D 5307	Crude Oil	Simulated distillation of crude petroleum by GC
D 5443	Gasoline (finished)	Benzene, toluene, ethylbenzene, xylene, C9 + aromatics and total aromatics by GC

Over the years, in this type of technique, there have been many studies and developments. Figure 2.10 represents the increase over the years of scientific articles on this matter. Naturally, this means more gases usage since it can be used in laboratory analysis to develop this technique.

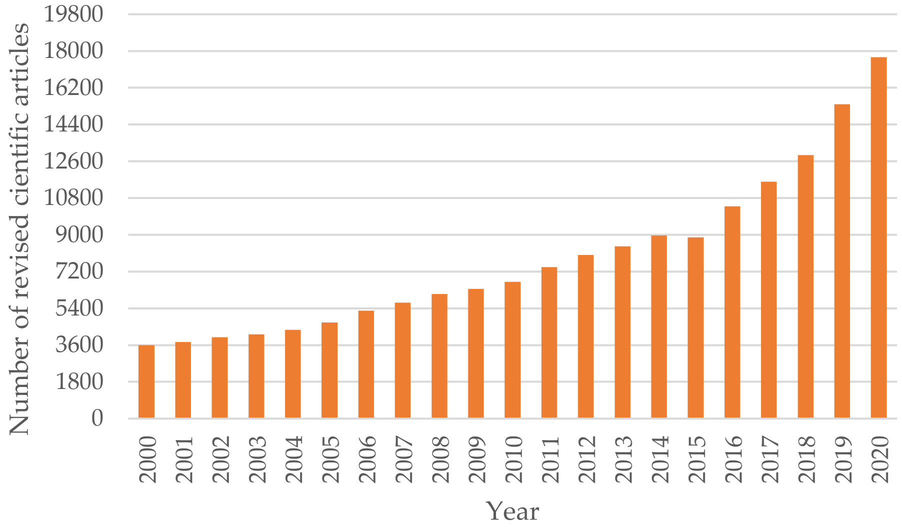


Figure 2.10- Number of revised scientific articles about GC over the years (Google Academic; gas chromatography fuel analysis)

With the Oil & Gas market restrictions growing, there is more demand for analysis, so the GC is a more requested technology for this market, increasing the gases usage and consecutively Air Liquide's need.

There have been many limitations over the years. Since 1992, the European Union has set up more stringent regulations to limit pollution from road transportation that is estimated to represent about 15% of the EU's CO2 emissions. The legal framework is called Euro n, with n = 1, 2, 3... being an increased number for each new stage voted every five years.

Table 2.13 represents the emissions standards timeline and the evolution until the last released, Euro 6. Euro 7 is planned to be released at the end of 2021.

Table 2.13- Emissions standards from Euro 1 to Euro 6: adapted from [27]

	Euro 1 (1993)		Euro 2 (1997)		Euro 3 (2001)		Euro 4 (2006)		Euro 5 (2008)		Euro 6 (2014)	
g/km	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel
CO	2,72	2,72	2,2	1,0	2,3	0,66	1,0	0,5	1,0	0,5	1,0	0,5
HC+NOx	0,97	0,97	0,5	0,7	-	0,56	-	0,3	-	0,23	-	0,17
PM	-	0,14	-	0,08	-	0,05	-	0,025	0,005	0,005	0,005	0,005
NOx	-	-	-	-	0,15	0,05	0,08	0,25	0,06	0,18	0,06	0,08
THC	-	-	-	-	0,2	-	0,1	-	0,1	-	0,1	-
NMHC	-	-	-	-	-	-	-	-	0,068	-	0,068	-

Air Liquide has adapted its offers to address this market needs. It has developed and commercialized a dedicated range named Alphagaz Auto, which includes pure gases and mixtures for Engine Emission Testing and homologation. It is an excellent example of Air Liquide's innovation that simplifies the analysis and calibration process.

2.5. Regulatory Environment

Over the years, the EU has been releasing several agreements and regulations for countries to follow in energy transition since it is an urgent matter.

2.5.1. The European Green Deal

The European Green Deal is a political initiative launched in 2019 by the European Commission to "make the EU's economy sustainable". The main goal is to become carbon neutral by not emitting GHG by 2050 and financial progress from resource usage.

This deal is an ambitious set of measures reaching from ambitiously reducing greenhouse gases emissions, investing in reducing margin research and innovation, and protecting Europe's natural environment. To deliver the Green Deal, a set of proposals were released aimed to make all sectors of the EU's economy right to meet this challenge [28, 29]:

- Transforming our economy and society.
- Making transport sustainable for all: since transports represent 25% of all emissions, there is expected a 55% reduction of emissions from cars, 50% reduction of emissions from vans by 2030 and zero emissions from new vehicles by 2035.
- Leading the third industrial revolution: since the industry sector only uses 12% of recycled material, there is an urgent call to make our industry a greener, competitive, and resilient sector worldwide.
- Cleaning our energy system: nowadays, energy production and use accounts for 75% of the EU's GHG emissions. So, until 2030 there is the ambition to reduce these emissions by at least 55%, 40% of the new renewable target and 36-39% new energy efficiency targets to final and primary energy consumption.
- Renovating buildings for a greener lifestyle.
- Working with nature to protect our planet and health.
- Boosting global climate action.

2.5.2. UN Sustainable Development Goals

In September 2015, all United Nations Member States adopted the Sustainable Development Goals (SDGs) to deliver a shared blueprint for peace and prosperity for people and the planet, now and in the future. The 17 SDGs are a global warning and a request for action by all countries. A worldwide relationship is integrated to reflect the nature of the many challenges humanity faces [30].

The SDGs were built on years of work between countries and the UN. It started in June 1992, at the Earth Summit in Brazil where more than 178 countries adopted Agenda 21 – a plan of action to be taken globally, nationally, and locally by organizations of the United Nations System, Governments, and Major Groups in every area in which human impacts on the environment. In September 2000, at UN Headquarters, Member States collectively adopted the Millennium Declaration at the Millennium Summit, which ran to the elaboration of eight Millennium Development Goals to reduce poverty by 2015. In 2012, at the UN Conference on Sustainable Development, Member States adopted the outcome of the "The Future We Want", in which they decided to launch a process to develop a set of SDGs upon the MDGs. In 2013, a group of 30- members were set to start creating them. 2015 was a year of multilateralism and international policy shaping with the adoption and development of several agreements such as the Paris Agreement of Climate Change [30].

The SGDs can be grouped into three categories:

- Human development (SDGs 1-6): taking revenue poverty, deprivation, lack of access to essential services (health, education, water, and sanitation) and gender discrimination.

- Economic development (SDGs 7-11 and 16-17): empowering conditions for poverty extinction, supplying access to energy, economic development, decent jobs, infrastructure and industry, declining inequality, housing, and peaceful societies.

- Environment (SDGs 12-15): ensuring that the poverty eradication plan is protected against ecological threats.

<u>Focus on Goal 13: Take urgent action to combat climate change and its impacts</u>

The Paris Agreement, implemented in 2015, aims to reinforce the global reaction to climate change risk by protecting a global temperature increase this century well below 2 degrees Celsius above pre-industrial levels.

According to the UN, 2019 was the second warmest year on record and the end of the warmest decade (2010-2019) ever described. Although the GHG emissions are projected to drop about 6% in 2020 due to travel prohibitions and economic strikes resulting from the COVID-19 pandemic, this progress is temporary [23].

Therefore, global temperatures could turn to a 1,5ºC ambitious target by the early-mid 2030s and the 2º level by 2050-2070. A 2ºC rise could lead to more heat waver, a ten-fold increase in the Arctic ice-free summers and destruction of the coral reefs.

It is an essential subject since fuels are 60% of the current GHG emissions; this change must pass through the transition for a greener path [23].

2.5.3. GHG Protocol

2.5.3.1. What are the GHG Protocol and history

The GHG Protocol was designed by the World Resources Institute (WRI). In addition, the World Business Council for Sustainable Development (WBCSD) delivers accounting and reporting standards, segment guidance, control tools, and training for businesses and local and national governments to help them track progress towards their climate goals.

The first version of Corporate Standards was issued in 2001 and has been updated with supplementary assistance that clarifies how companies can calculate emissions from electricity and other energy assets and account for emissions from all over their value chains [31].

2.5.3.2. Scopes 1, 2 & 3

The Kyoto Protocol covered seven greenhouse gases that the standards cover. This protocol was implemented in December 1997 and operationalized the UN Framework Convention on Climate Change by committing to industrialize countries and economies in transition to restrict and reduce the GHG emissions following agreed individual goals [32].

The seven GHG covered are carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PCFs), sulphur hexafluoride (SF6) and nitrogen trifluoride (NF3).

The GHG Protocol specifies direct and indirect emissions as respects [32]:

- Direct GHG emissions are from sources that are owned or monitored by a relating individual.
- Indirect GHG emissions result from the covered entity's activities but occur at sources owned or regulated by another entity.

To help categorize and delineate direct and indirect emission sources, improve transparency, and provide utility for different companies and various types of climate policies and business goals, three scopes are defined in figure 2.11 for emissions accounting and reporting.

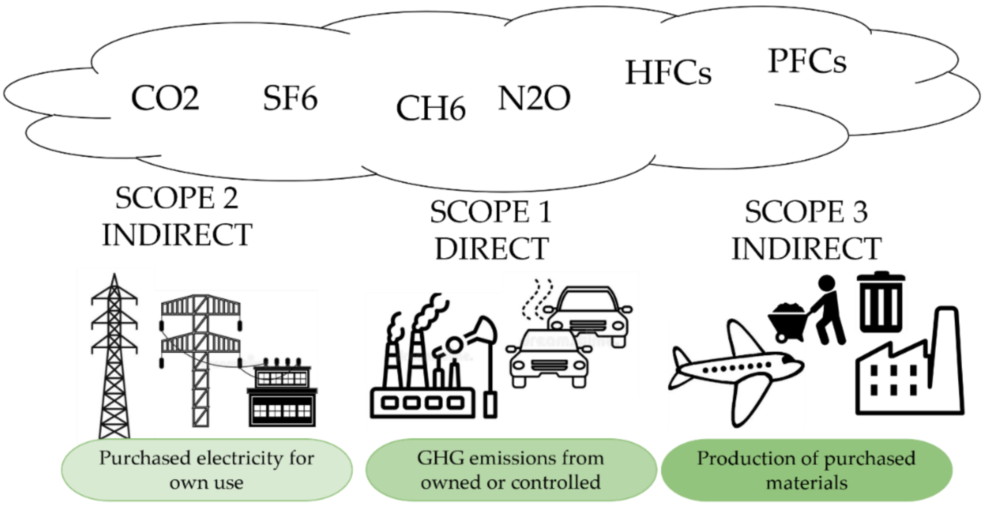


Figure 2.11- Overview of GHG Protocol scopes and emissions across the value chain: adapted from [31]

- Scope 1: All direct GHG emissions – this can occur from sources owned or operated by the entity, for example, emissions from combustion in owned boilers, automobiles, and more; emissions from chemical production held or retained process equipment.

- Scope 2: Indirect GHG emissions from the use of acquired electricity, heat, or steam. Physically take place at the facility where the electricity is produced.
- Scope 3: Other indirect emissions, for example, the extraction and production of acquired materials and fuels, transport-related movements in vehicles not owned or monitored by the reporting entity. This scope allows firms to assess their full value chain emissions impact and identify where to concentrate reduction activities.

Table 2.14 includes a 100-year time perspective of global warming potentials (GWP) relative to CO_2 of some GHG. The entire table can be found in Appendix B [33].

Table 2.14- Global Warming Potential relative to CO2: adapted from [33]

Industrial designation or general name	Chemical designation	Global Warming Potential (GWP) values relative to CO2
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265
HFC-23	CH_3	12 400
Sulfur hexafluoride	SF_6	23 500
Nitrogen trifluoride	NF_3	16 100
PFC-14	CF_4	6 630

2.5.4. 8th EAP (Environment Action Plan)

The financial part of the European Green Deal will be ensured until 2030 by the 8th EAP that will guide the environment policy during this period.

The offer of this action plan, proposed in October 2020, is to speed up the transition to a climate-neutral, resource-efficient, and regenerative economy. It has six priority objectives:

- Achieving the 2030 GHG emission target and carbon neutrality by 2050
- Improving adaptive capacity, increasing resilience, and decreasing vulnerability to global climate change

Developing towards a renewing growth model, decoupling economic increase from resource use and environmental degradation, and hastening the transition to a circular economy:

- Chasing a zero-pollution ambition, including for air, water, soil, and protecting the health and safety of Europeans.

- Defending, preserving, and rebuilding biodiversity and improving natural capital.
- Reducing environmental and climate demands related to production and consumption.

The EU plans to invest in policies set by the Green Deal through an investment plan which estimates at least 1 trillion euros in investment over a decade via different methods [34]:

- The most significant share, €503 bn, come up from the EU budget, releasing a further €114 bn from national governments from required contributions of member states.
- €279 bn would come mainly from the private sector encouraged to make risky green investments by the European Investment Bank loan assurances.
- Brussels has promised a €100 bn "just transition" mechanism to help retain employees who lose jobs in closed coal mines or steel factories.

2.5.5. Horizon 2020 and Horizon Europe

Horizon 2020 was the most significant EU research and innovative programme ruling between 2014 and 2020. Its history started in 2011 when EU Heads of State and Government called on the European Commission to collect the previous EU's research and innovation funding and structure them into a single framework. As a result, the Commission launched a wide-ranging consultation involving all stakeholders, leading to Horizon 2020 [35].

The EU's involvement in research activities goes since the 1970s with the adoption by the Council of the first Community research programmes. Before it was called Horizon, there were framework programmes (FP) beginning in the 1980s for investigation as a strategic tool to handle the adoption of research programmes more consistently. Figure 2.13 demonstrates the evolution of the EU's budget, which illustrates the clear ambition of the EU for its main R&I funding instrument and increases the relevance of science and technology in society to address our challenges [36].

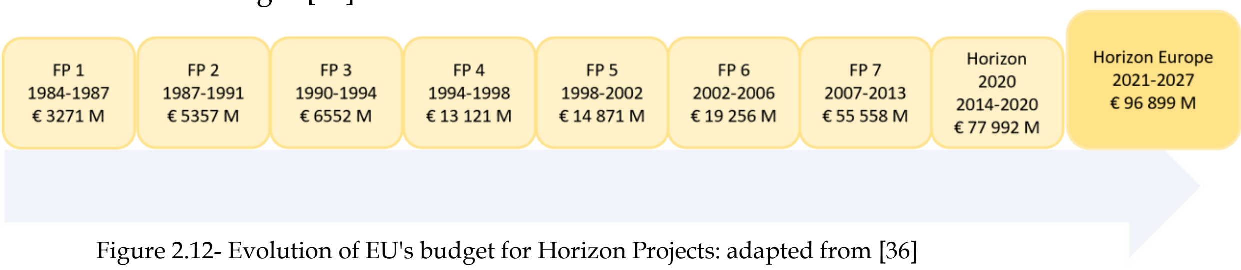


Figure 2.12- Evolution of EU's budget for Horizon Projects: adapted from [36]

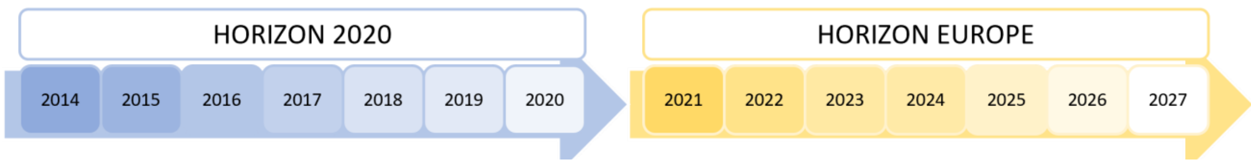


Figure 2.13- Horizons' programmes timeline: adapted from [37]

From 2014 until 2020, almost €77 bn of funding was available – this was used to finance projects to accomplish innovative, sustainable, and inclusive economic development. The goal was to guarantee Europe produces world-class science and technology, eliminates barriers to innovation and makes it simpler for the public and private sectors to work together to solve significant challenges [37].

After Horizon 2020, the next European programme, now in force, for Research and Innovation (R&I) is Horizon Europe. It will run between 2021 and 2027 with a budget of €100 bn.

This new framework relies on three pillars [37]:

1. Open Science: encourage the creation and diffusion of high-quality expertise.
2. Global Challenges and Industrial Competitiveness: reinforce the impact of R&I in helping EU policies
3. Open Innovation: encourage all forms of innovation and improve market deployment

During these programmes, many projects relating to environmental improvement are potential gases users by the companies who support them. Therefore, it is interesting to analyse the projects from Horizon 2020 and classify the companies to catch new potential customers for Air Liquide since the projects will only start from this year onwards [37].

Table 2.15- Pillars of Horizon Europe (2021-2027): adapted from [37]

<table>
<tr><th colspan="2">Pillar 1: Open Science
€ 25,8 bn</th><th colspan="2">Pillar 2: Global Challenges and Industrial Competitiveness
€ 52,7 bn</th><th colspan="2">Pillar 3: Open Innovation
€ 13,5 bn</th></tr>
<tr><td colspan="2">European Research Council (ERC)
€ 16,6 bn</td><td colspan="2">Health
€ 7,7 bn</td><td colspan="2">European Innovation Council (EIC)
€ 10 bn</td></tr>
<tr><td colspan="2">Marie Sklodowska-Curie Actions (MSCA)
€ 6,8 bn</td><td colspan="2">Inclusive and Secure Society
€ 2,8 bn</td><td colspan="2">European Innovation Ecosystems
€ 0,5 bn</td></tr>
<tr><td colspan="2">Infrastructures
€ 2,4 bn</td><td colspan="2">Digital and Industry
€ 15 bn</td><td colspan="2">European Institute of Innovation and Technology (EIT)
€ 3 bn</td></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Climate, Energy and Mobility
€ 15 bn</td><td colspan="2" rowspan="2"></td></tr>
<tr><td colspan="2">Joint Research Centre
€ 2,2 bn</td></tr>
<tr><td colspan="6">Strengthening the European Research Area</td></tr>
<tr><td colspan="3">Sharing Excellence
€ 1,7 bn</td><td colspan="3">Reforming and enhancing the European R&I System
€ 0,4 bn</td></tr>
</table>

2.5.6. LIFE

First started in 1992, the LIFE programme is the only EU fund devoted to environmental and climate goals. LIFE's general purpose is to help implement and develop policy and EU environment and climate regulation by co-financing projects with the European added benefit.

LIFE 2014-2020 has a budget of € 3.4 billion, and it is allocated into two sub-programmes: environment (representing 75% of the overall financial cover) and climate change (representing 25% of the total) [38].

The new LIFE programme will run between 2021 to 2027, with an increasing budget of 60% than the previous funding, with € 5,4 billion to support projects. The programme has the same sub-programmes in which €3,5 billion will be directed towards the environment, and €1,9 billion will go to climate action. With an increased budget, LIFE programme 2021-2027 expands to four new sub-programmes [38]:

- Nature and Biodiversity
- Circular Economy and Quality of life
- Climate Change Mitigation and Adaptation
- Clean Energy Transition

During these programmes, the same happens as Horizon 2020. Therefore, it is of interest to analyse the projects from LIFE and classify the companies to catch new potential customers for Air Liquide.

Over the years, this kind of programme has become more popular, and more projects have been uploaded concerning energy transition and more funding from the EU. As seen in section 4.1, there are several about the Oil & Gas industry. It can result in a growing demand for speciality gases due to this industry's quality control and environmental measurement.

2.5.7. Europe and Country Regulations

Europe analysed the regulations related to this market, energy emissions, mainly in the Oil & Gas sector.

For the four counties of the cluster, a resume table on the objectives for environmental ambitions was made, table 2.17. Although it was based on the 2021-2030 Integrated National Energy and Climate Plans (INECP), these documents are still pending parliament votes.

Table 2.16- Europe regulation targets until 2030: adapted from [28]

Renewable Energy	+ 32%
GHG emissions	- 40%
CO_2 emissions in transport sector	- 38%
Energy Efficiency	+ 33%
Fossil energy for primary energy consumption	- 40%
Final consumption of renewable energy in transport	+ 14%

Table 2.17- Countries targets until 2030: adapted from [39-42]

	France	Italy	Portugal	Spain
Reduction of GHG emissions	37%	33%	45% to 55%	23%
Energy efficiency	32,5%	35%	35%	39,5%
Renewable energy	33%	30%	47%	42%
Reductio of primary energy	25%	40%	35%	40%
Reduction of GHG emissions in transport sector	39%	22%	26%	33%
Reduction of fossil fuels consumption	30%	28%	27%	34%

2.6. Fuels Market Forecast

This chapter considers the rapid change in the sector of Oil & Gas due to environmental reasons. It presented several projections about the future of this sector, although it is very uncertain.

2.6.1. International Energy Agency (IEA) & BP Outlook

IEA is an agency created in 1974 during the oil crisis to ensure the security of oil supplies. The core mission is always energy security, but today has evolved into a global energy debate centre. They focused on various topics such as climate change, energy access, energy efficiency and air pollution. IEA works with several countries to establish the principal international forum for energy operation with international relations. The IEA's founding members were Austria, Belgium, Canada, Denmark, Germany, Ireland, Italy, Japan, Luxembourg, the Netherlands, Norway, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. They were followed by Greece (1976), New Zealand (1977), Australia (1979), Portugal (1981), Finland (1992), France (1992), Hungary (1997), Czech Republic (2001), Republic of Korea (2002), Slovak Republic (2007), Poland (2008), Estonia (2014), and Mexico (2018). Now, it works with a total of 30 countries worldwide [43].

IEA provides data about energy and how it will evolve in the future with examples of scenarios to comprehend better. It takes an all-fuels, all-technology approach and recommends policies that enhance reliability, affordability, and energy sustainability [43].

BP's history starts in 1908 with the discovery of oil in Persia. It has continually been about evolutions – from coal to oil, from oil to gas, and now forward towards a new mix of energy supplies as the world moves toward a lower-carbon future. Since 2011, BP has released every year Energy Outlooks which contains a projection of future energy. The objective is to identify long term energy trends and add their view on the evolution of the world economy, policy, and technology, to develop a projection for world energy markets [44, 45].

The BP's forecast presented is about 2019 and 2020, and it still doesn't represent the COVID-19 impact; only in 2021, this is released. The Outlook has scenarios made by BP, but it is important to reference that it doesn't represent predictions of what is likely to happen or what BP would like to happen. Instead, the scenarios help to illustrate the range of possible outcomes over the next 30 years, although the uncertainty is substantial.

The Rapid Transition Scenario (Rapid) introduces a series of policy measures, led by a significant increase in carbon prices and supported by sector-specific actions, which cause carbon emissions from energy use to fall by about 70% until 2050. The Net Zero Scenario assumes that the policy measures incorporated in Rapid are added and reinforced by significant changes in society's behaviour, which further accelerate the reduction in carbon emissions. Therefore, global carbon emissions from energy usage will fall by more than 95% by 2050. The Business-as-usual (BAU) scenario assumes that government policies, technologies and social preferences continue to evolve in a manner and speed seen in the past. The continuation of this progress, albeit relatively slow, means the peak of carbon emissions in the mid-2020s. However, little progress has been made despite this peak in reducing carbon emissions from energy use, with emissions in 2050 less than 10% below 2018 levels [46].

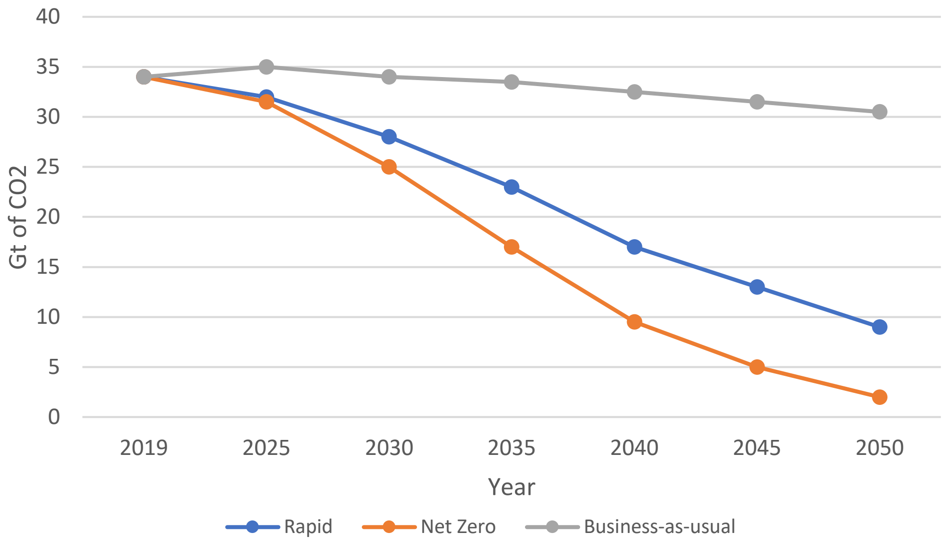


Figure 2.12- CO2 emissions from energy use with different scenarios: adapted from [47]

Since the predictions of CO_2 emissions are to have declined until 2050, the consumption for analysis of speciality gases is predicted to grow, correspond to the demand for that this sector will have, and have better environmental control.

For energy consumption forecast by a source of energy, BP Outlook 2019 had available for the European Union until 2040. For the projections of the cluster countries, a prediction was made based on each country's share compared with the EU in the year 2018. The assumption made was that the share wouldn't change over the years.

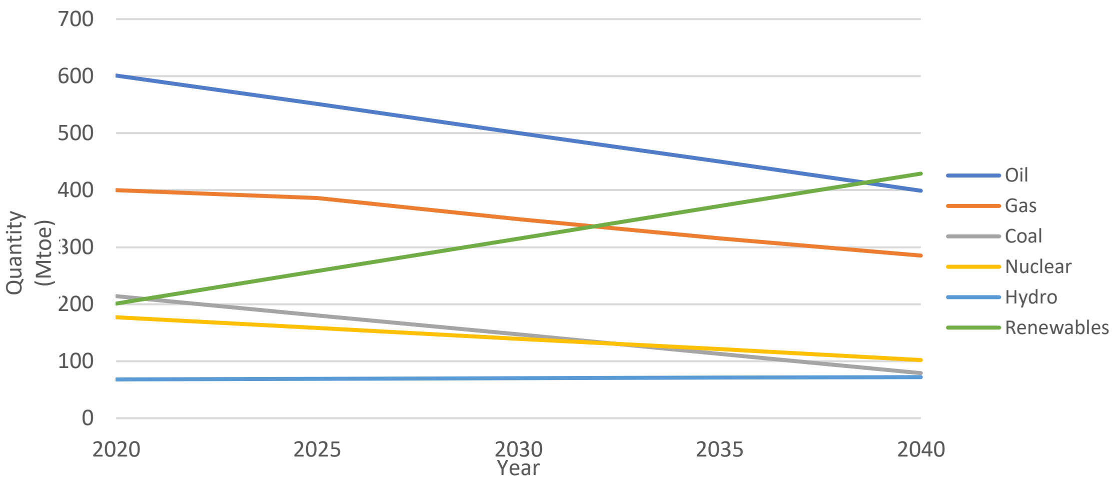


Figure 2.13- European Union's energy consumption forecast: adapted from [46]

In figure 2.16, is represented the forecast of the cluster. In addition, it has a CAGR (Compound Annual Growth Rate) by application described in Table 2.18. The result for each country is in Appendix C.

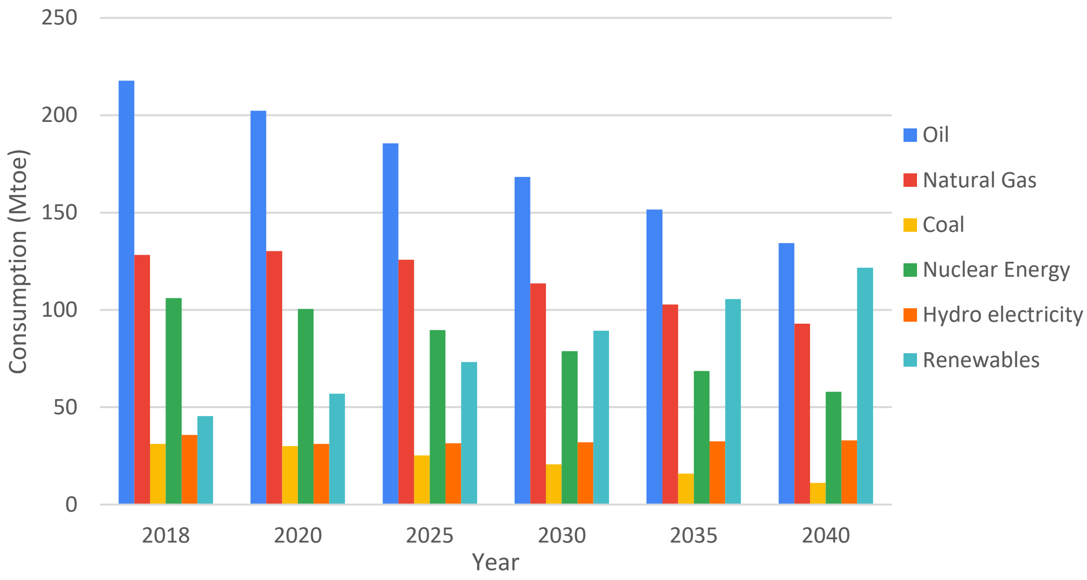


Figure 2.14- Cluster energy consumption forecast: adapted from [46]

Table 2.18- CAGR of energy consumption forecast of the cluster

	CAGR 2020-2040	CAGR 2020-2025
Oil	-1,6%	-1,7%
Natural Gas	-1,5%	-0,7%
Coal	-4,0%	-3,4%
Nuclear Energy	-2,2%	-2,2%
Hydro electricity	+0,2%	+0,3%
Renewables	+2,6%	+5,1%

The Natural Gas production and consumption of EU's will negatively impact the decrease in output of sites in northern Europe, as seen in figure 2.17. Still, in the next few years, natural gas will be consumed in several areas such as industrial and power, regarding the Rapid scenario from BP. On the horizon of 2050, natural gas will be replaced with more renewable sources that don't release emissions to the atmosphere. Still, this application is the most durable one within the hydrocarbons [46].

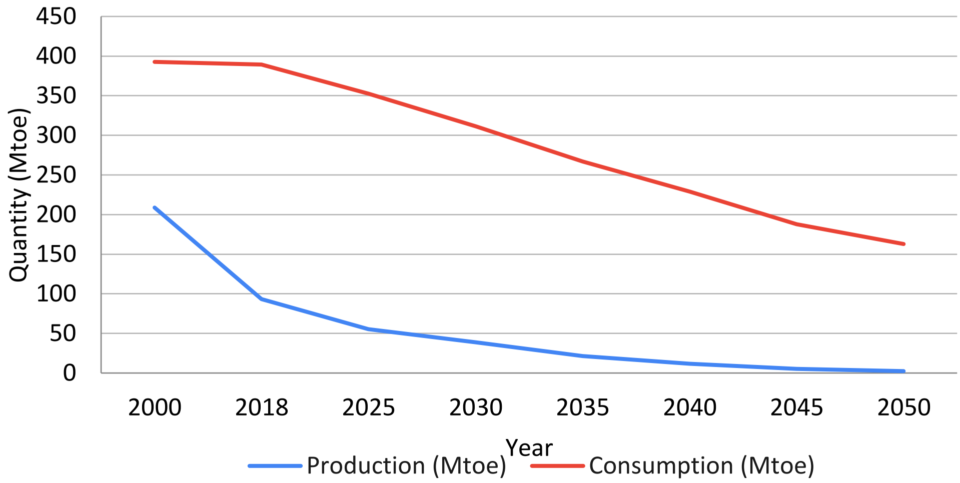


Figure 2.15- European Union's Natural gas consumption and production: adapted from [46]

The refinery forecast is a sensitive subject since the predictions are not very optimistic. Until 2040, we can see the production decreasing over the years; this is felt by the shutdown of several refineries in Europe, such as Galp from Portugal, Total from France, and Gela Refinery (Eni) from Italy.

Refiners will have to concentrate on petrochemical integration to offset decreases in transport fuels. However, this application will also need to make critical strategic decisions as the path to decarbonization will offer challenges and opportunities. For example, the market for traditional refined products will shrink, replaced by biofuels and other low carbon options [46].

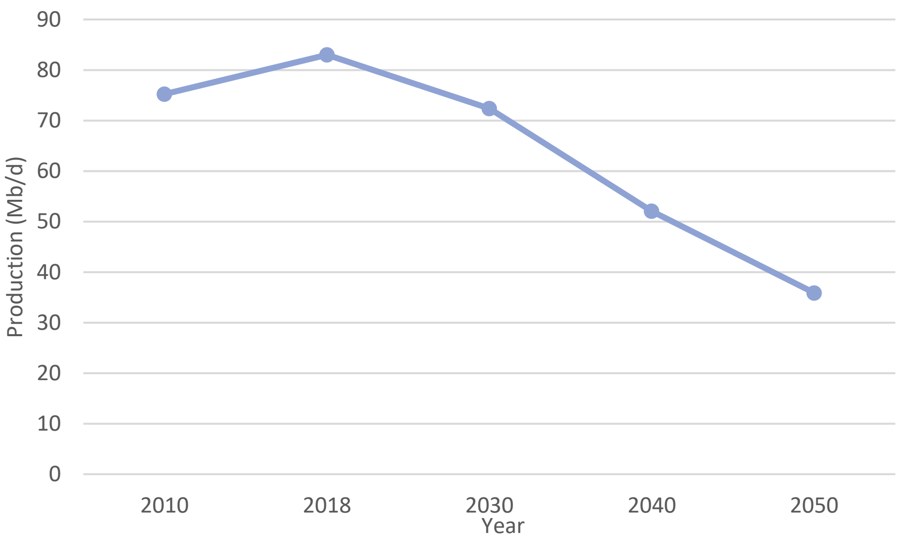


Figure 2.16- Europe's refinery production forecast: adapted from [46]

One of the upcoming sources of energy is biomethane. It is an upgrade of biogas which can be used as a direct substitute for natural gas across all sectors since it can deliver the energy system benefits of natural gas while being carbon neutral. Moreover, by turning organic waste into a renewable energy resource, biogas or biomethane production presents a window onto a world in which assets are continuously used and reused. Thus, the rising demand for energy services can be met while also delivering more comprehensive environmental benefits.

The demand for biomethane will increase substantially in Europe because of countries with significant influence on production like France, Italy, and Germany.

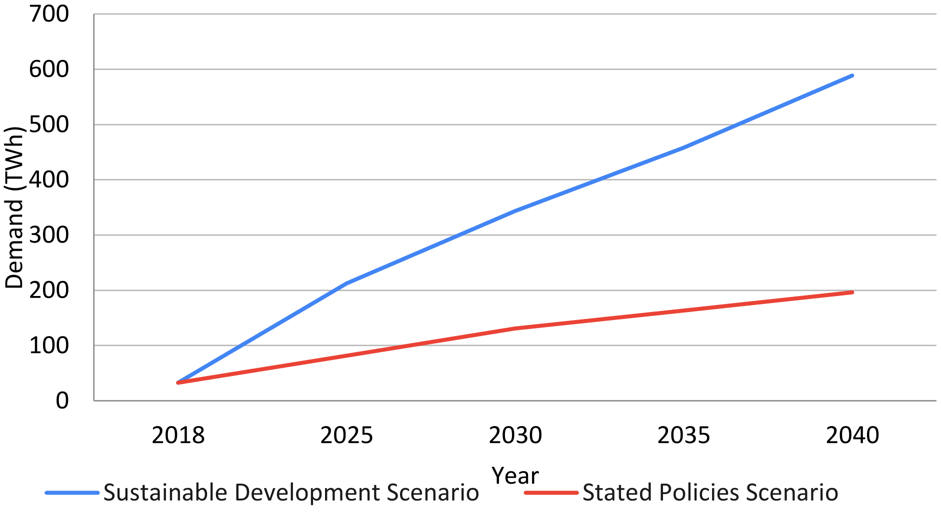


Figure 2.17- Europe's biomethane demand by scenario: adapted from [48]

Two scenarios are presented; the Stated Policies Scenarios (STEPS) represent the IEA's assessment of nowadays energy and climate policies. This scenario gives a sense of the direction in which the global energy system is heading. The Sustainable Development Scenario (SDS) takes the opposite approach; in this case, it supposes and fixes the endpoint, the full achievement of various energy-related sustainable development goals, and then works out the pathway to reach them. As a result, it significantly hurts a path for the global energy sector to align with the Paris Agreement [48].

For the biomethane production forecast, it was available for the countries of the cluster. Italy is a significant biogas producer, with 2041 plants in 2019, a top 3 producer in Europe [47]. It is foreseeable that they will reuse the biogas production sites and adapt them into biomethane production sites. For France, we see a significant increase between 2023 and 2030 which will be responsible for a substantial rise in biomethane production sites. These countries are beneficial because they have government support to develop this kind of technology.

Iberia is expected to remain constant with almost zero biomethane production since there are no prospects of possible sites opening soon.

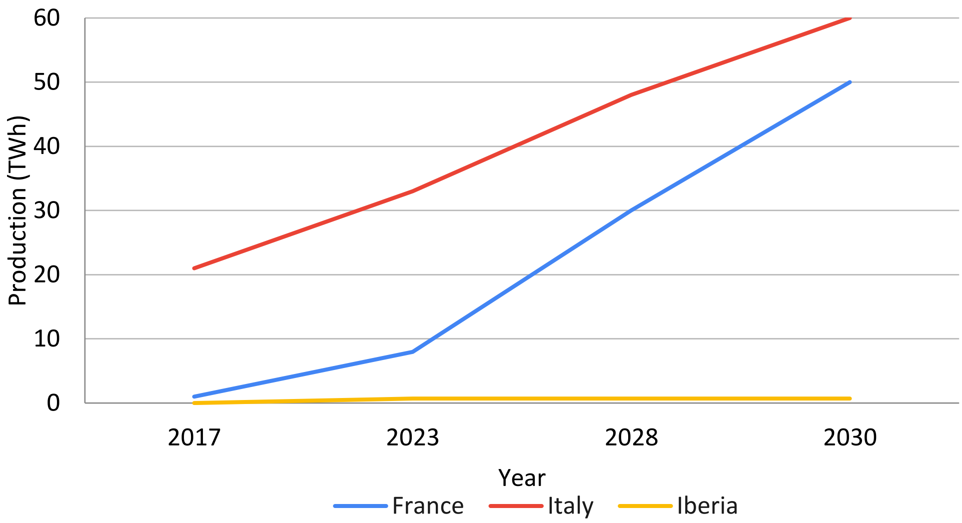


Figure 2.18- Biomethane production forecast for countries of the cluster: adapted from [49]

Hydrogen will also be an upcoming source of energy, mainly for transport usage. In the future, transportation will have different sources of hydrogen such as fuel cells, hydrogen fuel stations, and injection into the gas grid. Although clean energy progress is in progress, the production and demand for hydrogen have been continuously growing over the years, according to figure 2.21. It can be tracked using three indicators [50]:

- The extent to which low-carbon hydrogen production replaces conventional hydrogen in existing industrial applications.
- Demand in new sectors, such as transportations, industrial applications, gas grid injection and electricity storage.
- Scale-up cost reductions and improvements of technologies.

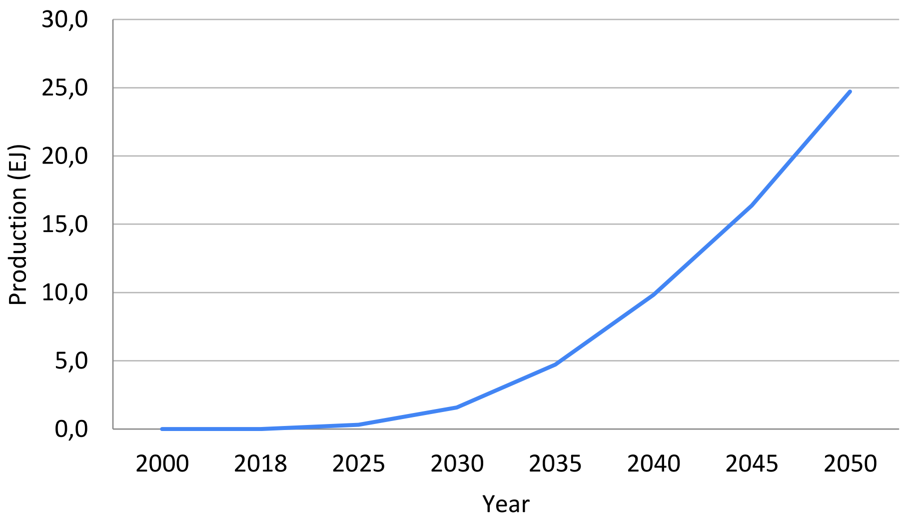


Figure 2.19- Projection of hydrogen production for Europe – SDS scenario: adapted from [50]

2.7. Market Analysis

2.7.1. Market Characterization

Before the definition of the market, there are two concepts worth mentioning: supply and demand. These concepts are the forces that make market economies work; they define the quantity of each good or service made and the value at which it is sold. In addition, the terms refer to people's behaviour as they interact with one another in competitive markets.

A market is a class of sellers and purchasers of a particular good or service. The buyer's group determines the necessity for the product, and the seller's unit decides the supply of the product. Markets can take many forms, well organized or less organized. In well-organized markets, buyers and sellers meet at a specific time and place where an auctioneer helps set prices and arrange sales. More often, markets are less organized. In this case, there is not an auctioneer calling out the costs. Instead, each seller posts a price for a good, and each buyer decides how much good to buy.

A competitive market is a market where there are so many buyers and retailers that each has an insignificant influence on the market price because other sellers offer similar products. To reach the most excellent form of competition, a *perfectly competitive* market must have two characteristics: The goods offered for sale are all the same. The consumers and retailers are so numerous that no single buyer or seller has any effect over the market price, and they must accept the price the market establishes – they are *price takers*.

Some markets have only one seller, and this seller decides the price. Such a seller is called a *monopoly,* and it is also a *price marker* because it can affect the market price of its products [51].

An industry is a natural monopoly when one firm can deliver a good or service to an entire market at a lower cost than two or more firms. This type of market occurs when there are economies of scale over the range of output. For example, in the case of figure 2.22, when production is divided between more firms, each firm produces more minor and the average total cost increases. As a result, one firm can produce any given amount at the least cost.

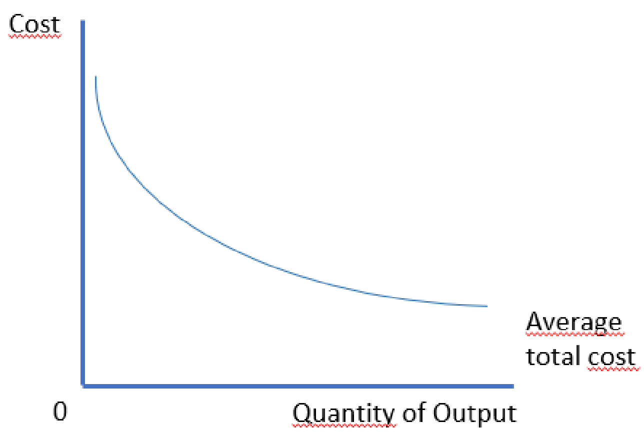


Figure 2.20- Economies of scale as a cause of monopoly: adapted from [51]

Oligopoly is an imperfect market, with only a few firms proposing a similar or identical product to the goods offered by other companies in the market. Firms in an oligopoly are concerned with what their competitors are offering and how they would react to what it might do.

Another type of imperfect market is monopolistic competition; this describes a market in which many companies offer similar but not identical products. This market is characterised by the following attributes: many sellers, product differentiation and free entry and exit – which means firms can enter or exit the market without restrictions [52].

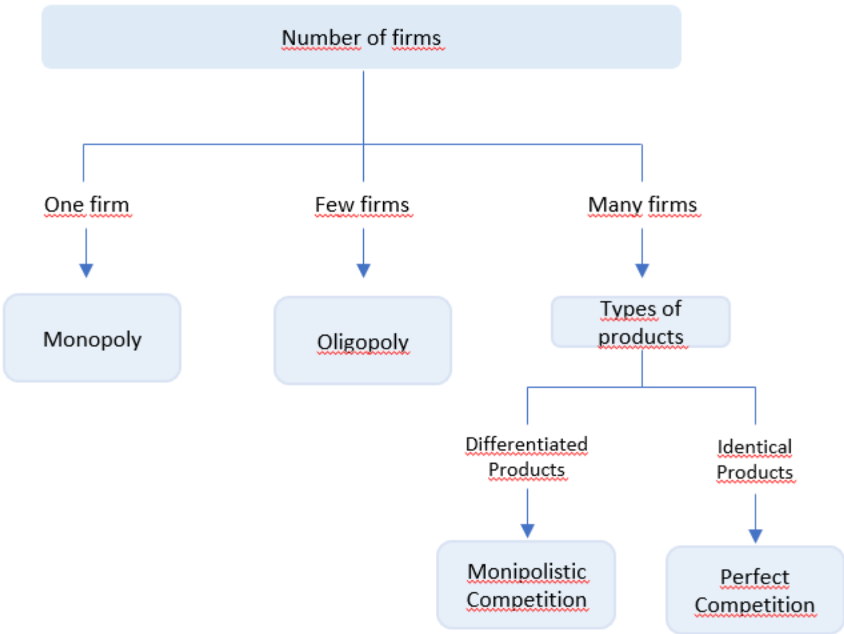


Figure 2.21- Four types of markets structure: adapted from [52]

Regarding the gases markets, more specifically the Air Liquide company, it is a specialized market – an oligopoly – which offers many solutions to its customers and has a very competitive environment. Hence, it is essential to analyse them and see how AL's position inside this market is made.

2.7.2. Market study practices

Nowadays, data-based marketing has conquered the business world. Quantifiable performance and accountability have become the key to a successful company and are performed by metrics. Metrics is a measuring system that quantifies a trend, dynamic, or characteristic. It is also a numeric fluency, and it is a crucial skill for every business to quantify market opportunities and competitive threats.

One of the metrics used is market share. It is a marker of how good a firm is doing compared to its competitors, complemented by sales revenue changes, helping managers estimate both primary and selective demand of the market. So it is, it allows them to judge not only the total market progress or decline but also the trends of the customers towards competitors [53].

Market share analysis has three main characteristics: competitive, descriptive and profit-oriented. Competitive because the effect of one’s actions must be analysed in conjunction with market positions and movements for competitors. Descriptive and predictive, because the ability to make accurate forecasts of future shares is essential, but not enough, the analysis should also provide important information about the market structure and competition and the influence of marketing actions on brand performance. Third, market share is profit-oriented, meaning that any company is interested in market-share movement and profit consequences [54].

This indicator can be measured by unit sales (equation 2.1) or revenue (equation 2.2).

$$\text{Unit Market Share (\%)} = \frac{\text{Unit Sales (\#)}}{\text{Total Market Unit Sales (\#)}}$$

- count

Equation 2.1

$$\text{Revenue Market Share (\%)} = \frac{\text{Sales Revenue (€)}}{\text{Total Market Revenue (€)}}$$

Equation 2.2

The unit market share is the units marketed by a particular firm as a percentage of total market sales, calculated in the same units. The gases market can be measured in tons or cubic meters.

Market share is a fundamental concept, but there are a series of obstacles until getting the indicator close enough to reality. This result is affected by their firm and competitors, so a market share based on their volume (firm and competitors) can easily present twisted results. It is possible to have more accurate conclusions using specialized firms used to this work [54].

Some aspects are worth studying to reach better conclusions about a company's position concerning competitors. First, identifying the stakeholders is essential to define the target consumers and then place new potential customers. Second, quantifying the gases market is made by accounting for the consumers and competitors.

Penetration is a measure of product attractiveness, and it is specified as the number of people who buy a specific brand of goods at least once in each period.

Market penetration (equation 2.3) measures category acceptance by a defined population. Helpful in tracking the acceptance of new products. Penetration rate (equation 2.4) is a comparative acceptance of goods within a category.

$$\text{Market Penetration (\%)} = \frac{\text{Buyers who have purchased a Product in the category (\#)}}{\text{Total population (\#)}}$$

Equation 2.3

$$\text{Penetration Rate (\%)} = \frac{\text{Brand Penetration (\%)}}{\text{Market Penetration (\%)}}$$

Equation 2.4

One of the ways to understand the performance of a company is to calculate the penetration rate. To have this result, there is a need to identify the number of AL customers vs the total number of customers.

There are many ways to elaborate a market study. Still, some key figures must be included, explaining the assumptions and the truthfulness of the information presented. So, to do it, there has been a detailed methodology explained in section 3 to explain the kind of target market and the forecast of Air Liquide's R&A market in the Oil & Gas.

2.7.3. Data collection instruments

There are a lot of instruments to use for research, and they are used to obtain the relevant information for a research project simply. There isn't one single method or tool that gives excellent research, all methods are put in an equal position, and all have their strengths and weaknesses. It is possible to distinguish two steps of research on a market analysis [55]:

- Primary research: type of research that collects raw data, information relating to the behaviour of the market in analysis. Useful for segmentation.
- Secondary research: a type of research that collects publicly available data to retreat conclusions about the market. Helpful in analysing competitors.

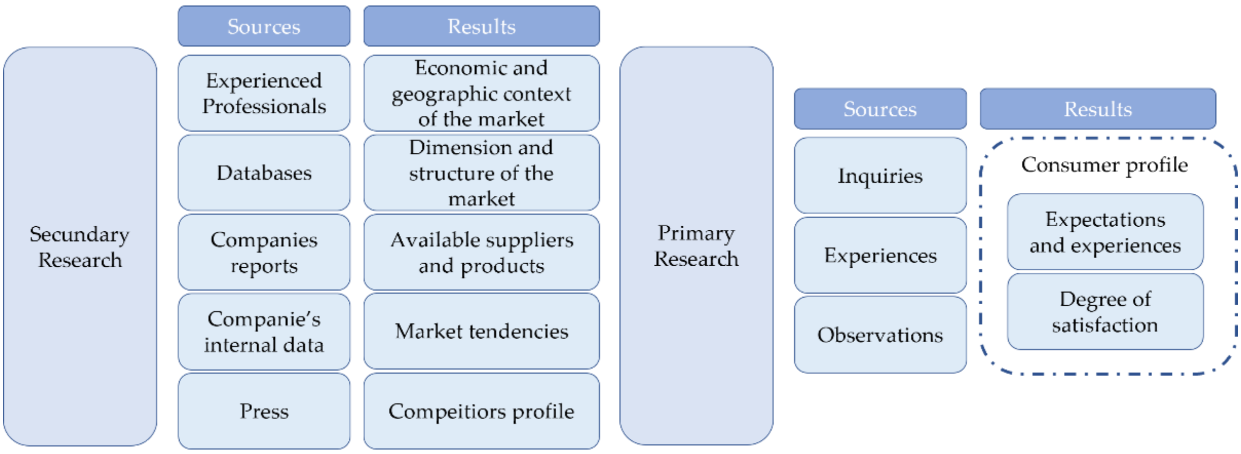


Figure 2.22- Examples of sources and results associated with each type of research

Secondary research, or desk research, can be easily obtained since it can collect more information in less time. It is an excellent tool to do a market framework and understand how this evolves and make a forecast of it with the help of information. One way to analyse the company position within the market is to do a competition and a SWOT analysis [56]. SWOT rises for Strengths, Weaknesses, Opportunities, and Threats. It is a tool for assessing aspects of a business by making a risk analysis on where the company stands inside the market [56].

There are many ways of gathering information in desk research, and table 2.19 represents most of them [57].

Table 2.19- Gathering information methods: adapted from [57]

Resource	Details
Industry Experts	Through direct contact with organizations and individuals that have the expertise of a particular matter.
Internet	Modern ways to access information and the two essential sources are companies or organizations and user groups made up of people interested in a particular matter.
Online databases and market data	Many databases and reports can be found on the internet.
Company data	Data for competitor benchmarking, sourcing supplies or building profiles of customers or identifying potential customers.
Government statistics	Access "hard" statistical data from most areas of business.
Market research reports	Specialists market research companies that speculatively carry out studies which then are sold as publications.
The press	One key source of information is the general, business and trade press.
Directories	Providers of information of companies that supply or consume goods and services are the usual source for preparing sample frames.

The market study in question uses secondary research due to the singularity of the data collected. Nevertheless, the gathered information is helpful to analyse and make predictions of the gases market in the Oil & Gas industry.

2.7.3.1. Sample selection

To do market research, it is always necessary to select a population, a target population, and a sample since it would be impracticable to collect data for the entire population. A target population is a subset of the population that is the focus or target of the research inquiry [58].

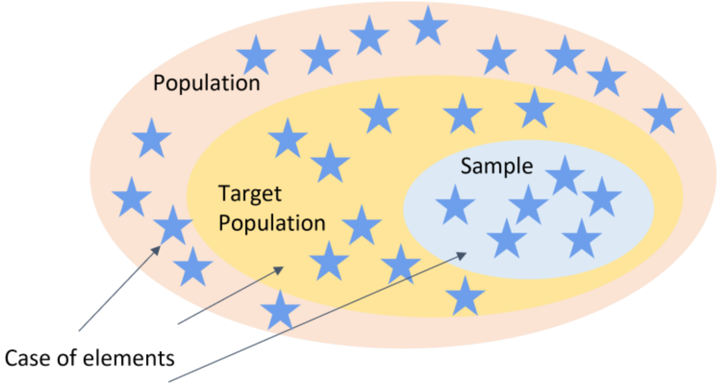


Figure 2.23- Population, target population, sample, and a case of elements: adapted from [59]

The sampling techniques can be divided into probability or non-probability sampling to distinguish the possibility of selecting each element. One of the requirements of probability sampling is to know the dimension of the population, so it is only possible to resort to non-probability sampling [58].

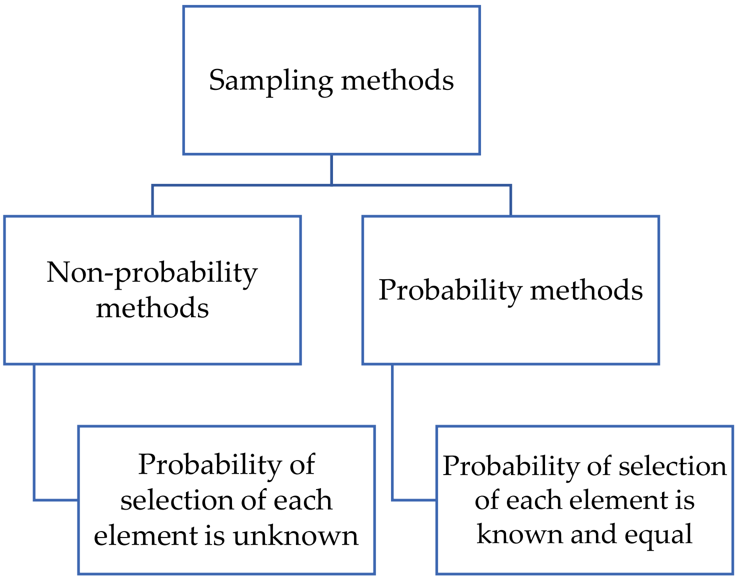


Figure 2.24- Existing sampling methods: adapted from [58]

To the market study in question, the population is all laboratories/companies with gases usage, and the target population is all those using gases to analyse fuels. Since, in the time available, it was complicated to explore all the laboratories or companies from the target population, it was to retrieve a sample. Therefore, that is all the ones analysed and collected to the database from the available sources.

2.7.3.2. Forecast market evolution

Besides evaluating Air Liquide within its competitors and market, it will be forecast the market evolution of the sales volume in the Oil & Gas market. This analysis will consider the sales made since 2018 and the market forecasts made by BP and IEA for each application. It will evaluate the performance and the predictions of the gas's usage in this range of customers.

The achievement of a prediction is one of the examples of a common practice in market studies. The objective is to evaluate the performance and analyse the actions that can be taken in the future.

According to J. Scott Armstrong, there are six ways of selecting forecasting methods, represented in table 2.20 [59].

Table 2.20- Methods to do a forecast: adapted from [59]

Convenience	"What's easy" - is inexpensive but risky.
Market popularity	"What others do" - unlikely to be of value because popularity and success may not be related, and it overlooks some methods.
Structured judgment	"What experts advise" - which is to rate methods against pre-specified criteria, is promising.
Statistical criteria	"What should work" - are widely used and valuable but risky if applied narrowly.
Relative track records	"What has worked in this situation" - expensive because they depend on conducting evaluation studies.
Guidelines from prior research	"What works in this type of situation" - relies on published research and offers a low cost, practical approach to selection.

In the present market study, structured judgement was used to do the forecast. However, since it is to study the future of the Oil & Gas market in Air Liquide based on the environmental regulations and restrictions of some applications in the future, some forecast methods were made. Then it was decided what the best way to predict the end of this market [59].

With the help of some experts in this field from the company, it was possible to do a structured forecast with accurate results and draw conclusions about the future of this market.

3. METHODOLOGY

To do a market study is essential to define the methodologies adopted along since they determine the quality and integrity of the results. This chapter is mainly composed of flow charts that present the methodologies chosen for each step of the study to schematize all the information. Flow charts are one of the seven quality tools and can be used to analyse a series of events and in any field to simplify a complex process to a more straightforward understanding [60].

3.1. Horizon and LIFE

To study the Horizon and Life programmes and define important projects that will be in course by several companies relating to environmental improvement, this was reviewed and analysed all the projects, to identify possible new customers. In figure 3.1 expresses the applied methodology to Horizon Programme until results analysis.

In figure 3.2 expresses the applied methodology to LIFE Programme until results analysis.

To results analysis, a proper count of customers and potential new customers was done that will be able to withdraw conclusions about this market.

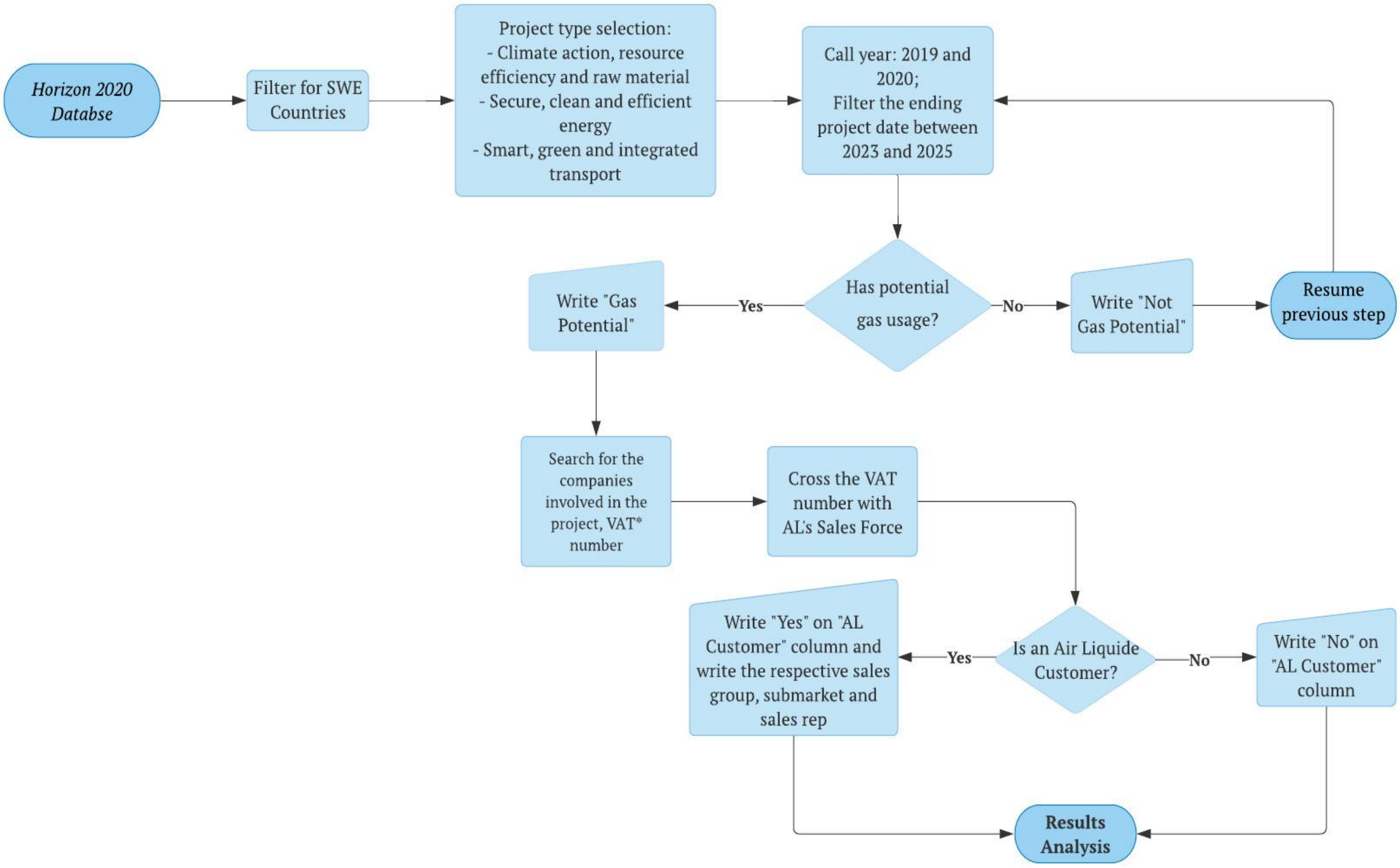


Figure 3.1- Horizon 2020 Methodology

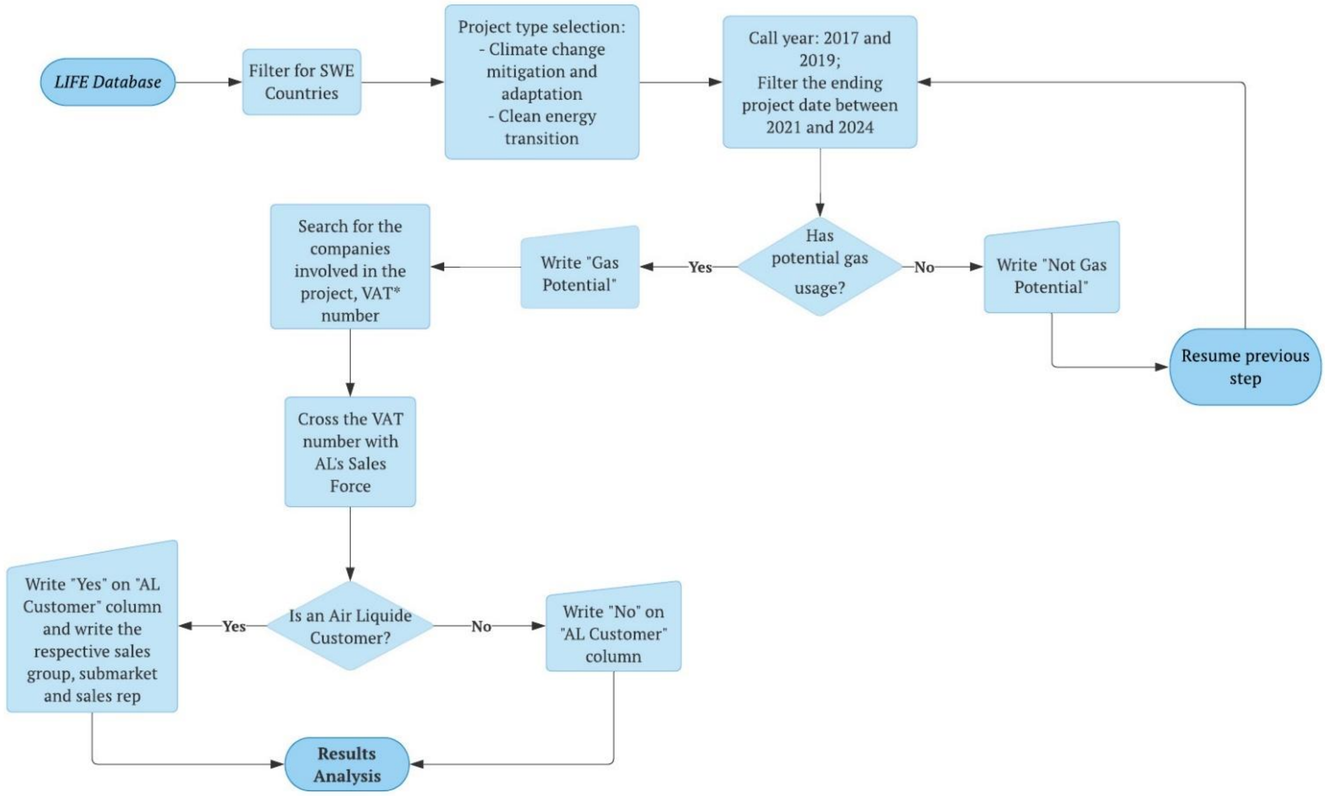


Figure 3.2- LIFE Methodology

3.2. Air Liquide's Market Forecast

The methodology presented is based on the forecast of BP Outlook and IEA adapted to the R&A and R&A+ market to view the future figures of the sectors and predict new incomes and businesses.

To better structure this study there was necessary to define a scope, that is the following:

- R&A04C – Oil & Gas Labs
- M&P02 – Refining & Oil, Coal and LNG Transportation
- M&P03 – Petrochemicals

The market R&A+ represents the sales made by the whole R&A plus the Speciality Gases of other markets. For the scope of this work, the Oil & Gas, the R&A segments concern are the R&A04C, and in the different markets, the segments are M&P02 and M&P03.

Inside the Oil & Gas market, there are sectors that are divided by:

– Refinery – all the gases used in refinery labs or in labs that measure refinery products

– Natural Gas – all the gases used in LNG or TSO labs or in labs that measure natural gas products
– Biomethane – all the gases used in biomethane sites labs or in labs that produce and measure biomethane
– Crackers
– Others: Independent Labs of R&A04C

Table 3.1 represents the percentage of sectors in each market. The R&A04C was the market of reference with the help of an Air Liquide's database to define the portion of each application. For the M&P02, it was made the same assumption but with only refinery and natural gas sectors, since there were the ones that fit this market. Finally, for M&P03, the segmentation only includes crackers, representing 100% of this market [61].

Table 3.1- The percentage of each sector in the respective market

<table>
<tr><th></th><th colspan="2">R&A04C</th><th colspan="2">M&P02</th><th>M&P03</th><th></th><th></th></tr>
<tr><th></th><th>% In market</th><th>Total % in market</th><th>% In market</th><th>Total % in market</th><th>Total % in market</th><th>Average % in market</th><th>Total average % in market</th></tr>
<tr><td>Refinery</td><td>72,1%</td><td rowspan="2">Refinery 81%</td><td>90,5%</td><td>90,5%</td><td>-</td><td>54%</td><td rowspan="2">90%</td></tr>
<tr><td>Crackers</td><td>8,8%</td><td>-</td><td>-</td><td>100%</td><td>36%</td></tr>
<tr><td>TSO</td><td>5,6%</td><td rowspan="2">Natural gas 6,3%</td><td>7,0%</td><td rowspan="2">Natural gas 7,9%</td><td>-</td><td>4,2%</td><td rowspan="2">4,8%</td></tr>
<tr><td>LNG</td><td>0,8%</td><td>0,9%</td><td>-</td><td>0,6%</td></tr>
<tr><td>Bio-methane</td><td>1,3%</td><td>1,3%</td><td>1,6%</td><td>1,6%</td><td>-</td><td>1,2%</td><td>1,2%</td></tr>
<tr><td>Others</td><td>11,4%</td><td>11,4%</td><td>-</td><td>-</td><td>-</td><td>4,0%</td><td>4,0%</td></tr>
</table>

The methodology adopted was based on the forecast made by BP Outlook and IEA, which applied the decrease or increase of these references in the AL market, considering that the company would remain with the same market share. Furthermore, for every forecast, it considered the year 2018, so it was applied the exact % of increase or decrease for this year's AL sales.

Table 3.2- Refinery Production Forecast: adapted from [47]

Year	2018	2025	2030	2035	2040
Refinery Production (Mb/d)	83	77,6	72,4	62,25	52,1
% Of decrease with 2018 as reference		-6,5%	-12,8%	-25%	-37,2%

Table 3.3- Natural gas Consumption Forecast: adapted from [46]

Year	2018	2025	2030	2035	2040
Natural Gas Consumption (Mtoe)	389,4	352,7	311,2	267,1	228,9
% Of decrease with 2018 as reference		-9%	-20%	-31%	-41%

Table 3.4- Biomethane Consumption Forecast: adapted from [48]

Year	2018	2025	2030	2035	2040
Biomethane Consumption (Mtoe)	2	13	21	28	36
% Of decrease with 2018 as reference		+5,5%	+9,5%	+13%	+17%

These tables represent the % that in section 4.3 will impact the Oil & Gas market.

3.3. Biomethane market size forecast

To study the potential market size of biomethane, since it is an upcoming energy source, countries like France and Italy have government support, and this type of energy is the future. Therefore, it studied the market size forecast to report the potential market for Air Liquide. The methodology adopted is represented in figure 3.3.

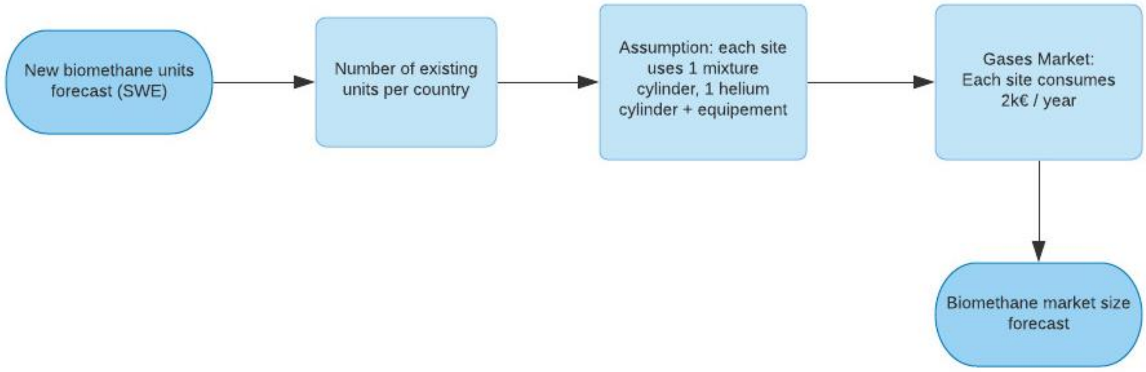


Figure 3.3- Biomethane market size methodology

3.4. Stakeholders and Penetration Rate

One of the critical goals of this analysis is to measure the company's performance in the Oil & Gas market. Therefore, one of the main results is obtaining the penetration rate and, if possible, the competitors.

To do so, was made a database with companies, certified and non-certified, of this market. The sources for each country are represented in table 3.5.

Table 3.5- Sources by country of certified and non-certified companies

Portugal	Spain	France	Italy
- Air Liquide Database - IPAC (Instituto Português de Acreditação) - Empresite - Iberinform	- Air Liquide Database - Accredita - Empresite	- Air Liquide Database - Cofrac - BMF TVerif - France Environment	- Air Liquide Database - Accredia - Empresite

In figure 3.4, is represented the methodology adopted. It is taking into consideration that this was made for the four counties of the cluster.

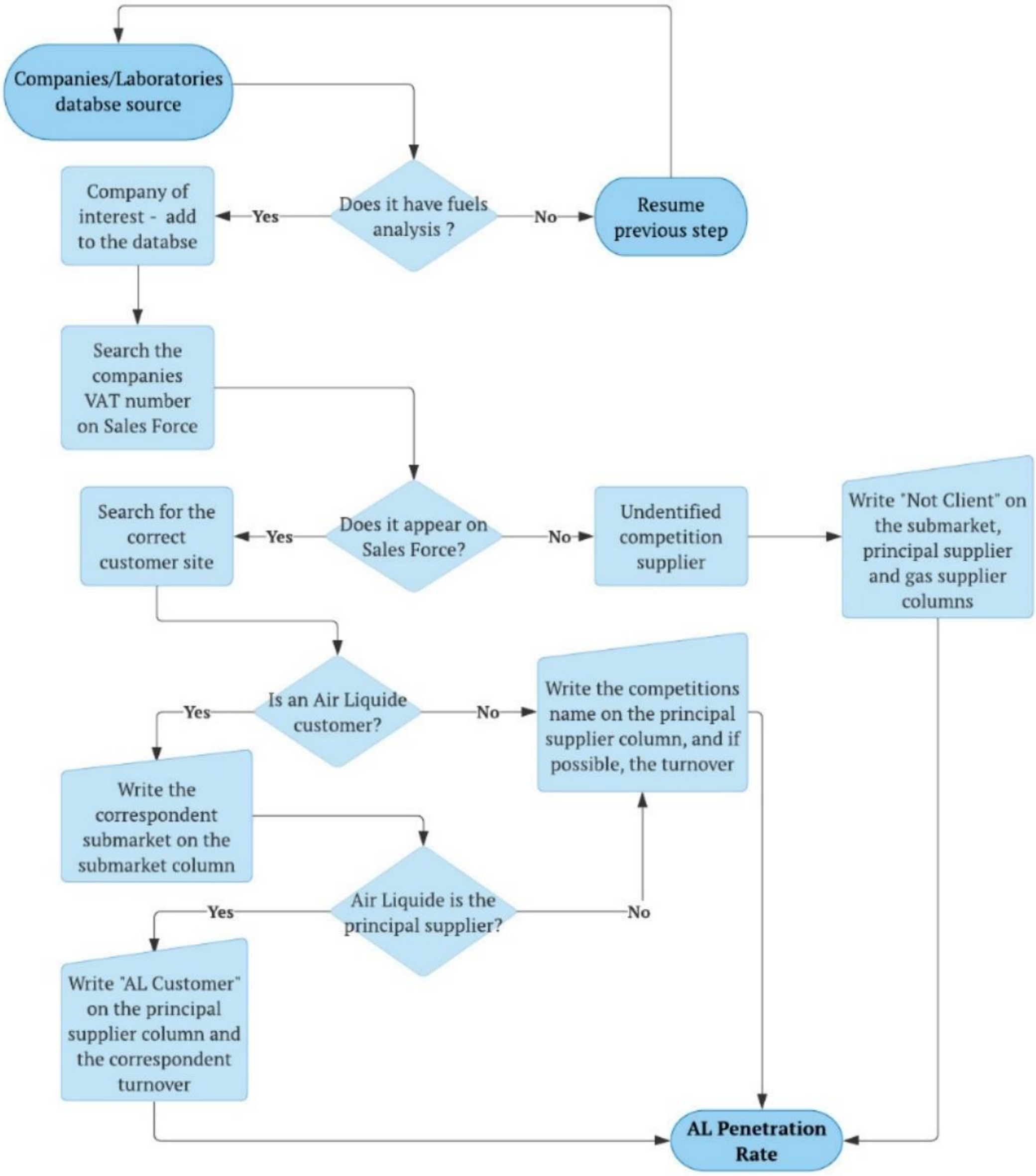


Figure 3.4- AL Penetration rate methodology

The company performance will be evaluated considering the penetration rate in absolute values by the number of Oil & Gas market clients.

3.5. Air Liquide's Market Share

One of the main characteristics of the market to analyse the performance of a company is the market share. To do it, followed a methodology presented in figure 3.5.

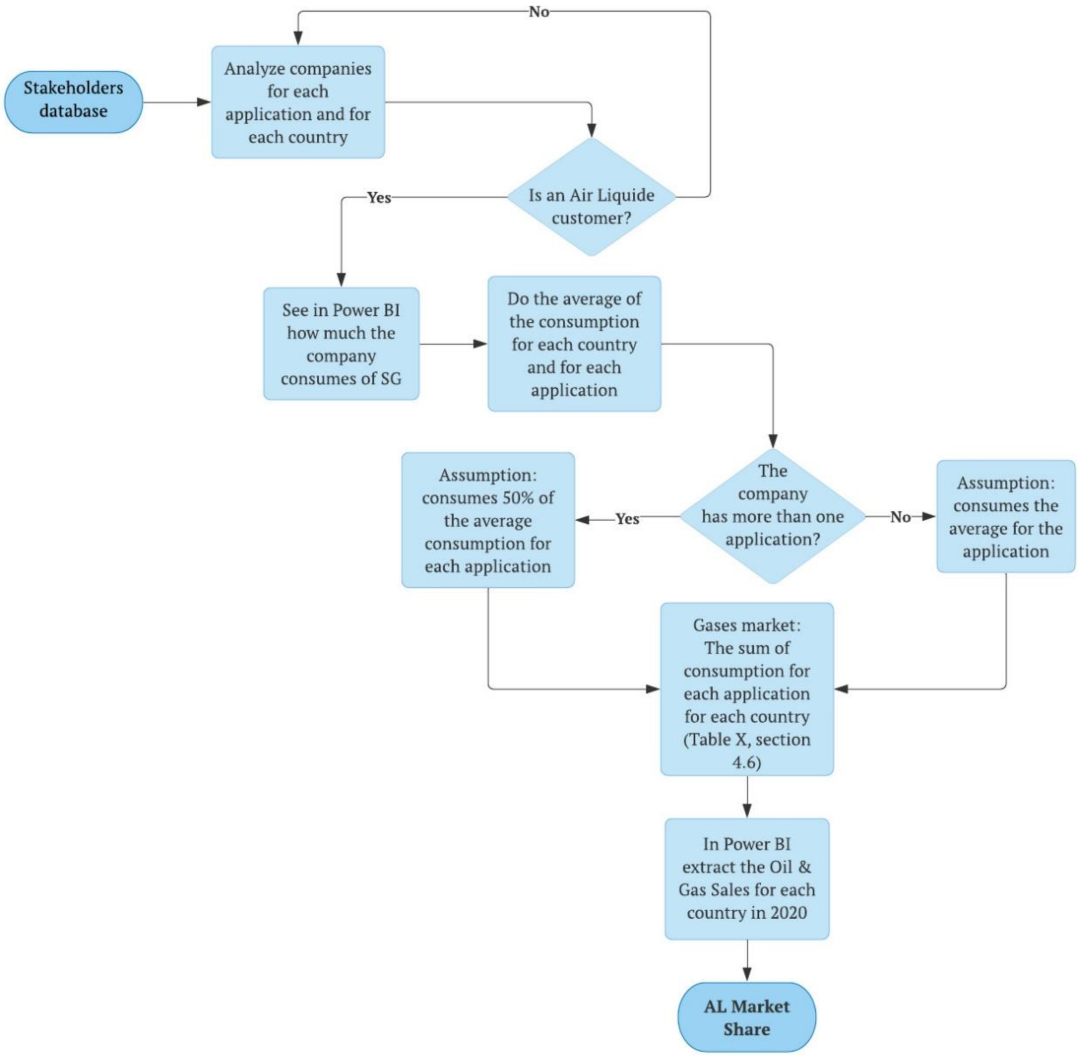


Figure 3.5- AL Market share methodology

4.
PRESENTATION AND DISCUSSION OF RESULTS

4.1. Horizon 2020 and LIFE

According to the methodology presented in 3.1., from database sources of Horizon 2020 and LIFE, it was possible to classify them as having gas potential or not gas potential for the cluster countries by analysing the companies and the project objective itself. The timeline of the projects call year for the LIFE programme is between 2017 and 2019 and 2019 to 2020 for Horizon's.

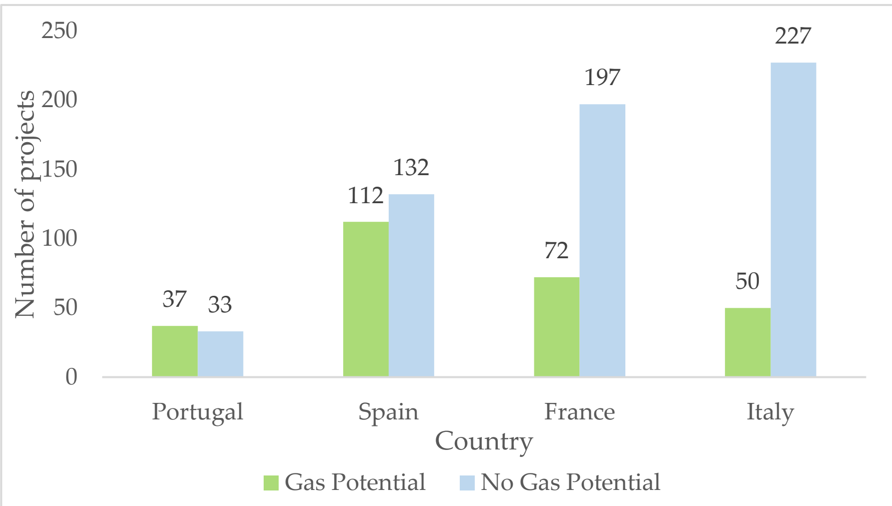


Figure 4.1- Classification of Horizon projects by country - the call year 2019-2020 [62]

Within the projects that have gas potential, they all focus on environmental improvement and climate action. For example, in Oil & Gas, most of the Horizon 2020 projects focus on energy efficiency and hydrogen fuel cells. In table 4.1, are represented the number of projects for each programme that have a focus on fuels.

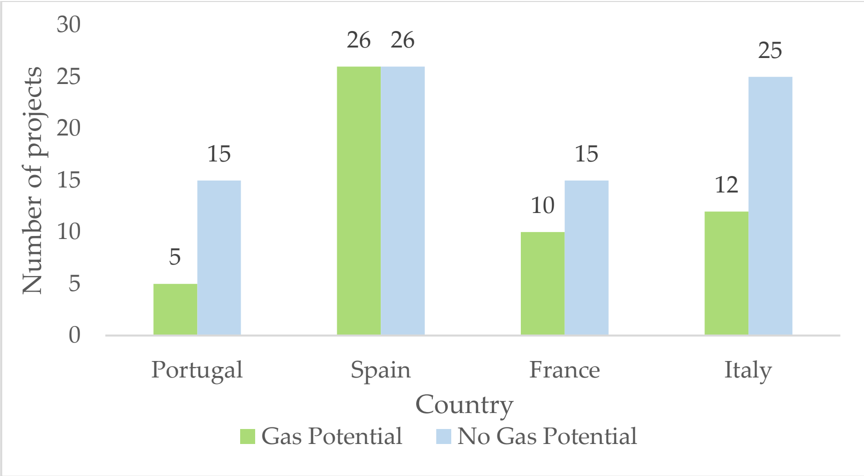


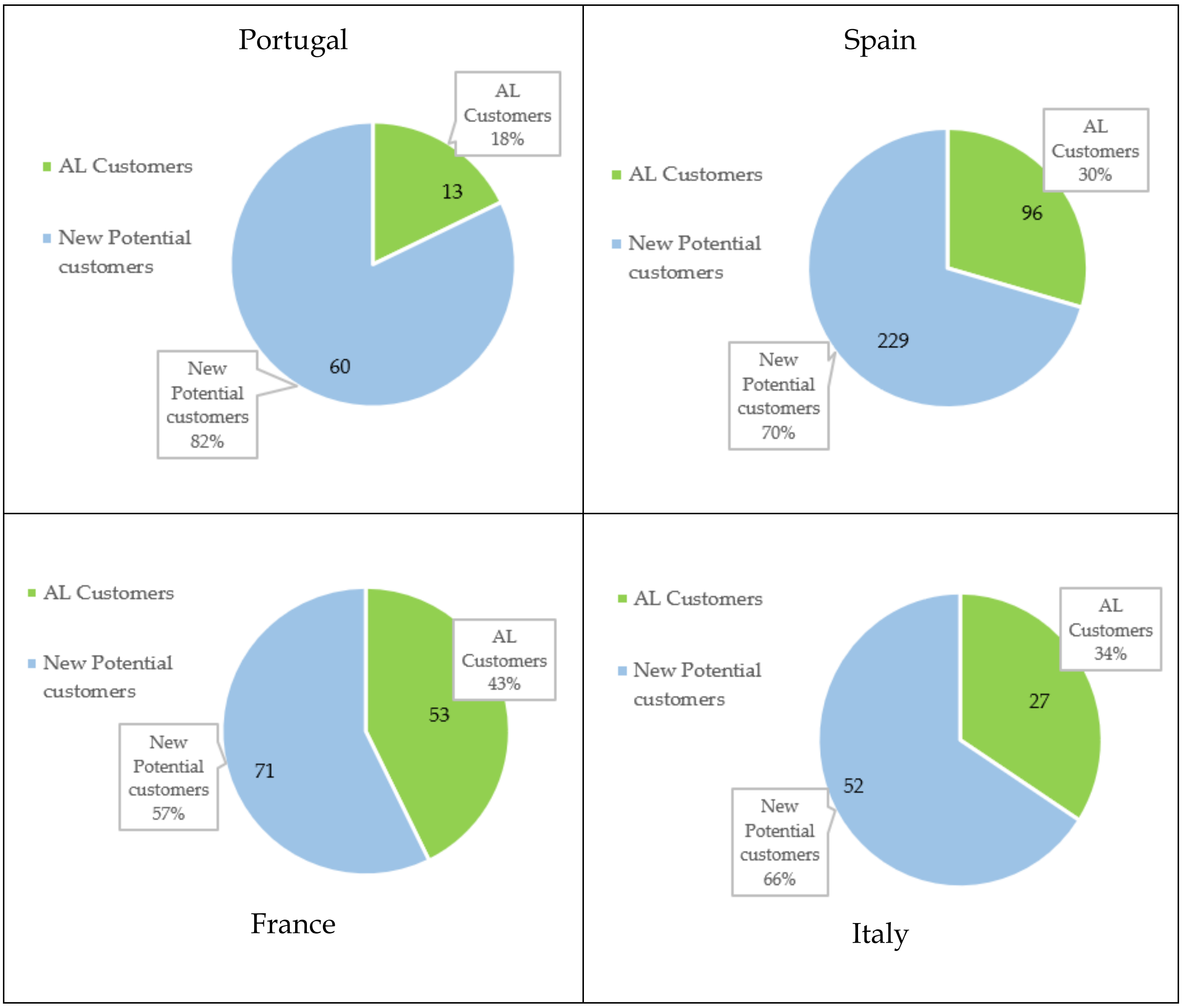
Figure 4.2- Classification of LIFE projects by country - the call year 2017-2019 [63]

Table 4.1- Number of projects of interest for the Oil & Gas by country [62, 63]

	Horizon 2020	LIFE
France	31	1
Italy	22	3
Portugal	7	1
Spain	16	2

It is possible to notice that countries focus on this topic for the energy transition since 40% of the projects of Italy and France have concentrated on the Oil & Gas industry. For Portugal, 19% and Spain, 11%.

Table 4.2- Classification of Horizon 2020 companies by country - the call year 2019-2020



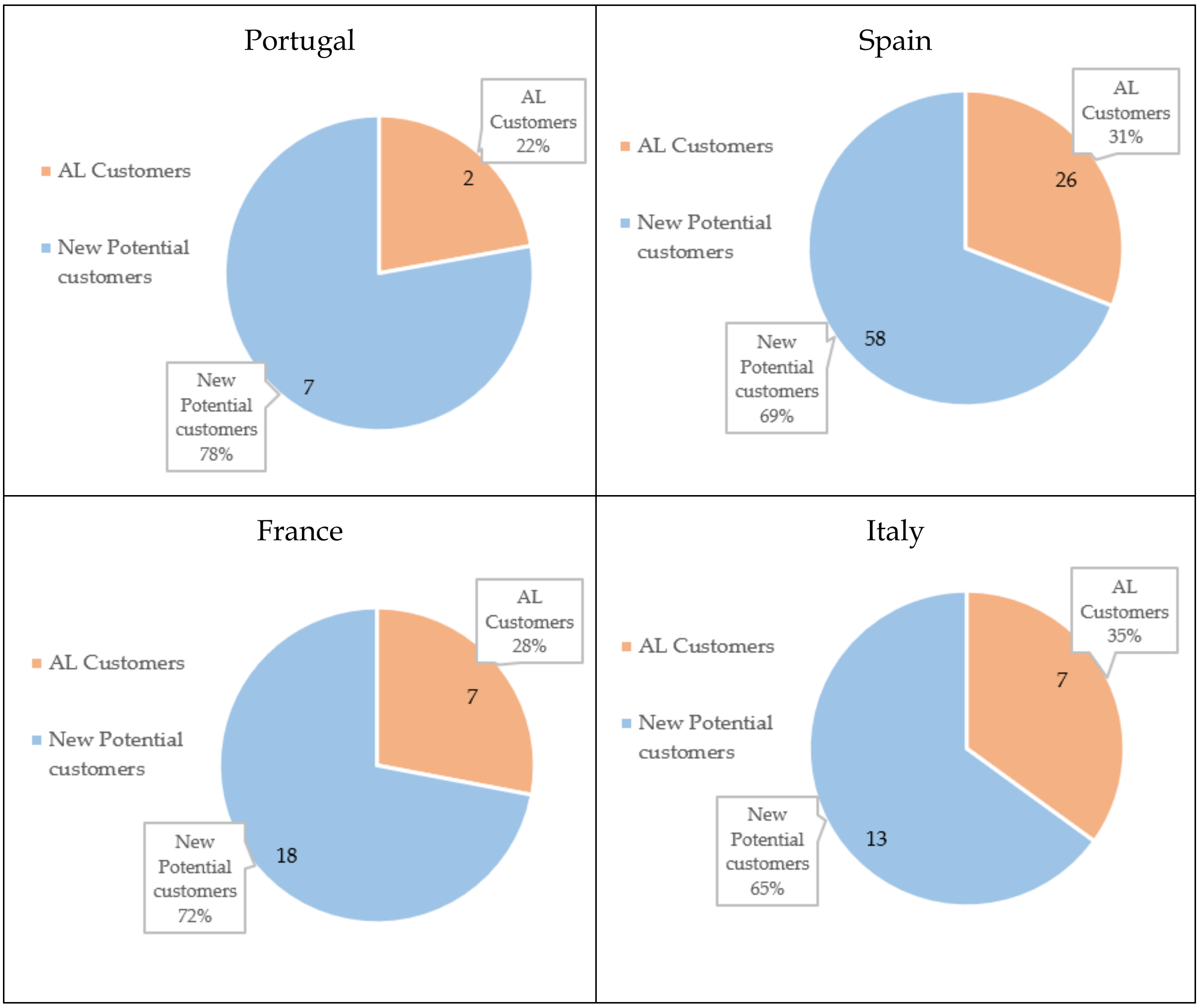
From table 4.2, it is possible to analyse that in all countries on the Horizon 2020 programme, there are more than 50% of new potential customers for the R&A market. Therefore, for Air Liquide, this is a good indicator for development to catch the companies in front of the projects to become consumers.

Table 4.3 represents the percentage of new customers who come out of the LIFE programme with gas potential. Again, the sample is smaller but unanimous that there are many new potential customers in all countries.

Within this sample of new potential customers, in the focus of the Oil & Gas sector, there are 13 for France, 17 for Italy, 5 for Portugal, and 11 for Spain. Therefore, this represents an excellent opportunity for Air Liquide to gain more customers in this market and increase its yield.

For budget purposes, the projects are all partially financed by the EU. Horizon 2020 contributes 82% of the total investment, focusing on the gas potential projects, and the LIFE programme has 55%.

Table 4.3- Classification of LIFE companies by country - the call year 2017-2019



4.2. Market Overview

To understand the Oil & Gas market, it needs to know where it fits inside the company sectors, what happened in the past, and what trends it has.

The Oil & Gas market at study is fitted at the R&A (Research & Analysis) market. This market includes customers who conduct research programmes, test prototypes, offer analytical bases services, conduct processes & product quality controls, and monitor emissions. The activities of these clients are mostly analysis (physical, electrochemical), testing, calibration services and product certification by the usage of Speciality Gases (pure, rare, chemical and mixture gases).

The business drivers of this market - that are the key inputs and activities that drive the operational and financial results of the industry are [61]:

- Growing European R&D (Research & Development) Expenditure
- More stringent environmental regulation
- Faster innovation cycles

– Manufacturing specialization & excellence: more complex products with more quality and process control points

There are sub-markets inside the R&A, figure 4.3, to divide the customers consonant their application.

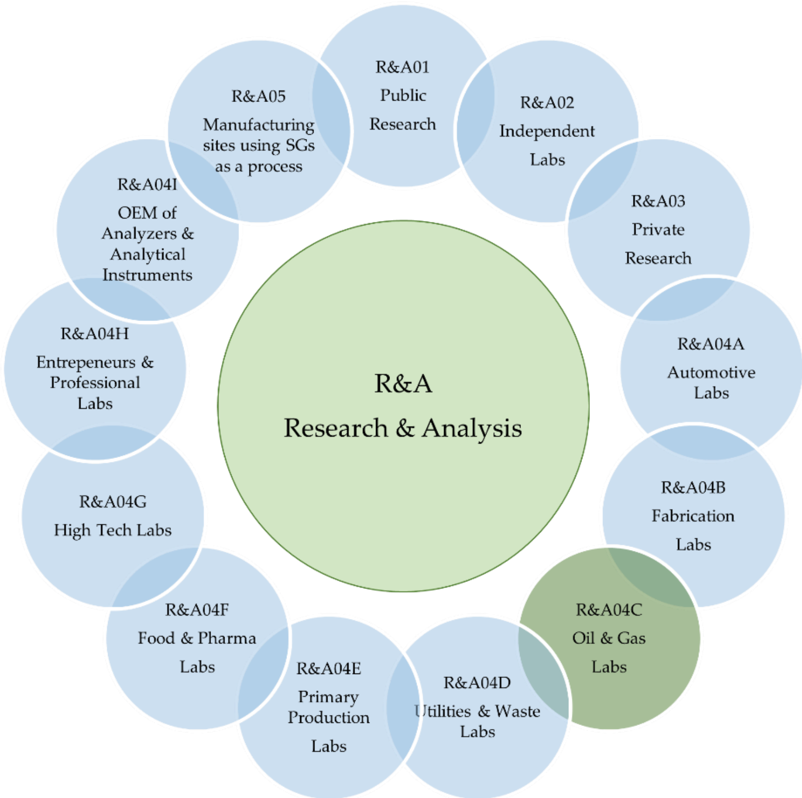


Figure 4.3- R&A sub-markets

From R&A, the sub-market in the study is R&A04C- Oil & Gas Labs, since it comprises the "on-site" laboratories/research departments of plants of companies involved in the extraction, transformation - refining - of crude petroleum and coal into usable products, and those sites involved in the production of chemicals (basic and speciality). This sub-market is responsible for 5% of the R&A sales.

The other sub-markets included in this study are:

- M&P02 - Refining & Oil, Coal and LNG Transportation (SG Sales)
- M&P03 - Petrochemicals (SG Sales)

To have a global overview of the Oil & Gas market, there is a need to check not only the R&A market but M&P02 and M&P03 markets, only SG sales. It happens because, in the M&P market, there are other applications besides analysis that uses speciality gases.

To understand the market of Oil & Gas is necessary to do an overview to comprehend what happened to the clients and the trends of this market.

For R&A04C Total Sales, figure 4.4, the market has been constant over the years.

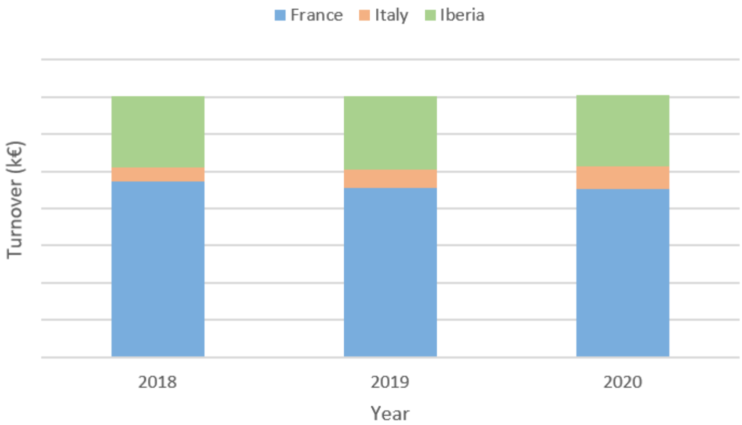


Figure 4.4- R&A04C (Oil&Gas Labs) Total Sales

With a CAGR of 0,3% between 2018 and 2020, this market hasn't had many changes over these years. It is also known by analysing the top 10 clients of the three years, which hasn't altered. The main difference is the increase in the % of Italy's market, which has improved by 3,5% by 2020.

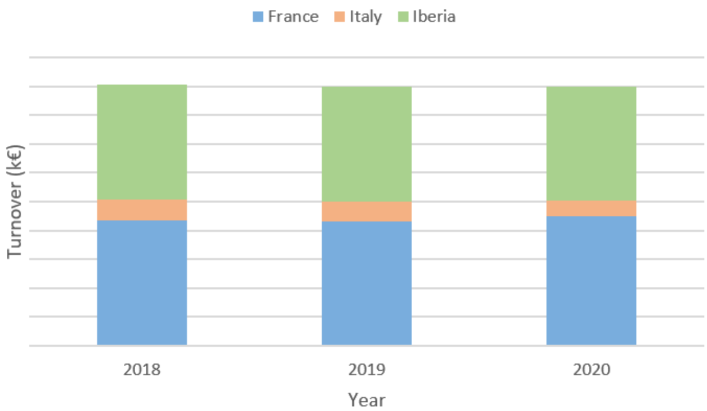


Figure 4.5- R&A04C (Oil&Gas Labs) SG Sales

For the R&A04C SG Sales, it is notable a decrease between 2019 and 2020. Italy reduced their weight on the market in 2020 because of the loss of a top 10 client, Geolog SRL, that didn't purchase SG; this can be justified by the fact that this client may not consume gases every year but still be an AL customer on the following years. Between 2018 and 2020, the CAGR was -0,6%.

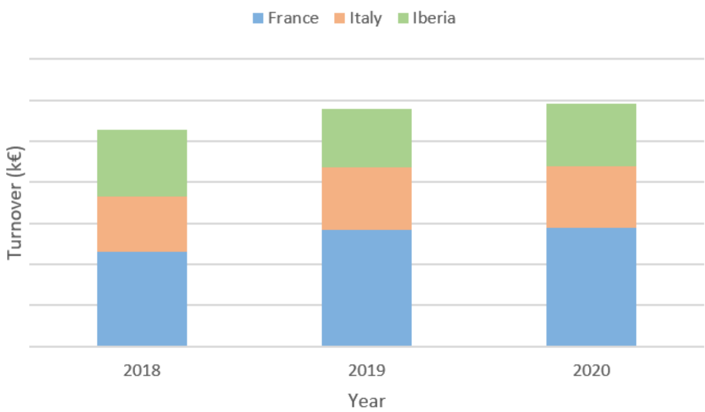


Figure 4.6- M&P02 (Refining & Oil, Coal and LNG Transportation) SG Sales

For the M&P02 SG Sales, between 2018 and 2019, there's a significant increase in volume sales; although the top 10 clients haven't changed, this is reflected with a higher amount of SG purchased by these main customers. That also happens, but not so sharply for the year 2020. As a result, this market has a CAGR of +5,2% between 2018 and 2020.

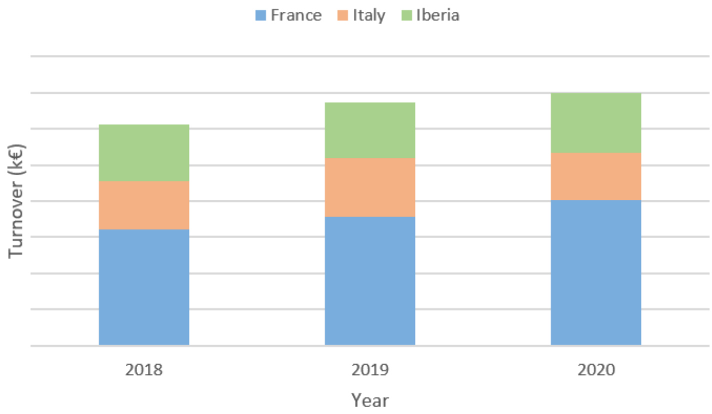


Figure 4.7- M&P03 (Petrochemicals) SG Sales

For the M&P03 SG market, the same happens with M&P02; the top clients increased their turnover, especially for France's market. As a result, this market has a CAGR between 2018 and 2020 of +7%.

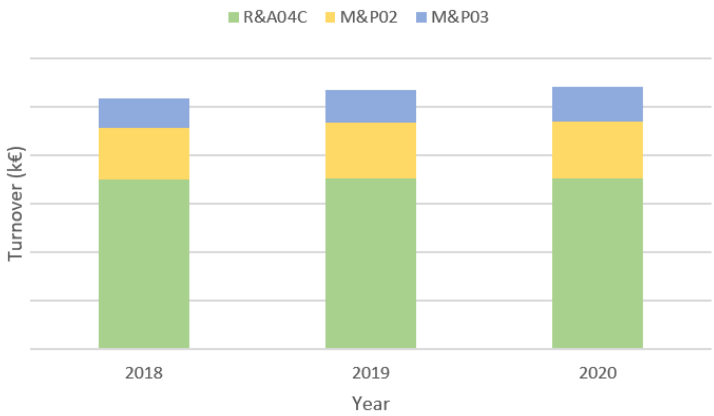


Figure 4.8- R&A+ market sales

The R&A+ market (R&A04C Total Sales + M&P02 SG Sales + M&P03 SG Sales) has been steadily growing over the years, as seen before, due to M&P02 and M&P03 clients. Between 2018 and 2020, it has a CAGR of +2,2%.

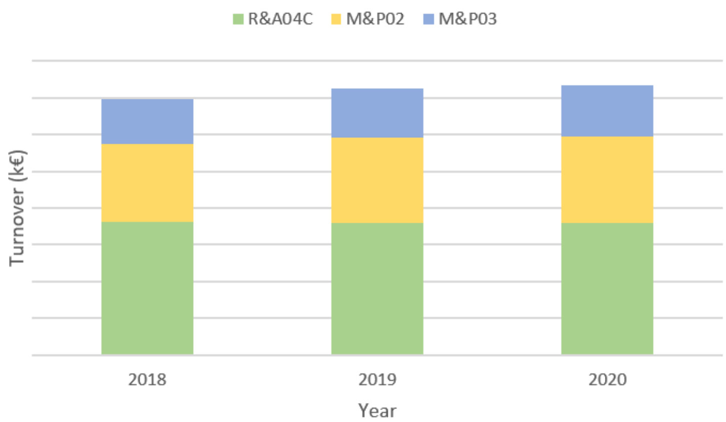


Figure 4.9- SG sales market

For the SG Sales, it is also seen an increase between 2018 and 2019 due to M&P02 and M&P03 markets. This market has a CAGR of +2,8%.

It can be concluded that the Oil & Gas market is stable and has increasing trends, with almost no COVID-19 impact on the 2020 year. It also has a stable position on the main customers, since there is not a lot of change over the years.

4.3. Air Liquides' Market Forecast

To study the future of the Oil & Gas market at Air Liquide was used the methodology was presented in section 3.2. Since the environmental regulations have tightened up even more due to European targets, the Air Liquide market can change and be directed in a new direction. Therefore, this section will study recent trends and how this market will evolve. This forecast was made assuming that Air Liquide would maintain the same market share without a price effect.

For the R&A04C sales, the forecast is divided into sectors: refinery (refinery + crackers), natural gas and biomethane. These were the sectors in the segmentation of this market, figure 4.10, 4.11 and 4.12.

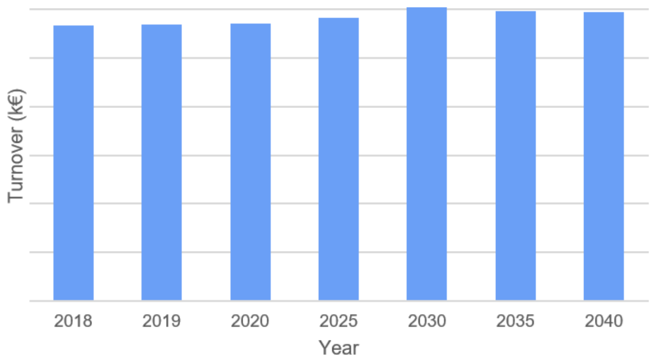


Figure 4.11- Expected refinery turnover forecast: R&A04C

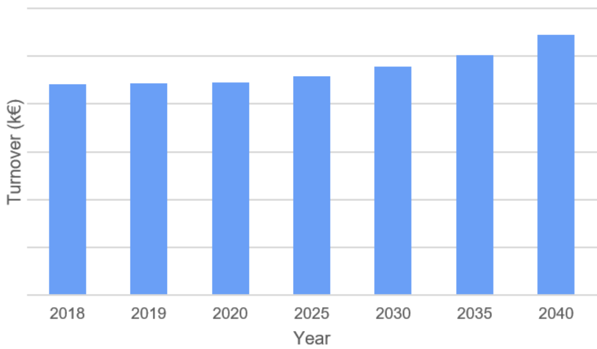


Figure 4.10- Expected natural gas turnover forecast: R&A04C

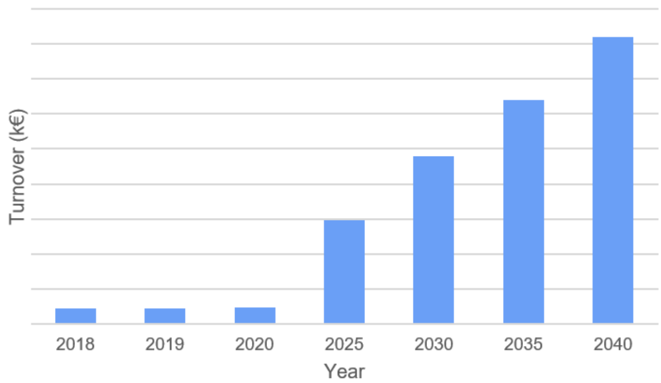


Figure 4.12- Expected biomethane turnover forecast: R&A04C

Table 4.4- CAGR of each sector for R&A04C

	CAGR 2020-2025	CAGR 2020-2040
Refinery	+0,4%	+0,2%
Natural Gas	+0,6%	+1,0%
Biomethane	+45%	+15,5%

For the refinery sector, an assumption, a CAGR of 1,75%, was applied because this sector will increase environmental measurements, emissions measurements, and CO_2 emissions control. Therefore, the consumption of refinery products will decrease over the years. Still, due to environmental measures that companies must follow, this application's measurement and quality control will increase and, consequently, the Air Liquide market will grow. The results, in figure 4.11, is that this application is expected to increase until 2030 and stabilise for the years after.

An assumption was also applied for the natural gas, a CAGR of 2,5%, due to the increased utilization of hydrogen injection at the natural gas site and growth of analysis demand. As a result, the Air Liquide market is expected to grow up consistently until 2040.

For biomethane, a significant increase is expected because it is a renewable energy source and will substitute some energies in this market for environmental improvement. It is carried by countries like France and Italy that have government support for this sector to make developments and a transition for this application.

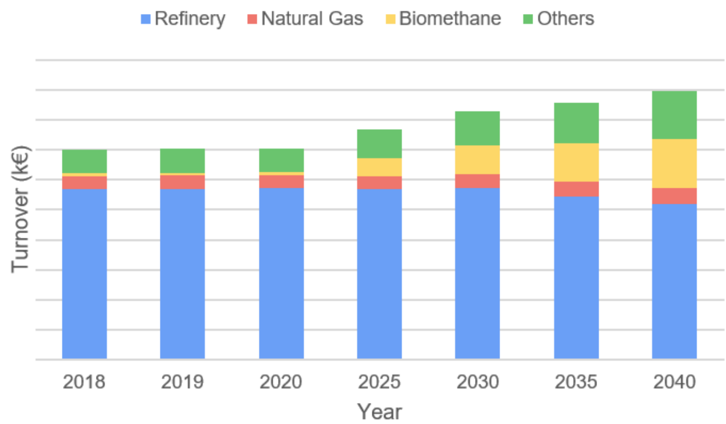


Figure 4.13- Expected R&A04C total sales turnover forecast

In figure 4.13, is shown how the market will behave due to the forecast presented before and how each application will impact this market. Based on figure 4.13, Biomethane will increase drastically, and refinery will decrease over the years.

Table 4.5- CAGR of R&A04C market

CAGR 2020-2025	CAGR 2020-2040
+1,7%	+1,2%

The SG market of R&A04C is found in Appendix D, and the results were very similar to the total sales market.

For the M&P02 SG sales, the forecast is also divided by sectors: refinery, natural gas and biomethane. These were the sectors in the segmentation of this market, figure 4.14, 4.15 and 4.16.

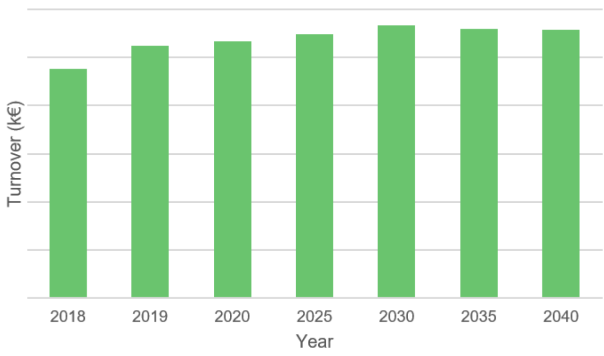


Figure 4.14- Expected refinery turnover forecast: M&P02 SG

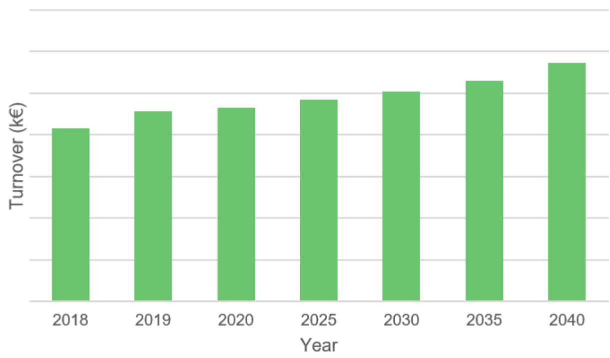


Figure 4.15- Expected natural gas turnover forecast: M&P02 SG

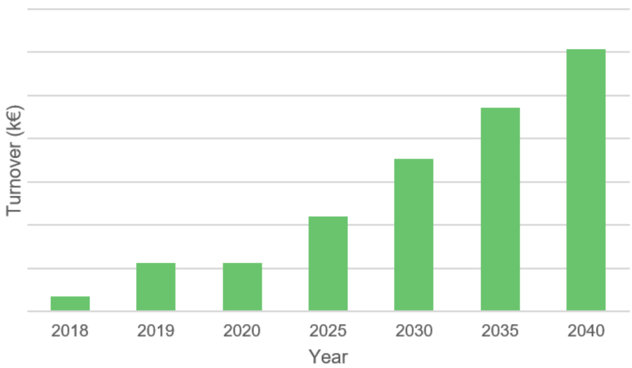


Figure 4.16- Expected biomethane turnover forecast: M&P02 SG

Table 4.6- CAGR of each sector for the M&P02 SG market

	CAGR 2020-2025	CAGR 2020-2040
Refinery	+0,5%	+0,2%
Natural Gas	+0,7%	+1,0%
Biomethane	+14,2%	+8,8%

For the M&P02 SG market, the same assumptions as R&A04C were made, and the results are very similar. An increase in the refinery and stabilization. An increase is due to analysis demand by the natural gas application. For biomethane, constant growth in this market is due to the utilization as fuel and required analysis.

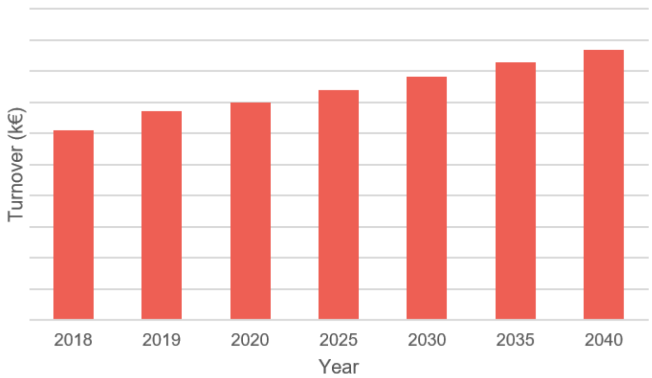


Figure 4.17- Expected crackers turnover forecast: M&P03 SG

Table 4.7- CAGR of M&P03 SG market

CAGR 2020-2025	CAGR 2020-2040
+1,6%	+1,6%

For the M&P03 SG Sales market, only the crackers were considered for the forecast, and it is a sector inside the refinery, in the segmentation, so this market also suffered the same assumption as the refinery, a CAGR of 1,75% due to environmental measurement and quality control increase. Therefore, the results are positive, with a uniform increase until 2040.

To better understand the Oil & Gas market in the future, the R&A+ and SG Sales markets were made based on the forecasts delivered before.

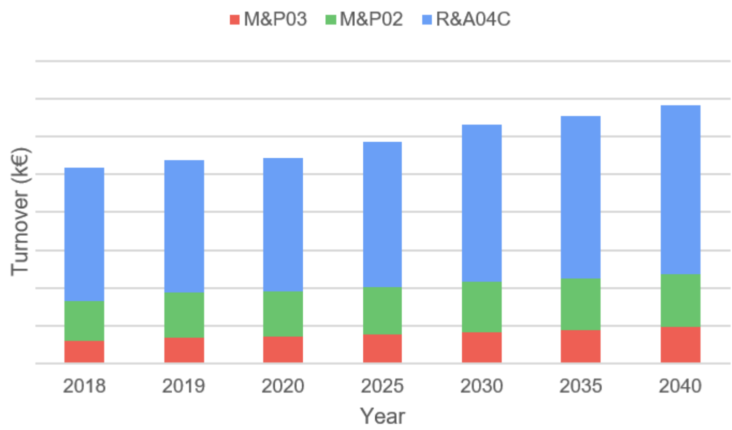


Figure 4.18- R&A+ turnover forecast by market

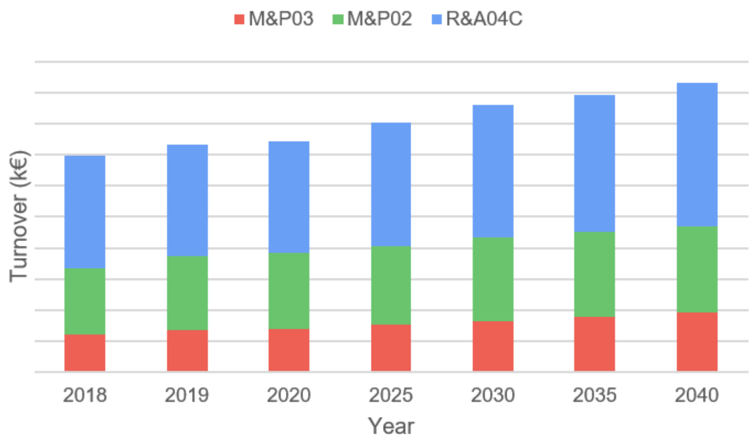


Figure 4.19- SG turnover forecast by market

Table 4.8- CAGR of R&A+ and SG markets

	CAGR 2020-2025	CAGR 2020-2040
R&A+ Market	+1,5%	+1,1%
SG Market	+1,6%	+1,1%

The forecasts present a positive insight for the future, with the significant increase of R&A04C and M&P02 due to the biomethane impact in these markets. However, although it's not a considerable increase, the perspectives for this market weren't positive because of the relation with the oil, coal, and natural gas since the world is trying to reduce these products. But since the Air Liquide market is directed for measurement with gases, quality control and composition, this can be seen as a business opportunity.

Each application represents a weight on the sub-market inserted. The current percentage is in table 3.1, section 3.2. But because of the market transformation, this weight will change over the years based on the forecasts. To gain an insight into this change, a prediction was made for the evolution of R&A04C and R&A+ markets.

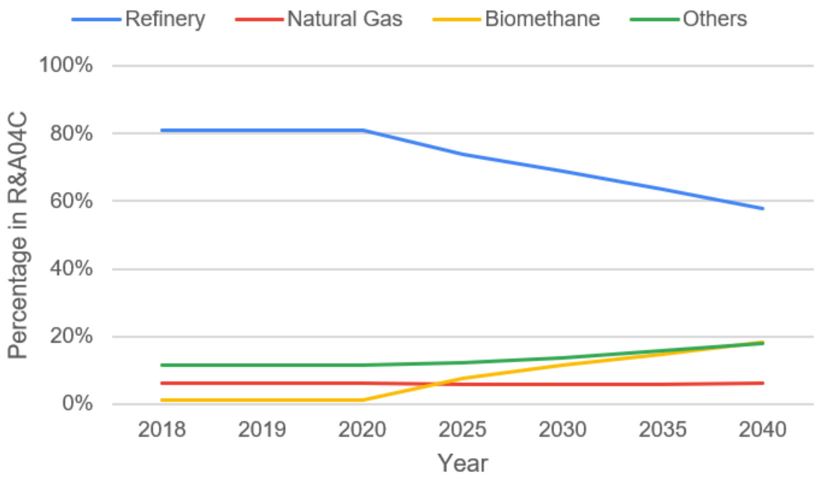


Figure 4.20- Percentage of each sector in R&A04C forecast

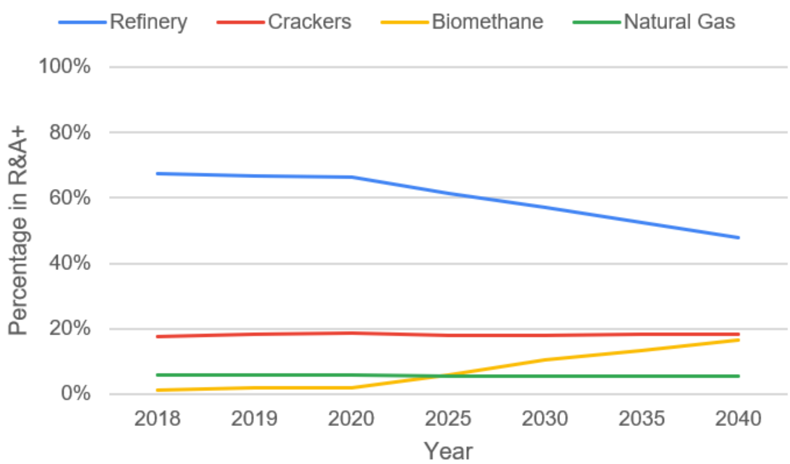


Figure 4.21- Percentage of each sector in R&A+ forecast

For the R&A04C market, the refinery is expected to decrease almost 20% over the years. On the other hand, biomethane is anticipated to increase nearly 20%, so it compensates for the decrease of the refinery application. Therefore, natural gas is expected to remain constant over the years. For the R&A+, the same happens with an increase of 15,2% of the biomethane.

4.4. Biomethane market forecast

To forecast the biomethane market, the methodology was used in figure 3.3, section 3. 3. First, the number of sites that will operate in each cluster country was estimated with the prediction of average growth in Europe of 5-10% per annum [64].

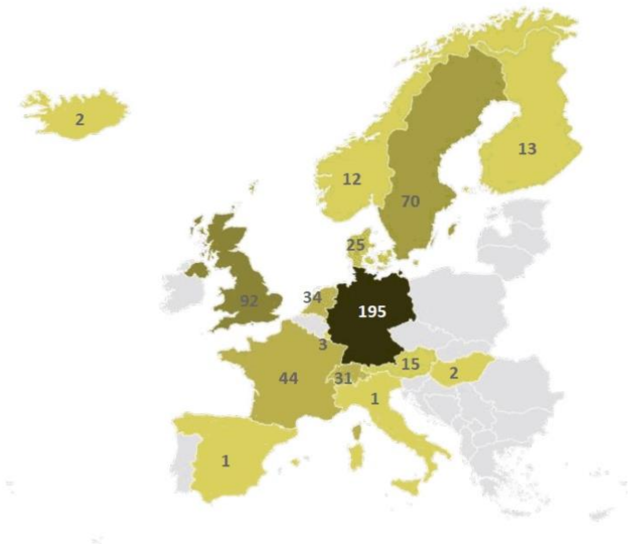


Figure 4.22- Number of biomethane sites in Europe (2017) [64]

For France, since it is the most ambitious country of the cluster on the biomethane sector with the predictions of hundreds of new biomethane sites, the growth applied was 15% per year. Italy is the next motivated to focus in this sector, and it was used an increase of 12%. Finally, Iberia, specifically Spain, is one of the worst countries in developing the biomethane sector, so the annual growth was 2% because Portugal doesn't have any biomethane sites and has no predictions to do it [65].

France and Italy are focusing on this sector because, despite it being expensive to produce, they have government support in supplying more and helping the energy transition, representing an essential sector for Air Liquide to invest and control.

Table 4.9- Forecast of biomethane sites until 2030

Year / Number of sites	France	Italy	Iberia
2018	76	8	1
2020	172	18	2
2025	346	32	2
2030	696	56	3

The turnover was predicted assuming that each site will consume one mixture cylinder, one helium cylinder, and equipment. Therefore, it gives a total of 2k €/year per site.

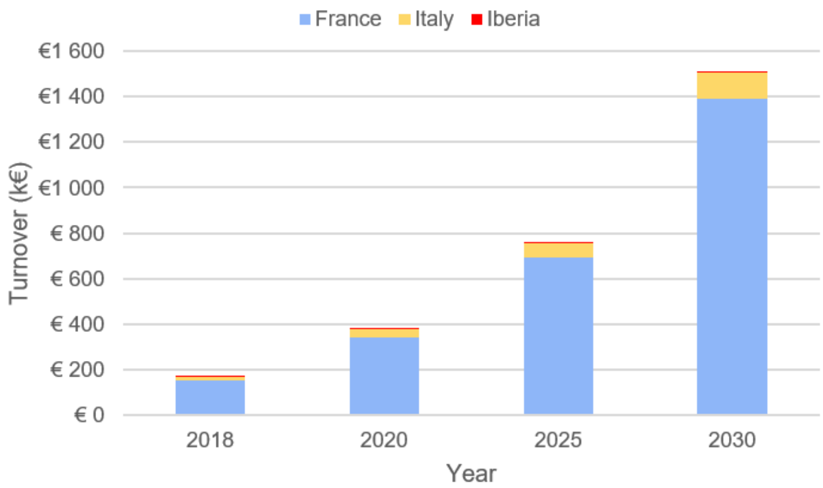


Figure 4.23- Expected biomethane market size per country until 2030

France will operate almost 700 biomethane sites by 2030. Moreover, these countries, France, and Italy have government incentives that significantly impact the development of this technology.

4.5. Stakeholders and Penetration Rate

To study the Air Liquide's penetration rate on the Oil & Gas, were necessary to identify the stakeholders of this market.

The same reasoning was made for each cluster country, with the methodology presented in section 3. 4.

Firstly, analysing the companies, it was searched for its gas provider company. Although the competitor's name can't be identified for confidentiality, the nomenclature adopted was "competitor X", X=1, 2, 3, etc. To remove the Air Liquide's penetration rate was used the equation 4.1.

$$\text{Penetration rate (\%)} = \frac{\text{Number of AL Clients}}{\text{Number of Companies analysing fuels}} \times 100$$

Equation 4.1

Secondly, the companies/laboratories were divided into applications:

- Refinery: refineries and companies that analyse refinery products
- Natural Gas: Natural gas sites and investigate natural gas fuels
- Biofuels: companies that produce and analyse biofuels
- Biomethane: companies that make and analyse biomethane
- Hydrogen: companies that produce and analyse hydrogen as a fuel

4.5.1. Portugal

The sources for this section are presented in section 3.4, table 3.5.

Table 4.10- Number of deliveries per company [66-68]

Company	Number of deliveries
Competitor 1	1
AL Customer	22
Competition not identified	3
Competitor 2	1
Competitor 3	3
Not Client	22
Competitor 4	3
Total	57

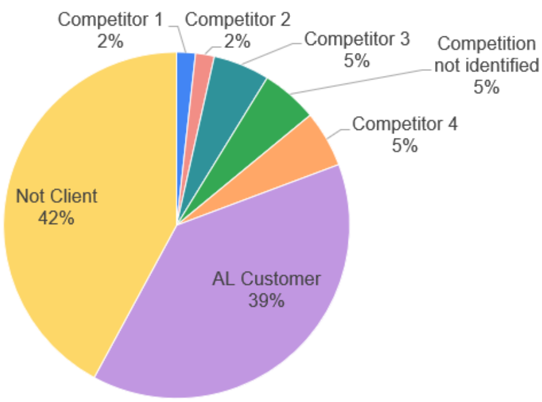


Figure 4.24- Air Liquide penetration rate: Portugal

For Portugal, AL has a penetration rate of 39%, which is a good value for the business. This is justified because Portugal is a smaller country and doesn't have many competitions in this sector.

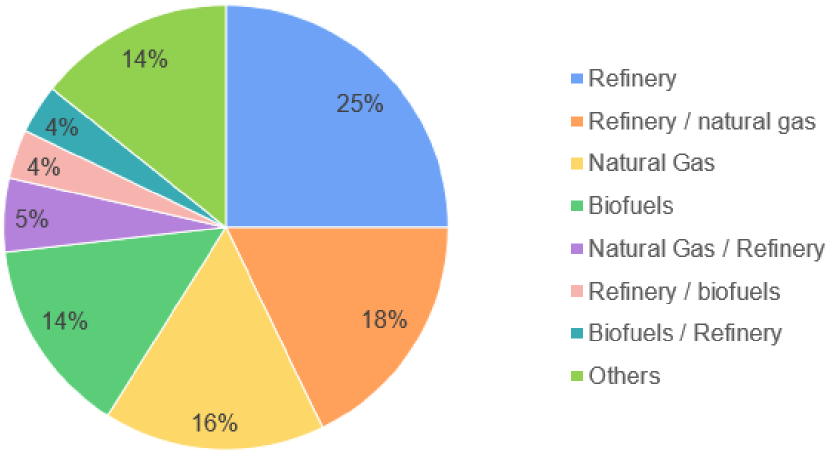
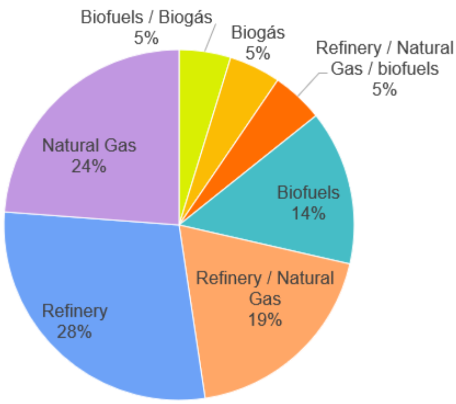


Figure 4.25- Distribution by sectors of the Oil & Gas companies: Portugal

For Portugal, refineries still occupy 1/4 of this market, followed by natural gas. However, biofuels are growing with a weight of 14% because, in the short/medium term, biofuels are expected to be a complementary contribution to achieving a low carbon transport economy [69].



In terms of Air Liquide customers divided by application, it is noticeable that refinery and natural gas occupy more than half of the customers. It relies on the reason that Portugal doesn't have much biogases production. Instead, the renewable sector focuses on biofuels.

Figure 4.26- Distribution by sectors of Air Liquide's Oil & Gas customers

4.5.2. Spain

Table 4.11- Number of deliveries per company [66, 68, 70]

Company	Number of deliveries
Competitor 1	5
AL Customer	26
Competition not identified	2
Competitor 3	1
Competitor 4	3
Not Client	45
Competitor 5	1
Total	86

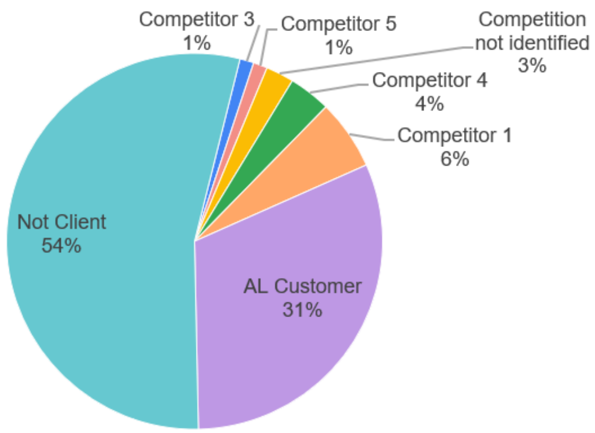


Figure 4.27- Air Liquide's penetration rate: Spain

Spain has a penetration rate of 31%. Therefore, it is a good market indicator for the Air Liquide business.

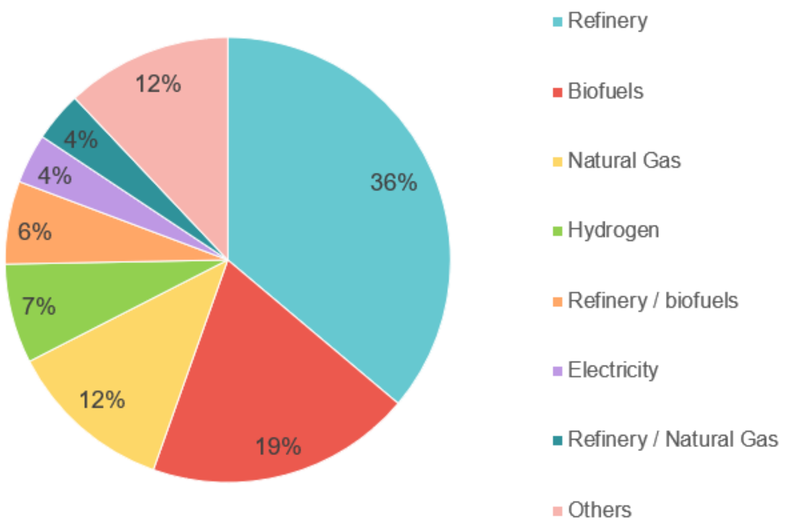
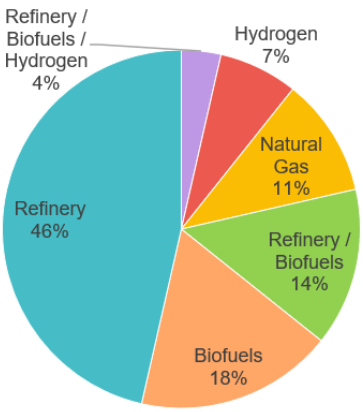


Figure 4.28- Distribution by sectors of the Oil & Gas companies: Spain

Refinery and natural gas occupy almost 50% of Spain's Oil & Gas industry. This country is still very dependent on these sources of energy. Still, implementing all the plans and strategies is expected to lose this dependency and direct the industry to renewables, which now represents more than 20%, which are electrified [71].



For the Air Liquide customers, the refinery still depends on the biofuels application, representing that AL still has customers concentrating on the energy transition since biofuels represent an essential role.

Figure 4.29- Distribution by sectors of Air Liquide's Oil & Gas customers

4.5.3. France

France's Penetration rate is 35%. It can be considered a small number since AL in France has the biggest market in terms of the cluster. To explain this number is because the sources used provided small companies starting to develop biogas and biomethane technologies since it is the future for this country. Many non-accredited companies aren't Air Liquide's customers.

Table 4.12- Number of deliveries per company [72-74]

Company	Number of deliveries
Competitor 1	9
AL Customer	49
Competition not identified	3
Competitor 3	1
Competitor 5	2
Not Client	78
Total	142

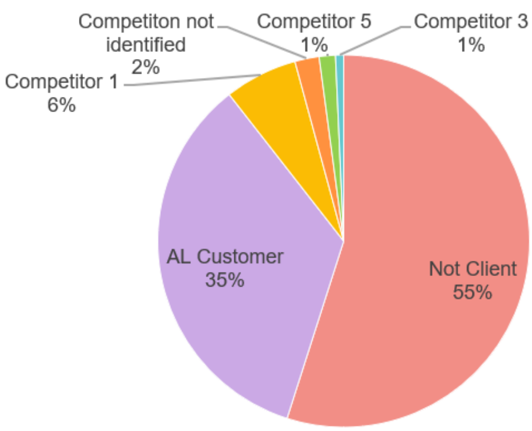


Figure 4.30- Air Liquide's penetration rate: France

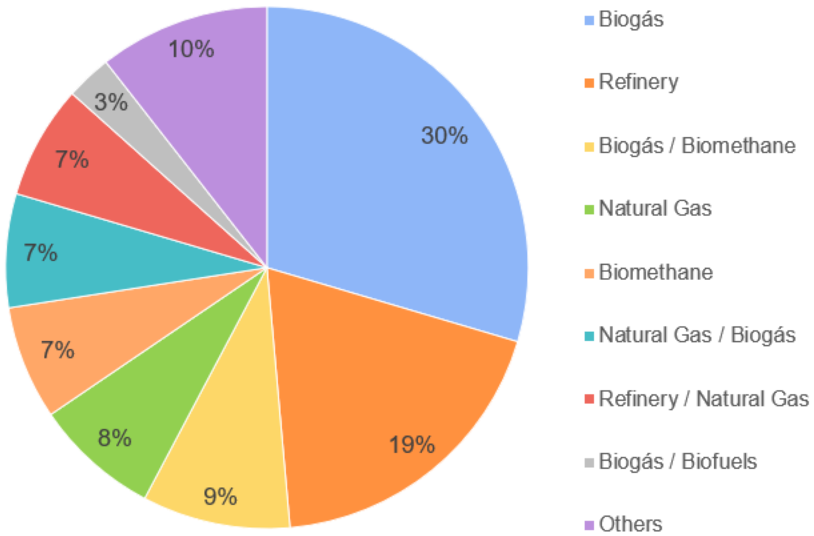


Figure 4.30- Distribution by sectors of the Oil & Gas companies: France

France is focused on producing biogas and biomethane with 46% of the industry with government support. However, since it is a new energy source, many companies are advancing, and science development in this kind of technology always needs measurement.

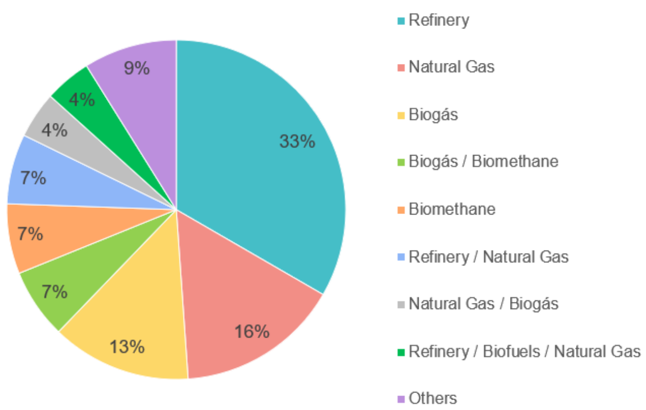


Figure 4.31- Distribution by sectors of Air Liquide's Oil & Gas customers

Analysing Air Liquide customers is confirmed that Air Liquide is still capturing biogas and biomethane producers and developers.

Refinery and natural gas have a significant share.

4.5.4. Italy

Table 4.13- Number of deliveries per company [68, 75, 76]

Company	Number of deliveries
Competitor 1	2
AL Customer	42
Competition not identified	2
Competitor 2	5
Competitor 3	6
Not Client	54
Competitor 5	1
Competitor 6	1
Competitor 7	5
Competitor 8	6
Total	124

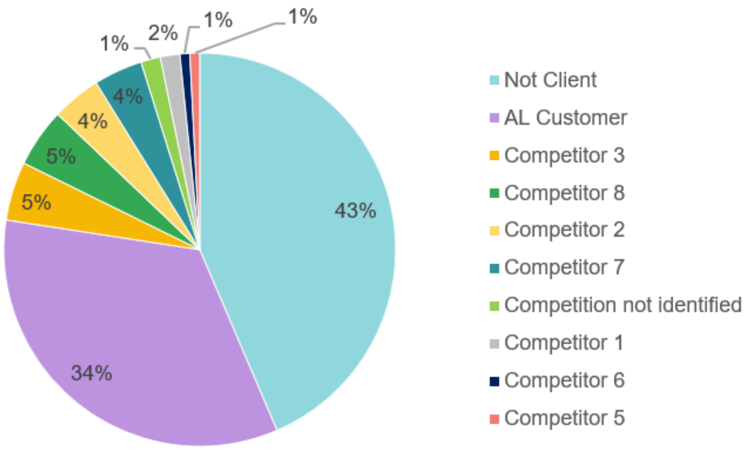


Figure 4.32- Air Liquide's penetration rate: Italy

Italy has a penetration rate of 34%. On the contrary of France, on the sources found, there is a more significant % of accredited companies on the database, explaining the more significant % of penetration in this market since Italy has the minor market in terms of a cluster.

In section 4.6, analysing the market share is possible to understand the differences between markets of each cluster country.

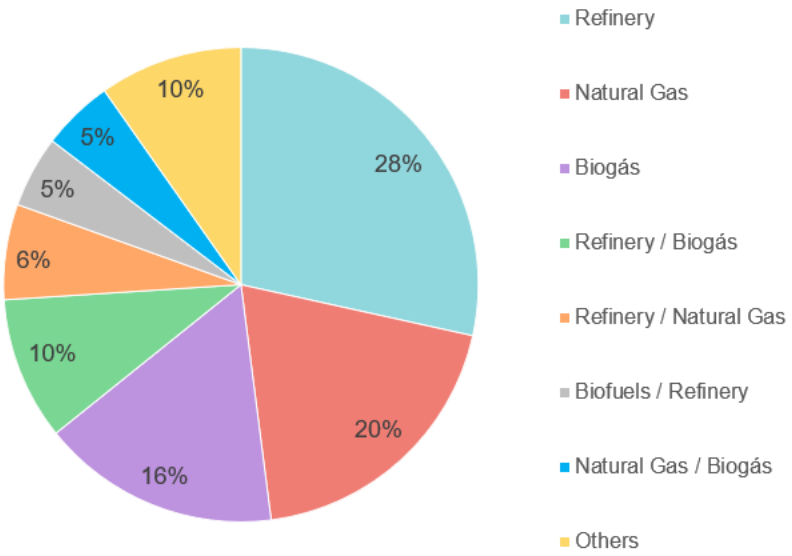


Figure 4.33- Distribution by sectors of the Oil & Gas companies: Italy

Italy's Oil & Gas industry, refinery, natural gas, and biogas are still the main actors. Italy is one of the significant biogas producers in Europe. Biogas, as seen before, still plays an essential role in this industry with considerable weight in this market.

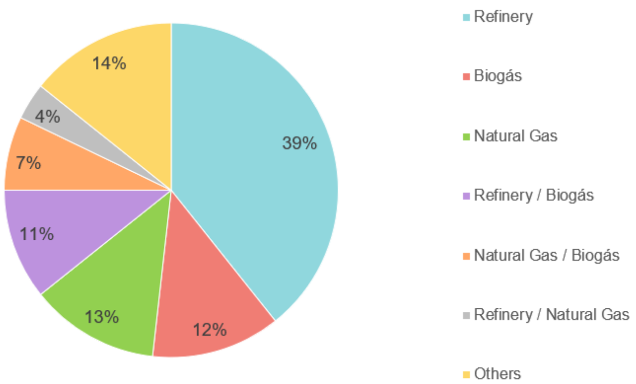


Figure 4.34- Distribution by sectors of Air Liquide's Oil & Gas customers

For Air Liquide's customers, biogas and natural gas have some critical weight necessary for the energy transition. However, the refinery still has a significant number of customers.

4.6. Air Liquide's Market Share

Market share represents the portion of the entire sales of the market in a specific industry. This case illustrates Air Liquide's sales compared to the overall Oil & Gas industry [77]. Following the methodology presented in figure 3.5, section 3.5., it was possible to calculate the market share for each cluster country.

In table 4.14, is represented the assumptions for each country and application for one year. Some companies do the measurement and quality control of more than one application, so in that case, the assumption is 50% of the total value of the application because the overall statement is that they consume fewer gases.

Table 4.14- Assumptions of gases usage for each sector by country

Average consumption per site	Refinery	Refinery and more	Natural gas	Natural gas and more	Biomethane /Biogas	Biomethane /Biogas and more	Hydrogen	Hydrogen and more
France	€100,000	€50,000	€6,000	€3,000	€6,000	€3,000	€4,000	€2,000
Italy	€90,000	€45,000	€2,500	€1,250	€3,000	€1,500	€3,000	€1,500
Portugal	€50,000	€25,000	€2,000	€1,000	€2,000	€1,000	€2,000	€1,000
Spain	€60,000	€30,000	€1,000	€500	€2,000	€1,000	€2,000	€1,000

Taking the sum of every company by the respective assumption, it was possible to calculate the Gases Market for 2020.

According to equation 4.2, to have the market share, it was necessary to retreat from the Power BI of each country's Oil & Gas sales in 2020.

The results are represented in table 4.15.

$$\text{Market Share (\%)} = \frac{\text{Oil \& Gas SG sales of AL (2020)}}{\text{Gases Market (2020)}} \times 100$$

Equation 4.2

Table 4.15- Market Share by country

k€	Gases Market (2020)	AL Oil & Gas SG Sales (2020)	AL Market Share
France	€ 5,123	€ 1,877	36,6 %
Italy	€ 5,352	€ 547	10,2 %
Portugal	€ 1,427	€ 383	26,8 %
Spain	€ 3,538	€ 868	24,5 %

4.7. Competition Analysis

To have a better view of the position of Air Liquide inside the Oil & Gas market, an analysis of the competition was made.

It is possible to see an increasing number of ISO-17205* and even ISO-17034** accredited competitor concentrations and molecules in Europe. Although the SWE still doesn't have any Oil & Gas accredited products, they depend entirely on other countries.

Linde's scope of accreditation is wider and broader (both the number of molecules and the range of molecules they offer). Moreover, it includes many hydrocarbons, which positions Linde as one of the leaders in Europe accredited mixtures [78].

In Italy, SIAD (now 100% independent) has ISO-17025/ISO-17034 accreditation to support the Energy Gases Market that they dominate. It should also be noted that SIAD has 17034 and are using this to export to many European countries [79].

In Spain, all significant players (Nippon and Linde) have relevant ISO-17025 scopes. Thus, for example, Linde's Barcelona plant has an excellent ISO-17025 accreditation to support Energy Gas Market - mainly in natural gas [80].

The active competitors are actively promoting their reduced uncertainty, which they can offer through their ISO-17034 accreditations.

Table 4.16 represents the competition analysis made. Again, Air Liquide has a weak spot in the accredited mixtures compared to the competitors, except in France, where the main competitor still doesn't have accreditation in this field.

*ISO 17025 - is valid for any organization that performs testing, sampling or calibration and wants reliable results. This includes all types of laboratories, whether owned and operated by government, industry or, in fact, any other organization [81].

**ISO 17034 - sets out the requirements following which reference materials are produced. It is intended to be used as part of the general quality assurance procedures of the reference material producer [82].

Table 4.16- Competition Analysis

Capabilities multi component mixtures	Air Liquide			Competition			
	Site 1	Site 2	Site 3	Competitor 1	Competitor 2	Competitor 3	Competitor 4
Non-accredited							
Nat Gas							
LNG							
Biogas/Bio CH4							
Refinery Gas							
Accredited							
Nat Gas							
LNG							
Biogas/Bio CH4							
Refinery Gas							

	Very good
	Good
	Weak/limited
	None

4.8. SWOT Analysis

This section presents a SWOT analysis of the Oil & Gas market compared with the leading competitors and previses the upcoming challenges.

Its construction is based on recognising strengths related to the market's potential and weaknesses, which allows it to identify risks hidden by the threats.

Table 4.17- SWOT Analysis

Strengths	Weaknesses
Industrial gases overall market position. Good position in the market with related products. Reasonable offers for existing and potential customers.	Late entering in the market of new offers. Competition has good accreditation capabilities that AL doesn't have. No overall substantial lead time and reliability.
Opportunities	**Threats**
Rapid changing requirements in the energy transition market due to the utilization of alternative fuels such as LBG, biomethane, biogas and H_2. Need to analyse new stakeholders for the biomethane sector - France and Italy. Need for different accredited mixtures to prove compliance to legislative standards on safety, quality, and calorific value. Need to qualify the H_2 and follow norms.	Lack of accreditation scope which doesn't fully match the market needs. Catching up with the capabilities with market needs will require time, money, and FTEs (full-time employees). Vulnerable position with existing customers.

5. CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions about the market study done for the Oil & Gas sector and the recommendations for Air Liquide in this subject.

5.1. Conclusions

Air Liquide is considered a leader in the gases market, so it aims to improve and remain at the top. The company is always trying to anticipate its customer's needs, catch new ones and develop new business opportunities. With the growing concern about energy transition, companies must follow restrictive norms about emissions and measurement. The present study aims to predict how the Oil & Gas market will behave due to environmental regulations and new market needs. The scope was the SWE (South West Europe) cluster in the market R&A (Research and Analysis).

Considering the performed analysis is possible to distribute the Oil & Gas market into sub-markets: R&A04C (Oil & Gas Labs), M&P02 (Refining & Oil, Coal and LNG Transportation), and M&P03 (Petrochemicals). Moreover, they were divided into sectors to understand the scope better: refinery, crackers, natural gas, and biomethane.

Horizon 2020 and LIFE programmes were essential to identify new potential customers for the R&A market. Within all the databases, focusing on Oil & Gas, it was possible to identify 32 new potential customers for France, 25 for Italy, 8 for Portugal and 18 for Spain. The energy transition is a topic of interest inside these programmes since they represent 40% of projects for Italy and France. For Portugal 19%, and Spain 11%.

Intending to predict the Oil & Gas market, the International Energy Agency and BP Outlook were the sources that based the forecast. Predictably, the consumption and demand of non-renewable sources will decrease over the years. But since they will not disappear immediately, and with the measurement, restrictions tighten to control the quality of these products, it can be an opportunity for the R&A market.

The main application of this market is the measurement and quality control of products. The refinery and natural gas sectors will continue to increase demand for these applications with substantial gas usage. Despite the regulations, these sectors still are the biggest market in the SWE countries. In addition, there are more gases consumption for measurement due to straightening more limits of gases releases and new regulations for more gases to be measured. It is predicted that this sectors will increase 0,2% for refinery and 1% for natural gas, until 2040.

This market is turning into a biomethane injection on natural gas sites to follow fuel emissions targets. This injection and usage demand measurement to understand if it has the required specifications. It is a consciously growing market, mainly in France and Italy, with government support for this sector. According to the forecast, this sector is predicted to grow by over 15% until 2040.

The R&A + and SG market is expected to increase by 1,5%. Therefore, even though the EU wants to decrease the GHG emissions with the cut of refinery and natural gas products, biomethane usage and require measurement will compensate for it. It is a good insight for Air Liquide.

Biomethane doesn't have zero impact on the environment since it releases GHG into the atmosphere. Its usage doesn't emit gases; Therefore, it is a positive energy source, but its production produces and releases gases with the combustion process. So, this sector is a medium-short term solution, for the next 30 years.

One solution that is medium-long term for this market is hydrogen. Since its green production and usage doesn't release GHG into the atmosphere. One growing market is the utilization of hydrogen on fuel cells. To use this component requires specific and restricted specifications to measure the quality; it has the demand of gases usage for calibration and measurement. Therefore, it is an opportunity for Air Liquide to analyse the stakeholders of this market and start investing in it.

The Oil & Gas market share was a good indicator of the company's position in the respective country. However, this indicator in R&A has a different status in different countries. While France has a much higher market share, above 35%, Portugal and Spain have a lower one, and Italy has the poorest, around 10%.

Another conclusion is that Air Liquide SWE must focus on getting accreditation for Oil & Gas products and increasing competitiveness. Unfortunately, Air Liquide lacks accreditation, with a subsequent vulnerable position with existing customers compared with the leading competitors.

5.2. Recommendations for Air Liquide

The recommendations presented below intend to confirm the results, and as well propose a continuous improvement of the company performance:

- Follow up on emissions regulation for the cluster countries in the Oil & Gas market.
- Follow up on specifications for biomethane, refinery and natural gas products and present solutions for customers' needs.
- Focus of the biomethane sector for France and follow for Italy. Watch out for incentives and government support for the Iberia.
- Understand the future needs of hydrogen potential in this market and present solutions for measurement and quality control.
- Need for different accredited mixtures to prove compliance to legislative standards on safety, quality, and calorific value.
- Invest in accreditation for the SWE Oil & Gas products.

REFERENCES

[1] N. A. Downie, "Industrial Gases", London: Kluwer Academic Publishers, 2002.

[2] H.-W. Häring, "Industrial Gases Processing", Weinheim: Wiley-VCH Verlag GmbH & Co, 2017.

[3] “Group history,” Air Liquide, [Online]. Available: ://www.airliquide.com/group/our-history. [Accessed May 2021].

[4] Air Liquide, “act- sustainable future,” Air Liquide, 2021. [Online]. Available: https://www.airliquide.com/magazine/energy-transition/taking-action-climate. [Accessed May 2021].

[5] Air Liquide, “Universal Registration Document 2019,” 3 March 2020. [Online]. Available: https://www.airliquide.com/sites/airliquide.com/files/2020/06/08/air-liquide-2019-universal-registration-document.pdf. [Accessed April 2021].

[6] B. Miller, "Fossil Fuel Emissions Control Technologies", Oxford: Elsevier, 2015.

[7] J. F. Shogren, Encyclopedia of energy, natural resource and environmental economics, Laramie: Elsevier, 2013.

[8] V. Rodríguez-Padilla, Encyclopedia of Energy, vol. 4, Elsevier, 2004.

[9] Air Liquide, “"Universal Registration Document 2020",” 3 March 2021. [Online]. Available: https://www.airliquide.com/sites/airliquide.com/files/2021/03/04/air-liquide-2020-universal-registration-document.pdf. [Accessed April 2021].

[10] A. Wellinger, J. Murphy and D. Baxter, "The biogas handbook", Oxford: Woodhead Publishing, 2013.

[11] O. Hijazi, S. Munro, B. Zerhunsen and M. Effenberger, “Renewable and Sustainable Energy Reviews,” *Review of life cycle assessment for biogas production in Europe,* pp. 1291-1300, 23 July 2015.

[12] C. Burratti, M. Barbanera and F. Fantozzi, “Applied Energy,” *Assessement of GHG Emissions of Biomethane from Energy Cereal Crops,* pp. 128-136, 3 April 2013.

[13] F. Petracchini, M. Segreto, L. Tomassetti, N. Naja and A. Cecinato, “Journal of Environmental Science and Health,” *Environmental impact of biogas: a short review of current knowledge,* pp. 899-906, 13 April 2018.

[14] Emerson, Biomethane analysis using gas chromatography, Canada: Emerson, 2020.

[15] S. Sherif, D. Y. Goswami, E. K. Stefanakos and A. Steinfeld, Handbook of Hydrogen Energy, London: CRC Press, 2014.

[16] Energy Government, “Hydrogen fuel basis,” U.S Departement of Energy, [Online]. Available: https://www.energy.gov/eere/fuelcells/hydrogen-fuel-basics. [Accessed September 2021].

[17] A. Zuttel, A. Borgschulte and L. Schlapbach, "Hydrogen as a Future Energy Carrier", Weinheim: Wiley-VCH Verlag GmbH & Co, 2008.

[18] J. M. Ohi, N. Vanderborgh and G. Voecks, “Hydrogen Fuel Quality Specifications for Polymer Electrolyte Fuel Cells in Road Vehicles,” U.S. Department of Energy, 2016.

[19] J. Straub, “Aerospace Science and Technology,” *In search of technology readiness level (TRL) 10,* pp. 312-320, 11 July 2015.

[20] H. Ritchie and M. Roser, “CO2 emissions by fuel,” World in Data, [Online]. Available: https://ourworldindata.org/emissions-by-fuel. [Accessed September 2021].

[21] H. Kelker, G. Tolg, H. Gunzler and A. Williams, Analytical Chemistry: Purpose and Pocedures, Frankfurt: Wiley-VCH, 2001.

[22] Purnendu K. Dasguspta, Kevin A. Schung, Gary D. Christian, Analytical Chemistry, Wiley , 2004.

[23] G. Guiochon, “Basic Principles of Chromatography,” in *Handbook of Analytical Techniques*, Wiley-VCH, 2001.

[24] D. E. Connor, PhD Thesis ETH Zurich, “Using Hydrogen as a Carrier Gas for GC,” 17 April 2015.

[25] H. Günzler, A. Williams, “Gas Chromatography,” in *Handbook of Analytical Techniques*, Gent, Wiley-VCH, 2001, pp. 199-258.

[26] B. Barman, V. L. Cebolla and L. Membrado, “Chromatography Techniques for Petroleum and Related Products,” *Critical Reviews in Analytical Chemistry,* pp. 75-120, 2000.

[27] "Euro 1 to Euro 6 guide – find out your vehicle's emissions standard," RAC, February 2020. [Online]. Available: https://www.rac.co.uk/drive/advice/emissions/euro-emissions-standards/. [Accessed October 2021].

[28] European Commission, "The European Green Deal," 11 December 2019. [Online]. Available: https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF. [Accessed April 2021].

[29] European Commission, "What is the European Green Deal ?," 2019. [Online]. Available: https://www.economist.com/the-economist-explains/2021/06/01/what-is-the-european-green-deal. [Accessed April 2021].

[30] United Nations, "Sustainable Development Goals Report," 2020. [Online]. Available: https://unstats.un.org/sdgs/report/2020/The-Sustainable-Development-Goals-Report-2020.pdf. [Accessed May 2021].

[31] World Business Council for Sustainable Development, "The Greenhouse Gas Protocol," World Resources Institute, Geneva, 2019. [Online]. Available: https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf. [Accessed May 2021].

[32] United Nations Framework Convention on Climate Change, "Kyoto Protocol Referencce Manual," 2009. [Online]. Available: https://unfccc.int/resource/docs/publications/08_unfccc_kp_ref_manual.pdf. [Accessed May 2021].

[33] Greenhouse Gas Protocol, "Global Warming Potential Values," 2019. [Online]. Available: https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf. [Accessed June 2021].

[34] European Comission, "Decision of the European Parliment and of the council on a General Union Environmental Action Programme to 2030," 14 October 2020. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020PC0652&from=EN. [Accessed June 2021].

[35] European Union, "Horizon 2020," 2014. [Online]. Available: https://ec.europa.eu/programmes/horizon2020/en/history-horizon-2020. [Accessed June 2021].

[36] European Comissions, Horizon 2020 in a brief, Brussels: European Union, 2014. [Online]. Availabe: https://ec.europa.eu/programmes/horizon2020/en/news/horizon-2020-brief-eu-framework-programme-research-innovation. [Accessed in June 2021].

[37] European Comissions, "Horizon Europe," European Commision, Brussels, 2021. [Online]. Available: https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en. [Accessed in June 2021].

[38] Environemntal Agency, "LIFE Report," 2020. [Online]. Available: https://www.environmentalprosecutors.eu/eu-life-project. [Accessed July 2021].

[39] France Commision, "Integrated national energy climate plan for France," March 2020. [Online]. Available: https://ec.europa.eu/energy/sites/default/files/documents/fr_final_necp_main_en.pdf. [Accessed March 2021].

[40] Ministry of economy development, "Integrated national energy climate plan Italy," December 2019. [Online]. Available: https://ec.europa.eu/energy/sites/default/files/documents/it_final_necp_main_en.pdf. [Accessed March 2021].

[41] Portugal Comission, "Integrated National Energy CLimate Plan Portugal," December 2019. [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/documents/pt_final_necp_main_en.pdf. [Accessed March 2021].

[42] Spain Comission, "Integrated National Energy Climate Plan," January 2020. [Online]. Available: https://ec.europa.eu/energy/sites/default/files/documents/es_final_necp_main_en.pdf. [Accessed March 2021].

[43] International Energy Agency, "History of IEA," 2021. [Online]. Available: https://www.iea.org/about/history. [Accessed August 2021].

[44] BP, "Our History," 2020. [Online]. Available: https://www.bp.com/en/global/corporate/who-we-are/our-history.html. [Accessed August 2021].

[45] BP, "BP Energy Outlook 2030," BP, London, 2011. [Online]. Available: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2011.pdf. [Accessed in May 2021].

[46] BP, "BP Outlook 2019," BP, London, 2020. [Online]. Available: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2019.pdf. [Accessed in May 2021].

[47] BP, "BP Outlook 2020," BP, London, 2021. [Online]. Available: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2020.pdf. [Accessed in May 2021].

[48] International Energy Agency, "The Outlook for biogas and biomethane 2040," March 2020. [Online]. Available: https://iea.blob.core.windows.net/assets/03aeb10c-c38c-4d10-bcec-de92e9ab815f/Outlook_for_biogas_and_biomethane.pdf. [Accessed June 2021].

[49] Climate Analysis Center, "Biomethane Observatory," 2020.

[50] International Energy Agency, “Hydrogen,” IEA, 2021.

[51] N. G. Mankiw, "Principles of Economics", Stamford: Cengage Learning, 2015.

[52] D. Salvatore and E. Diulio, Outline of Theory and Problems of Principles of Economics, New York: McGraw-Hill, 2003.

[53] L. G. Cooper and M. Nakanishi, Market Share Analysis: Evaluating Competitive Marketing Effectiveness, Boston: Kluwer Academic Publishers, 1998.

[54] P. W. Farris, N. T. Bendle, P. E. Pfeifer and D. J. Reibstein, Marketing Metrics: 50+ Metrics Every Executive Should Master, New Jersey: Wharton School Puvlishing, 2006.

[55] D. Wilkinson and P. Birmingham, Using Research Instruments: A Guide for Researchers, London: Routledge Falmer, 2003.

[56] E. K. Valentin, “Journal of Marketing Theory and Practice,” *Swot Analysis from a Resource-Based View,* pp. 54-69, 8 December 2015.

[57] P. Alasuutari, L. Bickman and J. Brannen, The SAGE Handbook of Social Research Methods, London: SAGE Publications, 2008.

[58] M. Saunders, P. Lewis and A. Thornhill, Research Methods for Business Students, Lomdon: Pearson, 2012.

[59] J. S. Armstrong, “Principles of Forecasting: A Handbook for Researchers and Practitioners,” *Selecting Forecasting Methods,* 16 December 2009.

[60] Tallyfy, “Tallyfy quality tools,” Tallyfy, [Online]. Available: https://tallyfy.com/quality-tools/. [Accessed September 2021].

[61] Air Liquide, “Segmentation IM,” Air Lquide, France, 2015.

[62] European Commission, “H2020 projects,” European Comisison, [Online]. Available: https://webgate.ec.europa.eu/dashboard/sense/app/93297a69-09fd-4ef5-889f-b83c4e21d33e/sheet/a879124b-bfc3-493f-93a9-34f0e7fba124/state/analysis. [Accessed March 2021].

[63] European Commission, “LIFE Public Database,” European Comission, 2020. [Online]. Available: https://webgate.ec.europa.eu/life/publicWebsite/search/advanced. [Accessed March 2021].

[64] European Biogas Association, “EBA Statistical Report 2020,” 2021. [Online]. Available: https://www.europeanbiogas.eu/wp-content/uploads/2021/01/EBA_Statistical Report2020_abridged.pdf. [Accessed August 2021].

[65] Sustainable Agribusiness Forum, “Production of Biomethane in Europe,” Brussels, 2019.

[66] Iberinform, "Iberinform," 2021. [Online]. Available: https://www.iberinform.pt/. [Accessed July 2021].

[67] IPAC, "Instituto Português de Acreditação," 2021. [Online]. Available: http://www .ipac.pt/. [Accessed July 2021].

[68] Jornal de Negócios, "Empresite," 2021. [Online]. Available: https://empresite .jornaldenegocios.pt/. [Accessed July 2021].

[69] LNEG, "Biofuels," 25 May 2019. [Online]. Available: https://www.lneg.pt/ area/energia/bioenergia/biocombustiveis/. [Accessed September 2021].

[70] ENAC, "ENAC," ENAC, 2021. [Online]. Available: https://www.enac.es/. [Accessed July 2021].

[71] International Energy Agency, "Spain 2021," May 2021. [Online]. Available: https://www.iea.org/reports/spain-2021. [Accessed September 2021].

[72] BFM Verif, "BFM Verif," 2021. [Online]. Available: https://www.verif.com/societe/BMF-387816226/. [Accessed August 2021].

[73] COFRAC, "COFRAC," COFRAC, 2021. [Online]. Available: https://www.cofrac.fr/. [Accessed August 2021].

[74] F. Env, "France Env," 2021. [Online]. Available: https://www.franceenv.com/. [Accessed August 2021].

[75] Accredia Italia, "Accredia Italia," 2021. [Online]. Available: https://www.accredia.it/. [Accessed August 2021].

[76] I. B. Register, "Italian Business Register," 2021. [Online]. Available: https://italian businessregister.it/?gclid=CjwKCAjwq9mLBhB2EiwAuYdMtc1USrYCs7eMCqu-CfA7DDZTMfjBeh8z8Rma-ldyXgAcwgUS3aodVxoCWkoQAvD_BwE.[Accessed August 2021].

[77] J. Gordon, "Market Share," *What is Market Share?,* 2021.

[78] Linde, "Linde Speciality Products," 2021. [Online]. Available: https://www.linde-gas.com/en/products_and_supply/speciality_gas_equipment/index.html. [Accessed September 2021].

[79] SIAD, "ISO/IEC 17025 and ISO 17034," 2020. [Online]. Available: https://www. siad.com/siad/certifications/uni-cei-en-iso-17025-2018-uni-cei-en-iso-17034-2017. [Accessed 2021].

[80] ILAC, "ILAC," 2021. [Online]. Available: https://ilac.org/signatory-search/. [Accessed September 2021].

[81] ISO, “ISO-IEC-17205,” 2018. [Online]. Available: https://www.iso.org/ISO-IEC-17025-testing-and-calibration-laboratories.html. [Accessed September 2021].

[82] ISO, “ISO 17024:2016,” 2017. [Online]. Available: https://www.iso .org/standard/29357.html. [Accessed September 2021].

[83] B. F. Towler, The Future of Energy, Elsevier, Brislbane, 2014.

[84] International Energy Agency, “Biogas and biomethane in Italy,” July 2021. [Online]. Available: https://iea.blob.core.windows.net/assets/ced91034-a399-404e-b8be-dea83b9b3187/1.4_PelliniAlessandro_13Jul2021.pdf. [Accessed October 2021].

[85] A. Gollakota, N. Kishore and S. Gu, “Renewable and Sustainable Energy Reviews,” *A review on hydrotermal liquefaction of biomass,* pp. 1378-1392, 20 May 2017.

Appendix A - Categorization system used commercially (ASTM)

There are two classification systems to grade coal: the ASTM (American Society of Testing Materials) system in America and an international ECE (Economic Commission for Europe) Codification system developed in Europe. The categorization systems used commercially are primarily based on volatile matter is in table A.1.

Table A.1- ASTM coal classification by rank

Group	Fixed carbon [a] (%)	Volatile matter [b] (%)	Heating value[b] (Btu/lb)
Anthracitic			
Metaanthracite	> 98	< 2	
Anthracite	92 – 98	2 – 8	
Semianthracite	86 – 92	8 – 14	
Bituminous			
Low volatile	78 – 86	14 – 22	
Medium volatile	69 – 78	22 – 31	
High volatile A	< 69	> 31	> 14,000
High volatile B			13,000 – 14,000
High volatile C			10,500 – 13,000[c]
Subbituminous			
Subbituminous A			10,500 – 11,500[c]
Subbituminous B			9,500 – 10,500
Subbituminous C			8,300 – 9,500
Lignitic			
Lignite A			6,300 – 8,300
Lignite B			< 6,300

[a]Calculated on dry, mineral matter-free coal; the Parr formula corrects ash to the material; mineral matter = 1.08[percent ash + 0-55(percent sulfur). Ash and sulfur are on a dry source.

[b]Calculated on mineral matter-free coal with bed moisture content.

[c]Coals with heating values between 10,500 and 11,500 Btu/lb are categorized as high volatile C bituminous if they possess caking properties or a subbituminous A if they do not.

Appendix B - Global Warming Potential Values

Table B.1 includes a 100-year time perspective of global warming potentials (GWP) relative to CO_2 of some GHG.

Table B.1- GWP Values [33]

Industrial designation/common name	Chemical formula	GWP values for 100-year-time horizon
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265
Substances controlled by the Montreal Protocol		
CFC-11	CCl_3F	4 660
CFC-12	CCl_2F_2	10 200
CFC-13	CCl_3F_3	13 900
CFC-113	CCl_2FCClF_2	5 820
CFC-114	CCl_2FCClF_2	8 590
CFC-115	$CClF_2CF_3$	7 670
Halon-1301	$CBrF_3$	6 290
Halon-1211	$CBrClF_2$	1 750
Halon-2402	$CBrF_2CBrF_2$	1 470
Carbon tetrachloride	CCl_4	1 730
Methyl bromide	CH_3Br	2
Methyl chloroform	CH_3CCl_3	160
HCFC-21	$CHCl_2F$	148
HCFC-22	$CHCl_2F_2$	1 760
HCFC-123	$CHCl_2F_3$	79
HCFC-124	$CHClFCF_3$	527
HCFC-141	$CH3CCl_2F$	782
HCFC-142	$CH3CCl_2F_3$	1 980
HCFC-225a	$CHCl_2CF_2CF_3$	127
HCFC-225b	$CHClFCF_2CClF_2$	525
Hydrofluorocarbons (HFCs)		
HFC-23	CHF_3	12 400
HFC-32	CH_2F_2	677

HFC-41	CH_3F_2	116
HFC-125	CHF_2CF_3	3 170
HFC-134	CHF_2CHF_2	1 120
HFC-134a	CH_2FCF_3	1 300
HFC-143	CH_2FCHF_2	328
HFC-143a	CH_3CF_3	4 800
HFC-152	CH_2FCH_2F	16
HFC-152a	CH_3CHF_2	138
HFC-161	CH_3CH_2F	4
HFC-227ea	CF_3CHFCF_3	3 350
HFC-236cb	CHF_2CHFCF_3	1 210
HFC-236fa	$CF_3CH_2CF_3$	1 330
HFC-245ca	$CH_2FCF_2CHF_2$	8 060
HFC-245fa	$CHF_2CH_2CF_3$	716
HFC-365mfc	CH3CF2CH2CF3	858
HFC-43-10mee	CF3CHFCHFCF2CF3	804
Perfluorinated compounds		
Sulfur hexafluoride	SF_6	23 500
Nitrogen trifluoride	NF_3	16 100
PFC-14	CF_4	6 630
PFC-116	C_2F_6	11 100
PFC-218	C_3F_8	8 900
PFC-318	c-C_4F_8	9 540
PFC-31-10	C_4F_{10}	9 200
PFC-41-12	C_5F_{12}	8 550
PFC-51-14	C_6F_{14}	7 910
PFC-91-18	$C_{10}F_{18}$	7 190
Trifluoromehtyl sulfur pentafluoride	SF_5CF_3	17 400
Perfluorocyclopropane	c-C_3F_6	9 200
Fluorinated ethers		
HFE-125	CHF_2OCF_3	12 400
HFE-134	CHF_2OCHF_2	5 560
HFE-143a	CH_3OCF_3	523
HFE-235da2	$CHF_2OCHClCF_3$	491

HFE-cb2	$CH_3OCF_2CF_3$	654
HFE-fa2	$CHF_2OCH_2CF_3$	812
HFE-347mcc3	$CH_3OCF_2CF_2CHF_2$	530
HFE-347pcf2	$CHF_2CF_2CF_2CHF_2$	889
HFE-356pcc3	$CH_3OCF_2CF_2CF_3$	530
HFE-7100	C4F90CH3	421
HFE-7200	C4F9OC2H5	57
HFE-43-10pccc124	$CHF_2OCF_2OC_2F_4OCHF_2$	2 820
HFE-236ca12	CHF20CF2OCHF2	5 350
HFE-338pcc13	$CH_2OCF_2CF_2OCHF_2$	2 910
HFE-227ea	$CF_3CHFOCF_3$	6 450
HFE-236ea2	$CHF_2OCHFCF_3$	1 790
HFE-236fa	$CF_3CH_2OCF_3$	979
HFE-245fa1	$CHF_2CF_2OCF_3$	828
HFE-263fb2	$CF_3CH_2OCH_3$	1
HFE-329mcc2	$CHF_2CF_2OCF_2CF_3$	3 070
HFE-338mcf2	$CF_3CH_2OCF_2CF_3$	929
HFE-347mcf2	$CHF_2CH_2OCF_2CHFCF_3$	854
HFE-356mec3	$CH_3OCF_2CHFCF_3$	387
HFE-356pcf2	$CHF_2CH_2OCF_2CHF_2$	719
Perfluoropolyethers		
PFPMIE	$CF_3OCF(CF_3)CF_2OCF_2OCF_3$	9 710
Hydrocarbons and other compounds - direct effects		
Chloroform	$CHCl_3$	16
Methylene chloride	CH_2Cl_2	9
Methyl chloride	CH_3Cl	12
halon-1201	$CHBrF_2$	376

Appendix C - Forecast energy consumption per country

In section 2.6 it was presented the forecast of energy consumption based on BP Outlook for the cluster. This appendix is represented the same forecast for each country of the cluster independently.

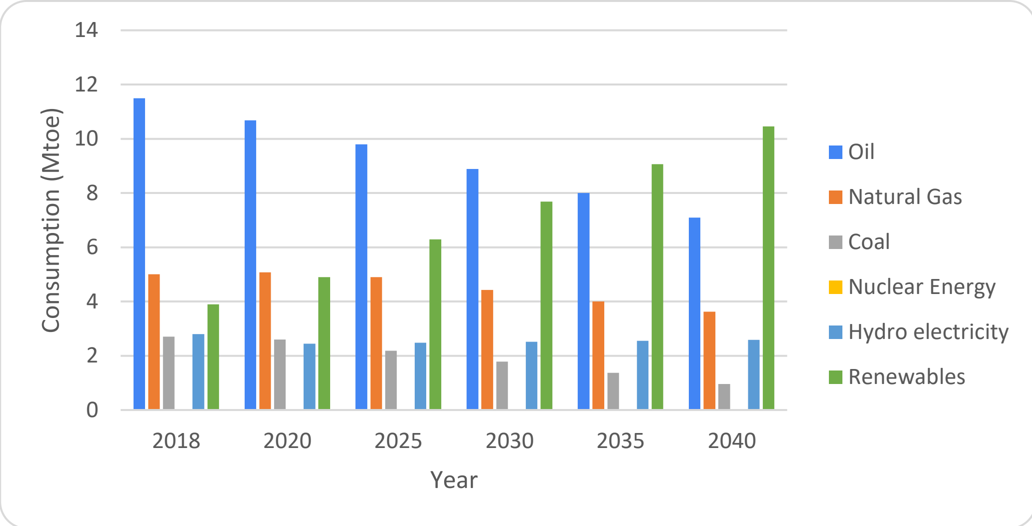


Figure C.1- Portugal's Energy Consumption Forecast

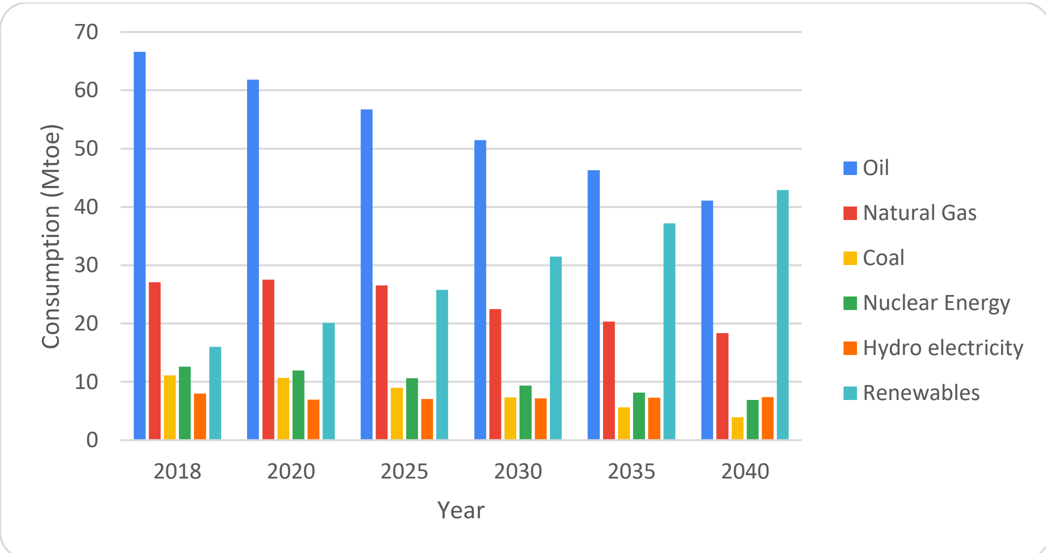


Figure C.2- Spain's Energy Consumption Forecast

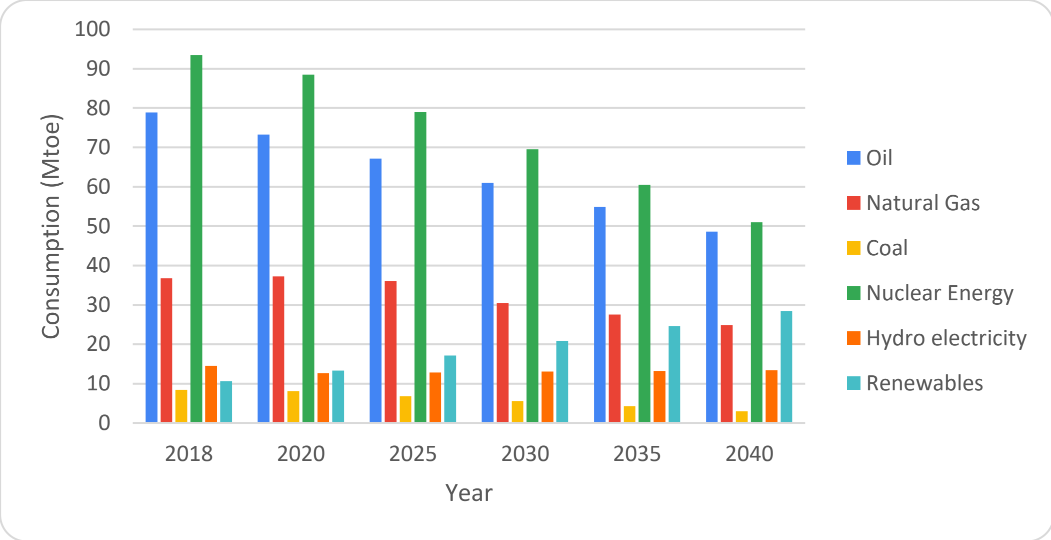


Figure C.3- France's Energy Consumption Forecast

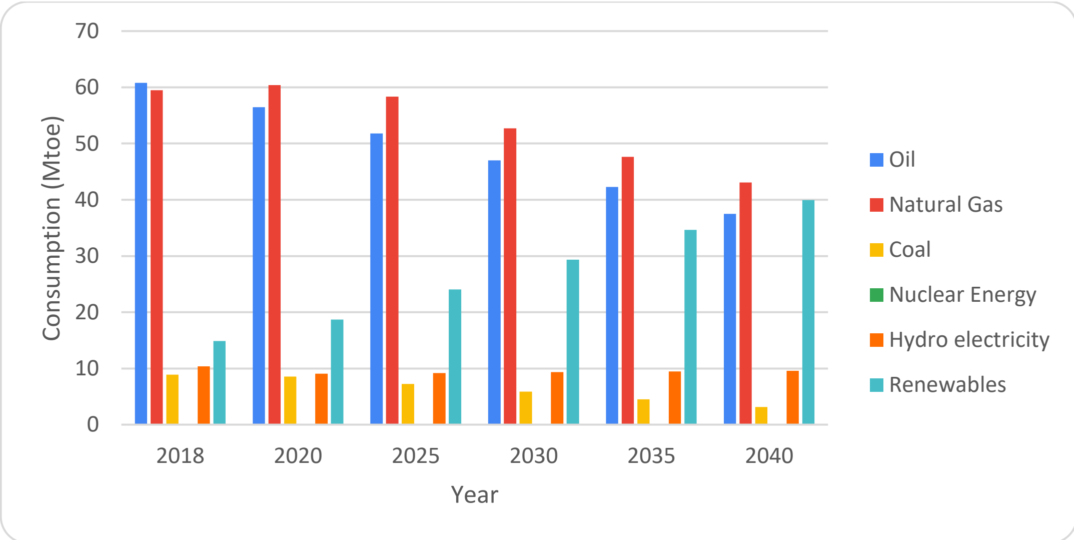


Figure C.4- Italy's Energy Consumption Forecast

Appendix D - R&A04C Sg Sales Market Forecast

To obtain the SG Sales Market results, a forecast was also made for the R&A04C, with the following results. As mentioned before, the results are very similar to the R&A04C Total Sales Forecast, with the same tendencies.

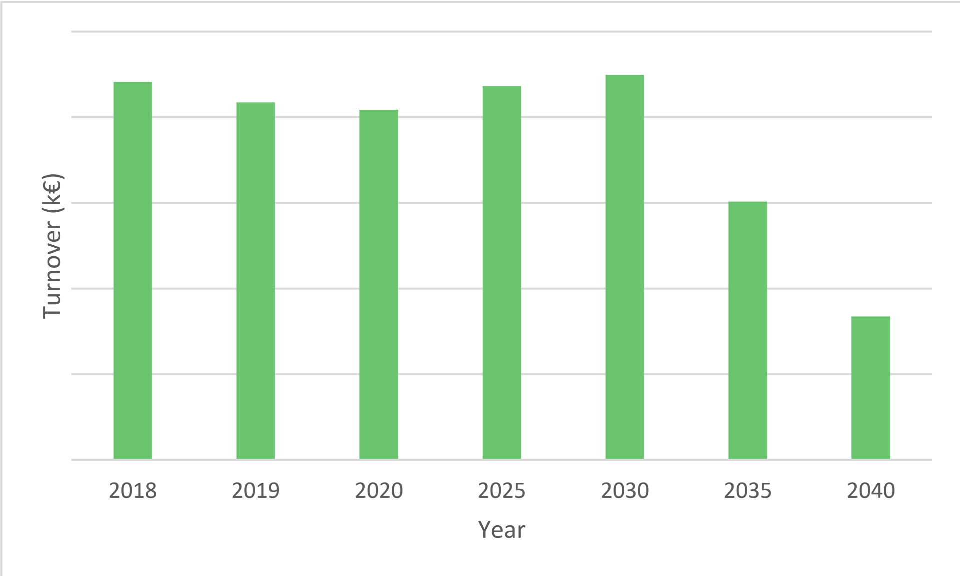


Figure D.1- Refinery SG Sales Forecast

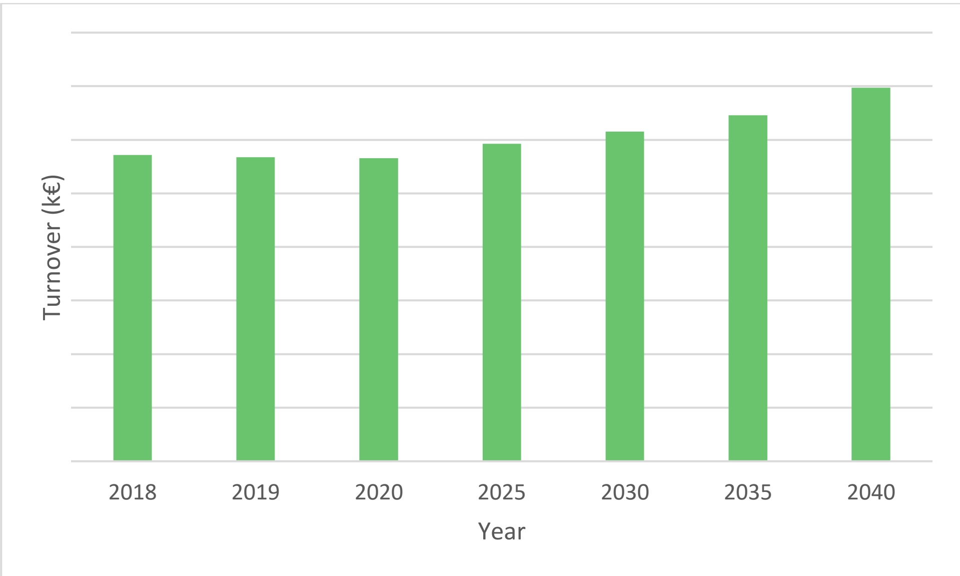


Figure D.2- Natural Gas SG Sales Forecast

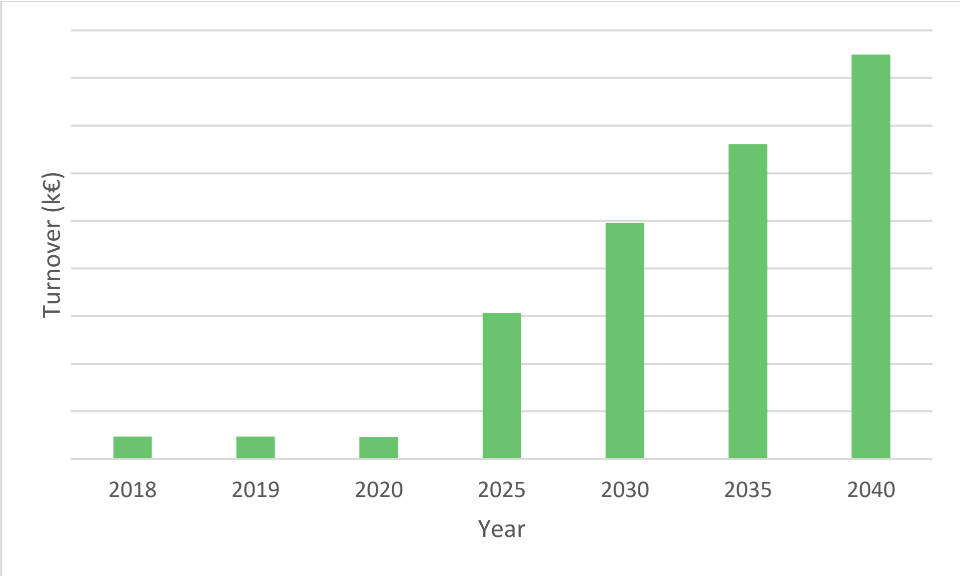


Figure D.3- Biomethane SG Sales Forecast

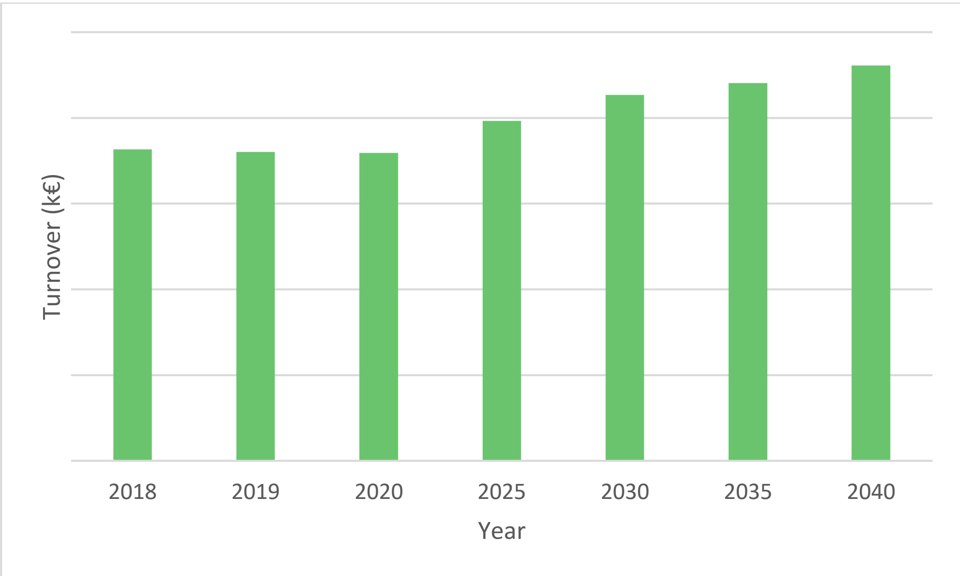


Figure D.4- SG Sales Forecast

2021

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Air Liquide impact in Environment improvement –

Fuels emissions and measurement

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