DEPARTAMENT OF CHEMISTRY

Paulo Rodrigues Pescada Mendes Farinha

Bachelor’s in Chemical and Biochemical Engineering

Analysis needs market study Petrochemical products substitutes New fuels and new processes

Dissertation to obtain the Master’s degree in Chemical and Biochemical Engineering

MASTER IN CHEMICAL AND BIOCHEMICAL ENGINEERING

NOVA University Lisbon
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“The only reason for time is so that
everything doesn't happen at once.”
(Albert Einstein).

Abstract

The petrochemical industry is being subject to some gradual shifts that are altering its course. From new laws and policies applied to meet the current environment standards, to a need for more efficient technologies that aim to change a stagnating market, the changes are becoming more noticeable. These changes promote new and more advanced processes that might affect the whole the gas industry. As a key player in the industrial gas market, Air Liquide needs to stay ahead of the competition by performing market studies that offer insights to possible market fluctuations and give proper direction on how to tackle future developments in the industry.

Through the examination of the future number of plants in each of the key markets, it was possible to predict the future gas market revenue and evaluate how the company should move forward.

With the aid of scenarios, it was possible to predict that the future gas market industry would grow from 2021 until 2030 in the best-case scenario by 2.5 million euros or in the worst-case scenario by 53 thousand euros, with a compound annual growth rate of 2.39% and 0.06%, respectively. This means that in the space of 9 years the whole market will have small growth opportunities.

Air Liquide's position in the oil & gas industry is stable, having a considerable market share and penetration rate. These factors seem to be higher in both Portugal and France, where the company has an advantage, with the first having a market share of 57.4% and the latter 68.4%. Italy and Spain have a more competitive market, namely the first, where the analysis of the competition also revealed that the company lacks in the production of accredited mixtures when compared to the competitors. These were calculated to have a market share of 22.8% and 35.9%, respectively.

Keywords: Air Liquide, Petrochemistry, Analysis, Gas Chromatography, Market study

RESUMO

A indústria petroquímica está a ser sujeita a alterações graduais que estão a alterar a sua direção. Desde novas leis aplicadas para atingir os padrões ambientais atuais, até à procura de tecnologias mais eficientes para mudar um mercado estagnado, as alterações estão a começar a ser mais significativas. Estas possibilitam o aumento da oferta de processos novos e mais avançados que podem afetar o mercado dos gases industriais. Sendo um competidor principal do mercado dos gases industriais, a Air Liquide necessita de ficar à frente da competição através da elaboração de estudos de mercado que ofereçam uma compreensão para possíveis variações do mercado e dar uma direção em como avançar face a futuros desenvolvimentos.

Através da análise do número futuro de instalações de cada processo, foi possível prever o futuro volume de negócios do mercado dos gases e avaliar como a empresa deve avançar.

Com a ajuda de cenários, foi possível prever que o volume de negócios deste mercado irá crescer de 2021 até 2030 na melhor das hipóteses 2.5 milhões de euros e na pior das hipóteses 53 mil euros, com uma taxa de crescimento anual de 2.39% e 0.06%, respetivamente. Isto significa que no espaço de 9 anos a totalidade do mercado irá ter um crescimento baixo.

A posição da Air Liquide na indústria do petróleo e gás é estável, tendo uma cota de mercado e uma taxa de penetração razoáveis. Estes fatores aparentam ser superiores em Portugal e França, onde a empresa tem uma vantagem, sendo que o primeiro apresenta uma cota de mercado de 57.4% e o segundo de 68.4%. Itália e Espanha aparentam ter um mercado mais competitivo, nomeadamente Itália, onde a análise da competição revelou que a empresa não tem uma produção de misturas acreditadas ao nível das empresas rivais. A cota de mercado destes paises foi calculada em 22.8% e 35.9%, respetivamente.

Palavas chave: Air Liquide, Petroquímica, Análises, Cromatografia gasosa, Estudo de mercado

CONTENTS

LIST OF FIGURES

List of Tables

GLOSSARY

LI	Large Industries
IM	Industrial Merchant
HC	Healthcare
EL	Electronics
E&P	Entrepreneurs and Professionals
M&P	Materials and Process
F&P	Food and Pharma
R&A	Research and Analysis
SG	Specialty Gases
R&A04C	Oil & Gas Labs Submarket
M&P02	Refining & Oil, Coal and LNG Transportation Submarket
M&P03	Petrochemistry Submarket
R&D	Research and Development
GC	gas chromatography
IR	Infra-Red
ASU	Air Separation Unit
ppm	parts per million
ppb	parts per billion
LNG	liquified natural gas
LPG	liquified petroleum gas
EU	European Union
SMR	Steam methane reforming
CO2	Carbon dioxide
H2	Hydrogen
CO	Carbon monoxide
BTX	Benzene, Toluene and Xylene
PET	polyethylene terephthalate
PVC	polyvinyl chloride

HDPE	High density polyethylene
LDPE	Low density polyethylene
PTX	Power to X
PEM	Polymer electrolyte membrane
PTG	Power to Gas
PTL	Power to Liquid
CCUS	Carbon Capture Utilization and Storage
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
BECCS	Bio Energy with Carbon Capture and Storage
DAC	Direct air capture
COTC	Crude oil to chemicals
MTO	Methanol to Olefins
OCM	Oxidative coupling of methane
PDH	Propane dehydrogenation
TRL	Technology Readiness Level
CRI	Commercial Readiness Index
RED	Renewable energy directive
IED	Industrial emissions Directive
SWE	Southwest Europe
ETS	European Trading System
TWh	Terawatt hour
MWh	Megawatt hour
MFF	Multifinancial framework
NGEU	Next Generation European Union
NDIR	non-dispersive infrared
FTIR	Fourier transform infrared
QCL	Quantum Cascade Laser
TDL	Tunable Diode Laser
GDP	Gross domestic product
IPI	Industrial Production Index
AL	Air Liquide
CAGR	Compound Annual Growth Rate
BAT	Best Available Techniques

1

FRAMEWORK AND MOTIVATION

Throughout the years there have been many breakthroughs in the gas industry. Since the 18th century when oxygen and carbon dioxide were discovered, to further detections such as ammonia and noble gases, this field of study has been constantly evolving and improving on itself [1]. Acetylene was one such gas that was uncovered in those years. This particular compound was mainly used for lighting applications and created a need for its production to become cheaper. This proved to be an important step in the history of industrial gas, due to the innovation of liquified gas by Carle Von Linde. It was soon followed by the creation of a safe transportation of acetylene and a new process to separate oxygen through the liquefaction of air by Georges Claude [1]. This marked a period of heavy competition of constant search for further innovations and development of air separation technologies by the two main companies that dominated the gas industry, Linde and Air Liquide.

In 1902 Air Liquide was born when Georges Claude invented a process for liquefying air to separate oxygen and nitrogen by distillation [1]. In the following years Air Liquide expanded its market by building local production plants in various countries in Europe, and soon expanding overseas to North America and Japan. During this time of rapid growth some important milestones were achieved, namely the storage of gas in liquid form, the expansion to other markets such as space industry, electronics and healthcare and more recently the focus on hydrogen as a new energy source. Nowadays, Air Liquide bolsters a total of 3.8 million clients and patients and is present in 75 countries [2]. Currently, the gas industry is a consolidated market dominated by big companies such as Air Liquide, Air Products, Linde, TNS and Messer.

Air Liquide divided its focus into four main business areas: Large Industries (LI), Industrial Merchant (IM), Healthcare (HC) and Electronics (EL). Inside of the Industrial Merchant business line there are many distinct groups of customers with specific needs and behaviors that require different approaches. For that reason, this market is segmented in order to enable a greater understanding of the customers, to better monitor and adapt to their needs and to have more opportunities to grow. With that in mind, Air Liquide has identified 4 different Markets: E&P - Entrepreneurs and Professionals, M&P - Materials and Process, F&P - Food and Pharma and R&A - Research and Analysis. This project will be focused with more detail on the R&A Market.

The main activities of this market consist of research programs, testing prototypes, analysis, calibration services, product certification, quality control and emission control. This department is frequently associated with the use of specialty gases (pure, rare, chemical and calibration gas mixtures). The customers associated with the R&A market are the research centers, independent laboratories, sites whose main activities are R&A related, on-site laboratories of production sites and sites using SG as process gas.

Each market can be segmented into sub-markets to further specialize the necessary products and services. Since the theme of this project is related to the petrochemical industry, the Oil and Gas Labs sub-market (R&A04C) is the one where there will be more focus, with an extension on the Refining & Oil, Coal and LNG Transportation and the Petrochemistry sub-markets (M&P02 and M&P03, respectively).

In oil refineries and petrochemical plants, specialty gases are utilized for analysis. These analyses are performed in many different areas, such as on the process, in the control and R&D labs, for environmental monitoring and safety detection. There are a vast amount of analysis, each with a different method applied, with the main analyzers being the gas chromatography (GC) and Infra-Red (IR).

This study aims to examine the petrochemical industry and its ongoing transition to new processes due to improvements in old technologies, development of new technologies and current environmental regulations. At Air Liquide, some of the goals are having long-term vision, a clear strategy and a strong involvement in the markets of the future in order to stay ahead of the changes and constantly evolve. Therefore, this study will provide insights for the need of analysis in the future petrochemical processes.

There appears to be a gradual shift in the petrochemical industry. The ongoing trend of electric vehicles and raising fuel efficiency is making it so that the need for oil in the transportation sector is diminishing which in turn makes petrochemicals the largest driver of world oil demand growth [3].

One matter that cannot be understated is the constant transition to more sustainable processes, circular economy and the eventual long-term goal of decarbonization. Many measures were taken with policies and directives being ever present in this industry. These affected numerous industries by forcing them to follow strict rules and regulations in order to reduce and have a better control of emissions [4].

Given the sheer size and importance of the petrochemical industry, there is a need for this study to evaluate the future of Air Liquide’s gas market in this sector, the impact that it will have and possible responses as a means to answer the ongoing changes in this area.

1.1 Objectives

The objectives portrayed in this study are the following:

- Identify the analysis needs for petrochemical product substitutes (energy and non-energy based);
    - Identify new processes being implemented into the petrochemical industry;
    - Study the impact on Air Liquide gas supplies;
- Identify the stakeholders;
- Size the market that uses pure gases, calibration gases and associated gas equipment and services;
- Study the potential of the new market;
    - Estimated growth;
    - New potential Air Liquide offers;
- SWOT analysis

2

INTRODUCTION

2.1 Specialty Gases & Supply Chain

Industrial Gases encompass a large group of compounds that are in the gaseous state while at room temperature and pressure. They are widely used in a variety of sectors and represent the key product of Air Liquide [5]. The most common types of gases included in this group are oxygen, nitrogen, helium, carbon dioxide, carbon monoxide, hydrogen, methane and acetylene.

Most of these gases are present in the atmosphere, but in order to be able to use them, they need to be separated and purified. One of the most common ways of achieving this is with air separation units (ASU) [6]. This equipment utilizes compression, adsorption and cryogenic distillation technologies in order to separate air into its components, namely oxygen and nitrogen. Hydrogen on the other hand is commonly obtained through the steam methane reforming process or as a by-product. Other gases, such as helium and methane can be recovered from pockets of natural gas and later be extracted and liquefied [6].

Specialty gases represent a group of gases that suffer further purification steps. These gases are mainly used for analytical methods, such as gas chromatography, as a calibration, instrumentation or carrier gas. They can either be a pure gas or a mixture. Nowadays, the demand for these gases to have high levels of purity is rising as a means to be as precise and accurate as possible, reaching levels of purity in the parts per million (ppm) or even parts per billion (ppb) [7]. This means that there are lower amounts of impurities that can affect the instrumentation and the results of the analysis.

When compared with the other groups of gases, medical and industrial grade as is seen in Table 2.1, these contain the highest level of purity and complexity since they can have up to 30 different compounds in a single cylinder, all while being able to reach a level of uncertainty of +/-1% [7]. In order to reach these levels, there exists a big necessity of avoiding contamination since it can drastically change the composition of the mixture, damage the precision of the analysis and risks being uncompliant with the regulations imposed.

Table 2.1 Specifications and applications of the different gas grades extracted from [7]

	Purity	Uncertainty	Mixture Complexity	Supply	Application
Industrial gas	<99.995%	<5%	2-3 molecules	Pipeline, Bulk	Inerting, Welding and Cutting
Medical gas	>99.5%	<5%	2-3 molecules	Bulk, Cylinders	Healthcare
Specialty gas	>99.995%	<1%	2-30 molecules	Cylinders	Calibration, Analysis

2.2 Industry

2.2.1 Oil & Gas Industry

It was only in the 19th century when the first oil well was drilled on purpose, in northwestern Pennsylvania [8], marking the beginning of its industrial utilization and the evolution to the commercial use that we know of today.

Currently, the oil and gas industry is one of the major influencers in the global economy, namely due to its role as the primary source of fuel in the power and transportation market [9]. Petroleum and natural gas are the products more closely associated with this industry, due to their huge demand worldwide.

Although they are some of the biggest drivers for the energy market, this industry is in the midst of a transitional era due to the growing demands for the reduction of greenhouse gas emissions, especially carbon dioxide, and the increase in oil and gas prices [10]. The former are a response to the Paris Agreement, which stated that the rise of global temperature should be well below 2ºC [10]. This in turn resulted in the increase of social and environmental pressures that we see today. The latter are the side effects of the ongoing pandemic and, more recently, the war on Ukraine which made the prices of oil and gas become extremely volatile.

2.2.1.1 Petroleum and Natural Gas

Petroleum and natural gas production consists of four stages that are separated based on the feed stream. The first process is exploration and it includes the prospecting, seismic and drilling activities that are done before the extraction start. The following process is called upstream and is the first major step where the oil is extracted from the reservoirs either on-shore or off-shore and the production of raw crude oil and natural gas. The next major stage is the midstream which includes the process, storage, transport of oil, natural gas and liquified natural gas (LNG). This step includes the production of LNG and the regasification process which are used for the ease of transportation of natural gas when a pipeline is not available. Finally, the last stage is named downstream and is closely related to the refineries that process the crude oil provided from the previous stages into marketable products utilized in the transport, power or petrochemical industry [8]. One of the main focuses of this study will be on the two last stages since they are the most present in Europe.

In order to refine crude oil into petroleum products, the refining units break down the feedstock into various components which are later separated and reconfigured into new products. The main steps are separation, conversion and treatment.

The separation step consists of utilizing a fractional distillation process. In this, the feedstock is previously heated to a boiling point and is sent to the distillation column where it is separated into different fractions. Since the column is of the reflux type, thermal zones are formed in the column. These provide the ability to drain each specific product in the respective zone [11]. Figure 2.1 represents a simplified sketch of the process as well as the different fractions and the temperatures that they leave the column.

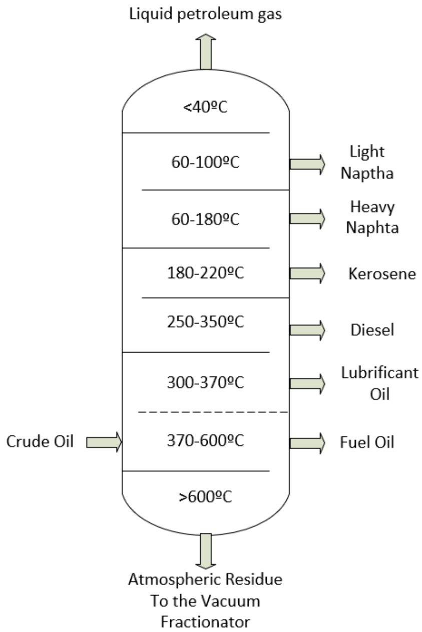

Figure 2.1 Simplified schematic of fractional distillation based on [12]

Liquified petroleum gas (LPG) and naphtha are commonly used for the petrochemistry industry as feedstock or in the case of LPG as a domestic gas. The remaining products are used mainly as a fuel source with the exception of lubricating oils, which, as the name suggests, are utilized for lubricants and bitumen, which is utilized in the construction industry. Although these products are all separated in the distillation column, they still need to go through the conversion and treatment steps in order to be commercially ready [8].

Some of the most important conversion methods are the cracking units, which include fluid catalytic cracking (FCC) and hydrocracking. In the first process, oil is cracked in the presence of a catalyst and is maintained in a fluidized state by oil vapors. This operation consists of two sections. The first, where the fluid catalyst is circulated between the regenerator and the reactor to vaporize and raise the temperature of the preheated hydrocarbon charge and then crack it. In the second section, the resultant product stream is sent to a fractionating column where it is separated into fractions [13].

Some other notable processes are the naphtha hydrotreater, where sulfur is removed from the hydrocarbons with the use of hydrogen and the catalytic reformer, which converts naphtha molecules into higher octane reformate [8].

2.2.1.2 Biofuels

Biofuels are not as associated with the oil and gas industry as the other mentioned products, but this is a growing market that emerged due to the downsides present in the refinery process and as a way to obtain fuel in a more environmentally friendly way. They are renewable materials made from biomass that serve as an alternative to fossil fuels and are an important source in helping the reduction of greenhouse gas emissions [8]. They are often called carbon neutral fuels because the carbon dioxide that is released from their combustion is used by plants (feedstock for biofuels) when they are growing. Of these the most notable are biodiesel, bioethanol and biogas [14].

Bioethanol is produced by the fermentation of the carbohydrate components of plant materials, some of which include corn, grain, wheat and sugarcane. It is mostly utilized as a fuel but can also be applied in the chemical sector [15].

In the European Union biodiesel is one of the most important biofuels, this region being the world's largest producer, constituting about 75% of the total transport biofuel market [8]. It was first developed in the 1990s and with the help of directives, tax incentives and changing oil prices it has rapidly expanded in this region. The typical feedstock of choice in the EU is rapeseed oil, but other options include vegetable oil, cooking oil and palm oil. The process to produce biodiesel is called transesterification. In it, the triglycerides, (molecules that are present in the feedstocks) are broken down into individual alkyl esters, whereby glycerin is separated from the fatty acids. Next, methanol is added and heated with a strong base used as a catalyst, as a means to deprotonate the alcohol [8]. Although these materials are obtained in an environmentally friendly way, they still raise some concerns due to the use of agricultural lands, that could instead be used for food production.

Biogas is a renewable gas composed mostly of methane, carbon dioxide and small quantities of other gases that is produced mostly through anaerobic digestion. This is a process where organic materials are decomposed by being placed in a digester containing bacteria and in the absence of oxygen [16]. Although the process behind its production is generally the same, it is usually produced through three different pathways: biodigester, landfill gas recovery systems and wastewater treatment plants. These will change the composition of the biogas, but it usually ranges from 45% to 75% of methane, the rest being mainly CO_2 [17]. Nowadays there are numerous biogas plants, however the majority have little capacity, producing very low amounts of this product. The feedstock does not have the backlash present in biodiesel since it is mainly composed of crop residues that do not compete for agricultural land used for food production, animal manure and wastewater sludge. Nowadays there is a growing demand for this gas, which is helping it start to become available in numerous areas and cost-competitive with the main fuel competitors. Europe is the current largest producer and is driving its production upwards in order to achieve the climate targets [16].

2.2.1.3 Hydrogen

Hydrogen has long since been used as an energy source. From the first combustion engines, to providing lift to balloons and finally being utilized as a fuel for rockets, the need for hydrogen has kept growing and by extension its uses. More recently it changed its initial purpose, by being utilized in the oil, steel and ammonia production, these being the main drivers for its current demand [18]. Nowadays because of the policies that are appearing to combat the environmental issues and due to the war and the pandemic, hydrogen is having a resurgence in the energy sector as a potential source of clean energy. This also serves as a way to diminish the carbon dioxide emissions produced in other markets that utilize hydrogen as feedstock for their production. The interest in hydrogen comes from its properties, as it is a light, storable, reactive product, that has high energy contents and is readily produced at an industrial scale [18]. Its potential use as a clean energy carrier made its interest even higher.

Due to the potential of hydrogen, Air Liquide is making great developments in this market since it aligns with the current goals of decarbonization and energy transition that the company is striving to achieve [19].

Hydrogen has many alternative sources and in order to differentiate each from one another the energy industry applied a color code that depends on which source was used for its production [20]. Figure 2.2 shows the different types of hydrogen and their feedstocks.

Figure 2.2 Types of hydrogen

The most common types utilized are gray, blue and green, the latter two being new processes, thus are going to be further discussed in chapter 2.3. Gray hydrogen is by far the most used type, since it utilizes fossil fuels as its feedstock and it is present in most refineries and ammonia production plants [21]. The main processes of this type include hydrogen obtained as a by-product, and the main technology for its production which is steam methane reforming (SMR) [21].

This process starts with the pretreatment of the feedstock through means of desulphurization and heating, followed by the mixture with steam and an optional step of pre-reforming in order to convert some of the heavier hydrocarbons into lighter ones. In the next step the steam mixture is heated with the presence of a catalyst in the reformer, obtaining syngas (a mixture of H_2, CO and CO_2) and a later step that shifts the carbon monoxide into additional carbon dioxide and hydrogen, thus raising the concentration [22]. Finally, the hydrogen is separated through a pressure swing adsorption process, obtaining a purity of 99.99% [22] and releasing the remaining gas into the atmosphere.

2.2.2 Petrochemical Industry

Chemical products are associated with many elements in our everyday life, from materials present in transports, plastics, electronics, food packaging, clothes and many others. They are closely related with the modernization of society due to its development which in turn improves our living standards. This dependence on chemicals has been growing at a steady pace making it so that the petrochemical sector is one of the largest industries in the world, producing a total of about 95% of all manufactured goods [3]. In addition, it accounts for 10% of total final energy consumption and 30% of industrial final energy consumption [3], while also being one of the most demanding industries in both oil and natural gas with 14% and 8% [3], respectively as is shown in Figure 2.3.

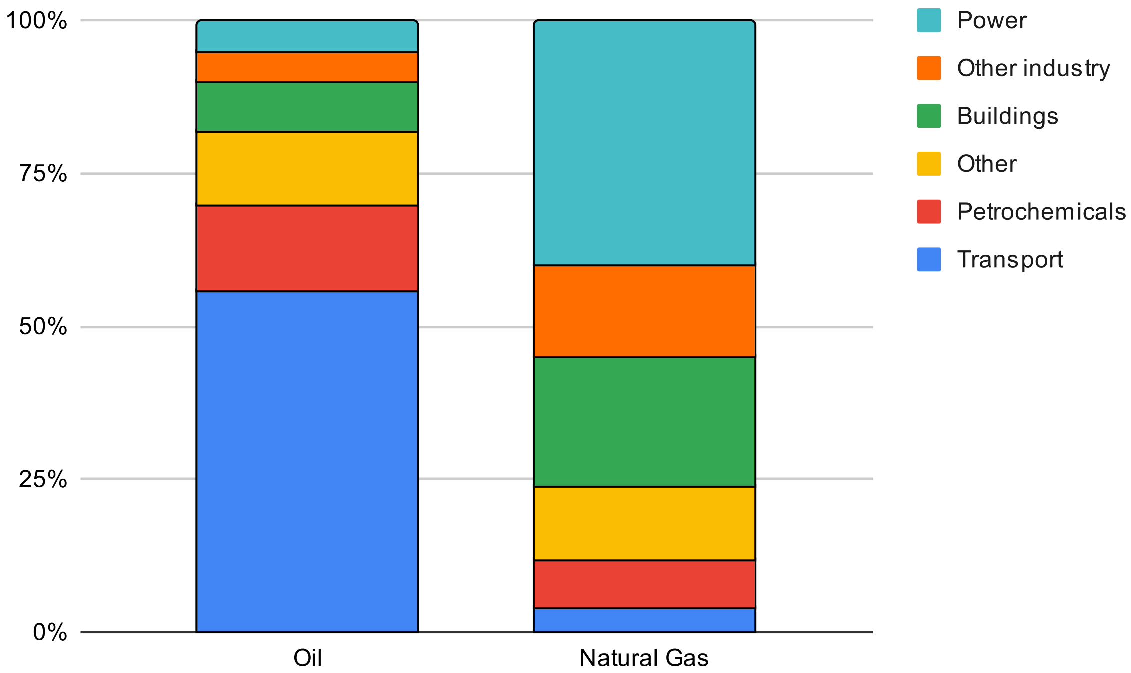

Figure 2.3 Oil and gas demand by industry sector extracted from [3]

Since the petrochemical industry provides the main raw materials for other industries, it is highly influenced by their demand, making it one of the main drivers for its consumption, besides the availability of feedstock and advances in technology [23].

Inside of the chemical industry, petrochemicals account for 90% of the total demand for oil, natural gas and coal [3]. In this sector, the main chemicals in which the petrochemical industry is based are ammonia, methanol, ethylene, propylene, benzene, toluene and xylene.

Due to the sheer size of this industry and for simplicity purposes, in this project the main building blocks of petrochemistry, mentioned above, will be considered as the whole industry, with their main intermediate and end-use applications being mentioned for extra information but not accounted for in any of the values used. The next topic will focus more in depth on each of the building blocks explaining their uses and conventional methods for their production.

2.2.2.1 Ammonia

Ammonia is the main source of synthetic nitrogen fertilizers, making it one of the main industrial chemicals [3]. It is produced by combining nitrogen with hydrogen and globally half of its production is converted to urea which in turn is used to produce fertilizers. Both products are associated with one another since the production of ammonia releases large quantities of CO_2 which is then used in the production of urea. Thus, they are usually produced in integrated facilities. 80% of the total ammonia demand comes from agriculture but this chemical can be used for other applications such as explosives and cleaning products [3].

Ammonia is produced via the Haber-Bosch process, where nitrogen reacts with hydrogen. For this reaction to happen, nitrogen is recovered through the distillation of liquid air. As for the hydrogen, it is typically obtained as a by-product of various feedstocks or through the steam reforming process [24]. Both processes are applied by Air Liquide and were described in the previous chapters.

2.2.2.2 Methanol

Methanol is the simplest alcohol and it can be used as a final product as a fuel or as a solvent, or as an intermediate for formaldehyde - accounting for 31% of its demand - antifreeze, solvents and adsorbing agents [3]. Lately it has been subject to many studies on how to use it as fuel, accounting for 37% of its global demand [3].

This compound is produced through various processes, though the conventional method involves the aforementioned steam reforming process followed by methanol synthesis. The last process is dictated by the hydrogen reacting with both carbon monoxide and carbon dioxide [24].

2.2.2.3 Olefins

Propylene and ethylene - commonly referred to as light olefins - are relatively stable compounds with one or more carbon atoms, linked by a double bond. These types of compounds are widely used for the production of polymers, due to the formation of two new single bonds when the double bond is broken. This constitutes around 85% of the olefins applications [3].

Ethylene in particular is one of the most produced chemicals worldwide. About 30% of all petrochemicals derive from ethylene [3]. Some of the intermediate compounds are all variations of polyethylene and ethylene dichloride, which constitutes 60% and 15% of ethylene’s production for Western Europe, respectively [3]. It is used as a raw material in a variety of applications such as polymer plastics, fibers, packaging, transportation and for the construction industry [3].

Propylene has similar uses to ethylene. Its main application is polypropylene followed by propylene oxide, accounting for 56% and 16% of the total propylene production in Western Europe, respectively [3].

The main process for light olefin production is steam cracking. This is a very mature technology in which saturated hydrocarbons break into smaller unsaturated ones by means of a reaction with steam. This process utilizes a variety of feedstocks, such as ethane, propane, butane, naphtha and gas oils, depending on the market in question and their availability. Although there are many different raw materials, the process always follows the same main steps: pyrolysis and cooling, primary fractionation/compression and cryogenic cooling and product separation [25].

The main step of this process is done in the cracking furnace. Due to the process being highly endothermic, the feedstock is initially preheated and vaporized with superheated steam with the mixture needing to be constantly heated. These temperatures vary with the type of raw material utilized. The mixture is then sent to the fired tubular reactor where the reactions occur. Here, the hydrocarbons are cracked into smaller molecules such as olefins. The residence time is very short, usually between 0.1 and 1 seconds in order to avoid the formation of carbon [26]. Next, the stream is quenched and then cooled, as a means to prevent loss via side reactions, thus raising olefin yield. It is then condensed to remove heavy hydrocarbon compounds and the remaining mixture results in a purified gas after being compressed and dried. Primary fractionation only applies to naphtha and gasoil and compression removes condensates and acid gases. The gas is then sent to the main fractionation section where the separation occurs. Here the usual method applied is the cryogenic separation [26].

The leading factors that affect product yield in this process can be temperature, residence time, steam to hydrocarbon ratio, but the one that affects it the most is the type of feedstock chosen.

As shown in Table 2.2 ethylene has a higher yield when the feedstock is ethane. Hydrogen and methane are also produced in a high amount. As it was said before, the choice of feedstock depends on market factors and availability. Since ethane is the most used feedstock in the United States due to the existence of shale oil, the production of propylene has dropped.

Table 2.2 Yields of steam cracking products from various feedstocks extracted from [26]

Yield by weight (%)	Ethane	Propane	Butane	Naphtha	Gasoil
Hydrogen and methane	13	28	24	26	18
Ethylene	80	45	37	30	25
Propylene	2	15	18	13	14
Butadiene	1	2	2	5	5
Mixed butenes	2	1	6	8	6
C5+	2	9	13	8	7
Benzene	0	0	0	5	5
Toluene	0	0	0	4	3
Fuel oil	0	0	0	2	1

As for propylene, it is mostly obtained as a co-product of ethylene manufacture or through fluid catalytic cracking (FCC), accounting for 56% and 33% of its worldwide production, respectively [24]. The remaining percentage comes from direct approaches - such as the dehydrogenation of propane and metathesis - or from coal-to-oil processes and deep catalytic cracking of vacuum gas oil [24].

2.2.2.4 BTX

Benzene, toluene and xylenes are a group of chemicals that have an aromatic ring in their molecule that emits a specific smell, thus they are commonly referred to as BTX aromatics. They have similar applications ranging from the production of polymers and other chemicals to solvents, paints and pharmaceuticals. They are often produced through the same process [24].

Benzene is the most produced aromatic and one of the largest-volume petrochemicals in general. It is mainly used as a chemical feedstock where 70 to 75% of it is consumed to produce ethylbenzene and cumene [24]. These chemicals are used primarily for the production of polystyrene and phenol or acetone, respectively.

Toluene is used mainly to produce the two other aromatics, where about 50% is converted to benzene, since its only other major use is for the production of toluene diisocyanates which are used for polyurethane applications [24].

Finally, xylene is composed of three different isomeric forms that depend on the position of the methyl group resulting in ortho-xylene, meta-xylene and para-xylene. The last compound is the most widely used since it is a raw material to produce polyethylene terephthalate (PET) or as it is commonly known, polyester, a chemical used for the production of plastic. There is also a lot of focus on ortho-xylene, this compound being mainly used to produce phthalic anhydride, an intermediate for the production of PVC plasticizers, pharmaceuticals and other chemicals [24].

The main sources of feedstock for aromatic production comes from pygas and reformate reformers, the latter being the most used with about 72% of production since most refineries have reformers [27]. The choice of feedstock is also affected by availability and market needs. Table 2.3 represents the compositions recovered from different feedstocks.

Table 2.3 Typical composition of component recovered from various feedstocks extracted from [27]

Component (% w/w)	Pygas	Reformate	Light Reformate	Coke oven Light oil
Benzene	30	3	24	65
Toluene	20	13	46	18
Xylenes	4	18	<0.5	6
Ethylbenzene	3	5	<0.5	2
C9+ aromatics	3	16	0	7
Naphthenes	High	Low	Low	High
Olefins	High	High	Low	High
Paraffins	Low	High	High	Low
Sulfur	Up to 1 000 ppm	< 1 ppm	Low	Up to 1% wt

The production of aromatics consists in the pretreatment of the feedstock, the fractionation and purification steps to separate the aromatics and the conversion of less valuable products into aromatics [28].

2.2.2.5 Plastics

As it was mentioned above, one of the main drivers for this industry is the demand from other industries, this being closely related to the main applications of petrochemistry. The material most commonly associated with petrochemistry is plastic.

The production of plastics has seen enormous growth since 1970, growing at a higher rate than any other bulk material [3]. This in turn made plastic one of the key products of the petrochemical sector and a material that drives the petrochemical market forward. Its growth can be explained due to its high versatility of applications, ranging from carrier bags to cars. There are many different types of plastics, also known as resins, each being used for different purposes. The most widely used plastics are the ones derived from ethylene and propylene, polyethylene (HDPE, LDPE and PET) and polypropylene, respectively. As for the end-use of plastic, the top three sectors are packaging, construction and textile, with 36%, 16% and 15%, respectively [3].

Due to the versatility of these materials, there are numerous ways of manufacture to respond to each need, be it the volume and cost, the complexity of the shape, the time it takes to produce it and finally the selected resin. In Table 2.4, it is possible to see the different types of manufacturing processes and each need responded to by them.

Table 2.4 Different types of plastic production based on [29]

	Complexity of Shapes	**Lead Time**	**Volume (nº of parts)**	**Cost***	**Process**
3D Printing	High	12h - 36h	1-1000	€€-€€€	Creates three-dimensional parts directly from CAD models by building material layer by layer
CNC Machining	Moderate	24h - 2w	1-5000	€€-€€€€	Solid plastic that is shaped by removing material through cutting, boring, drilling, and grinding.
Polymer Casting	High	24h - 1w	1-1000	€€-€€€	A reactive liquid resin or rubber fills a mold which reacts chemically and solidifies.
Rotational Molding	Moderate	4w - 6w	200-5000	€-€€€	Heating of a hollow mold filled with powdered thermoplastic and rotated around two axes to produce mainly large hollow objects.
Vacuum Forming	Limited	4w - 6w	Any	€-€€€€	Plastic is heated and formed, typically using a mold.
Injection Molding	Moderate to high	8w - 10w	5000+	€-€€€	Injecting molten thermoplastic into a mold.
Extrusion	Limited	2w - 4w	1000+	€-€€	Pushing plastic through a die.
Blow Molding	Limited	4w - 6w	5000+	€-€€€	Creates hollow plastic parts by inflating a heated plastic tube inside a mold until it forms into the desired shape.

*Where € is low is €€ medium low is €€€ is medium high and €€€€ is high

2.3 New processes in the petrochemical industry

As it was mentioned before, the industries included in this project are constantly improving making it so that one of their largest drivers are new processes and technologies. While the previous chapter was dedicated to each industry, their elements and each conventional process, this chapter will explore new methods that are emerging and that might soon change the way some products are obtained.

For it to be considered an emerging technology, the process in question must be a significantly different method of obtaining the specific product or it can be a similar process that produces a different product that corresponds to the same needs. The process can also already exist for some time or be applied for the production of other materials but still be considered as an emerging technology. Finally, while there are numerous developments in achieving higher efficiency and lower carbon emissions, these were not considered as a new method since they are mostly specific alterations or improvements in a particular step of a process and were thus excluded from this research.

2.3.1 Green H2 / Power to X (PTX)

Hydrogen is a key component of the future because of its potential to decarbonize many sectors of the industry. Nowadays the main type of production of hydrogen, gray hydrogen, is done, as was already stated, through the process of steam methane reforming, which releases copious amounts of carbon dioxide [30].

This created a need for processes that could release lower amounts of these unwanted gases or a way to deal with them. Green hydrogen is one of the answers to this problem. With water and renewable energies as its feedstocks, and through the process known as electrolysis, hydrogen is created. It is important to note that this process needs to use electricity provided from renewable sources in order to be considered green since the use of energy from fossil fuels can indirectly result in more emissions [31]. Electrolysis splits water into hydrogen and oxygen by applying an electric current that adds or removes electrons. Instead of having a traditional reactor, this process has an electrolyzer that contains an anode and a cathode that provide opposing charges to make protons or electrons move towards them. Anodes are positively charged and thus attract electrons and cathodes are negatively charged and attract the hydrogen protons [31].

There are three main types of electrolyzers that have some slight differences. The polymer electrolyte membrane (PEM), alkaline and solid oxide.

Alkaline electrolysers are the most mature technology, due to their use in the chlor-alkali industry. This makes them the most cost effective and efficient of the three electrolysers [32]. Even so PEM electrolysers are being further developed and more widely used due to their smaller carbon footprint and ability to obtain hydrogen at higher pressures. The last type is used for a more specific market that produces synthetic hydrocarbons, since it operates at very high temperatures [32].

The obtained hydrogen can be further developed with the use of a process called Power to X (PTX). This essentially is an extension of the green hydrogen, since it utilizes the previously described method of obtaining hydrogen and it transforms it into valuable products that serve as long term storage solutions and can be utilized in different sectors. The X can stand for gas (PTG) or liquid (PTL), due to the possibility of transforming the hydrogen into methanol or synthetic natural gas, respectively. The advantages provided by this process are the direct use of the compounds in the mobility, electrical and heat sectors since hydrogen still does not have the necessary infrastructures to be fully applied in these sectors [33].

Although there are numerous projects for these technologies, with the capacity growing at an exponential level, this is still a very expensive process compared to the conventional one, (USD 3-8/kg H2 compared to USD 0.5-1.7/kg H2) [30] and it only accounts for 0.03% of all hydrogen production [30]. In order to obtain better prices, there needs to be a drop in electrolyser costs and a growth in the renewable energy infrastructure.

2.3.2 Blue H2 / Carbon Capture, Utilization and Storage (CCUS)

Carbon capture utilization and storage is a group of technologies that are gaining much traction due to their potential of decarbonizing many industry sectors. They serve mostly as a coupling technology to conventional processes, that is, they are integrated into mature processes. The main interest of these technologies comes from their potential to reduce emissions from already existing production sites. They mainly consist of a method of capturing carbon dioxide from sources where there are large amounts of emissions or in some cases directly from the atmosphere and either use it on-site or being stored in reservoirs [34].

Although it is ordinary to be referred to as CCUS, there are four major types of this technology represented in Table 2.5.

Table 2.5 Types and applications of CCUS technologies based on [35]

	CCS	**CCU**	**BECCS**	**DAC**
	Carbon Capture and Storage	Carbon Capture and Utilization	Bio Energy with CCS	Direct Air Capture
Main Purpose	Reducing CO_2 emissions	Reducing and utilizing captured CO_2	Removing CO_2 form atmosphere	Reducing CO_2 emissions
Applications	Industrial processes	Concrete curing, synthetic fuels, EOR, others	Energy from biomass	Standalone
Achieve permanent CO2 removal	Yes	Yes*	Yes	Yes*

*Only through the use of EOR, concrete curing and mineralization

CCS is the most common type, having most of the project announcements and investments. CCU is not as used as the previous technology since there are many economic constraints associated with it. The last two types function has a way to achieve negative emissions. DAC suffers from low capture rates from the atmosphere, so it is hard to implement. Finally, BECCS is a growing market that works alongside biofuels and has seen some infrastructures being built even though its price is still high [35]. For simplicity purposes for the remainder of this study, CCUS will be used to refer to all the different types.

The process of CCUS, as the name suggests, starts with the capturing step. The most common type of capturing CO_2 being chemical absorption and physical separation. The first process consists of a reaction between carbon dioxide and an amine-base solvent such as ethanolamine. This is the most widely used and advanced method. The second can be based on adsorption, cryogenic separation, dehydration or compression, adsorption being the most used. In this, CO_2 is adsorbed with the use of a solid surface such as activated carbon or alumina and later it is separated by increasing the temperature or the pressure. After the capturing process is completed, CO_2 can be directly utilized or stored [34].

In the case of utilization, some pathways include fuels, chemicals and building materials. It is important to note that this is mostly used as a way to achieve carbon neutrality so there is a need to do a life-cycle analysis in order to assess if the pathway does not release more emissions [36].

As for the storage step, the CO_2 first needs to be transported since most storage reservoirs are located offshore. The most common way is by pipeline although the use of ship transportation is possible. There, the storage involves the injection of the captured CO_2 into underground reservoirs capable of preventing leaks to the atmosphere. These include depleted oil and gas reservoirs and deep saline formations [36].

This technology is often associated with blue hydrogen since its implementation into the conventional way of hydrogen production (SMR technology) provides a way of decarbonizing that sector. Although, currently it is seen as a better solution to reduce carbon emissions in the hydrogen industry, many sources predict that it will only be for the short and medium term, due to the rapid growth of green hydrogen. Once it becomes commercially viable blue hydrogen is expected to be a less competitive market compared to the green alternative [37].

2.3.3 Crude Oil to Chemicals (COTC)

One technology that is starting to get more attention is the COTC process. This innovation surged due to the shift that is starting to emerge in the transportation industry, where fuel needs are diminishing due to the increased demand of electric vehicles and the rise of fuel efficiency. This makes it so that there will be an increased demand for petrochemicals, thus the petrochemical market becoming the key driver for oil and gas products [38]. This new process merges the refineries and petrochemical plants and converts crude oil directly into valuable chemical products, therefore increasing the margins gained by refineries relative to fuel products [38].

A normal refinery obtains close to 8% of naphtha per barrel of oil, since its main purpose is to produce fuels and not petrochemical feedstocks. Even when the refinery is integrated with a petrochemical plant it can only achieve a conversion of 17% [39]. These values grow to 42% of chemicals per barrel of oil when the COTC process is applied, with these values expected to grow with the development of the technology into 70 to 80% [39].

This process is already being applied mostly in China, having already 3 running plants and Saudi Arabia with plans to start plant operations in 2025 [39].

The main processes for this technology include the processing of middle distillates and residues using hydrocracking technology, which is the strategy applied by Chinese plants. This process involves the hydrocracking of diesel and products from the vacuum distillation units and produce aromatic compounds. Another possible route is the integrated hydro-processing / de-asphalting and steam cracking applied by Saudi Aramco. This process is not as known since the plant has yet to start operations due to delays caused by the pandemic, but the company filed patents focused on these processes. It is also possible to do a direct processing of crude oil in steam cracking. This type had some problems due to coke formations and fouling but recently ExxonMobil managed to implement this technology although with lower yields compared to the previous two [40].

Even though this process shows promise to be a key method in the future, it still has its downsides. The high conversion rate, although good in most aspects, contains the risk of creating an oversupply in the market. This was already seen in China when the new COTC plant that doubled the capacity of the previously largest plant made the prices for para-xylene drop [41]. It is also a very expensive technology since it requires the repurposing of most equipment in order to obtain different products [41]. Currently, it is only viewed as being a viable technology in locations where the feedstock is cheap or available in high amounts, such as Saudi Arabia and China, the two countries where the method is being more expanded. This makes it very unlikely for the process to be used in Europe.

2.3.4 Biomethane

Biomethane is an almost pure source of methane that is nearly indistinguishable from natural gas. This makes it so that it does not require changes in infrastructures and can be directly injected into the grid or used in vehicles. Its calorific power is also similar to that of natural gas, so it is a clear step up from its counterpart, biogas [17]. Although there are many similarities between the two gases, most countries make a distinction between them even in statistical reports.

While not being an entirely different process, biomethane is mostly an extension of biogas since it is produced mostly by removing the excess CO_2 from biogas, in a process that can be called upgrading biogas. This is done through water scrubbing or methane separation. It is also possible to produce biomethane through thermal gasification of solid biomass followed by methanation, but it only accounts for 10% of its production [17].

Biomethane is one of the fastest growing markets in Europe, having the number of plants grow by 51% from 2018 to 2020 [42]. This rapid growth can be explained through the numerous policies and tariffs applied to this sector. Even so, the amount of biogas that is upgraded into biomethane is still relatively small, but it still is a sector with significant growth potential and one that it should be looked out for.

2.3.5 MTO, OCM and PDH

Out of all the petrochemical main building blocks, the ones that represent the largest demand are the olefins [31]. In chapter 2.2.2.3 the conventional processes of obtaining these chemicals were discussed, the main ones being steam cracking and fluid catalytic cracking. These processes, although very mature and widely used all over the world, are very pollutant and produce many by-products which makes the need for alternative methods necessary [31]. In order to respond to such needs the next three technologies represent possible ways to move forward.

Methanol to olefins (MTO) is a process that could represent a cleaner pathway to these products. Although it is a method mainly related to coal, since it is a mid-stage reaction from the coal to olefins process, if the feedstock utilized is biomethanol or methanol obtained in an environmentally friendlier way, it would be considered a clean process. It consists in the dehydration of methanol which is then further reacted to obtain ethylene and propylene [31]. There was only one reported pilot plant in Europe by Total Energies so it is very unlikely that it will have any future in this region [31].

Oxidative coupling of methane (OCM) represents another possible route for the production of ethylene. This is a relatively old process that began in the 1980s and it uses natural gas as its feedstock. In this process, the methane present in the feedstock reacts by contacting an oxide catalyst surface in order to remove a hydrogen atom and form a methyl radical. The methyl radicals later couple forming an ethane molecule which is later dehydrogenated to create ethylene. Although this is a well-studied method, there have been problems in the choice of the catalyst since it is a very slow process, limiting the reaction and allowing the occurrence of side reactions [31]. This is a process that has a lot of promise if it can be further developed, also opening a possibility to be utilized in conjunction with the growing markets of biogas or biomethane.

Finally, the propane dehydrogenation (PDH) technology provides a way of producing propylene as an on-purpose material instead of a by-product. This process provides an answer to one of the common problems of this chemical since it is usually connected to ethylene through the steam cracking process. Because of this, if the need for ethylene goes down or the feedstock for the process changes to one that has a lower yield for propylene, like it happened with the shale oil revolution, it will affect its market. Recently the demand for propylene has started to grow at a higher pace than that of ethylene and the process is already mature and economically viable enough for it to compete with the current processes, making this the better option for the future out of the three discussed [43].

The process consists of the dehydrogenation of propane, in the presence of a catalyst (chromium or platinum, depending on the license), converting it into propylene. The reaction is highly endothermic, meaning it needs to take place at high temperatures. This process has gained a lot of traction in China, having many already operating plants. In Europe there are currently no working plants but there are two big projects by *INEOS* and *Borealis* that plan on having a capacity for propylene utilizing this process of 750kt and 725kt, respectively [44].

2.3.6 Plastic recycling

Plastics remain as one of the most on demand products in the world. This makes the need for processes that provide clean alternatives to their production much more important. In order to respond to the ambitions of the environmental directives applied in the world, namely in Europe, and to promote circular economy and clean technologies, there is a new trend starting in the production of plastics, which is their production through recycling. This strategy answers many problems that these products have, such as the consumption of less feedstock and energy and the utilization of the end-use plastics instead of disposing them in landfills or releasing them into the environment. The potential for plastic recycling is very high, but currently it is estimated that only 18% of all plastic production is done by this method [45].

In Europe this percentage is higher, with 34.6% of all collected post-consumer waste being sent to recycling facilities [45]. In Figure 2.4 the evolution of post-consumer plastic waste treatment in Europe can be seen.

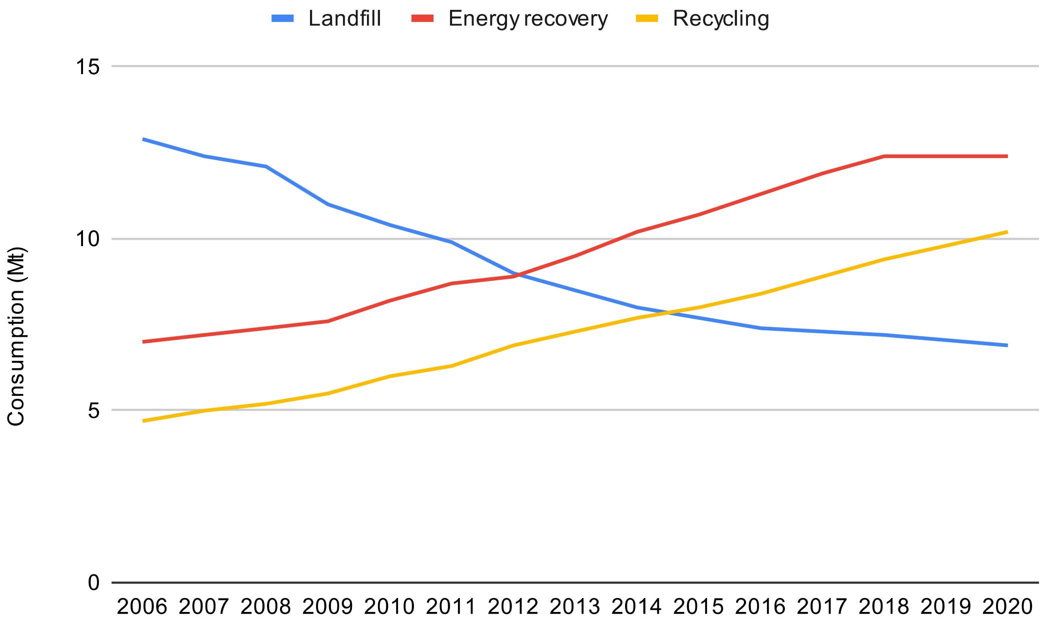

Figure 2.4 Evolution of plastic post- consumer waste treatment in Europe extracted from [45]

As it can be seen, Europe has improved in this area, but it is still nowhere near to the goals that it has. These values also only account for the collected waste and not the products that are not properly disposed of. This constitutes problems associated with recycling, such as the amount and quality of scrap and the level of recycling achieved.

There are two main categories of recycling, mechanical, which is the most used type, and chemical.

Mechanical recycling is a simple and low-cost solution that functions mostly as a secondary source for plastic production. The collected waste is sorted, cleaned and then grinded into smaller parts which are later re-melted and used for molding. Although this type of recycling is very common, it has its downsides. Not all types of plastics can be recycled, it cannot reach virgin-grade, that is, it does not convert waste back into its original monomers, and most of the waste that reaches the facilities is contaminated or mixed. This makes their use very limited in recycling and thus it often results in the plastics being incinerated or sent to landfills [46].

On the other hand, chemical recycling could be the answer to those problems, and effectively play an essential role in the promotion of a circular economy. This strategy involves the conversion of end-use plastics, back into its original monomers, oils or gases, effectively restarting the value-chain.

There are three major types of chemical recycling processes, depolymerization, pyrolysis and gasification.

Depolymerization is a process that returns plastic waste back into single-monomers or short polymer fragments, through glycolysis, methanolysis or hydrolysis. It can only be applied to some plastics, such as PET and polyamides [47].

In the pyrolysis process, plastics are broken down into basic hydrocarbons with the aid of heat and in the absence of oxygen. The products obtained are mostly oils and gas and although their main goal is for the production of plastics, they can be utilized in other processes to produce the main building blocks in petrochemistry or for fuel. This makes it so that the plastics produced through this method are considered virgin-grade [47].

In the gasification process, waste materials are heated to very high temperatures, between 1000 and 1500ºC, and in the presence of very low amounts of oxygen. The resultant product is syngas which can be utilized for a variety of purposes. Similar to the last process, the plastic produced through this method is considered virgin-grade [47].

The number of installed capacities is still very limited, with a total feed capacity of about 100MW as per some internal sources, but it can represent a very promising technology in the future.

2.4 Indexes to evaluate new technologies

In order to properly evaluate each technology and their possible expansions in Europe, this study uses two indexes, named technology readiness level (TRL) and commercial readiness index (CRI).

The TRL is a globally accepted measurement system used to assess the development stage of a process. It is used as a benchmarking tool to aid in the progression of a specific technology. This methodology was developed by Stan Sadin with NASA in 1974 and since then it has expanded its initial purpose of evaluating space exploration technology to a common index that is widely used for any process [48].

The index consists of nine levels, TRL 1 being the lowest and TRL 9 the highest. The first level represents the start of scientific research. The second occurs when the initial research has some possible theoretical application. This level is very speculative and does not have any experimental proof-of-concept. TRL 3 starts when there are both analytical and laboratory studies and a proof-of-concept model is constructed. The next two levels are very similar with multiple parts of the technology being tested, but in the fifth level the testing is more rigorous. A process enters the sixth level when it has a functional prototype or model. The last stages represent the start of commercial use, each level representing a scale up from the one before, starting from a small pilot scale in TRL 7, advancing to a larger pilot scale in TRL 8 and finally the fully operational system in the last stage [48]. Table 2.6 represents a simplification of the TRL and the description of each level.

Table 2.6 Technology readiness level description based on [48]

TRL Level	Meaning
1	Technology research
2	Technology concept
3	Proof of concept
4	Technology demonstration
5	Conceptual design and prototype demonstration
6	Preliminary design and prototype validation technology
7	Small pilot scale
8	Large pilot scale
9	System operational

The commercial readiness index represents an extension of the previous one that focuses more on the economic aspects of a specific technology. The CRI is a helpful index when used in tandem with the TRL, since there is always some commercial uncertainty and risk when each technology is in its deployment phase. The CRI consists of six levels where CRI 1 is the lowest and CRI 6 the highest. The first level is associated with the first 7 levels of TRL since they don't represent any real-world application so the commercial viability is still hypothetical. CRI 2 is associated with the last two levels of the TRL with some commercial trials being applied. When the technology is mature enough, that is, TRL 9, CRI levels from three to six represent the increase in commercial applications of the process [49]. Table 2.7 shows the descriptions of each level.

In this study these indexes were utilized to evaluate which technology had more potential of advancing in Europe, so the levels attributed to each technology were adapted to the region. The values attributed were based on other studies or by personal judgment.

Table 2.7 Commercial readiness index description based on [49]

CRI Level	Meaning
1	Technically and commercially untested and unproven
2	Commercial trials of the technology on a small scale
3	Commercial scale up of the technology
4	Multiple commercial applications of the technology
5	Market competition/industrial acceptance driving by widespread application of the technology
6	Readily financial support of the technology by banks

2.5 Regulations applied in Europe

Sustainable development is one of the key driving forces for the evolution of the industries in question. This includes many different objectives not only related to the mitigation of pollution such as decarbonization, but also related to the enhancement of efficiency and profitability of existing processes or the creation of new ones.

As the world and in particular Europe pushes to apply various policies and norms as a means to reduce the emissions released in the industry, there is a need to discuss the current actions that are being undertaken and how they might affect the future of petrochemistry. With this in mind, the next chapter will further detail these notions.

2.5.1 Paris Agreement

The Paris Agreement is the first legally binding global climate change treaty that was adopted at the Paris climate conference in December 2015. It aims to limit global warming to below 2ºC compared to industrial levels [50]. This was a measure meant to counter the rising greenhouse gas emissions and to try to reach a peak of emissions as soon as possible. In order to implement this agreement, there needs to be a global economic and social shift where every country communicates their actions to reduce emissions every 5 years [51].

2.5.2 European Green Deal

The European Green Deal is a roadmap developed by the EU in 2019 that has the objective of achieving net zero emissions by 2050 and serves as an implementation of the Paris Agreement. It also includes a reduction of emissions by 55% by 2030 [52]. It provides a growth strategy that aims to transition the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use [52].

In order to achieve the goals implemented by the European Green Deal, the actions taken will follow these elements [53]:

- Increasing the EU's Climate ambition for 2030 and 2050;
- Supplying clean affordable and secure energy;
- Mobilizing industry for a clean and circular economy;
- Building and renovating in an energy and resource efficient way;
- A zero-pollution ambition for a toxic free environment;
- Preserving and restoring ecosystems and biodiversity;
- A fair, healthy and environmentally friendly food system;
- Accelerating the shift to sustainable smart mobility;
- Financing the transition;
- Leaving no one behind;

Although there were already many sustainable directives in action, they would not be enough to achieve the goals of the agreement. Between the years 1990 and 2018 there was a reduction of greenhouse gas emission of 23% while the economy saw a growth of 61% [54]. It represents a positive change, but it does not achieve the goals of net zero emission by 2050. This required an alteration of many of these regulations. The Fit for 55 package is a set of proposals to revise and update the legislation in accordance with the goals of the European Green Deal. This is a continuous process that plans to review every EU law.

2.5.3 Directives

In order to achieve the goals set by the European Union, there needs to be a set of directives that define specific objectives. These are put in place as a means to make every country enforce policies and to delegate authority.

2.5.3.1 RED

The Renewable energy directive (RED) established in 2009 that the EU should achieve a target of 20% of its overall source of energy being provided by renewable energies [55]. Also included in the directive was the objective of the transport sector having a renewable energy-use target of 10% by the year 2020 [55]. These values were later altered into 32% and 14% by the year 2030 (the latter having 3,5% of it being provided from biofuels) with the implementation of the revised renewable energy directive (RED II) in 2018 [56]. The regulatory framework of this directive paves the way for a transition towards clean energy sources, in particular hydrogen and biofuels.

With the revised directive also came an introduction on sustainability for forestry feedstocks, making it harder to utilize croplands since it removes areas of potential agriculture sources and indirectly raises the amount of CO_2 released, negating the greenhouse gas savings caused by the use of biofuels [15]. As it was said before, this influences biofuels such as biodiesel and bioethanol.

2.5.3.1 IED

Industrial processes account for a considerable amount of the pollution present in Europe. The industrial emissions directive represents the main answer to the regulation of pollutant emissions from these installations. Created in 2011, it aims to protect human health and the environment by reducing harmful industrial emission by means of applying permits for the best available techniques (BAT) [57]. These BAT are defined by a committee composed of experts, industry and environmental organizations. The industrial installations are then required to operate according to the permits and emission limit values that are set to better apply the technologies. The permits are based on an integrated approach which means that they need to keep in mind the entirety of the plant performance, from the choice of feedstock to the emissions and energy efficiency [57].

Although this directive offers a good answer to tackle the environmental issues that process industries have, the techniques that are currently offered do not increase the competitiveness of the European industry which is currently declining [58]. This might force a change in the industry for new processes, but not a rise in production.

Although not associated with a direct change in the petrochemical industry, these directives have an effect on the surrounding compounds and inadvertently will affect it, both in energy sectors as well as in circular economy and climate change goals [59].

2.5.4 Policies and incentives

Policies are seen as guidelines or rules and can be different depending on the country on which they are applied. Incentives are payments that the government offers as a means to encourage companies into, in this case, applying new processes. Lately there has been an increased focus in both of these regulations regarding hydrogen, biogas and biomethane. This sub-chapter will focus on some that are being implemented in Europe, namely the SWE cluster and how they might be affecting their production.

Due to hydrogen’s potential to decarbonize many industrial sectors, policymakers have been increasingly focusing their efforts into turning it into a cost-effective solution. The policies applied were greatly affected by RED, ETS and the European Green Deal as well as other similar directives.

On a European scale, the Hydrogen Strategy was published. This provides a detailed roadmap for the future of hydrogen aligned with the goals of the European Green Deal. The main milestones regarded in the roadmap where the following [60]:

- 6 GW of green hydrogen electrolysers and 1 Mt of production by 2024;
- 40 GW of green hydrogen electrolysers and 10 Mt of production by 2030 in the EU;
- An additional 40 GW of electrolysers installed outside Europe by 2030.

As it can be seen from the milestones, there is a very high focus in the expansion of green hydrogen production. In order to achieve these goals each country needs to release their own national strategies. Table 2.8 shows a summary of the main goals that each country proposed.

Table 2.8 Main Targets of the SWE Hydrogen Plan by 2030 *by 2028 based on [21]

		Spain	Portugal	France	Italy
Production	Electrolyser capacity (GW)	4	2 - 2.5	6.5	5
	Share of H2 in final energy consumption (%)	-	5	-	-
Distribution	Blending ratio of H2 in natural gas grid (%)	-	10 - 15	-	2
Mobility	Passenger cars and LCVs	-	-	20,000 - 50,000*	-
	LDVs and HDVs	5,000 - 7,500	-	800 - 2,000*	-
	Buses	150 - 200	-	-	-
	Commercial hydrogen train lines	2	-	-	-
	Hydrogen refueling stations	100 - 150	50 - 100	400 - 1,000*	-
	Share of H2 in fuel for domestic maritime transporting (%)	-	3 - 5	-	-
	Share of H2 in road transport fuel consumption (%)	-	5	-	-
Industry	Decarbonized H2 share within hydrogen mixed in the industry (%)	25	5	20 - 40*	30
Funding	Public (billion €)	9	1 - 1.35	7	5
	Private (billion €)	-	6 - 7.65	-	5

France was the first country to propose its strategy and is the one with more ambitious targets [21]. Italy was the latest to publish and so it does not have any estimations for the transportation sector. Although Portugal is the smaller country it has the ambition to have a very high capacity for green hydrogen.

As for biogas and biomethane, the regulations change drastically depending on the country in question. Similar to the hydrogen market, France plans on being the leader of the European biomethane sector. It is one of the only countries that set out specific targets, namely 8TWh of biomethane produced by 2023 [61]. The primary way of encouraging companies to produce these renewable gases were Feed-in-Tariffs as a way to subsidize the sector, offering between 60 and 120€/MWh [61]. Feed-in-Tariffs are a technology support scheme providing a specific remuneration, long-term contracts and also guarantee access to the grid. These targets mixed with the government incentives made the French growth in this sector exponential, making it one of the main producers of biomethane. Italy is another country that plans on seriously investing in biomethane. They already have a very developed infrastructure for gas usage in the transportation sector and due to the similarities of biomethane to its fossil-based counterpart, there is no need for further alterations. Besides this, Italy has promoted the production of biomethane through allocation of certificates of release for consumption also known as CIC. These encourage the production of renewable energy by setting an obligatory target to producers, consumers or distributors. They provide an additional supplementary revenue if sold to the grid or the certificate itself can be sold on the green certificate market [62]. Spain on the other hand started its promotion of renewable energy very early with feed-in-tariffs and premiums but has since stopped its subsidy schemes, and has no plans on proposing new ones, making the development of biomethane in this country more unlikely. Finally, Portugal also does not have any incentives in place, but with the investments and current targets set by the country in order to be less dependent on fossil fuels, it is very likely that it will be implemented soon [63].

2.5.5 Funding

In order to implement all of the programs, incentives and policies that Europe has planned there needs to be some funding. The Multiannual Financial Framework (MFF) represents the total budget that the EU has to implement its internal and external policies for a seven-year period. The current long term budget spans from 2021 to 2027 and amounts to 1.2 trillion euros [64]. Due to the effects caused by the pandemic this budget was supplemented by a recovery instrument, NextGenerationEU (NGEU) which adds 806.9 billion euros totaling in around 2 trillion euros of EU budget [64].

The NGEU serves as a funding system for several stimulus packages that will help support Europe in green, digital and resilient projects. Most of the contributions will be allocated to recovery and resilience facilities with the rest being used for other programs [65].

Out of these programs the ones that have a greater effect on this study are the InvestEU, Life and Horizon Europe.

InvestEU supports sustainable investment, innovation and job creation in Europe and is one of the main sources of income for the EU Green Deal, the other one being the EU budget itself. The European Green Deal investment plan consists of 500 billion euros from the EU budget which represents half of the investment and 25% of the total budget [66]. This contribution accounts for the funding provided to Horizon and Life programs. The rest is funded by InvestEU where, through an initial guarantee of 47.5 billion euros provided from the EU budget, it will be able to mobilize 650 billion euros from public and private investments [66].

Horizon Europe is the biggest European program focused on research and innovation with a total budget of 95.5 billion euros [67]. It has the objectives of promoting climate change, helping the achievement of the United Nations Sustainable Development Goals and to boost EU's competitiveness and growth [68].

Life Program is a smaller funding system specifically dedicated to support innovative projects in the environment and climate sectors. It was created in 1992 and has the objective of helping the implementation and development of environmental and climate policy and legislations, such as the ones mentioned above. It has a total budget of 5.4 billion euros, this being divided into 4 sub-programs [69]:

- Nature and Biodiversity with 2.143 billion €
- Circular economy and quality of life with 1.345 billion €
- Climate change mitigation and adaptation with 947 million €
- Transition to clean energy with 997 million €

2.6 Analytical chemistry

The field of analytical chemistry is an ever expanding one. It has seen continuous growth in its instruments each increasing in power and scope. Nowadays there is a need for more sophisticated analytical instruments since all of the manual techniques are being replaced by these methods in order to achieve better and more accurate results. These are generally associated with the areas of research, development, quality control, monitoring and medical studies and thus are an important aspect of this study.

Analytical chemistry is used for the characterization of matter. This can be separated into two main types of analysis, qualitative and quantitative. The first is the identification of the different species present in a material while the latter is the determination of the quantity of substances that are present in the material. In other words, it deals with the separation, identification and determination of the substances in the material. Besides these, characterization of a material can avoid the chemical aspect and focus more on the structural and physical analysis of the material. The common approach for the analysis of a material follows these steps [70]:

- Definition of the problem;
- Choice of method;
- Sampling;
- Pretreatment;
- Measurement;
- Assessment of results.

Out of all, the one that should be executed with more rigor is the choice of method since the improper selection of the instrument can lead to a poor analysis. In order to choose the best method, certain aspects need to be evaluated, such as the range, precision and selectivity required, all while keeping the time and cost in mind [71]. This means that there is a need for basic knowledge of the range of instruments that are available and their uses. Table 2.9 briefly compares the most common methods available.

These methods have some importance for Air Liquide research and analysis market since their main clients are laboratories which use some of these techniques, the main one being gas chromatography [72].

Table 2.9 Comparison of different analytical methods based on [71]

	Approx. Range (mol/L)	Approx. 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, coulometry	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 spectroscopy	10^{-3}–10^{-9}	2–10	Good	Fast	Moderate - high	Inorg., multielement
Chromatography Mass Spectrometry	10^{-4}–10^{-9}	2–5	Good	Fast - moderate	Moderate - high	Org., multicomponent
Kinetics methods	10^{-2}–10^{-10}	2–10	Good - moderate	Fast - moderate	Moderate	Inorg., org., enzymes

2.6.1 Gas Chromatography

Chromatography is one of the most widely used methods, mainly due to its versatility and cost-effective results [73]. Its main uses are for the determination of organic compounds such as light and heavy hydrocarbons, lipids and others. It is a technique that separates chemicals based on their mobility on a static phase. Therefore, it is based on the principle that some compounds move faster or slower due to their attraction to the stationary phase. Depending on the physical state of the mobile phase, this method can be split into two categories: liquid or gas chromatography [73].

Gas chromatography (GC) consists of a flow control section, a sample injection port, a column, an oven and a detector. The sample is injected into the port which is connected to the column and, while at an appropriate temperature, it vaporizes and flows into the column with the help of the mobile phase. The mobile phase in GC is a carrier gas that is inert and is used to transport the molecules through the instrument [74]. These are usually hydrogen, nitrogen or helium.

Helium represents the safer and most efficient choice of the three, but it also is the most expensive one and currently is suffering of worldwide shortage [75]. Nitrogen is the cheapest but has the worst efficiency and varies depending on the average linear velocity. Hydrogen offers similar results to helium with the costs being lower, but it is not as safe and not as common to use, meaning there might be a need for the reconfiguration of the GC [76].

The rest of the process depends on the velocity at which each compound reaches the end of the column, since the process depends on the physicochemical properties and the nature of the column [76].

2.6.2 Other Analysis

Most of the other instrument-based methods do not need specialty gas for their regular operation, gas chromatography having the majority of the specialty gas consumption. Nevertheless, they need regular functional tests and periodic calibrations which consume specialty gases. Some of these include spectroscopy techniques such as non-dispersive infrared (NDIR) and Fourier transform infrared (FTIR), both of which are common tools for analysis in the petrochemical industry [77]. These methods are based on the principle that chemical bonds absorb light in the infrared spectrum.

Continuous gas analyzers offer an answer to emissions that must be measured according to the levels imposed by the authorities. Similarly to the ones mentioned above, these are usually spectroscopy techniques, with Quantum Cascade Laser (QCL) and Tunable Diode Laser (TDL) being the most commonly used [78].

2.7 Tools and models to make a market study

Market research is a marketing activity that is used to help achieve success in a business. Each company has their own philosophy in order to become a leader in its market, be it through innovation, quality, financial gains, or others. This makes it so that market research consists of the methods applied for a better understanding of the market and its customers' needs in order to choose the best course of action for the company.

These studies are best used when they are aligned with the goals of the business, thus should not be treated as a separate part of it. Instead, companies should strive to move forward with its culture in mind and use these tools as a guide to choose the correct path. Air Liquide's main strategy consists of having a strong financial performance, while progressing through better use of technologies, all while trying to be as sustainable as possible, in order to decarbonize the planet for everyone [79]. This market study will therefore follow the same path.

The elaboration of a market study consists of several techniques both qualitative and quantitative that need some previously obtained data to best answer the problems that it is trying to solve [80]. Regardless of the methods applied, the most important phase is the planning of the market study, which can be described in Figure 2.5.

The first step in planning a market study is the identification of the problem that makes the study in question necessary. This is a very important step since the proper definition of the real problem can lead to better and more secure results. Failing this step can affect the whole study by either obtaining poor results and thus making the wrong decision or in other cases answering the wrong question and having results for unnecessary problems and consequently losing time and money [81].

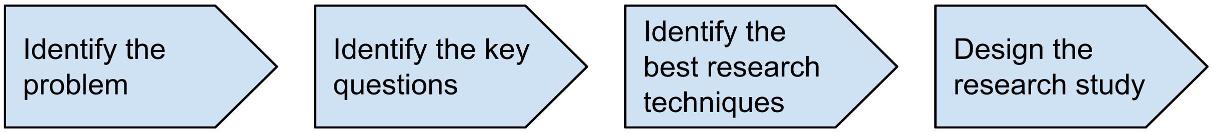

Figure 2.5 Planning process for marketing research based on [80]

The second step acts as an extension of the first and serves as the definition of the problem by identifying the key questions that need to be answered before the decision can be made. These can be seen as the main objectives of the study that will help in expanding the knowledge that will help in answering the main problem and finally reaching a decision [81].

The next step is the identification of the research techniques that would be appropriate for answering the questions from the previous step. These can vary both in the prediction models of the study, either being qualitative or quantitative, and on the methods for the collection of data, these being primary or secondary. This stage is going to be further developed in this chapter to have a better understanding of the approach utilized for the discussion, which is represented by the final stage of the planning phase [81]. With all the stages completed it is finally possible to reach a decision.

2.7.1 Best practices

Before advancing to the identification of the best research techniques it is worth discussing some common practices that are usually applied for the better understanding of the problem in question. These are usually a set of metrics that quantify trends or characteristics and are used to explain phenomena, diagnose causes, share findings and predict results of future events.

2.7.1.1 Macroeconomic factors

A common analysis technique applied by companies is the preparation of macroeconomic forecasts, which can then be followed by industry forecasts and finally the company sales forecast. The macroeconomic analysis helps with the projection of inflation, business investment, government expenditures, net exports, among others. These help with the forecasting of gross domestic product (GDP) and conversely the forecast of industry sales.

These can be applied to a series of different industries that are separated into statistical classifications of economic activities and products. On a European level these are called NACE and they provide the framework for collecting and presenting statistical data according to the economic activity. This study focuses on the following NACE codes [82]:

- **19.2 Manufacture of refined petroleum products -** Which includes the manufacture of liquid or gaseous fuels or other products from crude petroleum, bituminous minerals or their fractionation products
- **20.6 Manufacture of man-made fibers -** Which includes the manufacture of synthetic or artificial filament tow, staple fibers, filament garn, monofilament or strip

- **20.16 Manufacture of plastics in primary forms -** Which includes manufacture of resins, plastic materials and non-vulcanizable thermoplastic elastomers and non-customized synthetic resins.

Some of the macroeconomic factors analyzed in this study are the industrial production index (IPI), revenue and environmental investment.

IPI is one of the most powerful tools for the measurement of economic activity since production as a whole determines the use of resources and labors that will affect future economic growth. The developments described in this index provide knowledge in the economic cycles of a particular industry and consequently can be used to assess developments on the GDP [83]. The objective of the IPI is to measure volume changes in output through quantity and price changes on a monthly basis relative to a base year. In other words, it has the purpose to reflect developments in added value in a specific industry [83]. Gross added value can be calculated through equation (2.1).

$$\mathrm{GAV} = \mathrm{T} + \mathrm{cp} + \mathrm{oi} + \mathrm{cs} - \mathrm{pg} - \mathrm{tp} \qquad (2.1)$$

Where:
GAV = Gross added value;
T= turnover;
cp = capitalized product;
oi = operating income;
cs = changes in stocks;
pg = purchases of goods and services;
tp = taxes on products;

Given that added value is not available on a monthly basis in most countries, the values can be compiled through many different ways such as gross production value, output quantities, raw material consumption or turnover [83].

The calculation of IPI is done using the equations (2.2-2.4), the last one representing the value without inflation.

$$\mathrm{v_j} = \sum_{\mathrm{i}} \mathrm{v_{ij}} = \sum_{\mathrm{i}} \mathrm{p_{ij}} \times \mathrm{q_{ij}} \qquad (2.1)$$

$$\mathrm{R_{v\,j}(t)} = \frac{\mathrm{v_j(t)}}{\mathrm{v_j(0)}} \times 100 \qquad (2.3)$$

$$\mathrm{R_{VOL\,j}(t)} = \frac{\sum_{\mathrm{i}} \mathrm{p_{ij}(t)} \times \mathrm{q_{ij}(t)}}{\sum_{\mathrm{i}} \mathrm{p_{ij}(t)} \times \mathrm{q_{ij}(0)}} \times 100 \qquad (2.4)$$

Where:

v = production value

j = product group

i = production values for the products

p = price

q = quantity

R_v = relative value

R_{VOL} = relative volume

t = reference period

0 = base period

Changes in the values of IPIs depend on the following factors [83]:

- type and quality changes of feedstock;
- changes in stocks of goods;
- variations in technical input-output relations;
- Changes affected in the services, such as the assembling of production units, installations, reparations and others.

2.7.1.2 Stakeholders

A key goal of market research includes the definition of the target audience that will directly or indirectly have an effect on the activities pertained in the study. These are represented by potential customers and buyers of the product, also known as the stakeholders [80].

2.7.1.3 Market Share

Market share is one such concept that is defined by the percentage of the market accounted for by a specific entity. This is a key indicator for how competitive a market is and how well the company is doing related to the competition [84]. It can be obtained through equations (2.5-2.6), where the first is calculated through volume and the second through monetary value. This study utilizes the latter.

$$\text{Unit Market Share (\%)} = \frac{\text{Unit Sales (\#)}}{\text{Total Market Unit Sales (\#)}} \tag{2.2}$$

$$\text{Revenue Market Share (\%)} = \frac{\text{Sales Revenue (€)}}{\text{Total Market Revenue (€)}} \tag{2.3}$$

This metric when used in conjunction with changes in sales revenue can help in the evaluation of the total market growth and competition selection [84].

2.7.1.4 Penetration

Penetration is a metric that measures the popularity of a brand. In other words, it is defined by the proportion of people who bought a specific brand or product [84]. Market penetration, equation (2.7), measures category acceptance by a defined population. Whereas penetration rate, equation (2.8), is a comparative acceptance of goods within a category.

$$\text{Market Penetration (\%)} = \frac{\text{Customers who have purchased a product in the category (\#)}}{\text{Total Population(\#)}} \times 100 \qquad (2.4)$$

$$\text{Penetration Rate (\%)} = \frac{\text{Customers who have purchased the brand (\#)}}{\text{Customers who have purchased a product in the category(\#)}} \times 100 \qquad (2.8)$$

This metric can also be viewed as a strategy since it helps in the decision of whether to obtain a growth in the sales by acquiring customers from the competition or expanding the total population of brand users [84].

2.7.1.5 Competition

There is a need for the evaluation of the competition, this including both actual and potential rivals. The proper identification of the competition is always relevant to a study in order to better answer the customer needs by offering better products or going in a different direction if need be [80].

2.7.2 Prediction Models

As it was mentioned above, in order to make the correct decision there needs to be an identification of the best research techniques. Nowadays, forecasts are a must for a company to cope and stay ahead of future demands and trends. To better answer the variety and complexity of each market, many types of forecasting techniques were developed, each designed for a specific goal and a particular application. The selection of a method depends on many factors such as the relevance and availability of historical data, the desired accuracy, the time period, the cost/benefit and time availability. These will define which type of prediction model to use between the two basic types: qualitative and quantitative [85].

Quantitative research measures the market by calculating the market size and its segments, brand shares, purchase frequencies, distribution levels, and other statistical based data. This type of research can be further divided into two other types, time series analysis & projection and causal analysis.

Time series analysis & projection, focuses more on patterns and pattern changes, therefore being entirely based on historical data. These techniques need to have plenty of available data and should not be used as raw data since these trends are usually mixed with other factors. Some common types of techniques are the moving average, the exponential smoothing and trend projection [86].

Causal methods use highly refined and specific information in order to make some connections between each element. This is the most sophisticated kind of forecasting tool as it provides cause and effect results from the data, also being able to incorporate results from time series analysis. The regression, econometric and input-output models represent some techniques from this type of analysis [86].

Qualitative techniques are mainly used when there is not much data available. Their main goal is using personal judgment and rating schemes into information that can be quantified. It is common to apply this type of analysis in new technology areas where the market and penetration rates are still uncertain. Some basic forecasting techniques present in this type are the Delphi method, market research, panel consensus, visionary forecast and historical analogy [86]. Figure 2.6 shows a graph that resumes the different types of analysis and their forecasting techniques.

Although they are very distinct types of forecasting techniques, they are often utilized in conjunction for better results. With that in mind, this study applied both types mainly utilizing time series analysis & projection techniques, more specifically, trend projections. Qualitative techniques were also used, with market research and historical analogy being the main techniques that help guide personal judgment.

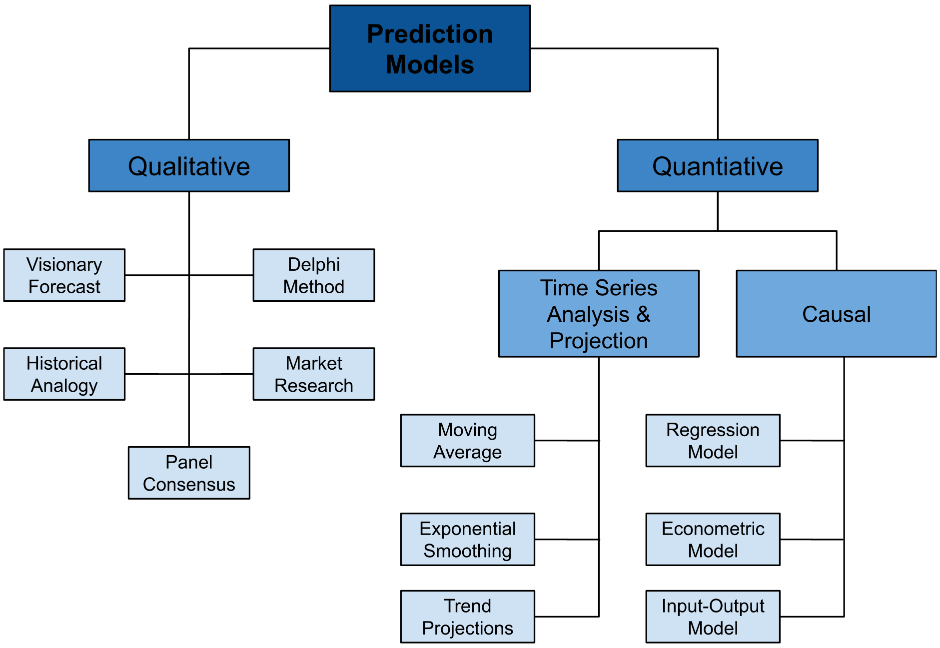

Figure 2.6 Forecasting techniques based on [86]

2.7.3 Data collection tools

The data collection phase is usually the most expensive and most likely to contain errors. This is due to the existence of many different ways of gathering information, be it through the use of surveys, interviews or simply researching on the Internet. There is no perfect method, each tool having its strengths and weaknesses and often, in order to obtain the highest amount of data, it is necessary to utilize multiple tools. From all these methods it is possible to distinguish two different types of data research: primary and secondary research [87].

Primary research consists of data that is freshly gathered specifically for the purposes of the research. This type is often used when the data is incomplete, inaccurate, unreliable or simply nonexistent so the researcher needs to look directly to a knowledgeable source. Common tools for this are observation, focus groups, surveys, interviews and behavior analysis [88].

Secondary research is a type of research that utilizes already existing sources that collected the data for another purpose. This data includes raw values and information from published summaries that is related to the subject of the study. The information can be derived from internal sources for analyzing the company's own tendencies or external sources such as databases, company reports, trusted news articles and so on for a better understanding of the competition and the tendencies of other markets [88].

Depending on the type of study, each method will offer different data for the problem in question. Secondary data is more useful for national and international comparisons, offering answers to the main questions in hand. Since this study focuses more on the potential appearance and growth of certain processes in different countries and how it will affect Air Liquide’s market as a whole, this is the primary source of data collection utilized.

3

METHODOLOGY

In the next chapter the methodologies used in the market will be described. They serve as an explanation of the types of research utilized, the data collection tools and the way that the analysis was performed. Ultimately, they offer the knowledge to determine the quality and integrity of the results and conclusions.

Following the notions given by chapter 2.7, this chapter provides a description in a schematic form of the procedures utilized to obtain the databases and the results. This way it is possible to validate the methods and, if need be, replicate them.

3.1 Market Forecast

The main objective of this study consisted in predicting the future analysis needs of new processes in the petrochemical industry.

The market forecasts were based on two principles, the number of plants per process and their cylinder consumption. These are two different notions that needed to be approached separately. For that matter, both principles are obtained separately as is shown in the first three methodologies below and later they are combined to obtain the desired results.

3.1.1 Number of plants

The number of plants was determined as one of the key factors that affects the consumption of gas in the industry. For that reason, it was necessary to evaluate the evolution of the number of plants of each of the processes and predict, using trend extrapolation methods, how it will fluctuate in the future. In the cases where it did not exist information, or the current growth is predicted to change drastically in the future, the trend extrapolation was not applied and so the values utilized were the ones given by trusted sources, as is the case for hydrogen.

The capacity for each process was also obtained to offer further notions of the total amount produced and if it follows the same patterns as the number of plants. This was also used as a way to apply different scenarios. Figure 3.1 represents the methodology utilized.

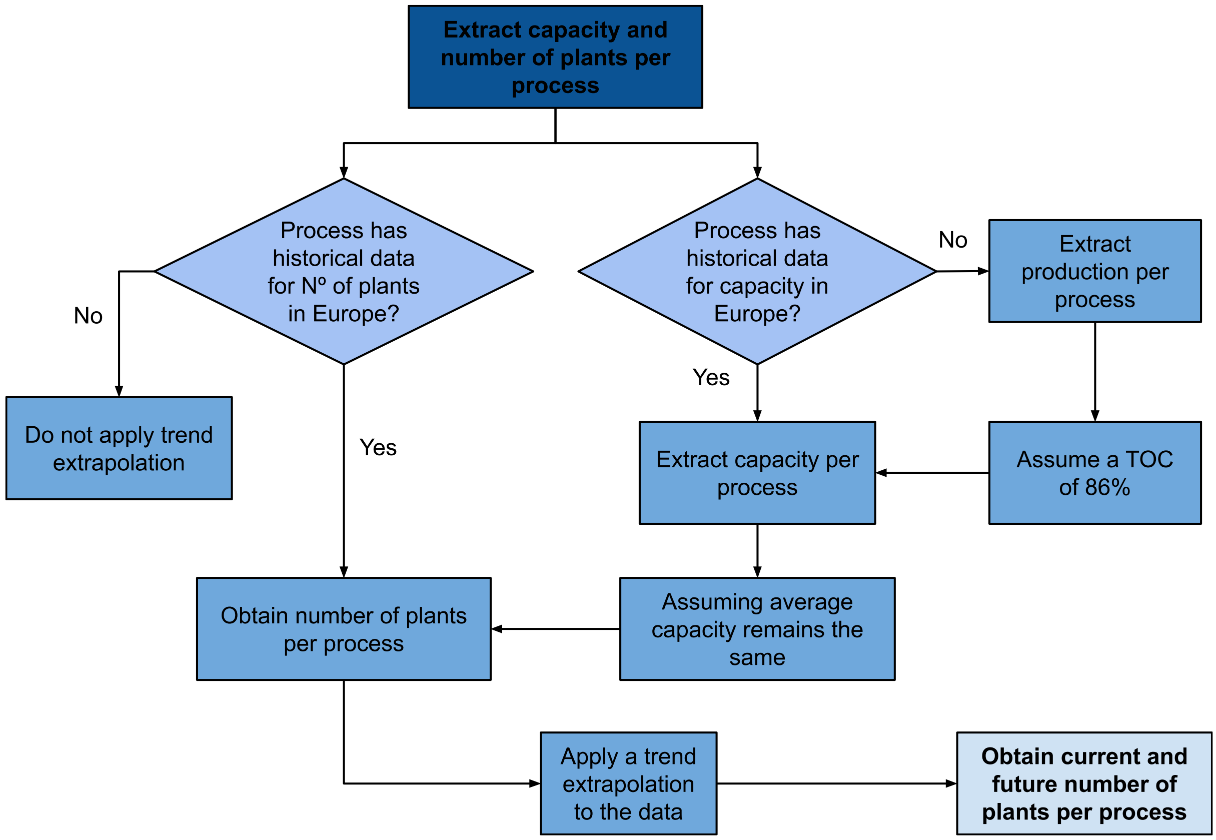

Figure 3.1 Forecast for number of plants methodology

3.1.2 Cylinder consumption

The cylinder consumption was a method applied to corelate the variations of the number of plants per process with the consumption of gases. This methodology was based on the notion that traditional processes need a higher number of analyzers due to their complexity compared to the newer processes.

For that reason, the Figure 3.2 represents the methodology applied to obtain the cylinder consumption per unit and year for each process.

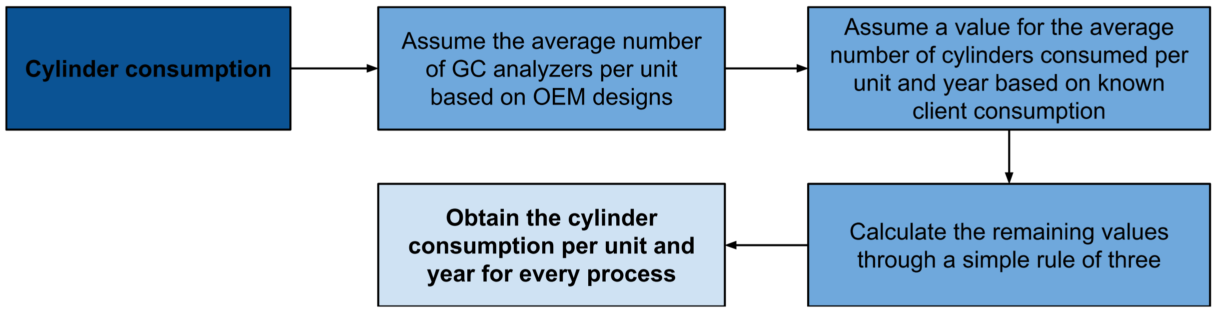

Figure 3.2 Cylinder consumption methdology

3.1.3 Scenarios

The next step of the market forecast consisted of the creation of scenarios. These offer different alternatives of the future and help in the planning of a business strategy.

As it can be seen in Figure 3.3 the scenarios were created firstly by separating the forecasts that were calculated while considering whether or not the average capacity remains the same as it is now. Secondly by choosing the trend lines that represented the maximum or minimum amount of cylinder consumption for each process.

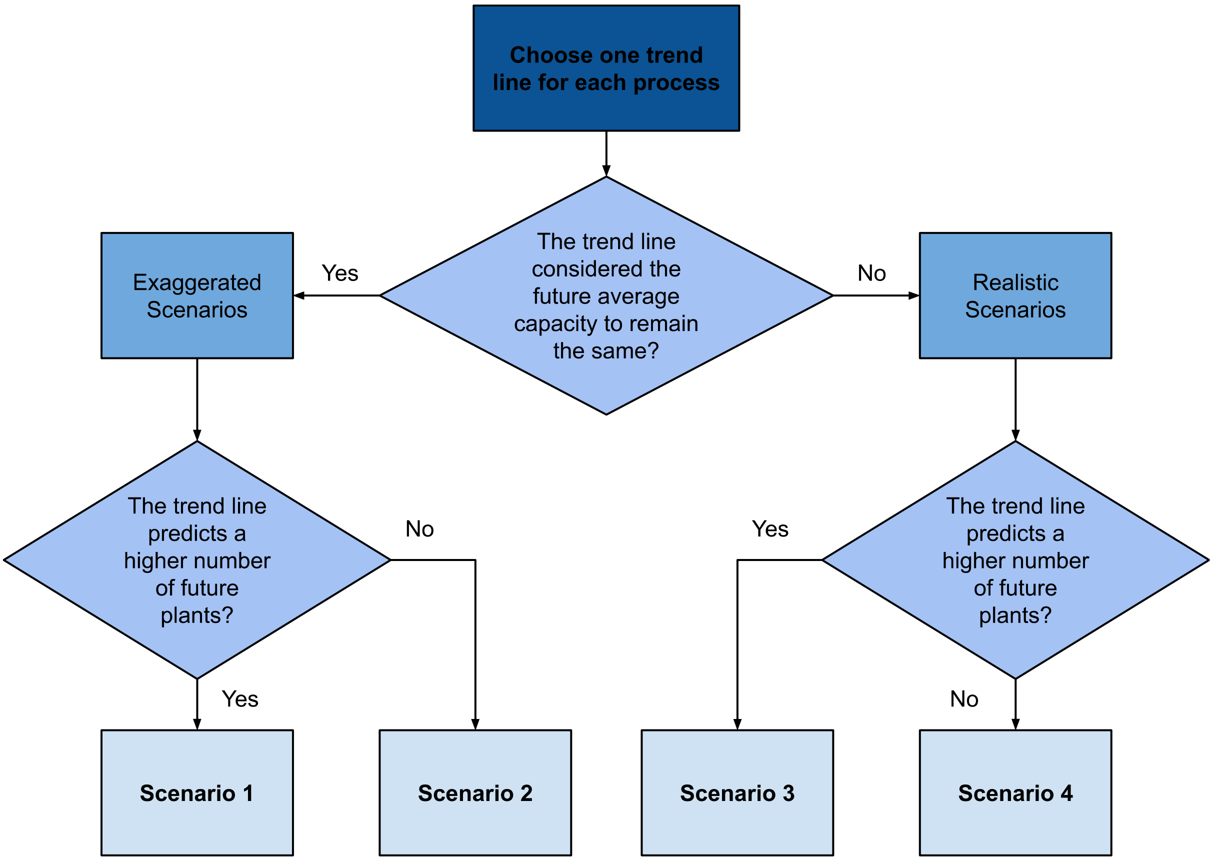

Figure 3.3 Scenario creation methodology

3.1.4 Gas market revenue

Finally, the methodology present in Figure 3.4 was utilized to obtain the gas market revenue for Europe and later for the SWE cluster, by combining the results obtained through the methodologies above.

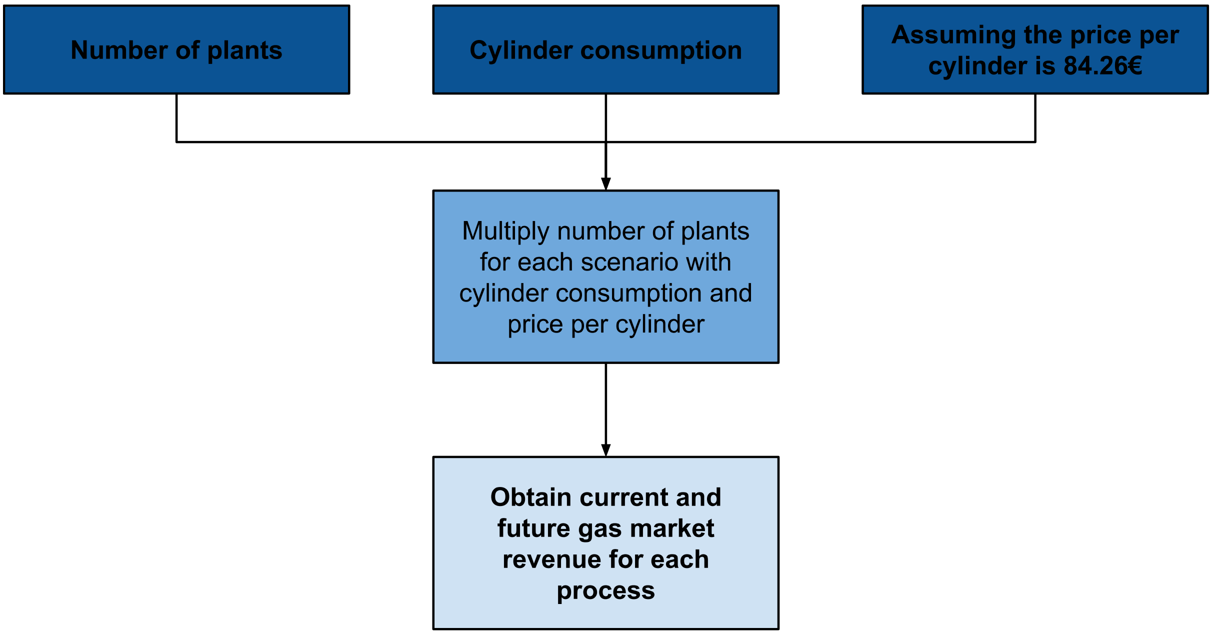

Figure 3.4 Market forecast methodology

3.2 Stakeholders database

The identification of the stakeholders represents a key objective of this study. For that matter Figure 3.6, Figure 3.7, Figure 3.8, Figure 3.9 and Figure 3.5 illustrate the methodologies applied for the creation of the databases for each region of the SWE cluster plus the original equipment manufacturers.

These figures showcase the sources from where the stakeholders were extracted as well as the filters applied. These were based on accredited company directory sources represented on the right and on the left public company directory sources are used to populate the rest of the database.

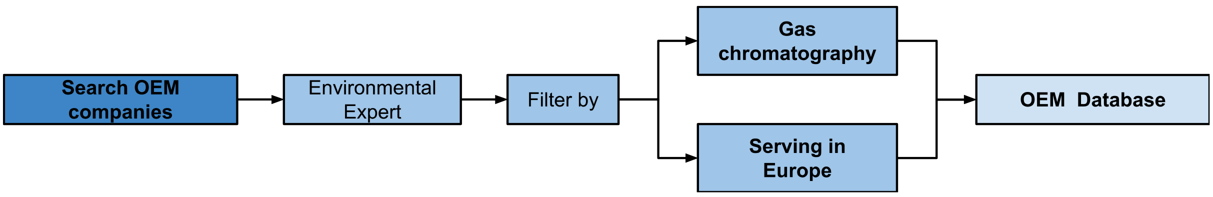

Figure 3.5 OEM database creation methodology

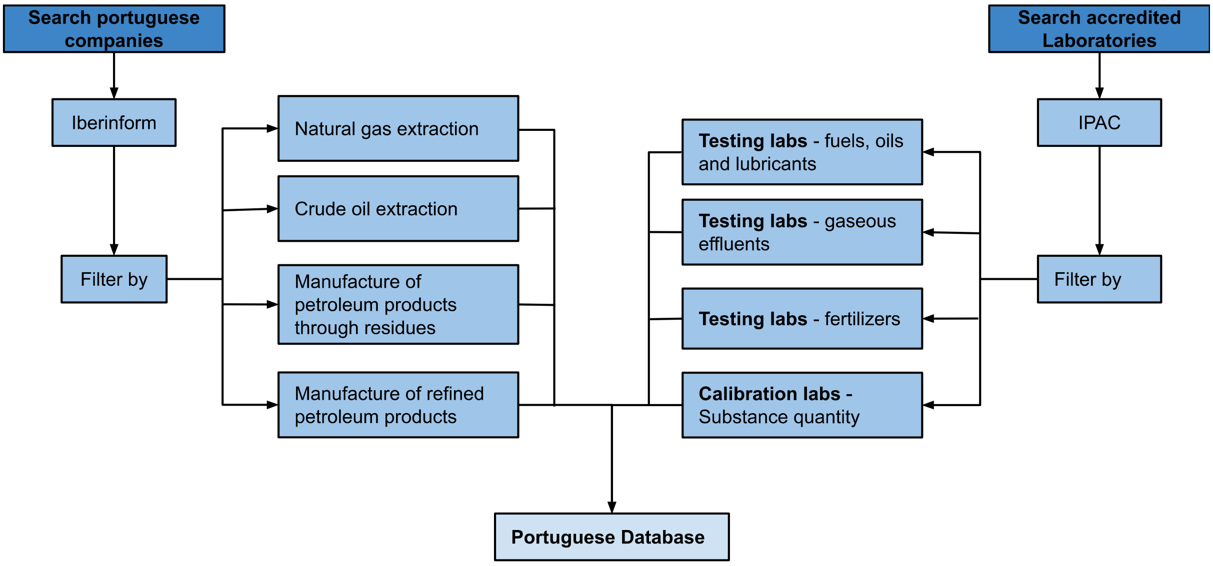

Figure 3.6 Portuguese database creation methodology

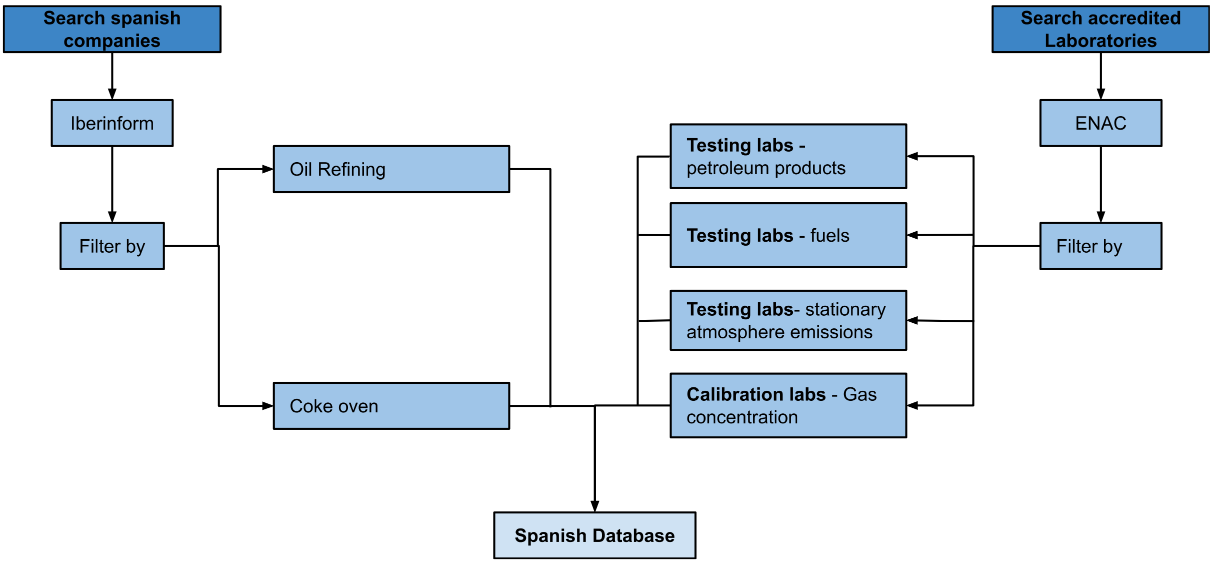

Figure 3.7 Spanish database creation methodology

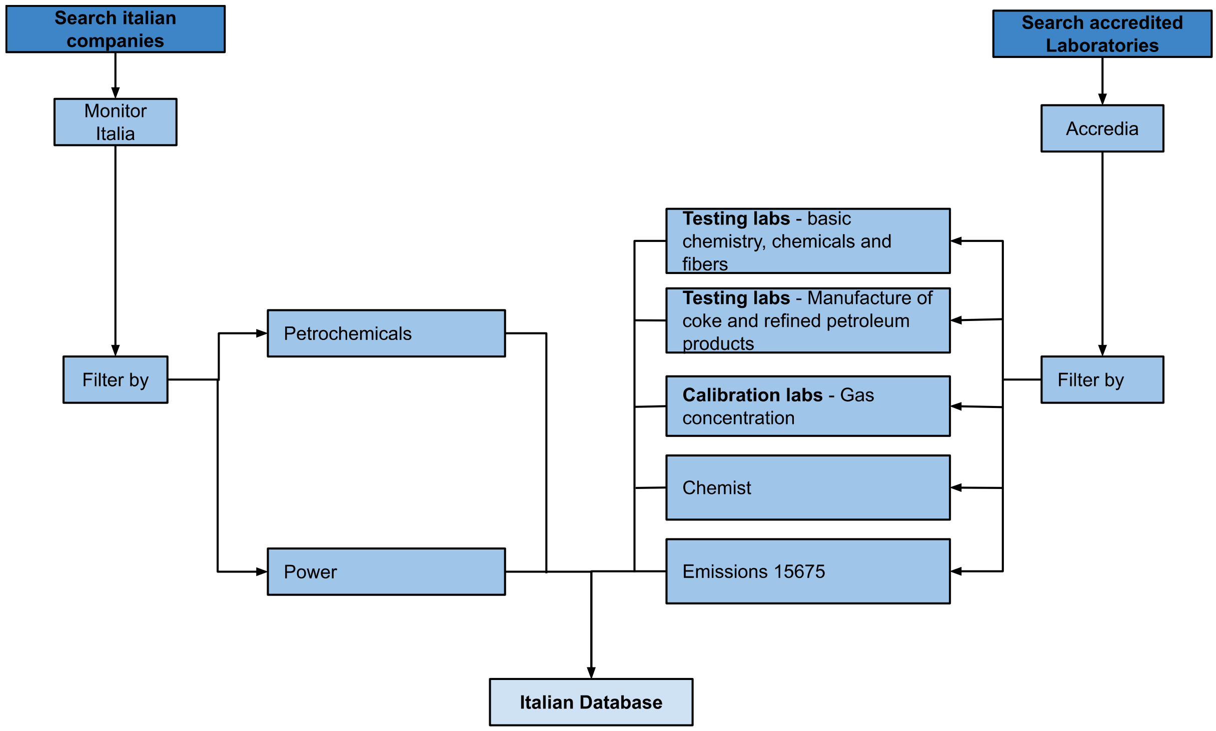

Figure 3.8 Italian database creation methodology

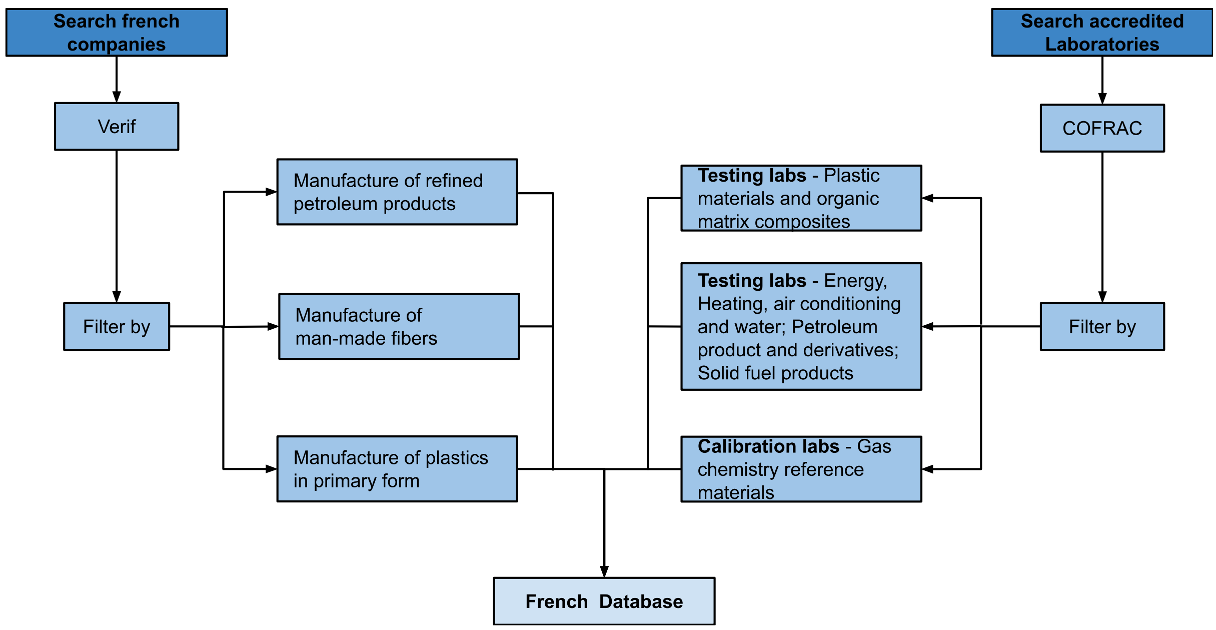

Figure 3.9 French database creation methodology

3.3 Penetration Rate

In order to validate the results, the penetration rate was calculated. This was done using the databases previously described. After populating the databases, it was necessary to do a further filtration process for the stakeholders to be aligned with the scope of the project. The remaining companies would then be examined if they are Air Liquide's clients, clients of the competition or if they are not identified. This methodology is represented in Figure 3.10.

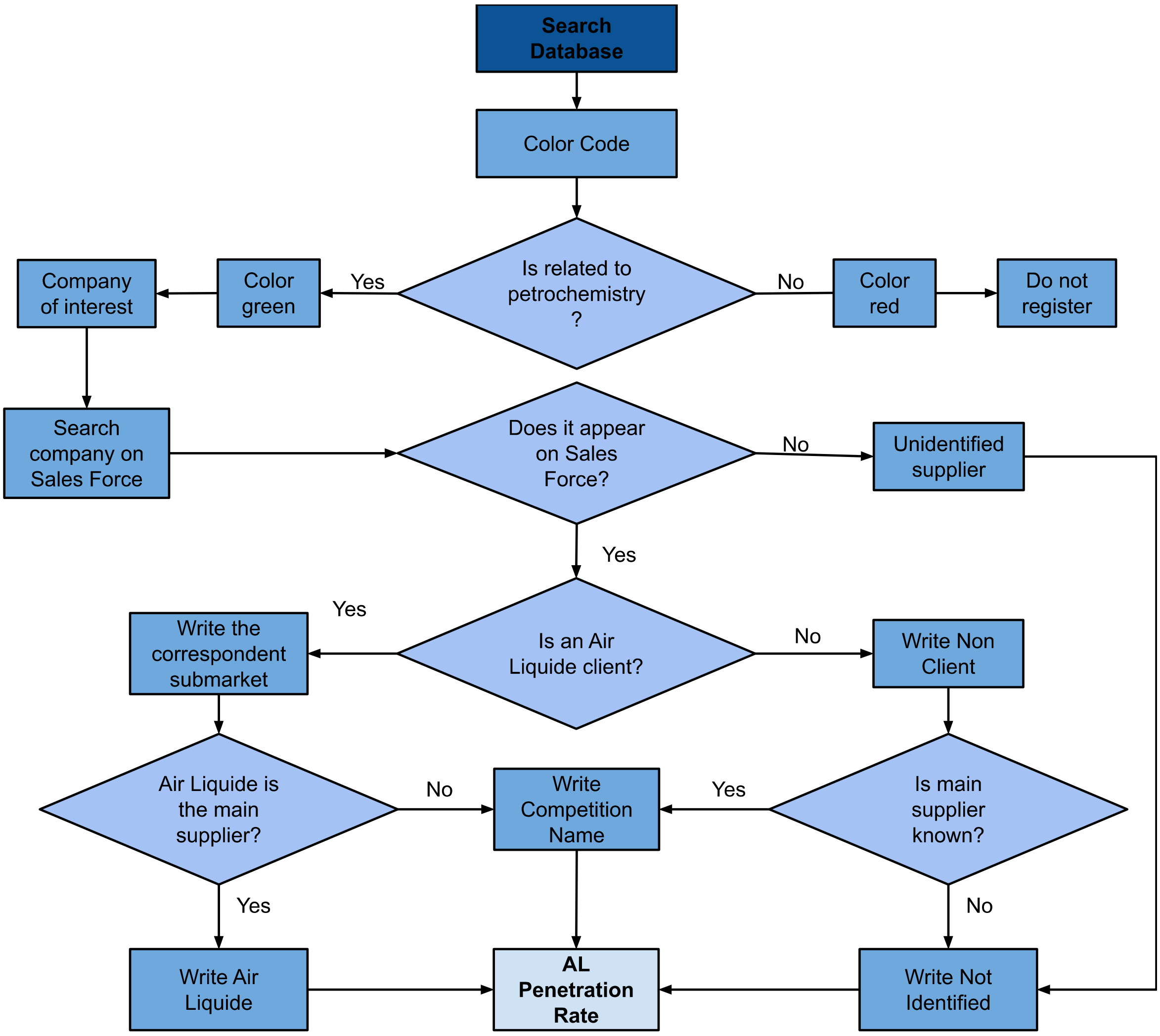

Figure 3.10 Penetration rate methodology

4

PRESENTATION AND DISCUSSION OF RESULTS

4.1 Market Overview

To better understand the scope of this study, it is necessary to see where the industry in question fits inside the company, how it is changing and how it will affect the future sales of Air Liquide.

This study's scope revolves around the petrochemical sector, more specifically the analytical needs in the SWE market. Thus, the main market in question is the R&A market. This market provides gases mainly to customers that work on analysis, testing, calibration services and product certification as their core activities. Specialty gases constitute the main product sold on the market.

In 2021 in the SWE market, the R&A sector contributed just above a tenth of the total sales of the IM business line, representing the smallest percentage compared to the other three markets.

Out of all the submarkets, the one that is related to the scope of the study is the Oil & Gas submarket, also known as R&A04C. It comprises the on-site laboratories and research departments of plants related to refining and petrochemical industries.

This submarket represents a very small portion of the total R&A market, constituting less than 5% of sales in 2021. This means that this market has effectively an impact lower than 1% on the whole SWE IM business line sales.

In order to properly study the whole market, it is necessary to include two other submarkets in the study:

- M&P02 - Refining & Oil, Coal and LNG Transportation
- M&P03 - Petrochemicals

Both of these markets are included since they also consume specialty gases but for applications other than analysis.

4.1.1 Sales

The sales of the markets in question can be seen in Figure 4.1. SWE sales grew in the first year but stayed relatively stable in the following years, showing similar margins. Over this period sales in the SWE cluster grew with a compound annual growth rate (CAGR) of +1.55%. The CAGR was calculated with equation (4.1). These changes were mainly felt in France, which is to be expected since it is the region where Air Liquide has the largest presence, representing over half of the sales. Therefore, any changes will have a bigger effect on the total SWE market. However, the changes felt in the French market were mainly due to the normal increase and decrease in sales to specific customers and not the total loss of a customer, which does not represent any major threat. As for the Portuguese market, it is the only region where the CAGR shows a decrease. This is mainly due to a loss in sales in the last year due to the closure of the Galp refinery in Matosinhos.

Something to take notice of is the sales after 2019. Due to the pandemic many industries were affected and saw their sales plummet. This was not the case for this market, where the sales stayed stable. This information coupled with the fact that this market represents a very small percentage of total sales furthers the notion that the pandemic did not have a direct major effect on this market. Overall, the top 10 customers remained roughly the same between all the countries between the years 2018 and 2019, which, with the previous analysis, reveals that this market is stable and tends to grow.

$$\mathrm{CAGR} = \left(\frac{\text{Final Value}}{\text{Initial Value}}\right)^{\frac{1}{\text{number of years}}} \times 100 \qquad (4.1)$$

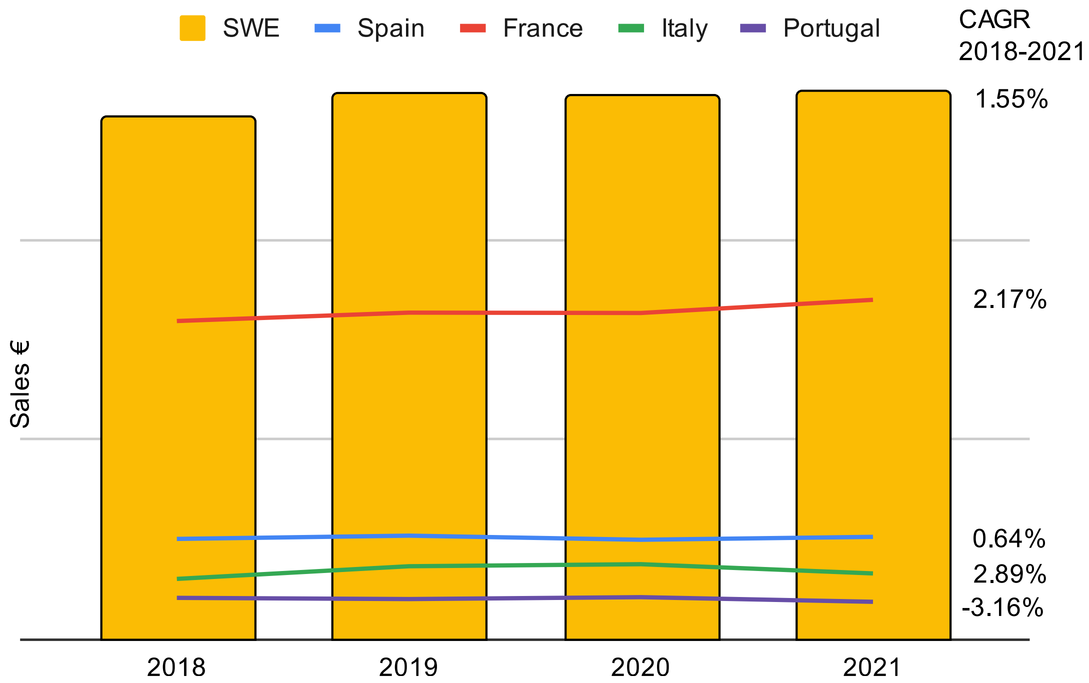

Figure 4.1 Sales in the M&P02, M&P03 (Specialty gas) and R&A04C markets from 2018 to 2021

4.1.2 Macroeconomic factors

In order to study the current trends, some macroeconomic factors were analyzed as a means to check if the current shifts in the industry have a direct impact on the Air Liquide sales. The factor utilized for this study was the Industrial Production Index. Analyzing other factors such as the Gross Domestic Product (GDP) and revenue of each industry would reveal similar trends to the IPI and therefore they are not included in the study.

Figure 4.2, Figure 4.3 and Figure 4.4 show the IPI of the industries whose economic activity has an impact on the scope of the project and were extracted from Eurostat. The data for Portugal was confidential and therefore it cannot be shown in the figures.

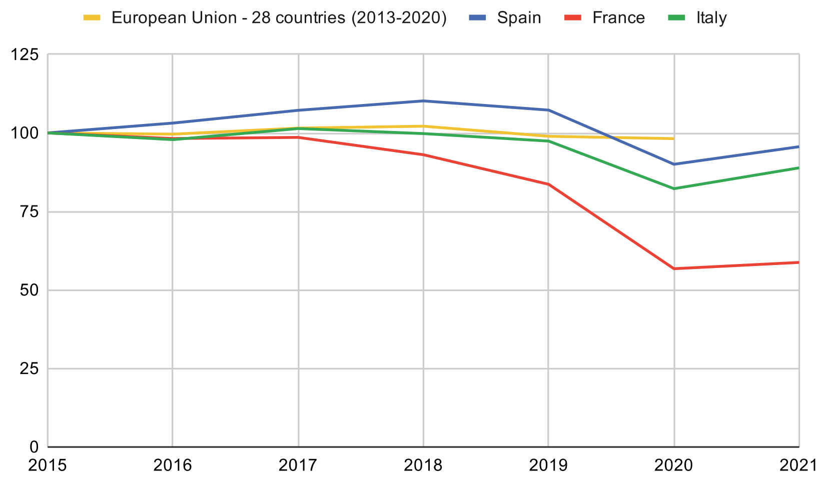

Figure 4.2 IPI for industries with economic activities related to the manufacture of refined petroleum products

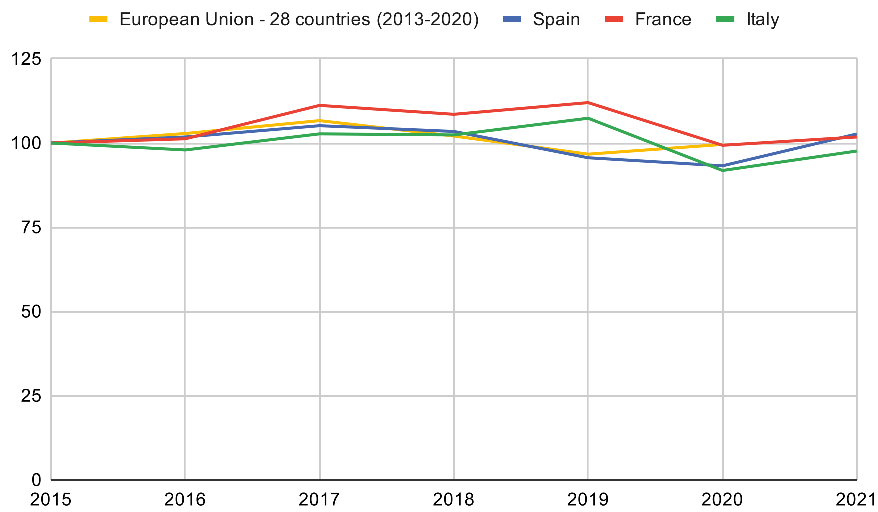

Figure 4.3 IPI for industries with economic activities related to the manufacture of plastic in primary forms

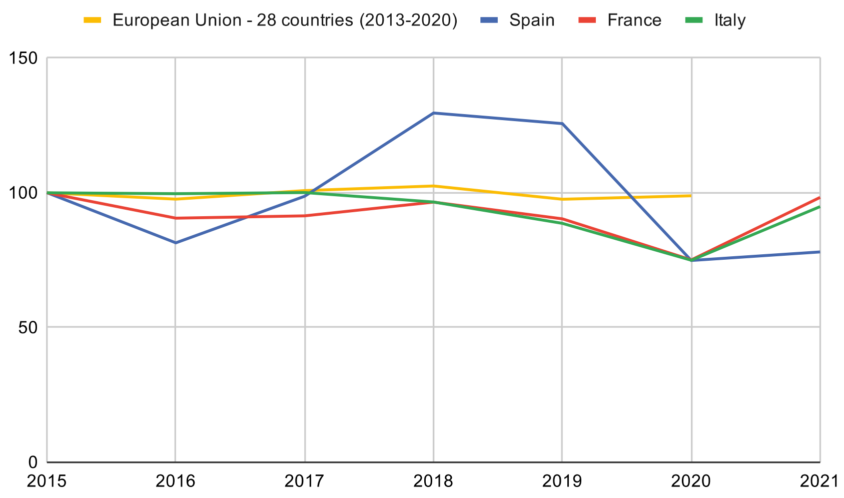

Figure 4.4 IPI for industries with economic activities related to the manufacture of man-made fibers

Other than some clear outliers, namely in Figure 4.4 with the Spanish market being so volatile and in Figure 4.2 where the French market showcases a downwards trend due to the closure of many plants in the industry, the graphs follow similar patterns. The common trends for most countries and industries are a slight growth of the IPI or maintaining the values relatively similar from 2015 until 2020 where they drop to levels below the base year, only to bounce back in the next. This reveals that these industries were heavily affected by the pandemic.

When compared to Air Liquide's sales, these do not follow the same patterns, since the drop in production and turnover is much more accentuated in the industry as a whole. Consequently, it can be assumed that external factors and changes seen in these industries do not have a direct impact on scope of the study. This is to be expected since a decrease in production of a particular product does not change the need for analyzing it. It is also worth mentioning that the calibration of certain equipment, such as the spectroscopy analyzers are not affected by this since calibration is always required for the equipment to properly function.

That being the case, it is possible to assume that the main source that impacts the sales in the R&A sector is the variation of the number of plants.

Other factors that might have some impacts are changes in customer consumption, the use of new processes, the raising or decrease of plant capacity or the choice of the customer towards the competition.

Since there is no correlation between macroeconomic variables and these sales, the prediction of future analysis needs was done through different means.

4.2 Market Forecast

In order to study the future oil & gas market at Air Liquide, the methodology present in chapter 3.1 was used. As it was seen before, this methodology was done on the basis that the main change in this market is provoked by the variation in the number of plants instead of being affected by the external factors and direct changes in the industry. Nevertheless, these will still be evaluated since they can have an impact on the future number of plants and therefore have an indirect influence on the gas market.

Although the scope of this study only encompasses the SWE cluster, the market forecasts were made for the whole of Europe in order to have a better understanding of its development. This was mainly due to some countries not having some processes and this way it was possible better define the growth of each country in each process. At a later stage the results were applied to the cluster.

Before starting the forecasts, it is necessary to make a selection of the new processes that are more likely to be and are being applied in the petrochemical industry. This choice was based on the analysis of each technology through the TRL and CRI indicators. Figure 4.5 shows a graph of the indexes of the new processes discussed in the study. The size of the bubble represents the likelihood of it having a future in Europe. All of these values were either based on studies that directly mentioned the current level for the technology or chosen from personal judgment.

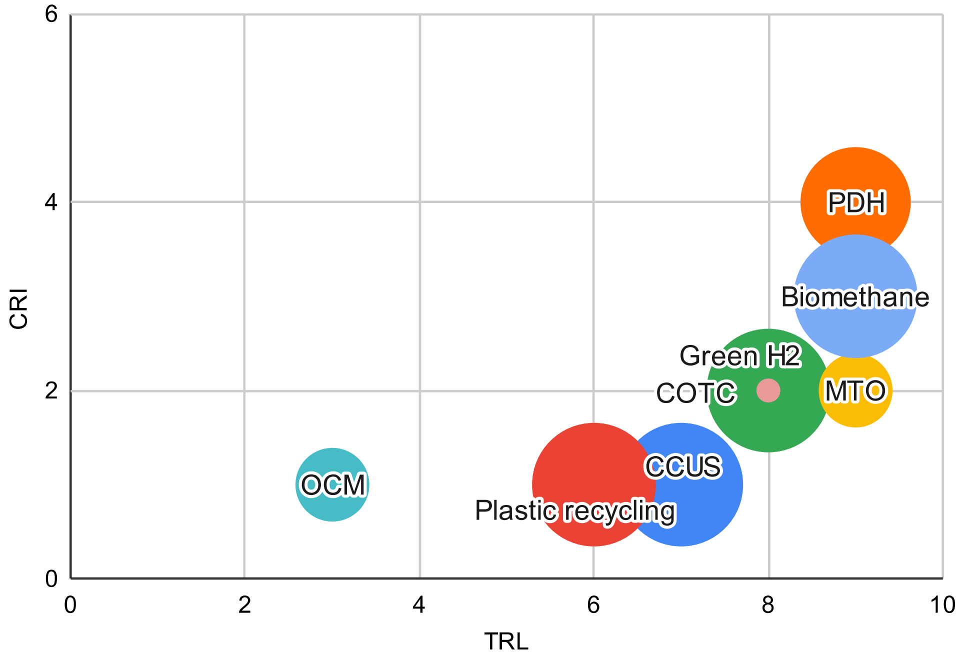

Figure 4.5 New processes TRL and CRI bubble size represents the likelihood of it having a future in Europe

The smaller bubbles - OCM, COTC, MTO - are technologies that do not show much promise in Europe. OCM has a lot of potential, but the technology is still too unviable and not advanced as it can be seen in the graph. On the other hand, COTC and MTO are technologies which are relatively advanced but, in this case, they are not likely to have a future in Europe. COTC is highly dependent on the feedstock (crude oil) being close and readily available to be reliable. MTO suffers because the main source of feedstock for methanol is coal. Once green methanol starts to be readily available in Europe, this process might have a higher interest.

Plastic recycling represents a very promising alternative to the production of plastics, that could have some impacts in the petrochemical market, but currently the only viable option is through mechanical means which are not the best alternative since they are not able to make the plastics reach the virgin state.

For these reasons, the technologies mentioned were excluded from the forecasts. Thus, the processes considered for the definition of the market present in this study are: refineries, petrochemistry (PDH included), biogas, biomethane, biodiesel, bioethanol, hydrogen (blue, green and gray) and CCUS.

The forecasts were made for all of the mentioned processes and studied using tendency lines with the exception of hydrogen due to the lack of historical data for the green and blue alternatives.

4.2.1 Number of plants

In order to predict the future number of plants for each process the methodology present in section 3.1.1 was utilized.

4.2.1.1 Refineries

The number of refineries and consequently the overall capacity for petroleum products in Europe has been going down since the stock market crash in 2008. The economic crisis started a trend that changed the whole oil & gas market, one that Europe has yet to truly recover from.

The following years saw the continuous shut down of refineries due to the lowering of demand for petroleum products namely fuel oil and gasoline. The downward trend was especially significant from 2011 until 2013 where several plants from key players went out of business most notably Petroplus, Tamoil and Shell [89].

From 2014 onwards the demand stabilized and even increased slightly, mainly due to the diesel and kerosene applications having an increased demand. Although there was a small growth in demand, the capacity remained low. This was possible due to the unusually high utilization rates that were seen in these years, being around 85% whereas the previous years it was on average around 78% [90]. After a relatively steady period, the pandemic brought the demand for petroleum products down by 12%, which caused a new wave of refinery shutdowns [90].

The lower demand caused by the pandemic and the economic crisis, coupled with high utilization rates in European refineries culminated in a total of 24 refineries shutting down from 2009 to 2021 with the capacity lowering from 809 million tons per year to 667 million tons per year [89].

This represents a considerable loss in a market as big as this, but one thing to note is that not all of the refineries were permanently closed. Some were converted into biofuel or hydrogen plants, such as Total Grandpuits refinery, Livorno's refinery and Shell's Wesseling site [3]. This reveals that some companies are already embracing and investing in green alternatives, which shows a potential way forward for the future of this market.

It is also worth mentioning that 30% of refineries are integrated with petrochemical plants and due to their increased yields and possibility of creating high value products, these are more likely to stay open [3]. Appendix D showcases additional information on the subject. Figure 4.6 and Figure 4.7 represent the forecasts for the capacity and number of plants of refineries in Europe.

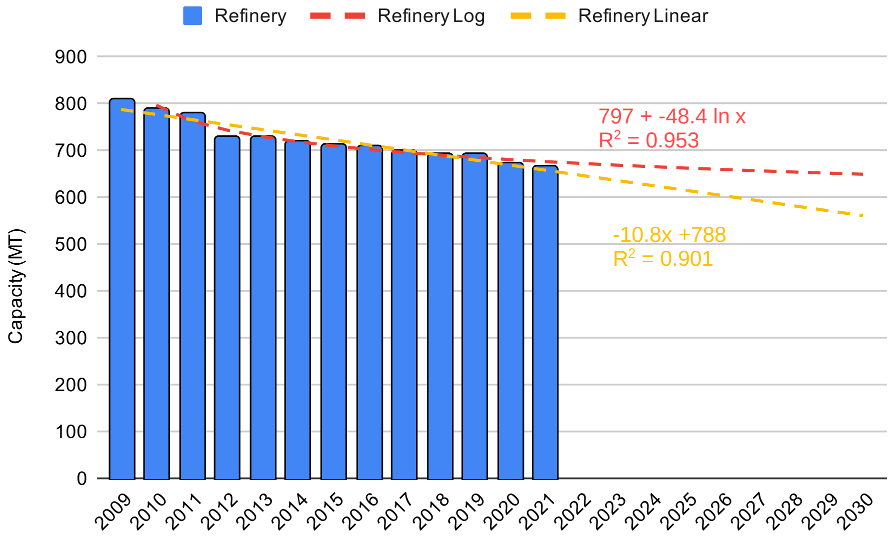

Figure 4.6 Forecast for capacity of refineries in Europe with current values extracted from [89]

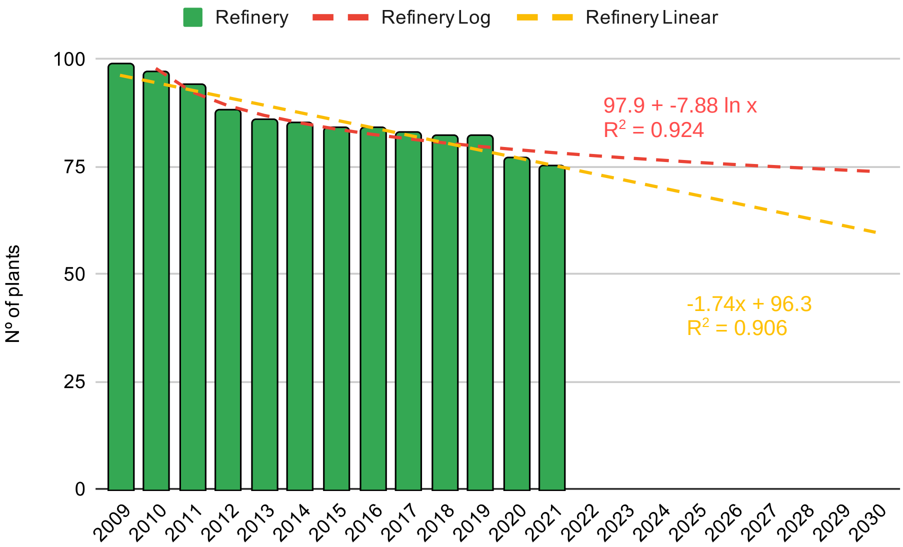

Figure 4.7 Forecast for number of refineries in Europe with current values extracted from [89]

With this information the two trend lines created for the forecasts of refineries were a logarithmic line and a linear line.

The first predicts that the refineries will ease their downwards trend and stabilize closer to 2030. This trend follows more in line with the recuperation years seen from 2012 until 2019 where this market did not see a major growth even though it was recovering from the previous crisis. This is the more optimistic outcome since it is very unlikely that this market will rise at a rapid pace after the war on Ukraine since it accelerated the need for other sources of fuel besides the fossil-based ones.

The war can also have more adverse effects in the future if it prolongs, thus the pessimistic outcome foresaw the continuous downward trend of refineries at a linear pace.

4.2.1.2 Petrochemistry

The European petrochemical market has been rather stagnant over the course of the last 20 years. The lack of investments in older plants and development on new processes made this industry stay in place and lose ground in favor of the Asian and American markets. This has been identified as a problem area and has been answered by some major players in the industry. For example, INEOS has announced “Project One” which will build an ethane cracker with a capacity of 1450kt of ethylene per year in Antwerp, Belgium that plans to lower the carbon dioxide footprint and achieve maximum energy efficiency [91]. Other big announcements are Repsol’s plant expansion in Sines, Portugal for polypropylene and linear polyethylene both with 300kt per year [92] and PK Orlen expanding its plant in Plock by adding a new steam cracker with a capacity of 740 kt of ethylene per year [93].

Although there are some recently announced projects, they are meant to substitute the older plants due to their inability to achieve today's standards both in environmental and efficiency goals. Therefore, a change in the number of plants or the total capacity is very unlikely.

This transitional period also saw the rise of production of plastics, one of the main end products for this industry in Asia, lowering the exports of plastic and their derivatives from Europe. These mainly affect HVCs, which constitute a big part of the petrochemical industry as a whole. Although the market seems to be going down outside of Europe, internally it continues to be strong having a majority of the petrochemical products being traded within Europe [94].

As it was said the number of plants did not vary much throughout the years, so the figures below only showcase the capacity of the petrochemical building blocks. For simplicity reasons propylene, ethylene and the BTX aromatics were grouped into high value chemicals (HVC's) as shown in Figure 4.8.

From 2011 to 2019 the capacity for HVC in Europe seemed to follow a trend of lowering for two years and in the third year, a growth in capacity would occur. This reveals a trend that can continue to happen for the following years. Taking that cycle into account, the trend lines that were drafted were made to show the interval that the capacity is predicted to be in for the coming years. This way the red line represents a linear function only utilizing the top values, that is, the values from the years 2011, 2014 and 2017 while the yellow line represents the bottom values utilizing the years 2013, 2016 and 2019.

Although these trendlines predict that the top and bottom values in 2030 will be similar to the ones we see nowadays, a slight decrease was accounted for. This represents the most likely outcome due to the lower plastic production in Europe and the eventual development of chemical recycling of plastic, which will make the need for HVCs lower.

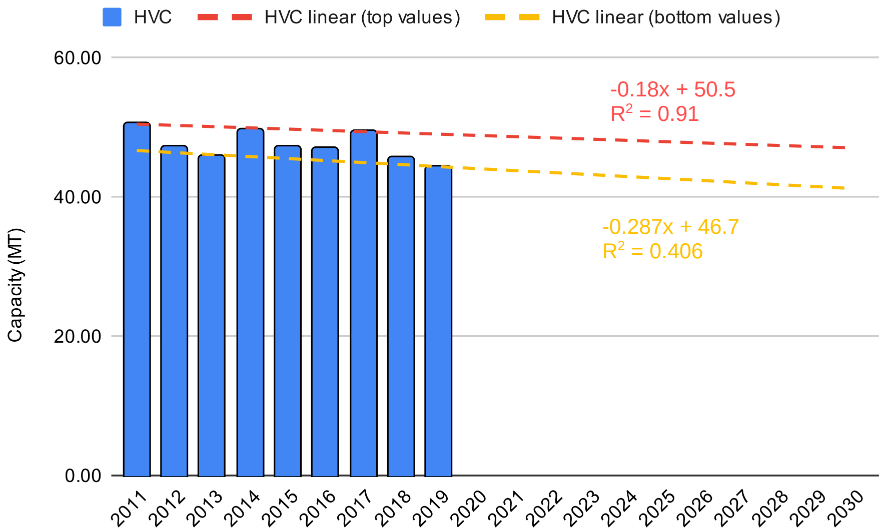

Figure 4.8 Forecast for capacity of HVC in Europe with current values extracted from Eurostat

The methanol market remained relatively stable in the early 2010s, resulting in its capacity not varying much in Europe and maintaining the same number of plants throughout these years. That changed in 2019 when in the year prior, there was a tight supply of methanol due to the postponement of the construction of numerous big plants, which resulted in prices rising [95]. These were planned to have double or more of the average capacity and were supposed to be located in Iran and Trinidad.

In 2019 a plant that produces methanol through bio methods, BioMCN, opened raising the capacity as it can be seen in the graph [95].

The trend lines that were applied for this product predict its growth, only varying the slope of each function. The red trend line predicts that the growth will be steadier, following the example of what happened in 2019. This year could be an exception and the growth of methanol might be similar to what was seen in years prior, so in that respect, the yellow line predicts a smaller growth that does not account for the last year.

Methanol is a product that will be highly dependent on the development of other green alternatives, such as hydrogen. This will have a direct impact on its production in Europe since the current methods for its production are not seen as a good alternative. This is due to its main feedstock being coal which releases high amounts of carbon dioxide.

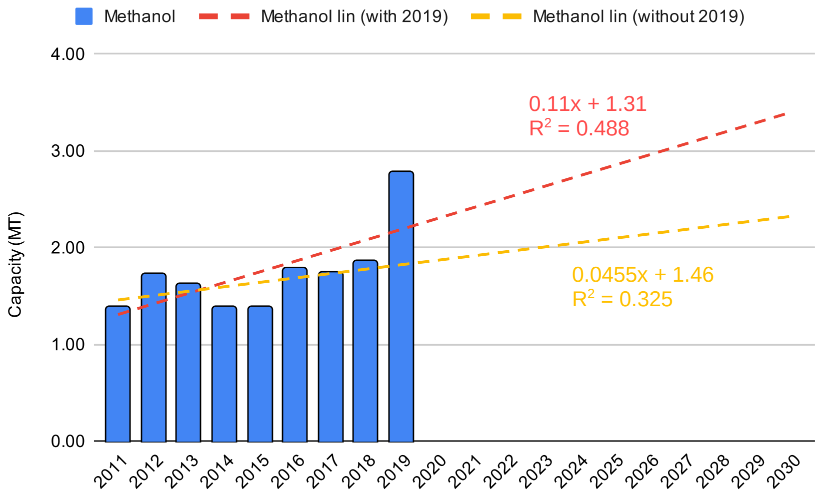

Figure 4.9 Forecast for capacity of methanol in Europe with current values extracted from Eurostat

Ammonia saw a small jump in its production from 2013 onwards due to an increase in the demand for fertilizers, its main application [96]. Despite this it has remained relatively stable throughout the years. This might not be the case in the future due to various factors that can affect its market. The war on Ukraine can have a very direct impact due to the country being one of the largest producers of wheat and fertilizers. In the case of the war extending for several years it will have a negative effect on the production of ammonia. This was then represented by the trend line in red.

On the other hand, there have been recent studies that showcase the potential of this product being used as a fuel source or a hydrogen carrier which might spur interest in it and consequently raising its production [97], and thus the yellow line predicts a more positive outcome.

Both methanol and ammonia are very dependent on gas prices and the new green technologies, namely hydrogen. The high gas prices greatly affect their market and make it difficult for growth to occur. On the other hand, the recent policies that were put in place to help the development of hydrogen might counter the negative effects and ultimately make these markets grow [98].

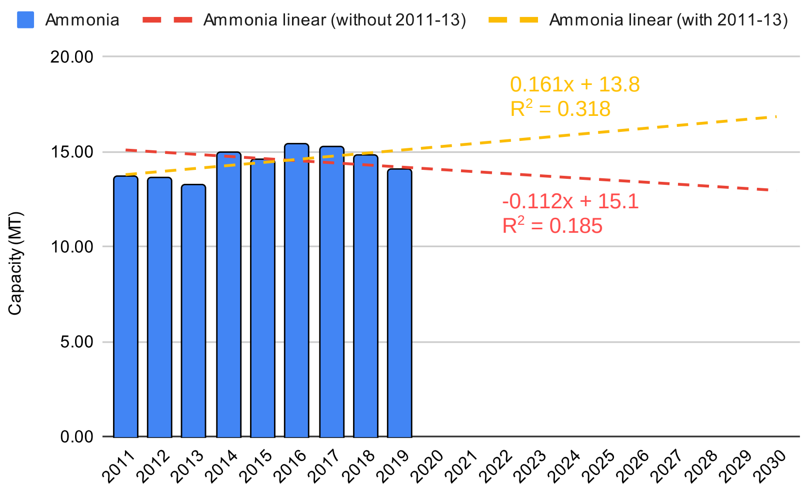

Figure 4.10 Forecast for capacity of ammonia in Europe with current values extracted from Eurostat

4.2.1.3 Bioethanol

At the start of the 21st century, biofuels started to emerge and gain popularity, namely biodiesel and bioethanol. The latter has seen continuous growth until 2010 where it stagnated but maintained its position. Until 2016, this market was affected by high import duties, adjustments to national blending mandates and a decline in its demand. It was also closely followed by numerous closures of plants with limited capacity, but this did not affect its market [15].

This market has currently changed after the new policies that were applied by the EU which promote the use of biofuels. This made the market regain a bit of its growth although not at the same accelerated rate seen before. Figure 4.11 and Figure 4.12 represent the forecasts for bioethanol.

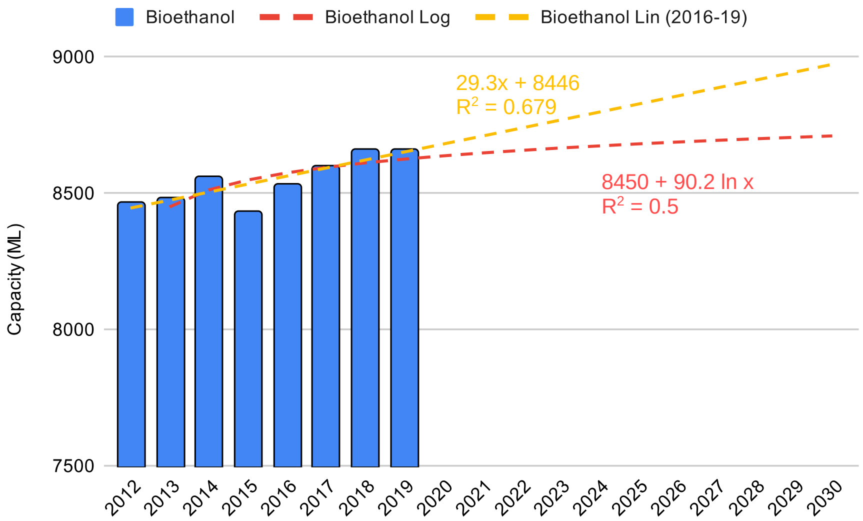

Figure 4.11 Forecast for capacity of bioethanol in Europe with current values extracted from [15]

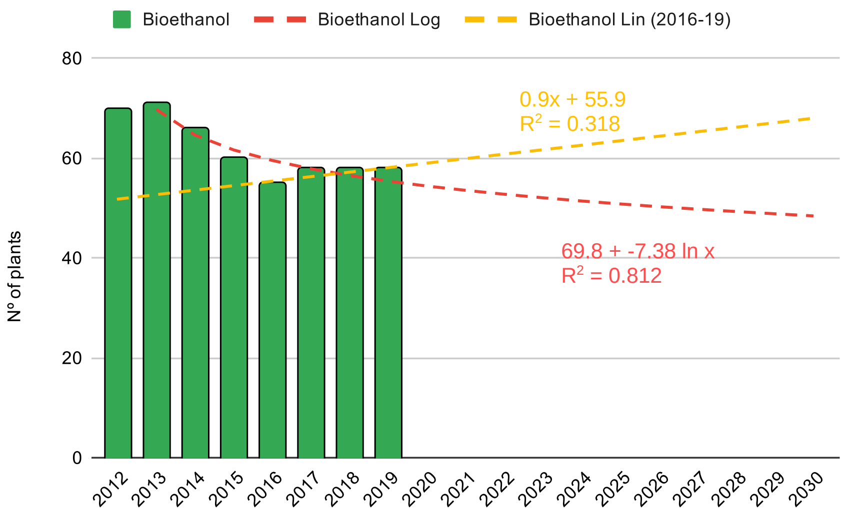

Figure 4.12 Forecast for number of plants of bioethanol in Europe with current values extracted from [15]

The trend lines for this product try to reflect both the stagnation seen in the first years as well as the new growth from 2016 onwards. Despite this growth the feedstock prices are currently very high which do not allow for very high margins, thus providing a limiting factor. This, coupled with the new rules for land-use applied by European governments, might make this market stagnate, following a pattern similar to the one shown in the red logarithmic line. Although there are some limiting factors, the current growth cannot be ignored especially considering the policies and incentives that were put in place for the use of biofuels. For that matter the yellow line predicts a more positive scenario in which the capacity will still grow at the same rate that it has for these last years.

4.2.1.4 Biodiesel

Similar to bioethanol, biodiesel saw an enormous rise in its production in the beginning of the century, at one point constituting around 75% of the total biofuel market [15]. It saw a rapid expansion in the EU, this region being one of the largest producers, due to the numerous tax incentives and policies that made this product a viable option.

Nowadays this product has lost some of its initial appeal, due to the use of agricultural crops that could be utilized to produce food and the regulations against diesel in general. These factors made the demand for biodiesel go down as can be seen in the graph. Some factors that also had some effect in this downward trend was the competition provided from cheap sources of this product, namely from Argentina and Indonesia, as well as the competition from renewable biodiesel which has more support from government policies than its counterpart [15].

There was a capacity growth in 2018 due to a plant expansion located in Italy, but for the most part many biodiesel plants are being operated at low levels or being shut down, which might indicate the most likely trends to happen in the near future [15]. Figure 4.13 and Figure 4.14 represent the forecasts for the capacity and number of plants of biodiesel in Europe.

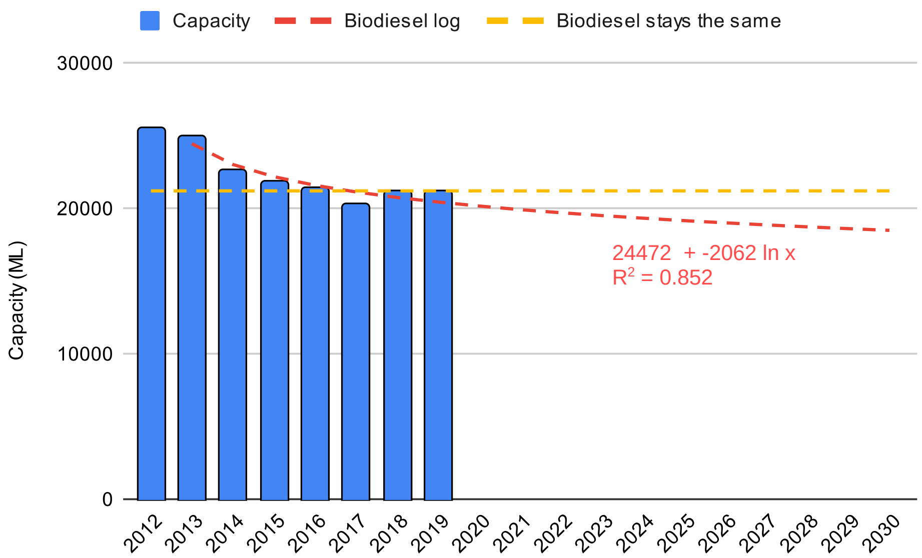

Figure 4.13 Forecast for capacity of biodiesel in Europe with current values extracted from [15]

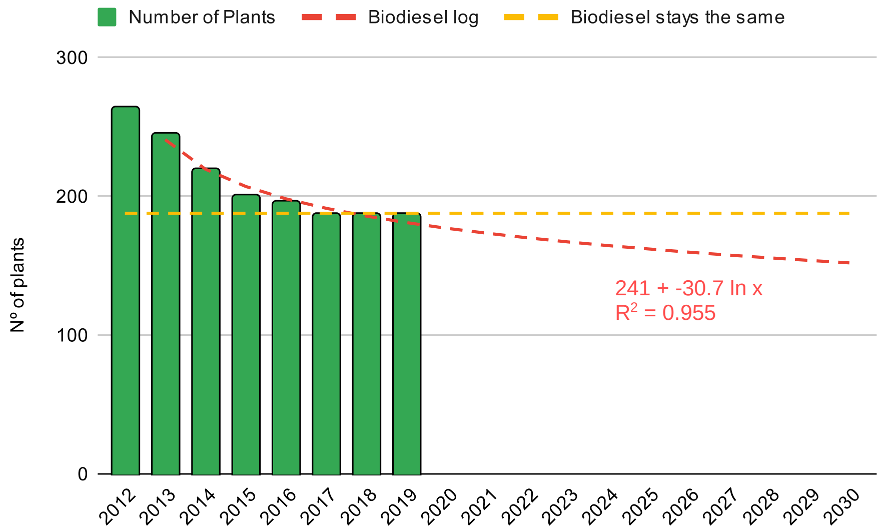

Figure 4.14 Forecast for number of plants of biodiesel in Europe with current values extracted from [15]

Although the production of biodiesel has some backlash and is being less supported by government policies in favor of more reliable sources of renewable energy, this product still constitutes a very good alternative to fossil-based fuels. Due to the effects that the war on Ukraine is causing on the oil & gas market, many different sources are being utilized, this being one of them. For that reason, the two drafted trend lines show the stabilization of the capacity of this product. The yellow line predicts that the capacity will remain the same throughout the next few years as per the years 2017 to 2019. Whereas the red line represents the continued downward trend seen throughout the years where it will eventually stabilize, having a lower overall capacity in the future.

4.2.1.5 Biogas

The number of plants and consequently the total capacity of biogas has been rising throughout the years at a steady pace indicating the robust nature of this market. This growth was especially prevalent in Germany, which is heavily investing in this sector, but more recently France has entered the race [99].

It is worth noting that, although there are numerous plants for biogas production, these are mainly for self-consumption and thus have very limited production [17]. Figure 4.15 and Figure 4.16 showcase the forecasts of biogas.

In order to forecast the future growth of this market, the two trend lines drafted depict a scenario where there will be a constant growth closely related to the one seen from the year 2012 and onwards or a scenario in which the number of plants will stabilize in the near future, represented by the yellow and red lines, respectively. This last scenario is the most likely to happen since biogas plants can be upgraded to produce biomethane, a product superior to biogas since it has a higher calorific value and is more similar to natural gas. This coupled with the growth of biomethane which will be described ahead, makes the red trend line a likely forecast.

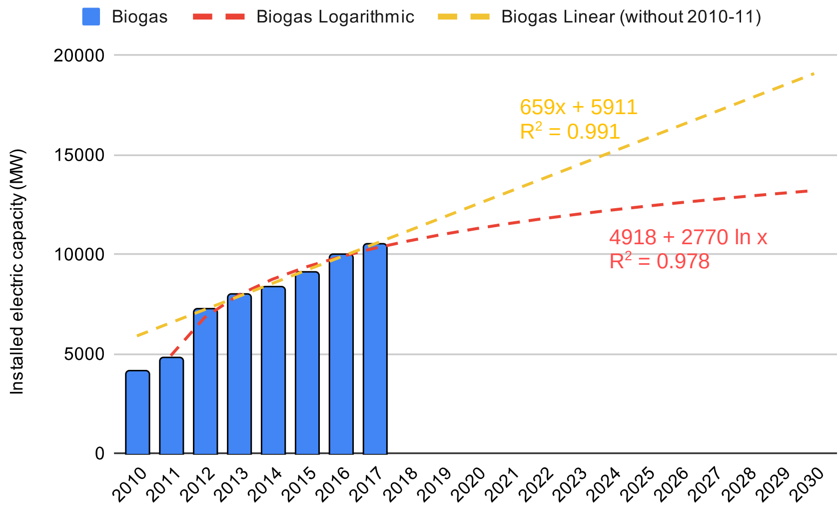

Figure 4.15 Forecast for capacity of biogas in Europe with current values extracted from [99]

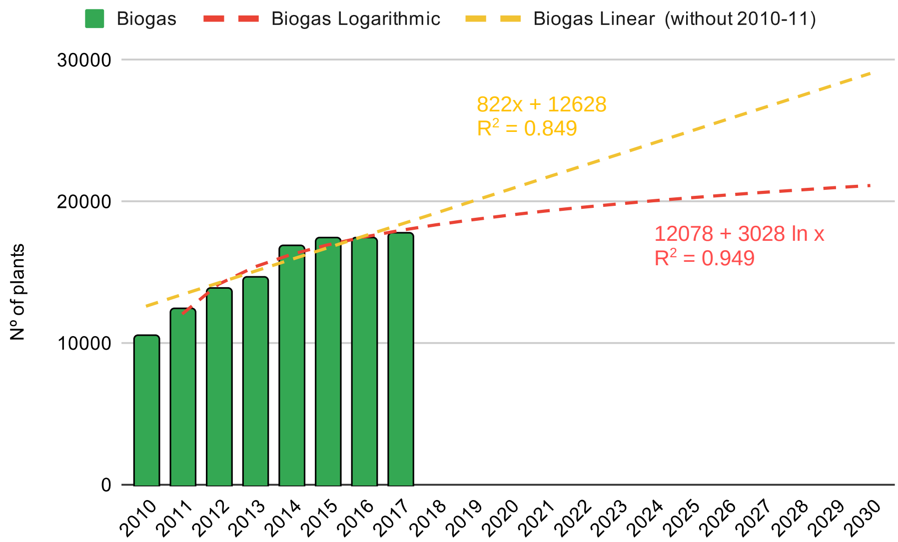

Figure 4.16 Forecast for number of plants of biogas in Europe with current values extracted from [99]

4.2.1.6 Biomethane

Biomethane has been a product of very high interest for many countries in Europe. Due to its potential of decarbonizing this sector and spurred by many policies that were applied both at a European and country level, it has seen continuous growth in its production and a ramping up in the number of opened plants [17]. Germany once again is the main producer with France a close second [100]. The forecasts for biomethane are represented in the Figure 4.17 and Figure 4.18.

Both trend lines for biomethane predict positive outcomes in the future, the yellow depicting a future in which the future growth will slow down and follow a more linear pace, whereas the red line follows the current trend of continuous growth year upon year, through a polynomial function. Both scenarios are likely and will depend on the continuation of the investments that each country is applying.

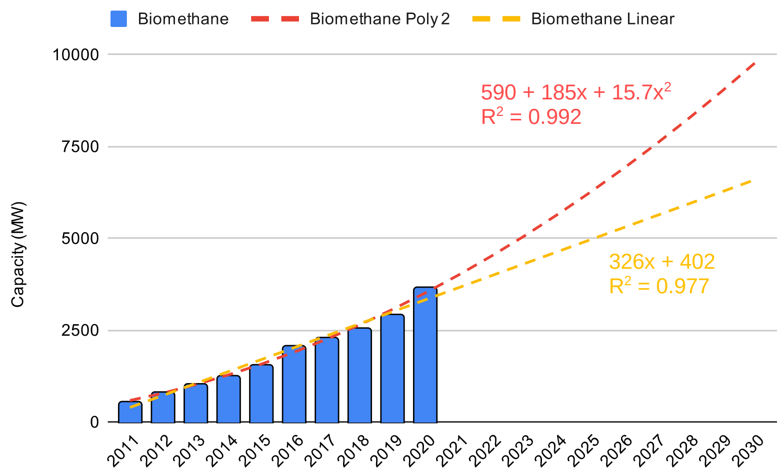

Figure 4.17 Forecast for capacity of biomethane in Europe with current values extracted from [100]

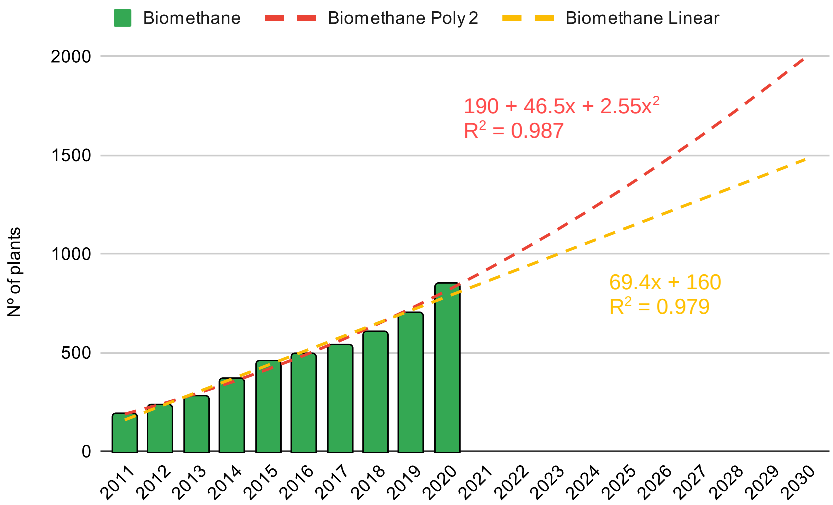

Figure 4.18 Forecast for number of plants of biomethane in Europe with current values extracted from [100]

4.2.1.7 Hydrogen

As it was previously mentioned, the alternative processes for the production of hydrogen are very recent and are only now being developed at a larger scale [21]. This means that the historical data for these products are very limited and thus it is unreliable to base the trend lines on. Additionally, due to the ambitious nature of the European policies and goals, the expected trend lines would not reflect the reality. For these reasons the forecasts seen in Figure 4.19 were based on the predicted values obtained via credible sources [101].

As it can be seen, grey hydrogen represents the majority of hydrogen that is currently produced, with green and blue hydrogen representing around 5% of the total production in Europe [101]. Out of 457 hydrogen sites 416 produce grey hydrogen, 39 green hydrogen and 2 blue hydrogen [101]. That is expected to change with the current goals and policies that are being applied.

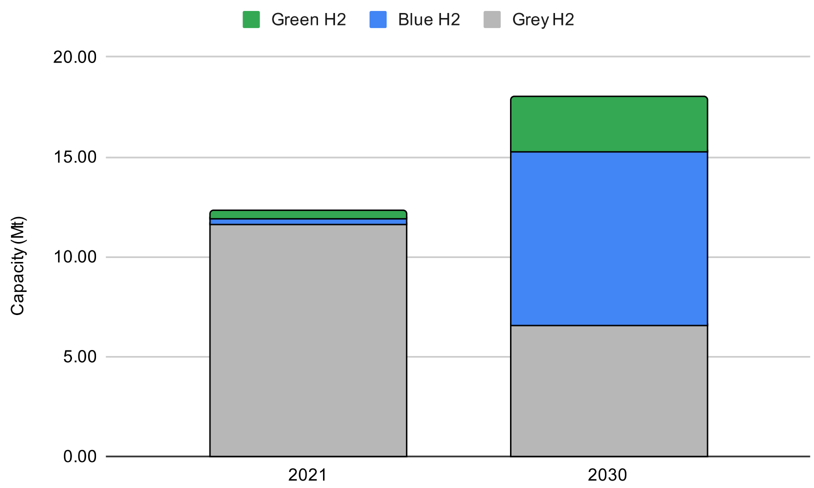

Figure 4.19 Forecast for capacity of hydrogen by technology in Europe with current and future values extracted from [101]

Although Europe has set the goal to reach a capacity of 40GW of hydrogen in 2030, it is very unlikely that it will be achieved. That value would mean that Europe would produce around 10Mt of green hydrogen in the time frame of 9 year. With the current evolution of this market and the price of hydrogen still being uncompetitive compared to fossil fuels, this goal was not used for the forecasts. Therefore, green hydrogen was predicted to have a future capacity of 9.1GW or around 2.5Mt based on the plants that are planned to open before 2030 [101].

Blue hydrogen has 12 announced projects expected to open before 2030, with the majority of them being located in the UK and Netherlands and only one in the scope of the project. Some of these projects plan on opening a brand-new plant while others are expected to retrofit the CCUS technology in the existing SMR plants which result in the decrease seen in grey hydrogen [101].

It is worth noting that, although blue hydrogen represents the most promising alternative for the near future as per the graph, this technology is seen as worse than its green counterpart and will serve as a placeholder for the eventual development of the more mainstream green hydrogen.

4.2.2 Cylinder consumption

After reviewing the market for all the processes that affect the oil & gas industry, it was necessary to evaluate the impact that each has on Air Liquide.

As it was said before, the R&A market is more affected by the changes in the number of plants. Each of these facilities have analyzers depending on the type of process that it uses, some being more complex and thus requiring more analysis and consequently more gases.

Due to the complexity of petroleum and petrochemical products, there is a very high need for analysis in each of the steps of the production process. Thus, as it was expected, the refinery and petrochemical processes will have a higher number of analyzers and consequently a higher consumption of gas. In order to benefit economically, meet the standards applied in the composition of certain products and stay in line with the environmental restrictions applied, these processes need to have numerous measuring points where it is possible to analyze the product [102]. These analyses mainly consist of measuring the composition of various streams, monitor the emission levels which are numerous and inevitable in this type of process, have gas detection systems in order to mitigate risks and finally have a regular quality control for components such as sulphur contents and octane levels [103].

The production of grey hydrogen also has some complexity to it, and due to its consumption of hydrocarbons and need of high temperatures, this process requires some gas analyzers, namely process gas chromatographs and continuous gas analyzers [104]. The main types of measurement consist of controlling the carbon/steam ratio for a better conversion, evaluating the calorific value of the product, monitoring the flue gases released and finally measuring the purity of the product in its later stage [105].

Blue hydrogen has a similar need for gas analyzers as to the grey type, since its production is based on the same process with the addition of utilizing CCUS technology. This additional process does not require the use of a gas chromatography analyzer, due to the main components being analyzed in this process being O_2 CO and CO_2 and some potential impurities. Ultimately this process only requires the use of Infrared analyzers, having a much lower consumption of gas, for flue gas analysis and composition analysis in the mid stages of the process [106].

On the other hand, hydrogen obtained via the green alternative does not have as many issues in its production phase regarding emissions, since it is a process that only releases oxygen and heat. Hence, it is only necessary for a green H_2 plant to have an analyzer to monitor the hydrogen blend rate when injected into the gas grid or to monitor the final composition of the product to evaluate its purity and calorific value [107].

Similarly to this last product, the main analysis that biofuels need is to verify the gas composition and quality parameters before being sent to the gas network. These generally contain traces of other components such as ammonia, siloxanes and halogenated hydrocarbons that act as impurities that need to be monitored due to their potential to provoke toxic gas leaks or corrosion [108]. Biodiesel and bioethanol need some more analysis due to their higher complexity of product and production but otherwise they act similar to the other biofuels [109].

With this information in mind the methodology presented in chapter 3.1.2 was applied. This section was needed to provide the bridge between each market in the oil & gas industry and the gas market in the R&A market. For that reason, a series of assumptions for the average number of gas chromatography analyzers per process was made. These were based on what was recommended by renowned OEMs, with some values being altered in order to better reflect reality. Following the methodology, it is possible to obtain an average number of cylinders consumed per unit and year. Table 4.1 summarizes the assumed and obtained values.

Table 4.1 Average number of GC analyzers per unit and average number of cylinders consumed per unit and year

	Average Nº of GC analysers / unit	Average nº of cylinders consumed / unit.year
Refineries	20	900
Petrochemical	25	1125
Bioethanol	1	45
Biodiesel	1	45
Biogas	0.1	4.50
Biomethane	0.7	32
Grey H2	7	315
Blue H2	7.5	338
Green H2	0.5	23
CCUS	0.5	23

With the consumption of cylinders per unit it is possible to calculate the total consumption of gases in each process and the values in the future depending on the opening and closure of plants.

4.2.3 Scenarios

To predict the future outcome of this market four scenarios were drafted according to the methodology presented in chapter 3.1.3. In these scenarios, the most positive and negative outcomes were created as well as some that are more likely to showcase the reality. This was done due to the high number of variables that could be changed between scenarios. Through this method, the scenarios give an interval of values in which the forecast can end up in the future according to the trend lines applied to each process.

With that being said, the first scenario is the most optimistic one and it uses the trendlines that predict the highest number of cylinder consumption possible while maintaining the average capacity of each process constant to what is seen nowadays. The trend lines utilized were the following:

- Refinery logarithmic function;
- Biogas linear function;
- Biomethane polynomial 2 function;
- Methanol linear (with 2019) function;
- Ammonia linear (with 2011-13) function;
- HVC linear (top values) function;
- Bioethanol linear (2016-19) function;
- Biodiesel stays the same;

The second scenario is the pessimistic one and therefore it is the opposite of the one shown before. In this scenario, the forecasts chosen were the ones that foresaw the least number of cylinders consumed in 2030 while the average capacity remained constant throughout the years. The trend lines chosen for this scenario were:

- Refinery linear function;
- Biogas logarithmic function;
- Biomethane linear function;
- Methanol linear (without 2019) function;
- Ammonia linear (without 2011-13) function;
- HVC linear (bottom values) function;
- Bioethanol logarithmic function;
- Biodiesel logarithmic function;

As it was said before, the two remaining scenarios represent forecasts that are more closely related to what might happen, since they take into account the variations in the average capacity.

Newer technologies are affected by this factor since, although they are expanding their capacity rapidly, throughout the years the technology will scale up and it will be possible to construct plants with higher capacities. This is the case for biomethane plants, since currently the bigger plants have a capacity of around 1MW and the prediction in 2030 is that some will reach 1GW. This will lower the need of having more plants which has a negative impact on the gas consumption but due to the capacity increase the consumption is likely to remain the same.

As for the more mature technologies, such as refineries, although the trend predicts that they are slowly shutting down, the ones that are more likely to do so are the plants which have a smaller capacity, so the capacity might go down slower than the number of plants.

Besides this key difference, the third and fourth scenarios will follow the trendlines stipulated in the first and second scenarios, respectively, with the added assumption that the petrochemistry industry will maintain the same number of plants.

With each scenario defined the predicted European cylinder consumption and gas market turnover can be seen in Figure 4.20. In appendix C a more detailed look at the values utilized for each scenario is present.

As it was said before, this market was firstly studied for Europe in order to understand the proper evolution of the market and to aid in the forecasts. The final step will then be converting the obtained results into the scope of the study. This was done by multiplying the consumption of cylinders of each process with the percentage of production by region in Europe which can be seen in the table present in appendix A.

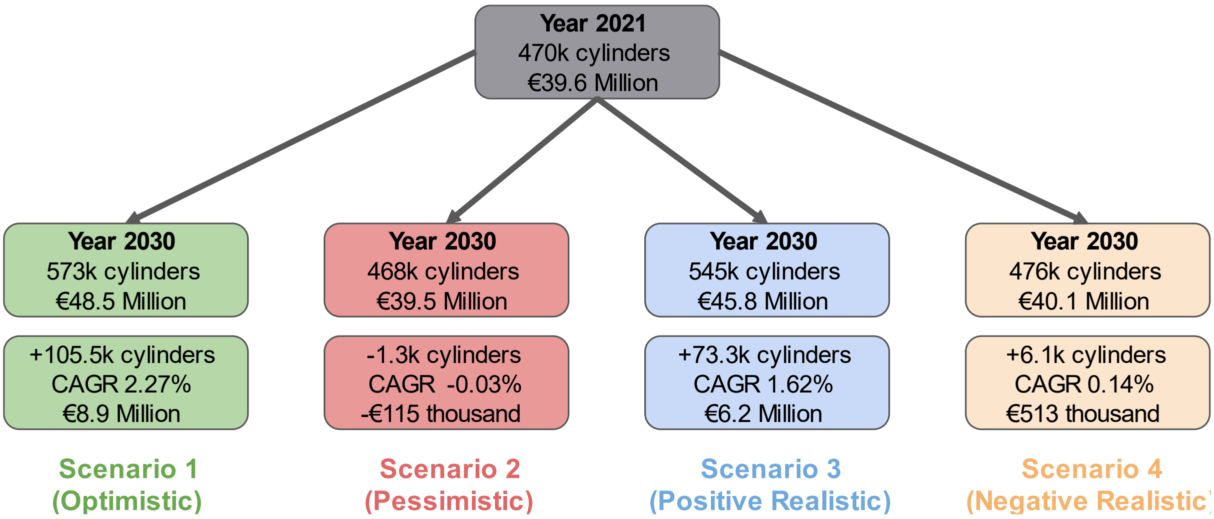

Figure 4.20 European Gas market turnover

The results of the gas market turnover for the SWE cluster can be seen in Figure 4.21. At the top of the figure the estimated total current cylinder consumption as well as the gas market turnover can be seen. Below, the estimated values in 2030 for each scenario is showcased as well as the difference in value and number of cylinders.

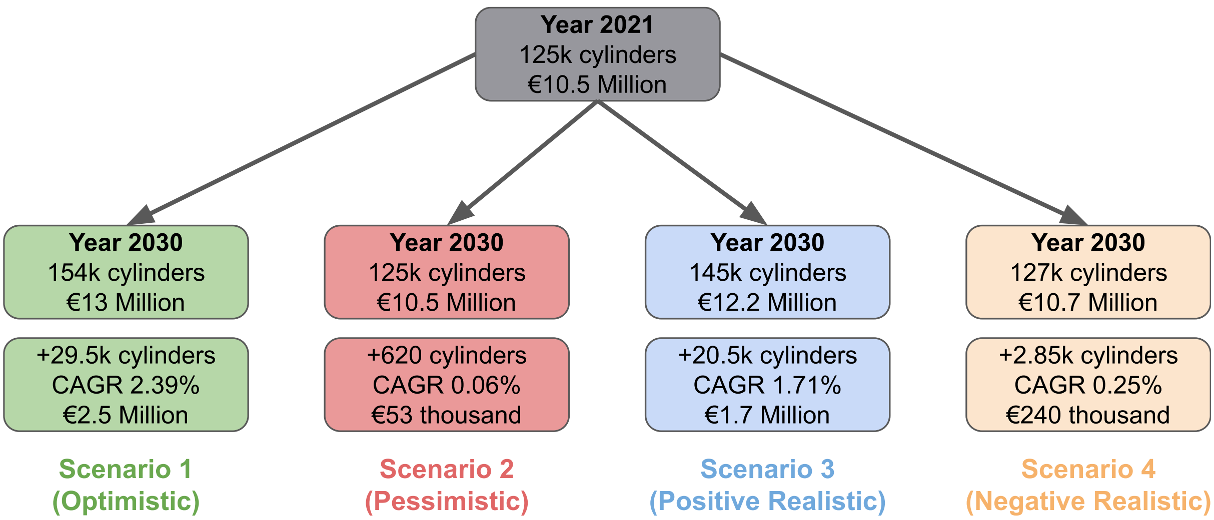

Figure 4.21 SWE Gas market turnover

As it can be seen, the gas market in this region is expected to grow in the best-case scenario with a CAGR of 2.39% and in the worst-case scenario by 0.06%. This represents a steady but very slow growth in the space of 9 years. This also represents the whole market for the scope of the study, which means that this value is shared between Air Liquide and its competitors, making the real available growth in the market that much smaller.

Nevertheless, even in the pessimistic scenario the market is expected to grow which means that there is some market that can be exploited in the future. The realistic scenarios do not differ much from the exaggerated results, which validate the results.

The values in the SWE cluster are heavily influenced by France which is predicted to have the biggest growth out of the region (Appendix B). The four scenarios predict it to grow while in the other countries the negative scenarios foresee a decline. This is to be expected since France is investing heavily on the markets that are predicted to have the largest growth, biomethane and hydrogen.

With these results it is possible to conclude that the optimal route to capture more market in the oil & gas industry is to compete with the competition for the current clients available. Although the gas usage is smaller in the greener processes, trying to capture clients in this expanding market is also recommended for the future of the company, especially in France.

4.3 Market Share

Market Share represents the percentage of sales that a company obtains from a specific market. In this chapter, Air Liquide's market share in the Oil & Gas industry will be determined.

This calculation will be based on the equation (4.2), where the dividends are the values of sales previously discussed in chapter 4.1.1 and the divisors are based on the values obtained from the previous chapter, which were assumed to represent the whole gas market revenue for the oil & gas industry. The results for the market share can be seen in Table 4.2.

$$\text{Market Share (\%)} = \frac{\text{AL Oil \& Gas Sales (2021)}}{\text{Gas Market Revenue (2021)}} \times 100 \tag{4.2}$$

Table 4.2 Market Share by country

	Market Share
PT	68.1%
ES	35.9%
FR	81.1%
IT	22.8%
SWE	52.0%

The calculated values should be as close to what experts anticipate of them in order to validate the results. These values can differ from market to market, but they usually do not deviate much.

Following that notion, Air Liquide's market in Italy is expected to be low due to the existence of a strong competitor, SIAD. Therefore, the expected value goes in line with what was obtained.

Spain on the other hand is a market that is divided through many players, but none have a majority of the market share. Once again, the obtained market share represents values that are expected.

The Portuguese market is similar to the one mentioned before, but Air Liquide should have a majority in the market share. Even though this is the case, 68.1% of the market is a higher value than what is expected.

France is a market that is expected to be dominated by Air Liquide and thus the market share should be high. Similarly to the Portuguese market, the value obtained is higher than what it should be.

Since the market share is calculated based on monetary values there is always the risk of having the results be either too inflated or too low. The assumed value of each cylinder was 84.26€, but since this is an average price, the final values might be affected. That being the case, the Portuguese and French market shares being so high can be explained due to the normal price of cylinders usually being higher and thus lowering the market shares. Assuming a value of 100€ per cylinder for both regions, it is possible to obtain values that align better with what is expected of them, 57.4% and 68.4 % for Portugal and France, respectively.

4.4 Stakeholders and penetration rate

The following chapter will focus on the identification of possible stakeholders in the oil & gas market with the goal of calculating Air Liquide's penetration rate in each country.

In order to name the relevant stakeholders for this study the methodologies described in chapter 3.2 were utilized.

The identification step has a high relevance to this study since it can verify the company's current knowledge of the market and, if need be, pinpoint the existence of previously unknown companies that should be further investigated.

Besides this notion, the stakeholder analysis offers a database for which other analysis can be based upon. One such tool is the penetration rate which will be used for the validation of the methods previously utilized. Equation (4.3) was used for this calculation.

$$\text{Penetration Rate (\%)} = \frac{\text{Number of AL clients}}{\text{Number of companies related to petrochemistry}} \times 100 \qquad (4.3)$$

The following figures represent Air Liquide's penetration rate for each country as well as the percentage of known and unknown companies that do not have Air Liquide as their primary supplier. For confidentiality reasons, the competitor's name was substituted with "competitor X", where X=1,2,3,

By analyzing Figure 4.22, it is possible to see that out of a sample of 101 French companies, Air Liquide revealed to have a penetration rate of over half, with 51.5%. This is a high value, but it is to be expected due to the presence of Air Liquide in this region.

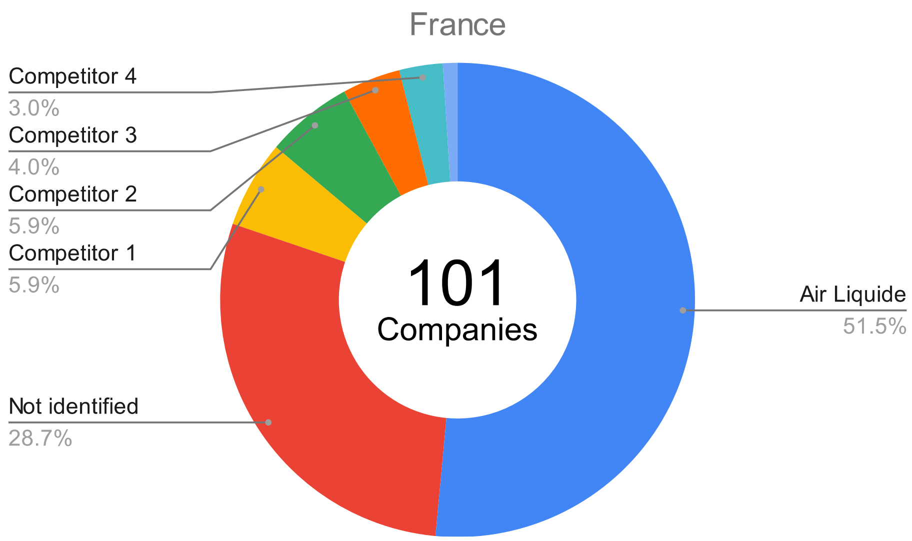

Figure 4.22 Air Liquide penetration rate France

The Spanish market reveals, through the analysis of Figure 4.23, a lower penetration rate for Air Liquide of 43.2% even though the sample size is smaller. However, this is more affected by the high number of unidentified clients rather than the competition having more clients.

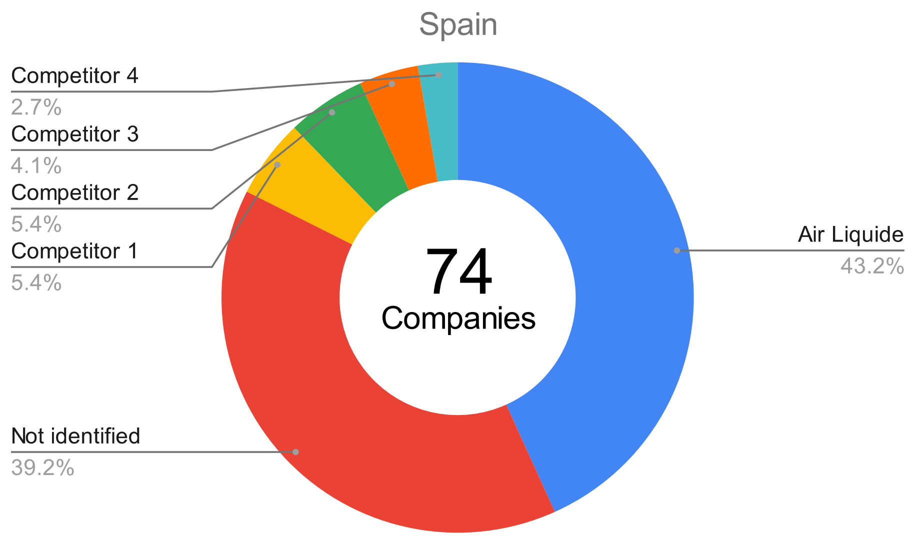

Figure 4.23 Air Liquide penetration rate Spain

For Portugal, Air Liquide has a penetration rate of 54.3%. This value is to be expected, because of the small size of the country and the lack of competitors in this market. Additionally, the company has a good presence in Portugal. Figure 4.24 showcases the results obtained for the country.

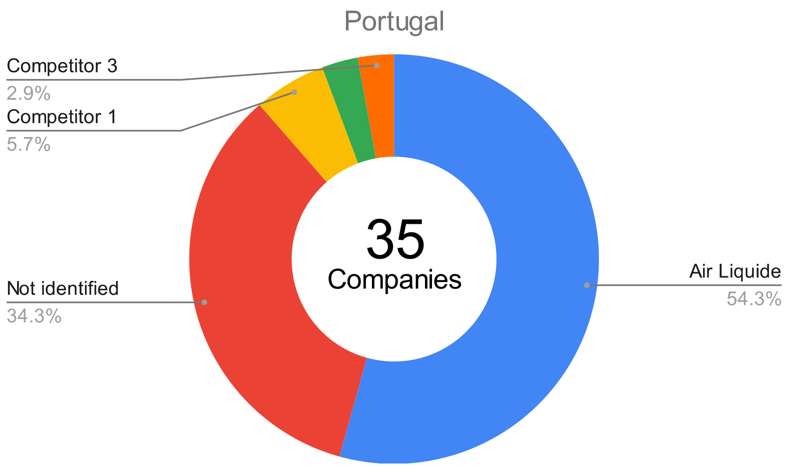

Figure 4.24 Air Liquide penetration rate Portugal

Finally in Italy (Figure 4.25), Air Liquide has a penetration rate of 42.2% which is the lowest out of the 4 countries. Although lower, this reflects the reality since Air Liquide has a smaller presence in the country. This region when compared to the others reveals a higher number of competitors. This is justified by most companies being sourced from Accredia, which is a database for accredited companies. This made the number of accredited companies higher affecting the number of unknown companies since it is much more likely to know the supplier if the company in question is accredited.

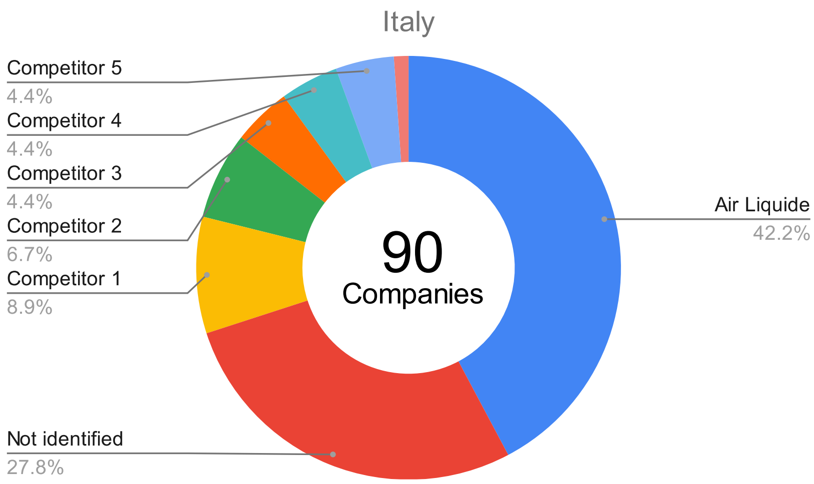

Figure 4.25 Air Liquide penetration rate Italy

These values are affected by the total number of companies identified and the source from which it was obtained. A small country such as Portugal is bound to have a lower sample size compared to the others which might have an effect on the values.

After analyzing each of the figures, it can be seen that they share many similarities. Although the penetration rate is higher in France and Portugal and lower in Spain and Italy, as expected, the values are rather close, varying between 40 to 55%. These values should reflect the values obtained in the market share, so if the company has a high share in a region the penetration rate should also be high. The difference being that one was calculated by monetary means and the other by number of companies.

Another common trend is the unusual high value of unidentified companies. This is due to Air Liquide having a great knowledge of its own market but a lack of knowledge of the outside market which can be seen as a weakness that could be addressed.

4.4.1 Original Equipment Manufacturers (OEM)

The OEMs were separated from the other stakeholders due to their broad scope of solutions offered to various markets and regions. This makes it more difficult to pinpoint the country of operation and if the product is used for the oil & gas industry or another market.

That being said, the main companies that produce the equipment for the scope of this study, these being gas chromatography analyzers and infra-red analyzers were analyzed. Figure 4.26 represents the number of OEM clients that Air Liquide has in the SWE cluster.

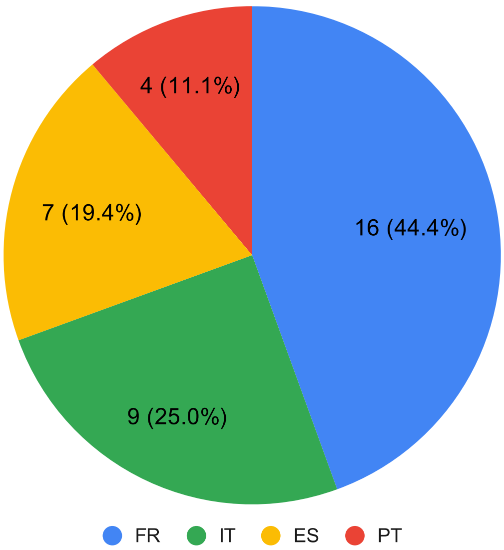

Figure 4.26 number of OEM clients in SWE

There are a total of 42 of OEMs present in this region. Out of those only 20 are Air Liquide clients. Portugal has a very low number of clients not only due to its size but also since BHB acts as an OEM representative for many companies in the region. France as expected has the majority of the clients. It is worth mentioning that most of the clients are well known manufacturing companies, these being present in the majority of regions. Whereas the non-clients are lesser-known companies that might have lower impact on the industry.

4.5 Competition

In an effort to better understand the current state of the market, it is necessary to evaluate how the competition is operating as a means to analyze if Air Liquide's strategy is going in the right direction or if there needs to be some alteration. In that respect, the production of accredited mixtures and their offer was analyzed.

Accredited mixtures offer a higher level of confidence to the client when choosing what gas mixture to buy. They provide a guarantee in quality to calibration mixtures since the product has already been put through an accredited testing, consequently eliminating the need for supplier auditing and having the uncertainty levels already incorporated into the mixtures.

Air Liquide and the majority of the competitors have the ISO/IEC 17025 certification. This is a procedure given by an authoritative body which defines whether or not a laboratory is recognized as competente to perform calibrations, sampling or testing. Nowadays, it is one of the most important standards for the measurement of products and is mandatory to have in all accreditation agencies and national standards bodies. Although mixtures do not need to have this accreditation in order to be sold, the need for this requisite is rising and many laboratories only buy gas mixtures if they are accredited.

For that matter, the companies with production of accredited mixtures in each country were evaluated and compared, to have a better understanding of how Air Liquide is performing against the competition.

The mixtures produced by each company were extracted, grouped and summarized in the Table 4.3 in order to make the comparisons easier. The detailed ranges and uncertainties that each company has can be found on Annex 1.

This comparison was made through the study of three components: concentration range, uncertainty and variety of molecules offered. In each category a symbol was attributed, these being used as a comparison between companies inside each country. As a general guide they should be seen as:

- ++ Great
- + Good
- - Poor
- – Very Poor

The molecules present in these mixtures can reach concentrations as low as 500ppb or as high as 99.99%, effectively being pure. Although the range of concentration being larger is usually a positive aspect, if there is no market for a specific range then it is not worth producing. Nevertheless, higher concentration ranges were seen as positives rather than negatives. Uncertainty is seen as a positive the lower it is, since the values of concentrations obtained in a mixture have a higher confidence. Finally, the variety of molecules acts similar to the concentration range, since it is normally helpful if there is a high variety, but it depends on the need of each market.

When needed there was also a distinction between binary mixtures (inert gas + another gas) and multi mixture (inert gas + 2 or more other gases).

France has the lowest number of companies that produce accredited mixtures. This is due to AL having a superiority in this market, hence why very few companies choose to produce these gas mixtures in this region. Nevertheless, Messer, the only other company that offers accredited mixtures, shows similar capabilities in concentration ranges, uncertainty values and variety of molecules with AL having a slight advantage.

Table 4.3 Competition Analysis based on values from Cofrac, ENAC and Accredia

	Mix Type	Company	Concentration Range	Uncertainty	Variety of molecules	CO	CO_2	C_3H_8	NO	O_2	SO_2	CH_4	NO_2	N_2O	Others **
France	Binary & Multi	Air Liquide	+	+	+*	green	green	green	green	green	green	green	red	red	red
		Messer	-	-	-*	red	green	green	green	green	red	green	red	red	red
Iberia	Binary	Air Liquide	+	++	++	green	green	green	green	green	green	red	green	red	red
		Linde	+	-	+	green	green	green	green	green	green	green	red	red	red
		Air Products	-	--	--	red	red	red	red	red	green	red	red	green	red
		Nippon	++	+	++	green	green	green	green	green	green	green	green	red	red
	Multi	Air Liquide	+	++	++	green	green	green	green	green	green	green	green	red	red
		Linde	+	-	-*	green	green	green	red	green	red	red	red	red	red
		Air Products	++	--	++	green	green	green	green	green	green	green	green	red	red
		Nippon	+	+	-*	green	green	green	red	green	red	red	red	red	red
Italy	Binary & Multi	Air Liquide	-	-	-*	green	green	red	green	green	red	red	red	red	red
		Air Products	+	+	+	green	green	green	green	green	green	green	green	red	red
		SIAD	++	++	++	green	green	green	green	green	green	green	green	green	green

* Only the common mixture of CO, CO_2, O_2 and NO/C_3H_8 **Includes BTEX, H_2, He, H_2O, H_2S
The last columns are green if the factory produces the respective gas; Where ++ Great, + Good, - Poor, -- Very Poor

Iberia is revealed to be the region with the highest number of companies that produce accredited mixtures. In this case Air Liquide and Nippon dominate the market for binary mixtures with Nippon offering better ranges but Air Liquide having the lowest uncertainties. Linde offers some competition in this area while Air Products does not appear to have many offers, besides being the only one that provides N_2O. On the other hand, for multi mixtures Air Products offers the same variety of products as Air Liquide, with better concentration ranges but having high uncertainty ranges. Once again Air Liquide maintains a strong position in this market for both binary and multi mixtures. As for the other two companies, both only have the most common mixture composed of CO, CO_2, O_2 and NO/C_3H_8, having a drop off compared to Air Products.

Finally, in Italy there is a clear company that dominates the market, SIAD, having the largest concentration ranges and lowest uncertainties compared to the other two. It also offers the highest variety of molecules even when compared to what is produced in other countries. Air Products offers some competition in this market, with Air Liquide clearly showing a lack of offers in this region. SIAD shows a high development in these mixtures having invested in them for over 10 years but facing the downside of mainly producing for Italy and not exporting to the outside market.

Although this study is meant to compare the different accredited mixtures produced in each country this does not consider the fact that these mixtures can be exported to different regions and thus do not account for the presence of other companies in each region. Ultimately the existence of these mixtures depends on the necessity and availability of each company in the respective market.

As a whole, Air Liquide appears to be in a stable position, often stronger than the opposition when it comes to producing accredited mixtures except in Italy where SIAD dominates the market.

4.6 Risk Analysis

This chapter addresses the risks that come with the oil & gas industry. For that matter the tool chosen for this analysis is the strengths, weaknesses, opportunities and threats (SWOT) analysis

The goal of the SWOT analysis is to evaluate both internal and external factors that might have an effect on the company, and effectively provide some insights on how it should move forward. At the internal level this tool analyses the strengths and weaknesses of the company, that is, where the company has the advantage and should have a big focus and where the company is lacking and should invest in order to better answer client needs.

Whereas the external analysis evaluates possible changes that might alter the whole market, affecting both the company and the competition. Knowing this information is very important for the development of future strategies, for the company to stay ahead of the competition.

With that being said, Table 4.4 shows some key points that were addressed throughout this study.

Table 4.4 SWOT Analysis

Strengths	**Weaknesses**
• Presence in all the SWE markets • Competitive advantage in France • Big focus on green projects	• Lower market share in Italy compared to the competition • Less accreditation capabilities
Opportunities	**Threats**
• Big advances in green technologies (Bio-methane & H2) • New petrochemical plants opening	• Helium shortage might affect GC • Petrochemistry plants & refineries are slowly dropping • Less need for gas in analysis (better equipment and green technologies) • War extension affects all industries

5

Conclusion and future work

5.1 Conclusions

As a world leader in the industrial gas market, Air Liquide aims to remain a key player in this industry. For that reason, the development of market studies acts as a powerful tool to understand the current markets that affect the company and predict possible changes that might occur in order to always stay ahead of the competition.

The petrochemical industry has been subject to a multitude of factors that currently placed it in a transitional era. These stem from a stagnation in the market that has been felt throughout these last few years, coupled with the current environmental policies and goals that European governments placed as a means to promote more sustainable processes and for the decarbonization of the industry made the need for innovative and more efficient processes much more necessary.

With this in mind, the present study was used to evaluate new processes that are starting to emerge in this industry, more specifically their gas needs for analysis, assess how they will affect the whole gas industry and by extension how Air Liquide should best answer these changes. The scope for this project was the R&A plus the M&P02 and M&P03 specialty gases market in the SWE cluster.

The first analysis consisted of evaluating the current processes that are present in the market as well as new emerging processes. Current processes are consisted by the more mature technologies of production of petroleum products and petrochemicals, provided from refineries and traditional petrochemical processes like steam cracking and grey hydrogen through the steam methane reforming (SMR) technology as well as the production of biofuels such as biodiesel, bioethanol and biogas. Through the analysis of their technology readiness level (TRL), commercial readiness index (CRI) and likelihood of advancing in Europe it was possible to predict that the main emerging technologies are biomethane, green and blue hydrogen, CCUS and propane dehydrogenation.

Intending to better understand the main factors that affect the R&A market, the sales of the company were compared to external factors. This allowed to understand that the market in question is not directly affected by these factors but in turn the number of plants are what causes the largest impact. This information was the basis of this study.

The market forecasts were created based on the number of plants that each process currently has and is predicted to have. As is expected the traditional processes, namely refineries, traditional petrochemical processes and grey hydrogen are the ones that have a higher need for analysis and subsequently a larger consumption of gas due to their complexity, when compared to the emerging technologies. This coupled with the fact that these technologies are showing signs of losing market whereas the new technologies are showing a considerable growth made the results that more important to the company. After applying a method for the extrapolation of tendency lines and relating the fluctuations that each market has in the number of plants with the consumption of gas for each process, some scenarios were drafted in order to showcase the highest and lowest possible revenues in the whole SWE gas market. These predicted in the best-case scenario a growth of 2.5 million euros and in the worst-case scenario a lower growth of 53 thousand euros, with a compound annual growth rate of 2.39% and 0.06%, respectively. Considering that the scope spans until the year 2030, the growth of the market seems to be very marginal considering the fact that it spans 9 years and needs to be divided between the competition. Therefore, it was concluded that although it is very advisable for the company to attempt to capture clients from the emerging processes, this submarket has very little growth opportunities in the future.

The market share was calculated as a means to evaluate the position of the company in each region. This factor yielded the expected results with the company having a lower representation in Spain and Italy, 36% and 23% respectively, and a higher presence in France and Portugal, 68% and 57% respectively.

The elaboration of a database for the stakeholders offered a better understanding of the clients present in each region for the scope of the study and allowed for the application of another analysis complementary to the one before, the penetration rate. The obtained values showed similar values to the ones before, where again Italy and Spain showed the lowest values and Portugal and France the highest, 42%, 43%, 54% and 51%, respectively. These values permitted to validate the market share results. Additionally, this analysis showed that the company has a very good knowledge of its own clients, but it lacks when it comes to non-clients, which makes the process of understanding whose clients the competition has and the reason as to why they have the advantage more difficult.

Finally, the competition was analyzed through their production of accredited mixtures in each region and the results once again showcased the good position that the company has in France, being the company that produces the highest quality mixtures and a lower position in Italy, lacking in this department when compared to the competition.

5.2 Future work

After the conclusions of this study, some notions and ideas that might be of interest to follow up on were gathered, either as a recommendation for Air Liquide in areas that it lacks and can improve upon or some insights on the continuation of this study to validate or alter the results, namely the forecasts if need be. These can be seen below:

- Follow up on new environmental regulations or updates to existing ones for monitoring of emissions and future decarbonization goals.
- Follow up on new processes that might appear, or the development of the ones mentioned on this study.
- Follow up on the application of governmental incentives for biogas and biomethane, namely in Iberia.
- Attempt to capture new clients on the emerging markets of biomethane and green and blue hydrogen.
- Develop the production of accredited mixtures in Italy to have a better answer against the competition.
- Attempt to capture existing clients of the competition in the Italian market.
- Increase the knowledge of the suppliers of existing companies related to the scope.

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A

Percentage of production of each process by region in Europe

This appendix contains Table A.1 where the percentage of production of each process that was utilized in the calculations of the gas market turnover is showcased. This was based on known data or, in other cases, the percentage would be calculated based on the total production and number of plants that each country has in Europe. The percentage of the SWE region is the sum of each country's percentage.

Table A.1 Percentage of production of each process in Europe per region

	PT%	ES%	IT%	FR%	SWE %
Biogas	0.5%	1.0%	9.3%	4.2%	15.0%
Biomethane	0.0%	0.4%	3.2%	39.6%	43.2%
Refineries	2.0%	12.0%	14.0%	9.3%	37.3%
Petrochemical	1.5%	10.1%	4.5%	13.0%	29.0%
Bioethanol	0.0%	6.0%	0.0%	11.5%	17.6%
Biodiesel	1.9%	11.0%	4.1%	8.4%	25.5%
Grey H2	2.0%	7.0%	7.0%	6.0%	22.0%
Blue H2	2.0%	7.0%	7.0%	6.0%	22.0%
Green H2	1.0%	4.0%	4.0%	12.9%	21.8%
CCUS	0.0%	1.8%	3.6%	5.5%	10.9%

B

NUMBER OF CYLINDERS AND GAS MARKET REVENUE FOR EACH REGION

Tables B.1-B.6 are present in this appendix. These contain the specific values of future number of cylinders and value, as well as the differences and CAGR for each country and region. This is used to offer more insight on the obtained results and evaluate the countries that shows more promise in this market.

Table B.1 Number of cylinders and gas market turnover for Europe

Europe	Nº of Cylinders	Difference	CAGR	Value	Value difference
Base Year	470080	-		€39,610,254	-
Scenario 1	575535	105455	2.27%	€48,496,144	€8,885,890
Scenario 2	468727	-1354	-0.03%	€39,496,201	-€114,053
Scenario 3	543445	73365	1.62%	€45,792,168	€6,181,913
Scenario 4	476168	6087	0.14%	€40,123,182	€512,928

Table B.2 Number of cylinders and gas market turnover for Southwest Europe

SWE	Nº of Cylinders	Difference	CAGR	Value	Value difference
Base Year	124473	-		€10,488,434	-
Scenario 1	153939	29466	2.39%	€12,971,308	€2,482,874
Scenario 2	125105	632	0.06%	€10,541,708	€53,274
Scenario 3	145025	20552	1.71%	€12,220,229	€1,731,795
Scenario 4	127324	2851	0.25%	€10,728,678	€240,244

Table B.3 Number of cylinders and gas market turnover for Portugal

PT	Nº of Cylinders	Difference	CAGR	Value	Value difference
Base Year	6599	-	-	€556,031	-
Scenario 1	6974	376	0.62%	€587,687	€31,655
Scenario 2	6112	-487	-0.85%	€515,012	-€41,019
Scenario 3	6739	140	0.23%	€567,849	€11,818
Scenario 4	6275	-324	-0.56%	€528,758	-€27,273

Table B.4 Number of cylinders and gas market turnover for Spain

ES	Nº of Cylinders	Difference	CAGR	Value	Value difference
Base Year	34006	-	-	€2,865,453	-
Scenario 1	35676	1669	0.53%	€3,006,116	€140,663
Scenario 2	30986	-3020	-1.03%	€2,610,948	-€254,506
Scenario 3	34360	354	0.12%	€2,895,307	€29,853
Scenario 4	32177	-1829	-0.61%	€2,711,352	-€154,101

Table B.5 Number of cylinders and gas market turnover for France

FR	Nº of Cylinders	Difference	CAGR	Value	Value difference
Base Year	49635	-	-	€4,182,419	-
Scenario 1	70729	21093	4.01%	€5,959,804	€1,777,385
Scenario 2	54890	5254	1.12%	€4,625,155	€442,735
Scenario 3	65202	15567	3.08%	€5,494,112	€1,311,693
Scenario 4	55832	6196	1.32%	€4,704,550	€522,131

Table B.6 Number of cylinders and gas market turnover for Italy

IT	Nº of Cylinders	Difference	CAGR	Value	Value difference
Base Year	34226	-	-	€2,883,982	-
Scenario 1	40550	6324	1.90%	€3,416,853	€532,871
Scenario 2	33111	-1115	-0.37%	€2,790,007	-€93,974
Scenario 3	38714	4488	1.38%	€3,262,183	€378,202
Scenario 4	33033	-1193	-0.39%	€2,783,452	-€100,529

C

EXTENDED RESULTS FOR THE FORECAST OF NUMBER OF PLANTS

This appendix showcases the extended results for the forecast of number of plants through Table C.1. It was utilized for the better understanding of the values obtained in the figures of the forecasts. This table also aids in the understanding of the calculations of the gas market turnover.

Table C.1 Extended results of forecast of number of plants and capacity

	Capacity		Nº plants		
	2021	2030	2021	2030	2030 (varying avr cap)
Refineries (Mt) log	667	650	75	73	74
Refineries (Mt) linear	667	561	75	63	60
HVC linear (MT) (top values)	46	47	88	90	88
HVC linear (MT) (bottom values)	46	41	88	78	88
Methanol lin (MT) (with 2019)	2	3	5	8	5
Methanol lin (MT) (without 2019)	2	2	5	5	5
Ammonia linear (MT) (without 2011-13)	15	13	48	42	48
Ammonia linear (MT) (with 2011-13)	15	17	48	55	48
Petrochemistry (MT) +	63	67	141	152	141
Petrochemistry (MT) -	63	57	141	126	141
Bioethanol lin (ML) (2016-2019)	8679	8973	59	61	72
Bioethanol (ML) log	8679	8711	59	59	48
Biodiesel (ML) stays the same	20586	21230	181	186	188
Biodiesel (ML) log	20586	18512	181	163	152
Biogas (MW) linear	12360	19091	20504	31670	29068
Biogas (MW) log	12360	13216	20504	21925	21149
Biomethane (MW) Poly 2	3836	9773	882	2274	1994
Biomethane (MW) Linear	3836	6596	882	1535	1479
Grey H2 (Mt)	11.63	7	351	199	199
Blue H2 (Mt)	0.28	9	4	139	139
Green H2 (Mt)	0.42	3	49	101	101
CCUS	-	-	1	55	55

D

EVOLUTION OF REFINERY PLANTS

This appendix showcases the evolution of refinery plants from 2009 to 2021 in Figure D.1. Although there are less refineries, the majority of the plants that closed had lower capacity. It is also noted that some opened or were expanded until 2021, majority of which had a larger capacity.

This shows that even though the total number of capacities is going down, the average capacity and the median are going up, the first one rising from 6.92 Mt/y to 7.17 Mt/y and the latter from 5.3 Mt/y to 5.8 Mt/y

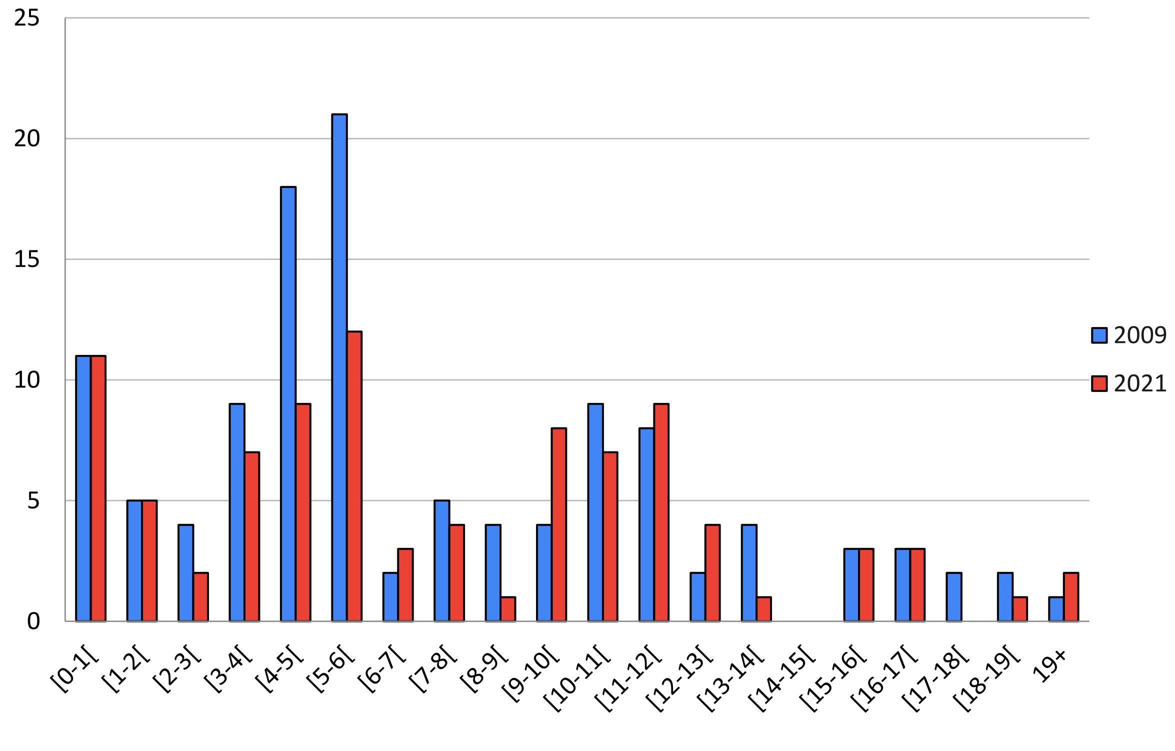

Figure D.1 Capacity of refineries from 2009 and 2021

2022

Paulo Farinha

Air Liquide analysis needs market study – Petrochemical products substitutes – new fuels and new processes

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