Iberian distribution planning of fuels - the impact of biofuel price quotations in decision-making

Galp Case Study

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Declaration

I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Declaração

Declaro que o presente documento é um trabalho original da minha autoria e que cumpre todos os requisitos do Código de Conduta e Boas Práticas da Universidade de Lisboa.

> I have long held an admiration for the work of engineers, a sentiment that is shared by other members of my family. (...) Throughout history, engineers have served their neighbours, their towns and their countries by making tools, machines and countless other things that improve every aspect of life. From information technology to medical science and mining, from building roads to space travel, engineers are working to make a difference to our standard of living, and with it our health, wealth and happiness. At its heart, engineering is about using science to find creative, practical solutions. It is a noble profession. (...) I have every hope that this Prize will be an aspiration of the international engineering community and an inspiration to young people everywhere, by letting them know that it is an exciting time to become an engineer and that by joining this profession they, too, can make a real impact on the way we live our lives.
>
> — *The Queen Elizabeth II*
> *2013*

Abstract

Barack Obama, the 44th President of the United States of America, stated that "*Climate Change is no longer some far-off problem; it is happening here, it is happening now*". Biofuels appear as renewable energy sources, with the potential to replace fossil fuels and might be part of the solution. Concerning the Iberian Peninsula, biofuels like biodiesel (FAME) and bioethanol are blended with either diesel or gasoline. Due to its relevance, the biofuel's quotation is an important factor to consider when designing and planning the downstream supply network. Bearing that thought, this dissertation has the goal to study the Iberian fuel distribution system, taking the perspective of one Iberian player - Galp - and looking into the specific problem of biofuels quotations and its impact in tactical and operational level of Galp's planning. For that purpose, different scenarios are built and tested in Galp's downstream optimisation model. The current model involves dozens of parameters such as transportation costs or energetic targets. Due to the obvious complexity of studying all the input parameters and their relationship with the biofuels quotations, it was decided to study several international reference prices - the exchange rate between dollar and euro and Methyl Tert-Butyl Ether (MTBE), methanol, gasoline and diesel quotations alongside with FAME and ethanol reference prices. Following the proposed methodology, the key results indicate that FAME's quotation has a larger impact in the downstream network compared to the Ethanol's quotations. This impact can be understood from different perspectives - either an impact in the supply assignment or an impact in the downstream supply costs.

Keywords

Downstream Planning; Biodiesel; Bioethanol; Oil distribution; Fuel Prices' Quotations.

Resumo

Barack Obama, o 44.º Presidente dos Estados Unidos da América, afirmou que "*a mudança climática já não é um problema distante; está a acontecer aqui, está a acontecer agora*". Os biocombustíveis aparecem como fontes de energia renovável, com potencial para substituir os combustíveis fósseis e fazer parte da solução. Relativamente à Península Ibérica, os biocombustíveis como o biodiesel (FAME) e o bioetanol são misturados com gasóleo ou gasolina. Devido à sua relevância, a cotação dos biocombustíveis é um importante fator a considerar ao projetar e planear a rede de distribuição. Seguindo essa ideia, esta dissertação tem como objetivo estudar o sistema Ibérico de distribuição de combustível, assumindo a perspetiva de um operador Ibérico – Galp – e analisar o problema específico da cotação dos biocombustíveis e o seu impacto a nível tático e operacional no planeamento da Galp. Para esse propósito, diferentes cenários são construídos e testados no modelo de otimização da rede de distribuição da Galp. O modelo atual envolve dezenas de parâmetros, como custos de transporte ou metas energéticas. Devido à óbvia complexidade do estudo de todos os parâmetros de entrada e sua relação com as cotações dos biocombustíveis, foi decidido analisar vários preços de referência internacional - a taxa de câmbio entre dólar e euro e as cotações de éter metil-terc-butílico (MTBE), metanol, gasolina e gasóleo, assim como a cotação do FAME e do etanol. Seguindo a metodologia proposta, os principais resultados indicam que a cotação de FAME tem um maior impacto na rede de distribuição em comparação com a cotação do Etanol. Esse impacto pode ser compreendido a partir de diferentes perspetivas - impacto no planeamento e impacto dos custos de fornecimento.

Palavras Chave

Planeamento de Distribuição; Biodiesel; Bioetanol; Distribuição de Produtos Petrolíferos; Cotações de Preços de Combustíveis.

Contents

List of Figures

List of Tables

Acronyms

CDM	Clean Development Mechanism
DPSC	Downstream Petroleum Supply Chain
ETBE	Ethyl-tertiary-butyl-ether
EU	European Union
FAME	Fatty Acid Methyl Esters
FQD	Fuel Quality Directive
GHG	Greenhouse Gas
HVO	Hydrotreated Vegetable Oil
IBSAL	Integrated Biomass Supply Analysis and Logistics
ILUC	Indirect Land Use Change
IPCC	Intergovernmental Panel on Climate Change
MILP	Mixed Integer Linear Programming
MIP	Mixed Integer Programming
MTBE	Methyl Tert-Butyl Ether
PSC	Petroleum Supply Chain
RED	Renewable Energy Directive
RES	Renewable Energy Sources
SC	Supply Chain
SCM	Supply Chain Management

1

Introduction

Contents

This chapter aims not merely to **contextualise the problem** for this research, but also to explain the **motivation**, **define goals** and describe the **document's structure** for this Master Thesis Dissertation. Thereupon, it is divided into these four sections.

1.1 General Context

Climate change is one of the most complex issues facing us today. It involves many dimensions - science, economics, society, politics and moral and ethical questions - and is a global problem, felt on local scales, that will be around for decades and centuries to come (Speth, 2009) (NASA, 2020b).

In 1979, scientists from 50 nations gathered in Geneva for the First World Climate Conference and acknowledged that alarming trends for climate change made it urgently necessary to act. Since then, analogous alarms have been made through Rio Summit (1992), the Kyoto Protocol (signed in 1997) and the Paris Agreement (2015), as well as other global assemblies and scientist's explicit warnings of insufficient progress (Ripple et al., 2017). Exacerbating this worldwide issue, in its 5th Assessment Report (IPCC, 2014), the Intergovernmental Panel on Climate Change (IPCC), a group of 1,300 independent scientific experts from countries all over the world under the auspices of the United Nations, concluded there is a more than 95 percent probability that human activities over the past 50 years have warmed our planet (NASA, 2020a) (IPCC, 2014) (Oreskes, 2004).

Carbon dioxide, the heat-trapping greenhouse gas that has driven recent global warming, lingers in the atmosphere for hundreds of years, and the planet (especially the oceans) takes a while to respond to warming (NASA, 2020b). The carbon dioxide is released through human activities (e.g. deforestation and burning of fossil fuels), as well as natural processes such as respiration and volcanic eruptions. Furthermore, considering global fossil fuel combustion and industrial processes, such emissions have seen dramatic inflation in usage. Recently, in 2018, the world saw about 36.57 billion tons of carbon dioxide emitted (Statista, 2019).

European legislation on Renewable Energy Sources (RES) promotion represents a pioneering and ambitious attempt to transform energy systems in the face of climate change. The European Union's renewable energy policy has been in the making for decades. Its history comprised small and incremental steps dating back to the 1970s (Nilsson, 2011). From the late 1990s onwards, however, in the wake of the single market agenda and the establishment of an international climate change regime, more substantial policy developments were put into motion. (Solorio & Jörgens, 2017).

European Union (EU) began implementing biofuel-related targets in 2003 with Directive 2003/30/EC. This first Biofuel Directive stated that *Member States should ensure that a minimum proportion of biofuels and other renewable fuels is placed on their markets, and, to that effect, shall set national indicative targets*. Therefore, a biofuel penetration target of 2% by the end of 2005 and 5.75% by the end of 2010 were indicated (both calculated on basis of energy content) (European Parliament, 2003).

Over the following years, the EU directives have evolved to fulfil more challenging environmental targets. For instance, the latest Renewable Energy Directive (RED) incorporates an overall target for 2030 of at least 32% of energy from renewable sources (European Parliament, 2018). This directive is further described in section 2.4.4.

1.2 Motivation and Brief Case Description: Galp Energia

Portugal, as a European Union's member, had to transpose the European legislation and directives in its national law. Consequently, companies within the oil industry were forced to readjust their businesses. In the beginning, those changes were mainly to meet legal requirements, although, over the years, apart from this legal constraint, biofuels became crucial in what concerns competitive leverage among rivals. This research will analyse a real and UpToDate case-study of the largest Portuguese oil company, Galp, focusing particularly on the importance and impact of biofuels in the Iberian supply planning and optimisation activities.

The downstream planning of fuel distribution is a complex problem since the number of demand locations escalates when including the primary and secondary segments. In a competitive environment of high-level of complexity, the regular search for efficiency is immense. Within this planning and optimisation context, efficiency should be portrayed as optimised costs. On this basis, this dissertation aims to analyse to impact of the biofuels' prices in the designed network of supply.

1.3 Dissertation's Objectives

The foremost objective of this research is to study the Iberian fuel distribution system, taking the perspective of one Iberian player - Galp - and looking into the specific problem of biofuels quotations and its impact in tactical and operational level of Galp's planning. Therefore, the ensuing objectives are the basis of this research:

- Shedding lights on several concepts directly related to logistics processes within the petroleum industry and its interaction with the biofuels' world;
- Understand the current legislation regarding biofuel targets, and its impact towards Galp's activities;
- Perceive and characterise the present case-study problem throughout a far-reaching explanation of the current and future paradigms of Galp's Planning decisions;
- Comprehend the fluctuation of the different biofuels reference prices;
- Develop a literature review enabling the researcher to scan, map, and evaluate the existing intellectual territory around planning within the petroleum and biofuel industries and the linkages between

biofuels and fuels prices.

- Propose a research methodology to be followed.
- Clearly define different and comparable scenarios for testing in an optimisation model software;
- Draw meaningful conclusions regarding regarding the different impacts on the diesel and gasoline networks.

1.4 Dissertation's Structure

For easier reading of the dissertation, which totals 80 pages, it is important to outline the adopted structure.

This thesis is partitioned in six different chapters. For the sake of clarity, at the beginning of each chapter (except in chapters four and 6), there is a table of contents of the correspondent chapter. The first chapter (with a total of 4 pages, from 1 to 4) is an introductory one, it begins with a contextualisation, motivation and characterisation of the problem, followed by a disclosure of the objectives and the adopted structure.

The second chapter (with a total of 15 pages, from 5 to 19) explores the key subjects leading to the problem's definition of this research. Therefore, the author further divides in two major parts. The first part conveys the problem's-related definition and subjects that goes beyond Galp's case study - explores the petroleum and biofuels' supply chains, its interactions and boundaries, the relevant European legislation and the Argus' and Platts' quotations. Diversely, the second part briefly describes Galp's structure, crossing the current downstream planning of Iberian Supply and the different paradigms in each side of the Iberian border, finishing with the problem's formulation and the roots for this study. The third chapter (with a total of 14 pages, from 20 to 33) is constituted by a comprehensive literature review. Again, the author divides this chapter in two major parts, following the key takeaways of the previous chapter. Hence, the first part encompasses planning-related literature where both petroleum and biofuels related papers are explored and analysed. Further, the second part comprehends price-transmission-related literature, focusing on oil and biofuels prices' relationships. It is noteworthy to mention that both analysis identify literature gaps in the acquired solid theoretical knowledge.

The fourth chapter (with a total of 3 pages, from 34 to 36) puts forward a methodology to be followed in this dissertation aligned with the identified literature gaps and Galp's Iberian Optimisation Planning and Supply department's challenge. Subsequently, the fifth chapter portrays the different results of this research by following the proposed methodology. This chapter is divided between the different segments of the petroleum downstream supply. Finally, chapter 6 wraps up the dissertation with the relevant conclusions of the current work.

The referencing and citation styles throughout the work follow the American Psychological Association (APA) manual.

2

Problem's formulation

Contents

This chapter will introduce the reader to the Case Study of this research. Readers unfamiliar with the petroleum industry, biofuels and related terminology should entirely understand the outcomes of this chapter. The author divides this chapter into three major categories. The first encompasses sections 2.1 to 2.5 where the biofuels and petroleum supply chains, their boundaries and interactions, crossing relevant European legislation and the Argus' quotations are explained. Thus, this initial part conveys the problem's definition that goes beyond Galp's case study. Diversely, the second part includes sections 2.6 to 2.8 where the specific case study of Galp is discussed. Finally, section 2.9 not merely summarises the present chapter but also establishes an interrelationship with chapter 3.

2.1 Biofuels: Overview

Fossil fuels are widely used as transportation and machinery energy source due to its high heating power, availability and quality combustion characteristics, although its reserve is depleting day by day. The diesel engine was invented by Dr Rudolph Diesel and it was run by peanut oil at the Paris Exposition in the year 1900 (Ghobadian et al., 2009). Hence it has been established from then that high temperature of the diesel engine can run on a variety of vegetable oils (Atabani et al., 2011).

Biofuels are liquid or gaseous transport fuels made from biomass (e.g. food, fibre and wood process residues from the industrial sector or energy crops, short-rotation crops and agricultural wastes from the agriculture sector) and have been seen as an alternative fuel source due to the depletion of petroleum fuel and environmental concern (Commission, 2012; United Nations, 2008). The complete substitution of petroleum-derived fuels by biofuel is impossible from the production capacity and engine compatibility point of view. Although, marginal replacement of conventional fuels by biofuels can prolong the depletion of petroleum resources and is an attractive mean to prevent further increase of carbon dioxide emissions and fight climate changes (Hassan & Kalam, 2013).

Biofuels production in Europe has grown significantly since early 2000 as a result of rising oil prices and the existence of favourable legislation adopted by the EU institutions (Silva, 2013), in which biofuels are crucial to meet renewable energy targets discussed in section 2.4. Figure 2.1 provides an overview of biofuels from resources to end-use.

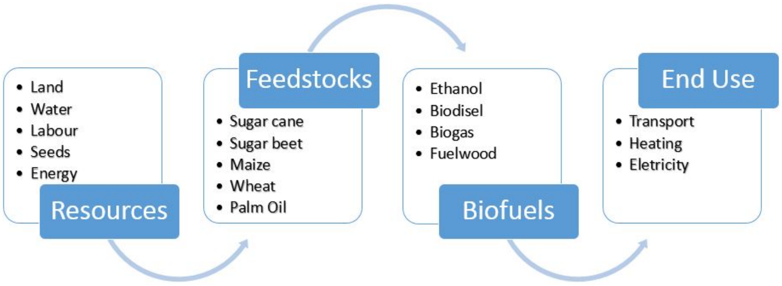


Figure 2.1: Biofuels – from resources to End Use.

2.1.1 Types of Biofuels

Biofuels can be classified according to different rules and patterns. The first type is dividing biofuels into different generations. Thus, First-Generation biofuels are directly related to biomass that is generally edible. They are produced from land using feedstock which can also be used for food and feed (Commission, 2012). Nowadays, these biofuels are on the market in considerable amounts, and their production technologies are well-established (Zinoviev et al., 2007). Second-Generation biofuels are defined as fuels originated from a wide array of different feedstock, ranging from lignocellulosic feedstocks to municipal solid wastes. Third-Generation biofuels are associated with algal biomass, although could, to a certain extent, be linked to utilisation of CO_2 (Lee & Lavoie, 2013). Further, there are some authors considering a Fourth-Generation. These biofuels are currently ongoing and has not generated as much attention as there are still pressing policy and other needs for first, second and third generations. Some fourth generation technology pathways include: pyrolysis, gasification and genetic manipulation of organisms to secrete hydrocarbons (Awudu & Zhang, 2012). Table 2.1 summarises the differences among of the first, second, third and fourth generation biofuel.

Table 2.1: Differences in biofuel generations.
Source: (Awudu & Zhang, 2012)

	First Generation	**Second and third Generations**	**Fourth Generation**
Type of biomass	Uses sugarcane, oil feed, corn and other food substitute as raw material	Uses switchgrass, wood waste and other cellulosic raw material	Uses combination or special process of first and second
Market for trading	Structured markets for trading	Not structured markets for trading	Not structured markets for trading
Feedstock availability	Readily available in large quantities	Extensive benefits on greenhouse gas emission	Benefits on greenhouse gas emission but not quantified
Cost of building plant and process	This is an expensive option for energy development	Not in commercial quantity, research is still ongoing	Not in commercial quantity, research is still ongoing

Further, different types of classification are outlined by United Nations (2008). The association states that biofuels can be classified according to source and type. Hence, in what concerns source, they may be derived from forest, agricultural or food industry. On the other hand, if considering the type, they may be solid, such as fuelwood, charcoal and wood pellets; liquid, such as ethanol, biodiesel and pyrolysis oils; or gaseous, such as biogas. Finally, a basic distinction is also made between primary (unprocessed) and secondary (processed) biofuels. Primary biofuels, such as firewood, wood chips and pellets are those where the organic material is used essentially in its natural form (as harvested). Such fuels are directly combusted, usually, to supply cooking fuel, heating or electricity production needs in small and industrial applications. Secondary biofuels in the form of solids (e.g. charcoal), liquids (e.g. ethanol, biodiesel and bio-oil), or gases (e.g. biogas, synthesis gas and hydrogen) can be used for a wider range of applications, including transport and high-temperature industrial processes.

2.1.2 Biodiesel

Biodiesel, the current biggest biofuel contributor in Europe (Statista, 2020), is a simplified term, often used regarding transport fuel produced from long-chained Fatty Acid Methyl Esters (FAME), derived from either vegetable oils or animal fats. While unmodified, vegetable oils cannot be used as transport fuels considering they are limited by their reduced viscosity, combustion speed and increased tendency to induce fuel injector fouling.

FAME production is simply a process to use the energy in vegetable oils in the fossil diesel pool (Philips, 2019). FAME can be used in pure form in specially adapted vehicles or be blended with automotive diesel (Zinoviev et al., 2007).

Besides the classic FAME, Hydrotreating of vegetable oils is a modern way to produce very high-quality bio-based diesel fuels, Hydrotreated Vegetable Oil (HVO), without compromising fuel logistics, engines, exhaust after-treatment devices, or exhaust emissions. These fuels are also referred to as *renewable diesel fuels* instead of *biodiesel* (reserved for FAME) (Zinoviev et al., 2007).

2.1.3 Bioethanol

Bioethanol is produced by fermenting sugars from starch and sugar biomass (e.g. cereal crops such as corn or maize and sugarcane). It may be used in pure form in specially adapted vehicles or blended with gasoline in any proportion up to 10%, provided that fuel specifications are met. Ethyl-tertiary-butyl-ether (ETBE) is synthesised from bioethanol and isobutylene. It can be blended with gasoline in any proportion up to 15% (Zinoviev et al., 2007).

2.1.4 Iberian synopsis

Concerning the Iberian Peninsula market and players (such as Galp) the relevant biofuels are summarised in figure 2.2. Those biofuels are blended with either diesel or gasoline and traded between the oil companies (refineries or distributors). Further, it is noteworthy that the Iberian car fleet is physically prepared to receive up to 7% of biodiesel (diesel engine) or 5% of bioethanol (gasoline engine).

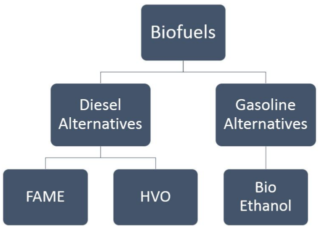


Figure 2.2: Biofuels for the transport sector in the Iberian Peninsula.

2.2 Petroleum Supply Chain: Overview

The global economy is significantly dependent on the oil and gas sector (Gardas, Raut, & Narkhede, 2019). Customers perceived refined products as commodity goods with there being negligible difference among brands, and so the cheapest supplier is sought. Subsequently, within the oil industry, there are strong competitive forces continually bearing down on selling prices. As an outcome of having selling prices fixed by the market, cost minimisation is of immense importance to every competing company. The key opportunity for cost minimisation is the planning of efficient supply chains (Sear, 1993). By optimising the distribution plan, the transportation efficiency of refined oil can be significantly improved, and the costs might decrease (Wang et al., 2019).

Across the literature, it has been a long debate whether the petroleum supply chain is divided into two or three segments, being the allocation of refinery operations the centre of the controversy (see chapter 3.1.2). For the aspirations of this research, it is considered the classification scheme, where the petroleum supply chain encompasses a set of functions which is divided into three major segments, namely: Upstream, Midstream and Downstream.

The Upstream segment comprises all functions from petroleum exploration, production and transportation until the refineries. On the other hand, the Midstream concerns about the conversion of the petroleum into refined products at refineries and petrochemicals.Lastly, the Downstream segment includes storage, primary and secondary distributions and marketing of refined products.

In each segment, there are petroleum companies which rely on physical infrastructures across the network to develop these functions (Fernandes, Relvas, & Póvoa, 2014; Lima, Relvas, & Póvoa, 2016). In Figure 2.3 it is illustrated an overview of the Petroleum Supply Chain as described.

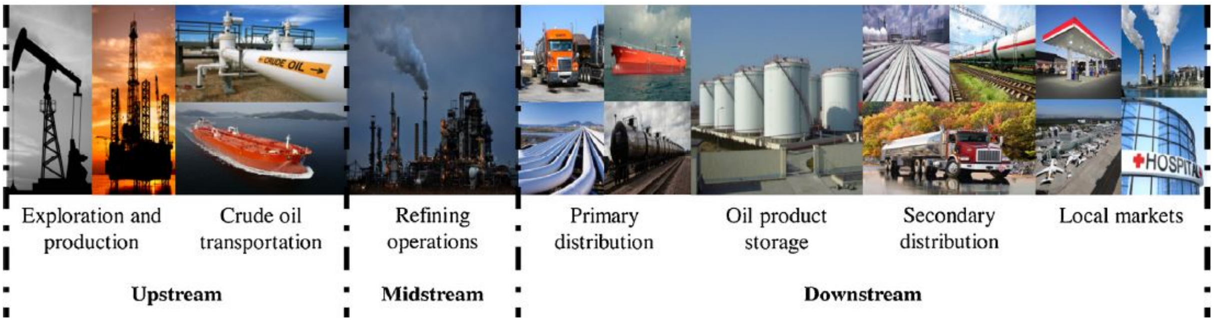


Figure 2.3: The Petroleum Supply Chain.
Source: Lima, Relvas, and Póvoa (2016)

2.3 Biofuel and Petroleum Supply Chain: Integration

Conventionally bio-refineries are considered independent of petroleum supply chains. However, with the development of advanced hydrocarbon biofuels, opportunities emerge for biofuel industry to take advantage of the existing infrastructure of petroleum supply chains (mainly refinery units and pipelines), thus saving substantial amounts of capital and operational costs. As illustrated in Figure 2.4, there are three insertion sites for biofuel supply chain to access the petroleum infrastructure:

(a) A bio-crude that can be co-processed with conventional crude oil;
(b) Refinery-ready intermediates compatible with specific refinery streams for further processing;
(c) A near-finished fuel or blend stock that will be processed at the refinery.

Thus, in insertion point (a), bio-crude (e.g., pyrolysis oil) can be mixed with petroleum crude oil, then sent to crude distillation units, and finally converted to fuel products via a sequence of upgrading units. Further, for injection point (b), bio-crude is sent to upgrading units after specific treatment to remove oxygen and other contaminants. Finally, there are two options regarding insertion point (c). Either blending biofuels with conventional fossil-fuels in the petroleum refinery and then shipping them to the customers using existing pipelines, or delivery of biofuels directly to distribution centres and blending there (Yue, You, & Snyder, 2014).

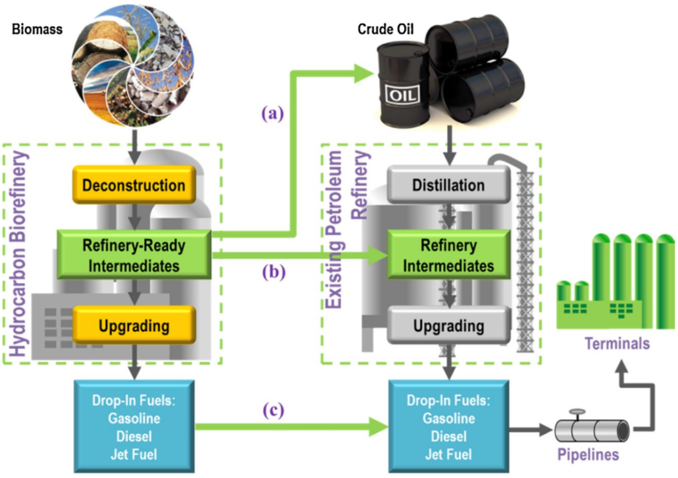


Figure 2.4: Entry Points for biomass resources into existing petroleum infrastructure. Source: Yue, You, and Snyder (2014)

2.4 Current Renewable Energy Policy

In 2009, the EU Commission established two major directives supporting the increased use of renewable fuels extending to 2020 - RED and Fuel Quality Directive (FQD). These directives should be analysed together since they are complementary.

RED, clearly explained in section 2.4.1, aims to promote renewable energies and energy efficiency in order to decrease Greenhouse Gas (GHG) emissions while FQD, detailed in section 2.4.2, evaluates and keeps track of those emissions.

In 2018, the EU Commission reformulated RED with new targets and a new time-horizon (until 2030). This reformulation kept the essence - promote renewable energies - but narrowed the target. This new European Directive is further detailed in section 2.4.4.

2.4.1 Renewable Energy Directive (European Parliament, 2009a)

This directive, which amends and repeals earlier directives like the already mentioned 2003/30/EC (see section 1.1), creates a common set of rules for the use of renewable energy in the EU to limit GHG emissions and promote cleaner transport. It sets national binding targets for all EU countries with the overall aim of making, in 2020, renewable energy sources account for 20% of EU energy and 10% of energy specifically in the transport sector (both measured in terms of gross final energy consumption, i.e. total energy consumed from all sources, including renewables). The Renewable Energy Directive allows that under national biofuel support systems, *the contribution made by biofuels produced from wastes, residues, non-food cellulosic material, and lignocellulosic material shall be considered to be twice that made by other biofuels* (in Article 21). Though, **double counting** is allowed.

2.4.2 Fuel Quality Directive (European Parliament, 2009b)

The Fuel Quality Directive places a target that the carbon intensity of European road transport fuel should be reduced by 6% by 2020 compared to the baseline (2010). It further imposes *indicative targets* (i.e. optional targets) for additional carbon intensity reductions of 4% for a total of 10% reduction in carbon intensity of the fuel mix. Therefore, half of the additional savings (2%) targets electrification and carbon capture and storage. Regarding the remaining 2%, the additional reduction would be achieved through the purchase of Clean Development Mechanism (CDM) credits. The Fuel Quality Directive does not allow double counting of any biofuels.

2.4.3 Indirect Land Use Change (Commission, 2012)

When biofuels are produced on existing agricultural land, the demand for food and feed crops remains, and may lead to someone producing more food and feed somewhere else. This can imply land-use change (e.g. changing forest into agricultural land) which indicates that a substantial amount of CO_2 emissions are released into the atmosphere.

The proposal sets out Indirect Land Use Change (ILUC) factors for different crop groups. These factors represent the estimated land-use change emissions that are taking place globally as a result of the crops being used for biofuels in the EU, rather than for food and feed. Simply put, all biofuels that use land will get an ILUC factor. Feedstock that does not require agricultural land for their production (i.e. waste, residues, algae) and those that cause direct land-use change (i.e. in which case operators need to calculate their actual emissions) are exempt from the factors.

Under the new rules, the estimated emissions from indirect land-use change (ILUC factors), are to be included in Member States' and fuel suppliers' reporting of GHG savings under the RED and the FQD respectively. The new rules will make biofuels used in the EU more sustainable and will help us to reduce further Greenhouse Gas emissions and encourage greater market penetration of advanced biofuels.

2.4.4 Renewable Energy Directive II (European Parliament, 2018)

This new RED directive (RED II) recasts and repeals previous legislation, such as RED (described in section 2.4.1). It establishes a common system to promote energy from renewable sources across different sectors. In particular, it aims to: set a binding EU target for its share in the energy mix in 2030; regulate self-consumption for the first time; and establish a common set of rules for the use of renewables in electricity, heating and cooling, and transport in the EU.

The increased use of energy from renewable sources will be crucial to combat climate change, protect our environment and reduce our energy dependency, as well as to contribute to the EU's technological and industrial leadership and the creation of jobs and growth, including in rural and isolated areas.

This directive is part of the *Clean Energy for All Europeans* package, which aims to provide new, comprehensive rules on energy regulation for the next decade. This new directive includes, among others, a binding EU overall target for 2030 of at least 32% of energy from renewable sources and, concerning the transport sector, a binding target of 14% with a specific sub-target for advanced biofuels of 3.5%. RED II has been applied since 24/12/2018 and has to become law in EU countries by 30/06/2021.

2.5 International Quotations: Argus and Platts

The Argus Biofuels service is a daily report that provides key international insights into the biodiesel, ethanol and feedstock markets. It is provided key prices for freight, spot prices, physical forward prices and spreads to navigate this growing international marketplace. All assessments are compliant with the Renewable Energy Directive (discussed in section 2.4) for sustainable biofuels (Argus, 2020). Further, Platts quotations' service provides insight within the petroleum-based products. Put differently, it gives daily reference prices for products like diesel or gasoline (SP Global, 2020).

Oil companies within the Iberian Peninsula may utilise these international quotations of the biofuels and petroleum markets, Argus and Platts, when trading and negotiating with each other the acquisition or selling of oil products (e.g. in refineries). Each company has its own mathematical formula of selling fuels and biofuels, although the roots are the Argus and Platts reference prices.

2.6 A brief context of Galp

The author of this Master Thesis dissertation focuses the research on the biggest and fully settled Portuguese oil company - Galp. The current dissertation was developed under a five-month curricular internship within the Iberian Optimisation Planning and Supply department at Galp's headquarters. This section provides an overview of the specific problem discussed within this department, namely with Engineers Pedro Alves and Nuno Braz Rodrigues.

2.6.1 History of the company

Galp's history goes back three centuries and is closely associated with the industrial evolution of Portugal. Firstly, in 1846, Queen Maria did not want to lag behind other European capitals and authorised the opening of a tender for the gas street lighting of Lisbon. As a result, in 1848, the *Companhia Lisbonense de Iluminação e Gás* (Lisbon Company of Gas Lightening) lighted the first 26 street lamps in the country (Galp, 2020b) (Martins, 2018).

Further, 1976 was a particularly important year in the company's history. On April 1st, almost two years after the Carnation Revolution, **Petrogal** emerged, as a result of the 4th Provisional Government to merge *SACOR*, *Sonap*, *Cidla* and *Petrosul*. With 6,193 employees and 28.21 billion Escudos of total assets, it was the largest Portuguese company at the time. With this merger came the need to create a unique brand. The answer to this challenge was given with four letters that constituted a brand that has long been part of the daily life and imagination of the Portuguese - GALP (Martins, 2018) (Galp, 2020b).

Finally, in 1999 **Galp Energia**, wholly owned by the Portuguese State, is incorporated to aggregate the business of *Petrogal*, *Gás de Portugal* and *Transgás*, and is the vehicle for restructuring the oil and natural gas sectors in Portugal (Galp, 2020b).

2.6.2 Current company structure

Nowadays, Galp is a Portuguese-based, publicly-traded energy company with an international presence and 6,389 employees. Their activities cover all phases of the energy sector value chain, from exploration and extraction of oil and natural gas, from reservoirs located kilometres below the sea surface to the development of energy-efficient and environmentally sustainable solutions for customers. The company also contributes to the economic development of the 11 countries in which they operate and to the social progress of the communities of those countries (Galp, 2020a).

Galp's structure comprehends 3 business segments: Exploration & Production, Refining & Marketing and Gas & Power (Figure 2.5). Galp's organic structure, at the operational level, is based on the following five business units: Upstream, Midstream, Commercial, Renewables & New Businesses and Infrastructure.

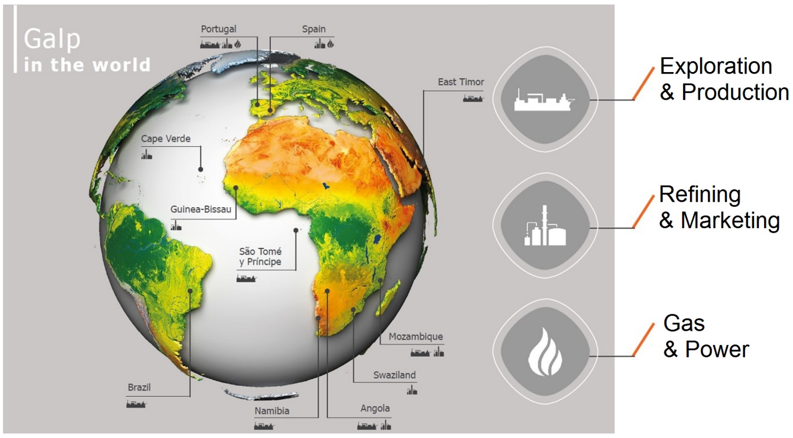


Figure 2.5: Overview of Galp in the world and its Business Segments.
Source: Galp (2019)

In legal terms, the Galp Group consists of the Company and its subsidiaries, which include, among others:

- Galp Energia E&P BV and its subsidiaries, which develop their activity in the exploration and production of oil and gas and biofuels;
- Petróleos de Portugal - Petrogal, S.A. and its subsidiaries, which carry out their activities in the area of crude oil refining and marketing of its derivatives;
- Galp Gas & Power SGPS, S.A. and its subsidiaries operating in the natural gas, electricity and renewable energy sectors;
- Galp Energia, S.A., a company that integrates the corporate services.
- The results of the Group companies are consolidated in the results of the parent company, Galp Energia, SGPS, S.A.

2.7 Galp's Downstream Planning of Iberian Supply

Considering the Iberian Fuel distribution system, Galp is the biggest player in Portugal and an important player in Spain. Therefore, in order to be successful, Galp needs not merely to play by the rules of this sector - either legal directives in each country, environmental legislation, technical and science *status* *quo* - but also to meet customers' expectations.

The downstream planning of fuel distribution is a complex problem, since the number of demand locations escalates when including the primary (refinery to depot) and secondary (depot to service station) segments (see figure 2.6). The complexity is also related with the fact that different products are present, with different supply locations and supply constraints. When several companies are present in the supply region, in order to remain competitive, each company has to carefully include all the related information in the planning procedure, so as to take the most informed and competitive decisions.

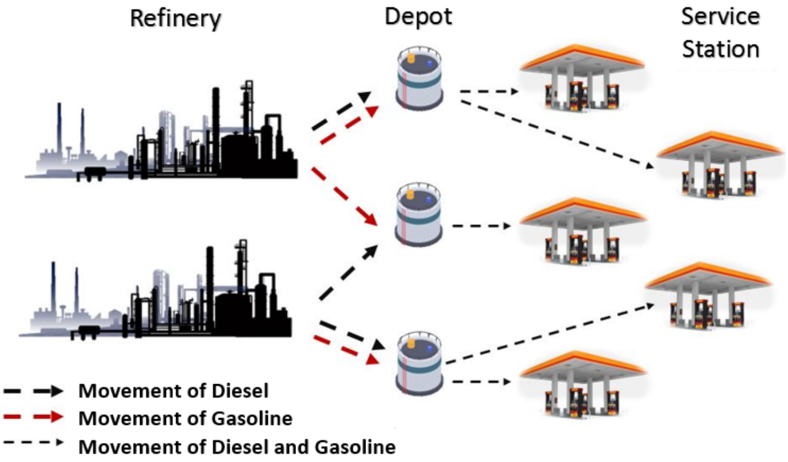


Figure 2.6: Overview of Petroleum downstream logistics.

The Iberian Peninsula comprehends two different paradigms for Galp. On the Portuguese side, Galp fully owns and explores all refineries, namely Matosinhos Refinery and Sines Refinery. Although, on the other side of the border, different Galp's competitors own and explore the 8 Spanish refineries - Repsol possesses 5, Cepsa has 2 and BP explores 1. Further, the logistics infrastructures are different in both countries. In Portugal, there is 1 oil pipeline (operated by CLC) whereas in Spain there is a complex network of pipelines (operated by CLH) connecting refineries to depots - in both sides of the border, whether pipelines are not available, the connections are operated by truck.

Figure 2.7 describes the Portuguese situation, illustrating both refineries, identifying the different players in each depot and the only oil pipeline. Diversely, figure 2.8 illustrates the complex Spanish pipeline network, the 8 refineries and its explorer and the main available depots (including 2 controlled by Galp, notwithstanding it also operates in CLH, Esergui and Decal depots).

The primary aim of Galp's downstream planning is to maximise results (margins) considering product supply and logistics costs. Understanding and adjusting the areas of influence of each refinery - which refinery supply each depot - and the areas of influence of each depot - which depot supply each service station - is crucial to accomplish such goal. Currently, this downstream planning is accomplished through an optimisation model developed through GRTMPS software.

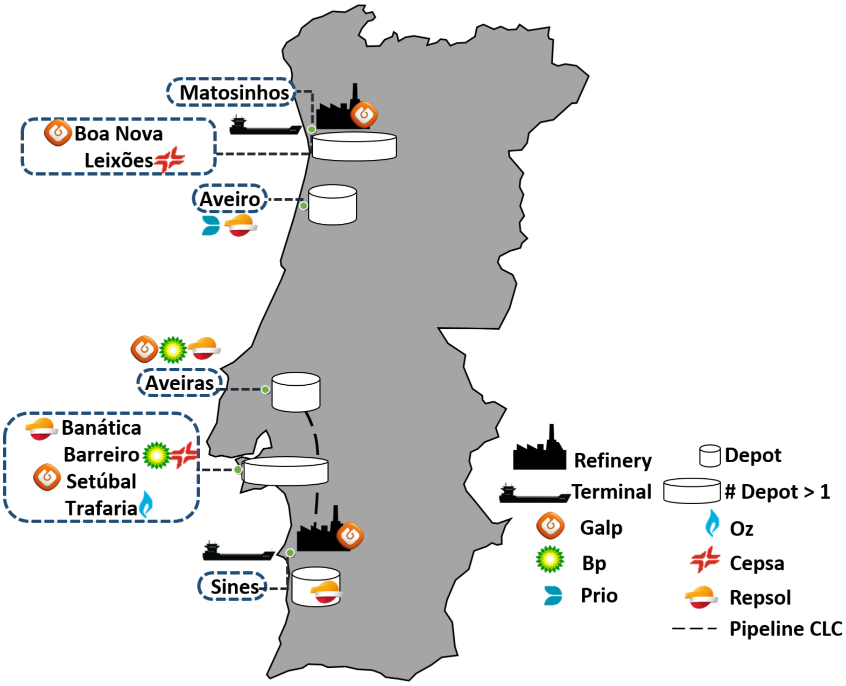


Figure 2.7: Overview of Portuguese Petroleum Downstream Logistics: From refineries to depots. Based on Autoridade da Concorrência (2018) report.

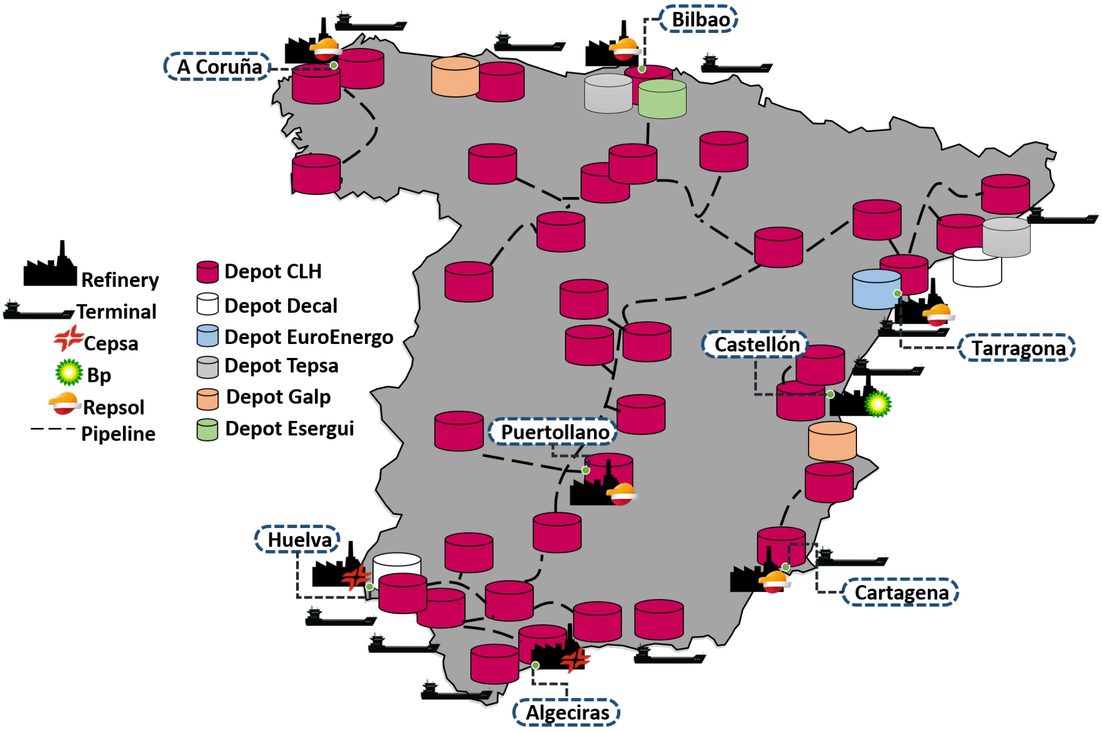


Figure 2.8: Overview of Spanish Petroleum Downstream Logistics: From refineries to depots. Based on CLH (2020) and Petromiralles (2014).

In general, GRTMPS, developed by Haverly, is used to determine optimal solutions in refining, petrochemical, energy, manufacturing, and other industries. Refineries use GRTMPS to develop economic plans across one or more time periods, determine best mix of products, feeds, and operational conditions to maximise profits and minimise costs (Haverly Systems, 2020). Regarding Galp, since GRTMPS was already used in Refining planning, the Downstream Planning Department adapted the model to their needs. Regarding the model itself, it is noteworthy to mention that it considers numerous inputs such as several international quotations (e.g. from Platts and Argus), distances between network facilities (refineries, depots and service stations) or demand across the network. Additionally, bearing in mind that the oil companies are legally compelled to introduce/blend biofuels within refined products in order to meet energetic targets, and since different biofuels have different impacts on the energetic target (non-linear relationship), the optimisation model is a non-linear model. The model aims to maximise results (margins) considering product supply and logistics costs. The output of the model is a complex network of downstream supply. It provides the optimal connections between refineries, depots and service stations.

Finally, Galp's downstream planning aims to fulfil customer's demand in over 1,200 Galp's service stations spread around the Iberia (figure 2.9).

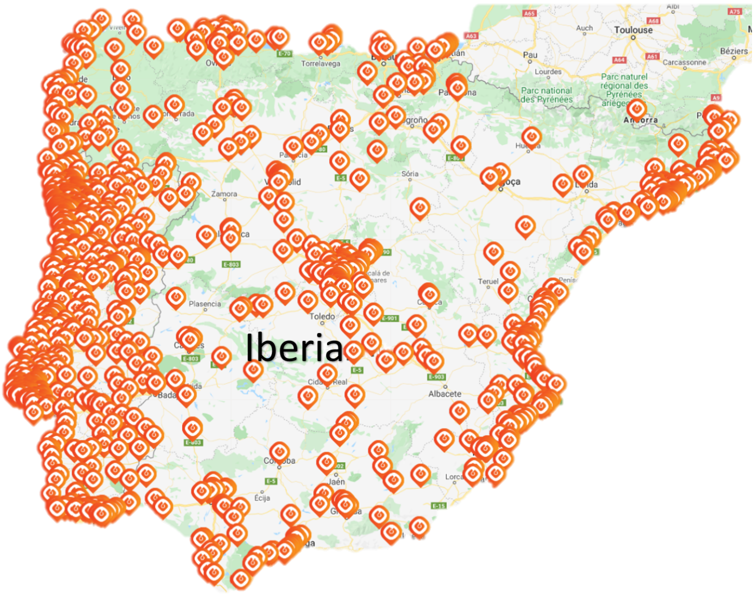


Figure 2.9: Galp's service station in Iberia mainland.
Source: Galp

2.8 Problem's Formulation

Along with this chapter, the relevance of biofuels within the fuel network has been discussed since petroleum companies are legally compelled to introduce biofuels in their fuel chain. As a result, these companies utilise several reference's prices of fuels and biofuels (discussed in section 2.5) when negotiating the acquisition or selling of oil products. Notwithstanding each corporation has its own mathematical formula of selling biofuels, the root and similarity is the daily Argus Quotation of FAME or Bioethanol combined with either diesel or gasoline Platts' reference prices.

The problem arises when analysing the evolution of combined pairs of quotations such as FAME (biodiesel) versus diesel and bioethanol (bio-gasoline) with gasoline. Figure 2.10 outlines the combined daily evolution of FAME and diesel (given as a differential) since 2013 until the beginning of 2020, which reaches a minimum of 60 €/ton and a maximum of 530 €/ton (source: Galp). Further, the same timeline and framework is suggested in figure 2.11, although comparing bioethanol and gasoline. In this case, the differential varies from -200 €/ton to 450 €/ton (source: Galp). The non-steady evolution displayed in both figures is the root for this research.

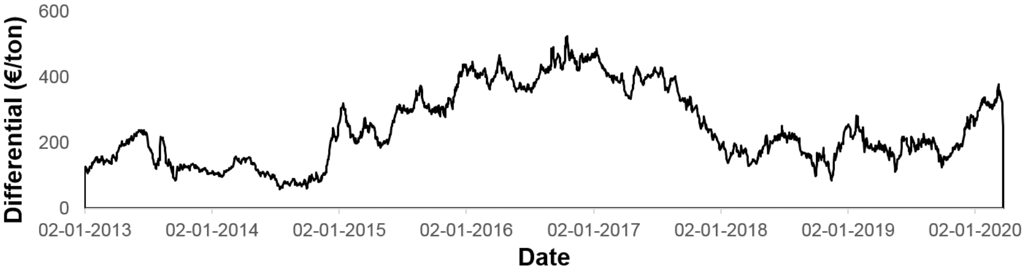


Figure 2.10: Daily differential of FAME and diesel's reference prices since 2013 until 2020. Source: Galp

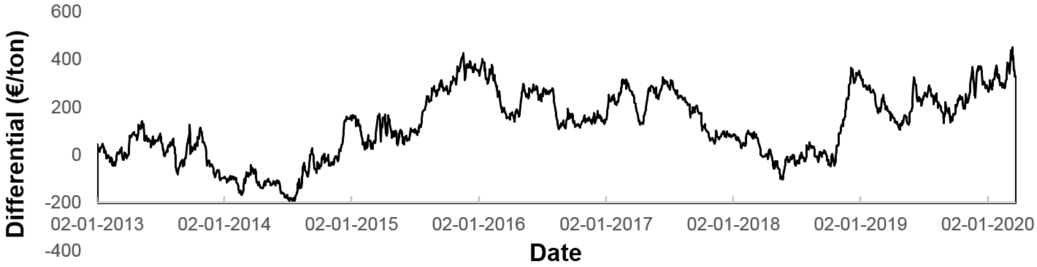


Figure 2.11: Daily differential of bioethanol and gasoline's reference prices since 2013 until 2020. Source: Galp

The work has the goal to study the Iberian fuel distribution system, taking the perspective of one Iberian player - Galp - and looking into the specific problem of biofuels quotations and its impact in tactical and operational level of Galp's downstream planning. The research aims to analyse the impact of biofuels quotations in the areas of influence of each refinery and depot (i.e. decide which refinery supplies each depot (and what type of fuel) and which depot supply each service station) while meeting all legal requirements such as the energy target - different biofuels have different impacts. Analysing the energy target with different biofuels in different frameworks/scenarios is the challenge proposed by Galp, since knowing with detail the impact that quotations have in the distribution planning is a competitive advantage.

2.9 Key Takeaways

This chapter presents the petroleum and biofuel industries, their boundaries and relationships, crossing relevant European legislation and finishing with Galp's presentation and problem's formulation. It is imperative to recognise the relevance of the distinct types of biofuels and the blending opportunities and specifications in the Iberian countries. Further, understand the current biofuel-related legislation illustrating that EU countries are conscious of biofuels importance. Finally, perceive that different quotations impact trading between oil companies and knowing its impact in downstream planning is a competitive advantage.

Apart from describing relevant concepts, this chapter presents the problem formulation which smoothly introduces the literature review presented in the following chapter. Therefore, petroleum and biofuel-related literature and their prices evolution are explored.

3

Literature Review

Contents

> *Undertaking a review of the literature is an important part of any research. The researcher both maps and assesses the relevant intellectual territory in order to specify a research question which will further develop the knowledge base. (...) A good systematic review should make it easier for the practitioner to understand the research by synthesising extensive primary research papers from which it was derived.*
>
> — Tranfield, Denyer, and Smart (2003)

The present chapter describes a review of existing literature and theoretical concepts linked with the problem of this research. This information is important to grasp future analysis that will be developed throughout the investigation and serve as a knowledge base to feed the study.

This literature review has two major purposes, therefore, the author divides the present chapter in two fundamental sections. The first part addresses important works around planning activities, either in petroleum and biofuels' supply chains, with particular focus on uncertainty considerations. Further, the second part is dedicated to the relevant studies around the petroleum and biofuels' prices, relationships and evolution.

Alongside the analysis in each section, the author cites several articles. Although, some are used to illustrate general concepts and do not entirely represent researches correlated with the heretofore defined problem of this paper. Hence, for the sake of clarity and consistency, at the end of each section tables 3.1 and 3.2 gather the problem-related articles providing a broader perspective of the revised literature while helping in identifying literature gaps.

The search was performed through some world-top citation databases such as *Web of Science*, using keywords such as *petroleum supply chain*, *biofuel supply chain* or *downstream planning* combined or not with *prices* and *supply chain management*.

3.1 Planning-related literature

3.1.1 Introduction

Beginning in the 1960s and 1970s, some corporations perceived themselves as intertwined functions to serve their customers. They availed of their material management structure and merged their functions to enhance customer service. This assimilation was called *material logistics management*.

By intensifying the integration, firms achieved a better performance and a higher customer satisfaction level. As a result, in the 1980s and 1990s, further companies followed this method while there was an increasing interest in the performance, design, and study of the supply chain (Sahebishahemabadi, 2013). The term *Supply Chain Management (SCM)* rose in the late 1980s, and its use grew in the 1990s.

According to Hugos (2011), other terms such as *logistics* and *operations management* were used.

Supply chain can be understood as a complex and dynamic system within a collaborative or competitive environment, whose entities may or not cooperate to fulfil customer requests for products or services, where data, product, and financial flows occur among different echelons over the time horizon. In this way, Larson (2001) highlights supply chain management as as being a set of efficient procedures blending entities to organise all tasks involved in fulfilling orders in the right quantities, right locations, and on time to minimise the overall costs, while satisfying the service level requirement (Lima, Relvas, & Póvoa, 2016).

Supply Chain Management operates at three levels: strategic, tactical, and operational, depending on its frequency and the time that it affects the network. Each decision level considers uncertainty over the decision horizon, although its extension varies over the planning stages - greater decision prospect across the supply chain planning implies further uncertainty. According to Paksoy, Özceylan, and Gökçen (2012), the strategic approach concerns the optimisation of network resources such as designing networks, location, and determination of the number of facilities. Tactical decisions affect the mid-term, including production levels at all plants, assembly policy, inventory levels, and lot sizes. Furthermore, operational decisions are related to how to make tactical decisions happen in the short-term, such as production planning and scheduling. Overall, there is a natural hierarchy among these stages, where the strategic planning imposes limits to the tactical planning, which in turn, establish policies for the operational level (Chopra & Meindl, 2007; Lima, Relvas, & Póvoa, 2016). As outlined by Al-Qahtani and Elkamel (2010), their mutual analysis, optimisation and integration are required to enhance the supply chain performance.

Starting in 1990, the globalisation boom has witnessed significant improvements in SCM. Particular characteristics of different problems have triggered new strategies and the definition of mathematical models (Fernandes, Relvas, & Póvoa, 2009).

Recalling the problem's definition - *understand the impact of biofuels quotations in the areas of influence of each refinery and depot* - it can be assumed that the planning activity of this study is a SCM problem within tactical and operational levels. The *areas of influence* are associated with fulfilling orders in the right place, right time and right quantities, while minimising the total cost.

This section is further divided into two categories: petroleum-related literature and biofuel-related literature. The aim is to analyse planning activities regarding the correlated industries of this research. Further, although the downstream planning within the petroleum industry is the major focus of the research, it is also relevant to perceive the biofuel industry since it may affect the biofuels quotations mentioned in the problem's formulation.

3.1.2 Petroleum Supply chain

The Petroleum Supply Chain (PSC), as the basis of the modern economy, influences global and national economies (Fernandes, Relvas, & Póvoa, 2014). According to the American Petroleum Institute (2014), in the petroleum industry, the revenues are as significant as the overall costs, such as costs of exploring, producing and supplying crude oil, as well as costs of refining and distributing the refined products.

Further, the petroleum supply chain is embedded in an unstable context shaped by geopolitical unrest, global competition and price volatility, where the business focuses on margins and the savings are carried out through improved forecasts and schedules with shorter planning horizon. Consequently, as outlined by Lima, Relvas, and Póvoa (2016), the request for devising and implementing new tools aims to establish an integrated and adaptive supply chain to improve the decision-making process, reduce costs, decrease inventories and enhance margins.

Across the literature, it has been a lengthy debate whether the petroleum supply chain is divided into two or three segments, being the allocation of refinery operations at the centre of the controversy. As outlined by Sahebishahemabadi (2013) and Lima, Relvas, and Póvoa (2016), the PSC might be categorised into three classification schemes. The first considers the PSC divided between upstream and downstream segments, incorporating the refinery and petrochemical plants within the downstream segment. Though, the second divides the network into upstream, midstream and downstream segments, where the mid-stream part covers the refinery and petrochemical operations. Ultimately, the third also considers the oil supply chain divided into three segments, although the midstream part refers to crude oil transportation to terminal and storage facilities.

3.1.3 Decision-making in Petroleum Supply Chain: Operational decisions

Operational level Supply Chain (SC) studies are associated with decisions that affect the short term (e.g.,hourly, daily, or weekly). Most operational-level studies of the petroleum-based fuel supply chain deal with the operations at refineries. Nonetheless, some researchers developed operational-level planning studies for downstream processes.

The first studies of the operational level of the petroleum-based fuel SC were reported in the 1960s. Aronofsky and Williams (1962) developed a multi-period, linear programming model to prescribe oil well production. They developed two models: one schedules production rates from either single or multi-well systems; the other, drilling and rig operations.

Ronen (1995) addressed a scheduling problem correlated with the distribution of petroleum products, acknowledging the two basic types of plants: refineries and lube plants. Refineries produce light products (e.g., gasoline, kerosene, diesel oil, aviation fuel) as well as heavy products (e.g., base stock for lubes, and residual oil). Lube plants manufacture lube oils, greases, and waxes. Ronen (1995) explained four different types of operational environments encountered in practice: light products transported in bulk from refineries to tank terminals and industrial customers; light products, from tank terminals to retail outlets; bulk lubes, from lube plants to industrial customers; and packaged lubes, from lube plants to retail outlets and industrial customers. He suggested two scheduling formulations: set partitioning for minimising cost and set packing for maximising profit (An, Wilhelm, & Searcy, 2011).

MirHassani (2008) considers a capacitated PSC network and proposes a linear programming model for operational planning of the transportation network between the existing refineries and depots to meet customer demand, minimising total inventory and transportation costs.The static modelling approach also computes inventory shortages and excesses in the presence of transportation route capacity bounds.

3.1.4 Decision-making in Petroleum Supply Chain: Tactical and Strategic decisions

Papageorgiou (2009) points out the benefits of the strategic and tactical planning to identify the optimal infrastructure network and the best usages of production, distribution and storage resources to satisfy the market demand in a cost-effective way. Further, when the tactical decisions are considered along with strategic decisions in the network design problem, the outcomes are improved, as described by Barbosa-Póvoa (2014). In strategic level problems, optimisation models assist the decision-making process across the network to improve the overall profitability - achieved through finding the equilibrium among sourcing, production, inventory and transportation costs - while accomplishing the required service levels as highlighted by Barbosa-Póvoa (2014) and Lima, Relvas, and Póvoa (2016).

Klingman et al. (1987) formulated a production and inventory planning model for refineries. The article describes the design and implementation of a model and computer system to address the complex tactical planning and operational issues associated with the supply, distribution, and marketing of refined petroleum products.

At the beginning of the century, Dempster et al. (2000) apply stochastic programming modelling and solution techniques to planning problems for a consortium of oil companies. A multi-period supply, transformation and distribution scheduling problem — the Depot and Refinery Optimization Problem — is formulated for strategic and tactical level planning of the consortium's activities.

Cheng and Duran (2004) developed a decision support system to examine and improve the combined inventory and transportation system in a representative world-wide petroleum supply problem. The decision support system is based on integrating discrete event simulation and stochastic optimal control of the inventory/transportation system - tactical level.

Further, a stochastic model was also addressed by Carneiro, Ribas, and Hamacher (2010) to analyse the strategic planning of a petroleum supply chain. They use a two-stage stochastic model with fixed recourse and incorporation of risk management. The model took a scenario-based approach and addressed three sources of uncertainty.

Fernandes, Relvas, and Póvoa (2015) present a stochastic Mixed Integer Linear Programming (MILP) that maximises the expected net present value while minimising a risk measure the conditional value-at-risk under demand uncertainty. The bi-objective MILP model determines the design decisions relating to installation, sizing and operation of infrastructures, the fair price strategic cost and tariffs and tactical decisions concerning periodic depot and route product affectations and inventory levels.

3.1.5 The downstream Petroleum Supply Chain Network

Fernandes, Relvas, and Póvoa (2013, 2014) define the Downstream Petroleum Supply Chain (DPSC) as a compound network that enables oil companies to develop specific activities, intending to move the oil products from refineries to the end consumer. The planning of DPSC is imperative to ensure that the demand of retail markets can be satisfied. The network comprises refineries, storage depots, transportation modes (railway, waterway, pipeline and road), and routes acting in coordination to fulfil the retail customer demands for multiple petroleum products in different regions. In figure 3.1, there is a schematic representation of the downstream petroleum supply chain network.

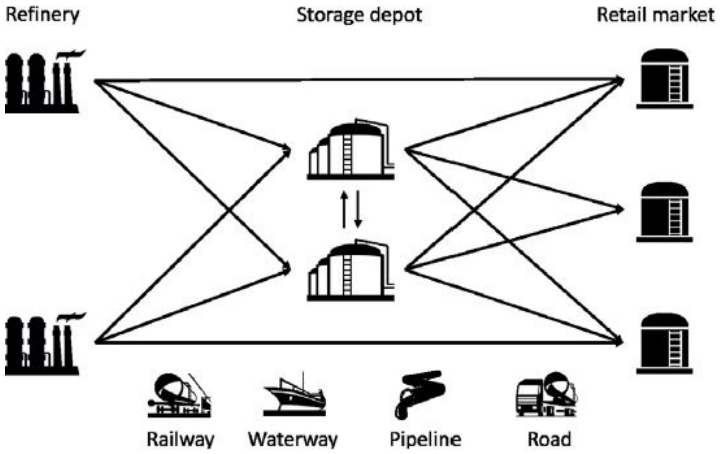


Figure 3.1: The Downstream Petroleum Supply Chain.
Source: Wang et al. (2019)

The downstream PSC was first researched by Sear (1993), who presented a qualitative and mathematical formulation for its strategic planning needs for logistics infrastructure and transportation. Two years later, Ronen (1995) identifies significant cost saving potential for transportation and inventory.

His research explores the diversity of operational environments which occur in dispatching petroleum products, and the operations research tools used by oil companies to dispatch such products.

Further, Relvas et al. (2006) suggested a MILP approach to model the problem of oil derivatives pipeline transportation scheduling and supply management. The aim of the model is to attain a high level of operation, satisfying clients and accounting for distribution center restrictions and mandatory tasks. Fernandes, Relvas, and Póvoa (2013), and Kazemi and Szmerekovsky (2015) suggested an analogous approach - MILP for the strategic design and planning - to determine the optimal depot locations, capacities and transportation modes.

Y. Kim et al. (2008) proposed an integrated model of the refinery supply network and production planning. Hence, they lowered the distribution cost by relocating the distribution centres and by redesigning their linkages to various markets. Further, Cornillier et al. (2008) develop a heuristic for a multi-period service-station replenishment problem. The research aims to determine product delivery quantities per vehicle and route to each service station, to maximise the total profit.

Ghaithan, Attia, and Duffuaa (2017) established a multi-objective optimisation model for a DPSC. Their model intended to minimise the total cost, maximise the total revenue, and maximise the service level. Two years later, intending to optimise a DPSC, Wang et al. (2019), developed a MILP model with new pipeline routing applied to an actual case in China.

According to Lima, Relvas, and Póvoa (2018), in the oil market, particularly at strategic and tactical levels, uncertainties emerge from a wide range of sources, leading to actual risks for the entire system, besides making it more exposed to stoppages and high costs. Uncertainties propagate through the petroleum supply chain from oil production (upstream), passing through oil refining (midstream), until the product distribution (downstream), where they shape the market prices and demands (Al-Othman et al., 2008; Lima, Relvas, & Póvoa, 2018). Consequently, modelling uncertainty is a crucial factor when designing a DPSC.

At the end of the last century, Escudero, Quintana, and Salmerón (1999) presented a modelling framework for the optimisations of a multi-period supply, transformations and distribution scheduling problem under uncertainty on the product demand, spot supply cost and spot selling price. Further, Ribas, Hamacher, and Street (2010), proposed a strategic planning model for an oil supply chain considering uncertainties from crude oil production, demand for refined products and market prices. They analyse uncertainty by three different approaches: a two-stage stochastic MILP model, a robust min-max regret model, and a max-min model.

Oliveira and Hamacher (2012) address the problem of epitomising the investment planning process of a logistics infrastructure for the distribution of petroleum products under uncertainty. In this case, the authors divide the mathematical formulation into two stages. The first stage comprises decisions regarding when and where the investments should be made before recognising the uncertainty. The second stage introduces the uncertainty factor since it represents the cost of supplying the demand given an investment decision for a particular understanding of the uncertain parameters.

Recently, Lima, Relvas, and Póvoa (2018), presented a multistage stochastic programming model to solve the distribution problem of refined products. The stochastic model relies on a time series analysis, as well as on a scenario tree analysis, in order to effectively deal and represent uncertainty in oil price and demand.

3.1.6 Biofuel Supply Chain

According to Akgul, Shah, and Papageorgiou (2012), a biofuel supply chain is a multi-echelon network consisting of biomass cultivation sites, ethanol production facilities and demand centres. In general, biomass raw materials are transported by trucks from the neighbouring farms to the biofuel refinery plant through the farm cooperatives.

According to Awudu and Zhang (2012), cooperatives act as the liaison between farms and bio-refineries. In most cases, the feedstock or raw materials are converted into finished goods such as bioethanol. The finished product is transported via trucks to terminals for blending. Blending the ethanol with gasoline is carried out so that the ethanol product will be used for fuel purposes only. This is usually done at the initial stage by denaturing it with other chemicals. The blending of ethanol and gasoline ensures the provision of various grades of ethanol and gasoline combinations such as E85 and E15. The E85 consists of 85% ethanol and 15% of gasoline, while the E15 consists 15% of ethanol and 85% of gasoline. The blended ethanol is subsequently sent to the gasoline retail outlets, where they are sold together with other types of fuel. A bio-refinery plant usually uses various conversion processes to convert the raw materials into the various end products depending on if it is from any type of the generations.

Finally, Awudu and Zhang (2012) proposes a biofuel supply chain with an extra level of detail, compared to Akgul, Shah, and Papageorgiou (2012), stating that the major elements in the biofuel supply chain are farms, storage facilities, bio-refinery plants, blending facilities, retail outlets and transportation. Figure 3.2 shows the general framework of the biofuel supply chain.

3.1.7 Decision-making in Biofuel Supply Chain: Operational decisions

Related biofuel SC studies have dealt with costs of operations, harvest scheduling, and upstream transportation. Early studies of the operational level of biofuel SCs analysed economic factors. In general, estimating the cost of each operation from farm to conversion plant was a regular practice. These early studies aimed to appraise the economic feasibility of the biofuel industry by evaluating the cost of

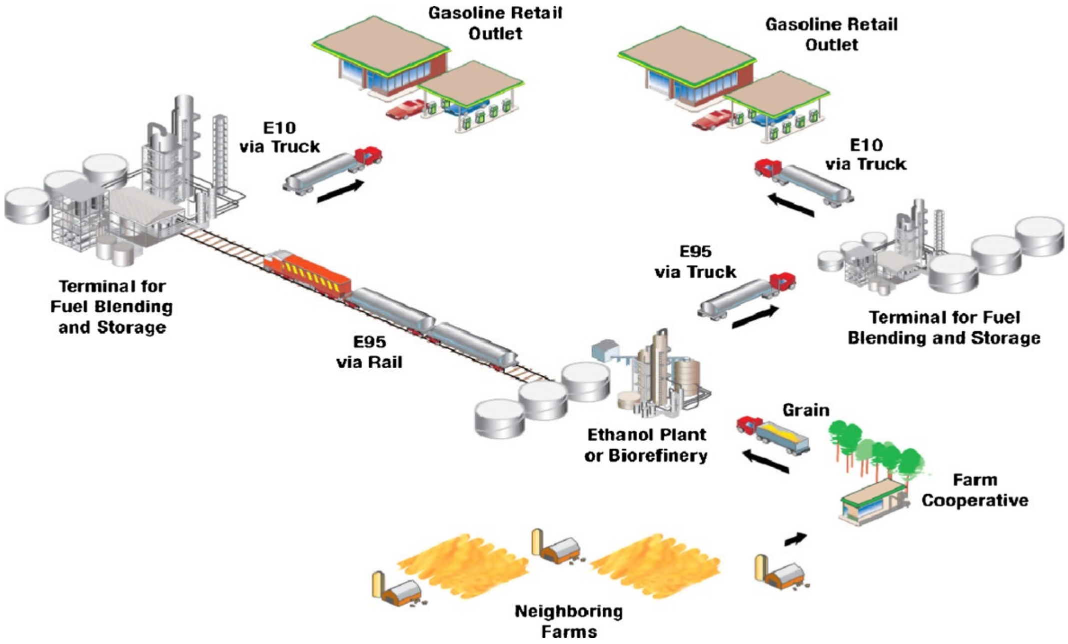


Figure 3.2: The biofuel Supply Chain.
Source: Awudu and Zhang (2012)

biomass logistics.

Jenkins et al. (1984), evaluated costs for alternative process in biomass logistics, including acquisition and transportation of several types of biomass (e.g. rice, wheat, and barley straws). Gemtos and Tsiricoglou (1999) and Tatsiopoulos and Tolis (2003) presented a similar analysis, based on the cotton stalk related with an electricity-generating plant in Greece (An, Wilhelm, & Searcy, 2011).

Daily production scheduling is used by Voivontas, Assimacopoulos, and Koukios (2001) in optimising the production of agricultural residues. The authors consider production scheduling as the operational decision, and the raw materials needed and capacity of power plants as some of the parameters in the model.

Hamelinck, Suurs, and Faaij (2005), approached international bio-energy logistics. They reported that several green-energy producers already import biomass, in Sweden and the Netherlands, requiring the supply of long-distance biomass transportation. They analysed SCs of Europe, including transportation of biomass from Latin America to conversion plants in Europe. They estimated the cost for each operation in such an international biomass SC. Further, for a region within Austria, Gronalt and Rauch (2007), proposed a method to assess the total cost of supplying woody biomass from forest to conversion plants, analysing central and local shipping alternatives. The system cost they calculated includes the costs of transportation from forest to terminals and from terminals to conversion plants and of operating terminals but does not include harvesting costs (An, Wilhelm, & Searcy, 2011).

Simulation models have been based on economic analyses to estimate essential measures, including cost, energy consumption, and carbon emission. Gallis (1996), provided a simulation model based in SLAM to assess the logistics cost of forest biomass for several scenarios in Greece. De Mol et al. (1997), introduced both simulation and optimisation models. Their simulation model analyses all operations and determines annual costs, energy consumption, and the flow of biomass from farm to conversion plant within a network of facilities.

Sokhansaj, Kumar, and Turhollow (2006), reported an Integrated Biomass Supply Analysis and Logistics (IBSAL) model. Their ExtendSim simulation model is similar to that of De Mol et al. (1997). However, it also calculates the carbon emissions that result from processing and transportation and includes formulas that give good estimates of logistics operations.

Moreover, some papers are dedicated to sugarcane SC. Higgins (1999, 2002) formulated a Mixed Integer Programming (MIP) to improve yield by scheduling sugarcane harvests and solved it using several heuristics. Higgins and Postma (2004) addressed a scheduling problem to optimise the rostering of harvesting groups into sugarcane rail and road sidings to reduce transportation and harvesting costs. They used a tabu search to solve their MIP, which uses a weighted, multi-objective function, including transportation capacity, the total amount of movement across sidings, and a measure of adherence to a schedule that reflects perfect equity between farmers.

3.1.8 Decision-making in Biofuel Supply Chain: Tactical and Strategic decisions

Within this section it is presented reviewed literature of both tactical and strategic levels of decision-making since most of the studies integrate and impact both levels.

Čuček et al. (2010) presents a method for the synthesis of regional renewable energy supply chains based on MILP. The paper focus on both strategic and tactical level decisions. In the same year, Huang, Chen, and Fan (2010) developed a mathematical model that integrates spatial and temporal dimensions for strategic planning of future bioethanol supply chain systems. The planning aim is to minimise the cost of the entire supply chain of biofuel from bio-waste feedstock fields to end users over the entire planning horizon, satisfy demand and technology constraints.

A case study concerning the corn-to-ethanol production supply chain in Northern Italy is used to illustrate the proposed modelling approach by Dal-Mas et al. (2011). The article describes a strategic design and investment capacity planning of the ethanol supply chain. In this work a dynamic and multi-echelon MILP modelling framework is presented to help decision-makers and potential investors assessing economic performances and risk on investment of the entire biomass-based ethanol supply chain. Uncertainty in ethanol market price and biomass purchase cost is taken into consideration.

Further, Leão, Hamacher, and Oliveira (2011) suggest an approach for formulating and planning an optimised supply chain of a biodiesel plant sourced from family farms, considering agricultural, logistic, industrial, and social aspects. This model was applied to the production chain of biodiesel fuel from castor oil in the semi-arid region of Brazil with affecting decisions on strategic and tactical levels. In the same year, Giarola, Zamboni, and Bezzo (2011) addresses the strategic design and planning of corn grain and stover-based bioethanol supply chains through first and second generation technologies. A MILP framework is introduced to optimise the environmental and financial performances.

J. Kim, Realff, and Lee (2011) present a two-stage mixed integer stochastic programming model for the optimal design of a biofuel supply chain network under the presence of uncertainties in biomass supply amounts, biofuel market demands, biomass and biofuel market prices and processing technologies. The model aims to maximise the expected profit over the scenarios under consideration. Robustness and global sensitivity of the optimised multiple-scenario design against the single-scenario design are analysed using Monte Carlo simulation.

One year later, Kostin et al. (2012) propose a multi-scenario MILP for the optimal design and strategic planning of integrated ethanol-sugar supply chains considering uncertainty in demand. The model seeks to optimise the economic performance of the supply chain by taking into account different financial risk measures such as value-at-risk, opportunity value and risk-area-ratio. Further, Akgul, Shah, and Papageorgiou (2012) proposed an optimisation model for the strategic design of a hybrid first/second generation ethanol supply chain in the United Kingdom. The model addresses sustainability issues such as the use of food crops, land use requirements of second generation crops and competition for biomass with diverse sectors.

Moreover, Osmani and Zhang (2013) considered an integrated multi-feedstock (i.e. switchgrass and crop residue) lignocellulosic-based bioethanol supply chain under occurring uncertainties in switchgrass yield, crop residue purchase price, bioethanol demand and sales price. A two-stage stochastic mathematical model is introduced to maximise expected profit by optimising the strategic and tactical decisions.

More recently, Santibañez-Aguilar et al. (2014) presents an optimisation model to design and plan sustainable bio-refinery supply chains that consider various relevant aspects (at both tactical and strategic levels). These aspects include the multiple available biomass feedstocks at various harvesting sites, the availability and seasonality of biomass resources, different potential geographical locations for processing plants that produce multiple products using diverse production technologies, economies of scale for the production technologies, demands and prices of multiple products in each market, locations of storage facilities and several transportation modes between the supply chain components. The author formulates the problem as a multi-objective, multi-period, MILP that seeks to maximise the profit of the supply chain, minimise its environmental impact and maximise the number of jobs generated by its implementation. In the same year, Tong, You, and Rong (2014) addresses the optimal design and planning of the advanced hydrocarbon biofuel supply chain with the unit cost objective. A mixed-integer linear programming model is proposed to consider the supply chain design, integration strategy selection, and production planning.

Recently, Babazadeh (2017) propose a multi-period and multi-product biodiesel supply chain network design model. The developed model determines the optimum numbers, locations, capacity of facilities, suitable transportation modes, appropriate technology at bio-refinery, material flow, and production planning in different periods - strategic and tactical levels.

3.1.9 Planning-related literature analysis

In this literature review section, relevant studies around planning within the petroleum and biofuel industries have been selected and analysed to picture the scientific coverage of these works. Some findings can be withdrawn about major subjects addressed by these reviewed articles, as well as issues not treated by them, which may guide future research to fulfil the existing voids.

Table 3.1 displays the primary contributions achieved within the reviewed papers which can be correlated to the formulated problem of this research.

Table 3.1: Main characteristics of planning-related articles.

Author	**Type of SC**		**Decision Levels**			**Uncertainty**		
	Biofuel	Oil	Operat.	Tact.	Strat.	Price	Demand	Other
Escudero, Quintana, and Salmerón (1999)	—	✓	—	—	—	✓	✓	✓
Dempster et al. (2000)	—	✓	—	✓	✓	—	✓	✓
Cheng and Duran (2004)	—	✓	—	✓	—	—	✓	✓
MirHassani (2008)	—	✓	✓	✓	—	—	✓	—
Al-Othman et al. (2008)	—	✓	✓	✓	—	✓	✓	—
Carneiro, Ribas, and Hamacher (2010)	—	✓	—	—	✓	✓	✓	✓
Ribas, Hamacher, and Street (2010)	—	✓	—	✓	✓	✓	✓	✓
Dal-Mas et al. (2011)	✓	—	—	✓	✓	✓	—	—
J. Kim, Realff, and Lee (2011)	✓	—	—	✓	✓	✓	✓	✓
Leão, Hamacher, and Oliveira (2011)	✓	—	—	—	✓	—	—	✓
Kostin et al. (2012)	✓	—	—	—	✓	—	✓	—
Oliveira and Hamacher (2012)	—	✓	—	✓	✓	—	✓	—
Osmani and Zhang (2013)	✓	—	—	✓	✓	✓	✓	✓
Tong, You, and Rong (2014)	✓	✓	—	✓	✓	—	✓	✓
Fernandes, Relvas, and Póvoa (2015)	—	✓	—	✓	—	—	✓	—
Lima, Relvas, and Póvoa (2018)	—	✓	—	✓	—	✓	✓	—
Wang et al. (2019)	—	✓	—	✓	✓	—	✓	✓

The major outcomes can be consulted within the themes in which this work has been focused: different decision levels of Supply Chain Management within Biofuel and Oil industries focusing on distinct types of uncertainties. Hence, from table 3.1, it is possible to understand that supply chains have been fairly studied as individual supply chains and rarely as a combined supply chain. Further, these studies illustrate that planning activities are deeply explored in the literature, although there is a gap in understanding the biofuels prices' impact in downstream petroleum supply chain planning. Finally, uncertainties are mainly treated by stochastic MILP approaches. According to Tong et al. (2014), the stochastic programming is a good choice when the uncertainty can be represented by a probability distribution obtained from the historical data.

3.2 Price transmission-related literature

3.2.1 Introduction

The formulated problem for this research, apart from the planning perspective, also requires the analysis of fuels and biofuels' reference price evolution. Thus, this last section of the present chapter addresses the fuels and biofuels price transmission in the literature.

Scepticism around the benefits of promoting biofuels has grown as these have been criticised for being one cause of the 2007/08 and the 2010/11 global food crises, having negative environmental and social impacts. Though much of the interest among the press and the academic world has been on the implications of biofuels for food prices, some researchers also investigate how biofuels affect fossil fuel prices (Serra & Zilberman, 2013).

3.2.2 Fuel and Biofuel prices' relationship

Campiche et al. (2007) find corn and soybean prices to be cointegrated with crude oil prices after the outbreak of the biofuels market, with crude prices driving feedstock prices. Saghaian (2010) supports cointegration between crude oil, ethanol, wheat, corn and soybean prices.

Balcombe and Rapsomanikis (2008) use ethanol, sugar and crude oil prices to investigate the Brazilian ethanol industry. The article relies on generalised (non-linear) version of error-correction models. While sugar–oil and ethanol–oil are found to be non-linearly cointegrated, ethanol–sugar prices are linearly cointegrated. The study indicates that crude oil prices drive long-run feedstock price levels, while the latter drive long-run biofuel prices. Two years later, Chen, Kuo, and Chen (2010) detect evidence of positive short-run relationships between crude oil and grain prices, which are attributed to the influence of biofuels (the links are specially relevant during high crude oil price periods).

Further, Serra et al. (2010) provide evidence of two cointegration relationships: crude oil–gasoline (representing the gasoline market equilibrium) and ethanol–corn–gasoline (representing the ethanol market equilibrium). Corn responds to ethanol market fluctuation, but not to gasoline market disequilibrium, which suggests that energy–agricultural price links occur through the biofuels market. Corn responds to ethanol market fluctuation, but not to gasoline market disequilibrium, which suggests that energy–agricultural price links occur through the biofuels market.

Kristoufek, Janda, and Zilberman (2012a) and Vacha et al. (2013) study US and German biofuel markets. They find biodiesel prices to be more connected to fuel prices, while ethanol is more related to food prices. Further, Kristoufek, Janda, and Zilberman (2012b) find that both ethanol and biodiesel prices are responsive to their production factors as well as their substitute fossil fuels (ethanol with corn, sugarcane and the US gasoline; and biodiesel with soybeans and German diesel).

Finally, in the Spanish biodiesel industry, Hassouneh et al. (2012) found evidence of a single cointegration relationship among crude oil, biodiesel and sunflower oil prices.

3.2.3 Price transmission-related literature analysis

This section broad reviews research on fuels and biofuels price transmission. Hence, table 3.2 summarises main conclusions and relationships between prices and illustrates the aspects of the reviewed articles divided by commodities, ethanol, biodiesel and oil prices.

Table 3.2: Key conclusions and characteristics of fuel price transmission-related literature.

Author	Commodities	Ethanol	Biodiesel	Oil	Conclusions & Relationships
Campiche et al. (2007)	✓	—	—	✓	Oil drives biofuel
Balcombe and Rapsomanikis (2008)	✓	✓	—	✓	Oil drives sugar
Saghaian (2010)	✓	✓	—	✓	Oil drives ethanol
Chen, Kuo, and Chen (2010)	✓	—	—	✓	Oil drives grains
Serra et al. (2010)	✓	✓	—	✓	Oil drives corn; ethanol drives gasoline
Kristoufek, Janda, and Zilberman (2012a)	✓	✓	✓	✓	Biodiesel connects to fuel
Kristoufek, Janda, and Zilberman (2012b)	✓	✓	✓	✓	Connections with prod. factors
Hassouneh et al. (2012)	—	—	✓	✓	Oil and biodiesel
Vacha et al. (2013)	✓	✓	✓	✓	Ethanol with corn; Biodiesel with diesel

Most of the studies reviewed in this section provide evidence that biofuel and/or oil prices affect agricultural price levels in the long-run. Further, a majority of studies shows a relationship between oil and biofuels prices, although not consistent in its impact. Finally, only one paper research an Iberian market, therefore, there is a literature gap in the field in which this dissertation explores.

4

Research Methodology

From the literature review chapter, becomes explicit that the downstream planning is thoroughly explored, although, to the best of our knowledge, fail to address the integrated planning of operations considering both oil products and biofuels. On the other hand, regarding price transmission-related literature, the study of the Iberian market has not been explored. Therefore, this dissertation aspires at filling these gaps while answering to the challenge proposed by the Optimisation Planning and Supply department of Galp.

The foremost objective of this chapter is to propose a methodology to be followed in this Master Dissertation. This methodology comprehends four steps: 1 - historical analysis of biofuels and fuels quotations; 2 - build-up of different planning scenario's settings; 3 - programming and testing in Galp's planning software; and 4 - data-driven sensitivity analysis.

Regarding the first step, historical analysis of fuels and biofuels quotations, the key idea is to retrieve data from the last decade (starting in 2013 when Galp started collecting biofuel-related data) regarding the daily price quotation's evolution of fuels (diesel and gasoline) and different biofuels - FAME and ethanol. As described in the problem's formulation (see section 2.8), those reference prices are the basis of the Iberian companies' mathematical formula of negotiating fuels and biofuels. The analysis will be conducted through some statistical parameters such as mean and/or maximum and minimum values. The outputs of this step will further assist in the scenario-building situation.

Further, the formulation of various quotation's scenarios comprehends two distinct stages. First, based on the first step key results, the author proposes different scenarios for reference prices' variation. Afterwards, these scenarios are reviewed and discussed with the Iberian Optimisation Planning and Supply department. Therefore, the outcome of this step are merged scenarios derived from both stages which, thereafter, are implemented in Galp's planning software, GRTMPS. Consequently, the third step will involve programming and testing of the defined scenarios in the optimisation software. The output of this stage are areas of influence of refineries and depots which are deeply analysed in the last stage.

The fourth and last stage is a strongly data-driven analysis to understand how Galp's planning reacts in different scenarios. In other words, a sensitivity analysis is provided and some conclusions are withdrawn and discussed with Galp's planning department.

Figure 4.1 briefly illustrates the proposed methodology with the inputs and outputs of each stage.

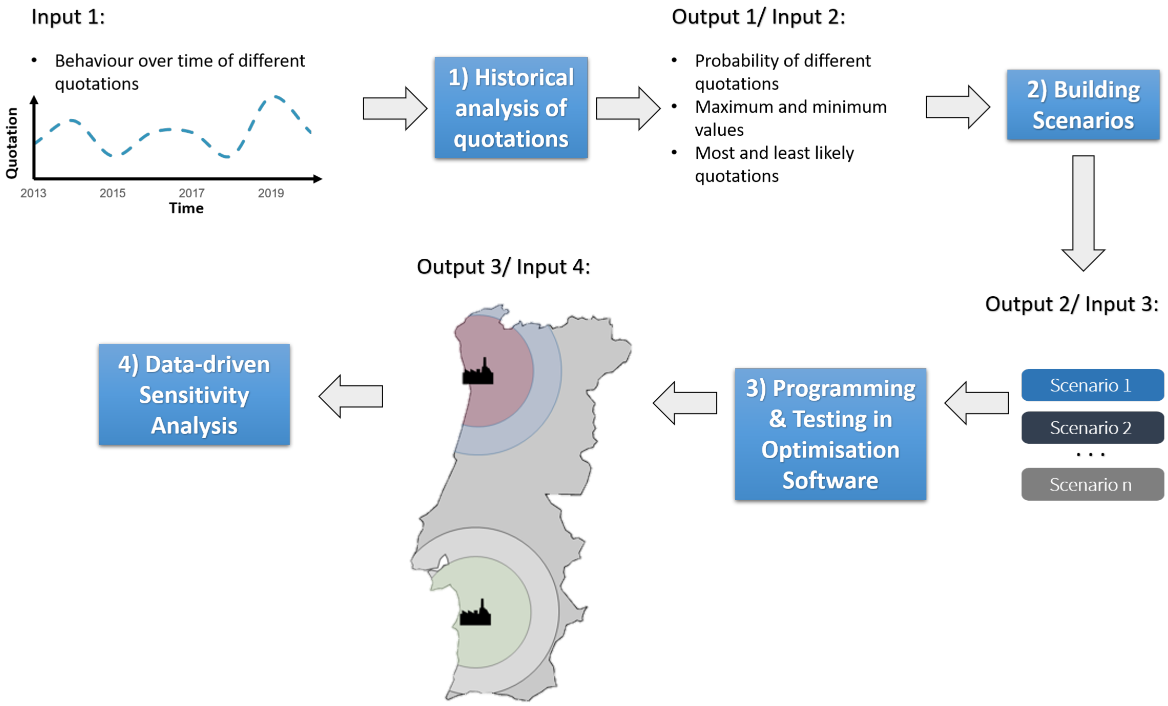


Figure 4.1: Schematic representation of the proposed methodology and its 4 steps.

5

Methodology Analysis and Results

Contents

This chapter is entirely dedicated to the results and analysis of the proposed methodology described in chapter 4. Hence, it is divided in the different inputs, outputs and analysis of each stage.

5.1 Introduction

The goal of this thesis is to understand the impact of biofuels quotations in the areas of influence of refineries and depots. As a result, it is clear that FAME and bioethanol quotations are crucial for this study.

A key point for this research was the decision of which Galp's planning model parameters to include in the study. The current downstream optimisation model involves dozens of parameters such as transportation costs, distances between refineries, depots and service stations, several international quotations, energetic targets, contracts between key players, etc. Due to the obvious complexity of studying all the input parameters and their relationship with the biofuels quotations, the author aligned with the Iberian Optimisation Planning and Supply department of Galp decided to study several international reference prices - the **exchange rate between dollar and euro** and **Methyl Tert-Butyl Ether (MTBE)**, **methanol**, **gasoline** and **diesel** quotations alongside with **FAME** and **ethanol** reference prices.

5.2 Input 1

As a result, the input of the first stage of the proposed methodology is the behaviour over time of the different international quotations. The author had access to daily quotations of the different mentioned reference prices from 2013 to the beginning of 2020. Although, due to the pandemic coronavirus crisis and its impact in the international quotations, the author decided to exclude 2020 of the study.

The different quotations are described in figures 5.1, 5.2 and 5.3. For the sake of clarity and to avoid sharing sensitive information, these figures do not represent a daily evolution of the different quotations, but a monthly evolution of those (by considering the average per month) and are divided between those 3 figures. Despite this visual simplification, this study was conducted considering the daily evolution of such quotations.

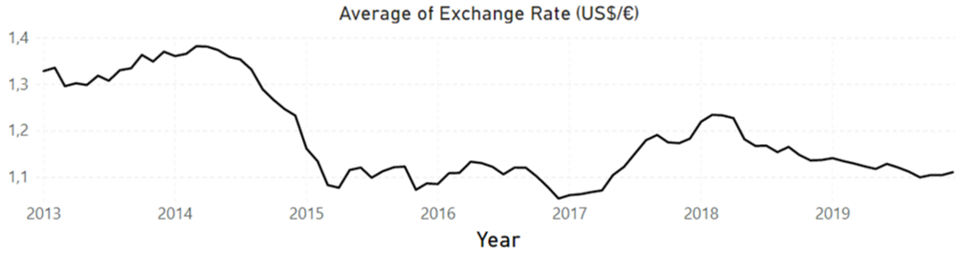


Figure 5.1: Monthly average of the Exchange Rate between US dollar and euro.

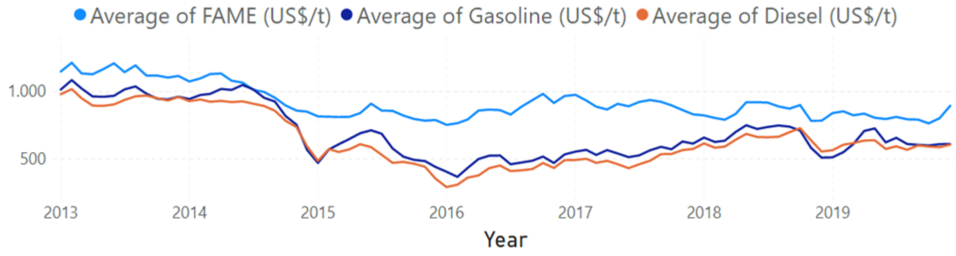


Figure 5.2: Monthly average evolution of FAME (US$/t), Gasoline (US$/t) and Diesel (US$/t).

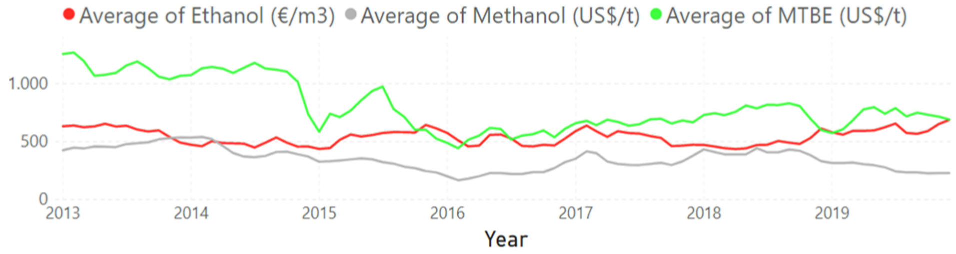


Figure 5.3: Monthly average evolution of Ethanol (€/m^3), Methanol (US$/t) and MTBE (US$/t).

5.3 1st stage: Historical Analysis of quotations

The purpose of this first step is to provide the foundations for the following stage which involves building different scenarios. As a result, and in order to provide key insights of the different quotations, some statistical parameters such as the minimum, maximum and arithmetic mean values, the standard deviation, the coefficient of variation and different percentiles are evaluated.

Minimum and maximum values are self explanatory and are crucial to bound the different quotations. Further, the sample mean ($\bar{x}$) (or mean) is the average of each set of quotations and can be seen as a measure of central tendency. Equation 5.1 defines the mean of each series of quotations, where N represents the total number of samples (in this case, the total number of days), and x portrays the quotation value.

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{5.1}$$

The standard deviation (σ) is a measure of the amount of dispersion of the set of values (a low standard deviation indicates that the values tend to be close to the mean). Equation 5.2 describes its calculation.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2} \tag{5.2}$$

The coefficient of variation (c_v) is defined as a ratio of the standard deviation to the mean. It shows the extent of variability in relation to the mean of the population. Equation 5.3 illustrates its calculation.

$$c_v = \frac{\sigma}{\bar{x}} \tag{5.3}$$

A percentile is a measure used in statistics indicating the value below which a given percentage of observations in a group of observations falls. For example, the 50th percentile is the value below which 50% of the observations may be found. Since these calculations does not follow a simple equation but multiple steps, the author used a Python script to compute different percentiles.

5.4 Output 1/ Input 2

Table 5.1 summarises the different results obtained for each quotation based on equations 5.1, 5.2, 5.3 and the Python script previously mentioned.

Table 5.1: Summarised results of historical analysis of quotations

	Exchange Rate (US$/€)	**Ethanol (€/m^3)**	**Methanol (US$/t)**	**MTBE (US$/t)**	**FAME (US$/t)**	**Gasoline (US$/t)**	**Diesel (US$/t)**
Mean	1.19	540.15	349.74	807.49	919.71	689.06	638.60
Standard Deviation	0.10	68.61	94.47	220.69	126.81	195.84	194.42
Coefficient of variation (%)	8.40	12.70	27.01	27.33	13.79	28.42	30.44
Minimum	1.04	416.75	160.79	400.25	720.00	336.00	246.75
25th percentile	1.11	475.69	282.83	645.38	822.00	532.69	484.50
50th percentile	1.14	543.13	340.86	739.50	881.00	622.63	590.63
75th percentile	1.28	591.25	418.15	1042.63	979.25	897.50	832.44
Maximum	1.40	714.50	550.90	1390.00	1244.00	1114.00	1042.50

Taking a closer look at table 5.1, there are some interesting conclusions. Firstly, both FAME and Ethanol have a lower coefficient of variation when compared to the refined products like diesel or gasoline. In fact, both biofuels have a similar coefficient of variation which is crucial to further define variations inside the scenarios in the following section.

Further, the difference between the maximum and minimum values is also higher in the refined products compared to the biofuels. Finally, comparing the mean values, FAME has a higher value compared to Diesel whereas ethanol has a lower value compared to gasoline.

5.5 Building Scenarios

At this point, the challenge is how to create relationships between the different quotations. It is a critical stage since the input parameters for the planning model software need to be meaningful for this thesis to be considered relevant. For instance, it would be irrelevant to study a scenario in which the diesel quotation is near to its highest value whereas the gasoline quotation is close to its lowest value (see figure 5.2 where these both quotations have a similar behaviour throughout the records).

Further, these relationships between quotations need to translate the fuel market insights and tendencies, and this raises a debating point - the tremendous complexity of such markets. As a result, instead of inferring rules from the market and applying them to the different quotations, the author decided to discover the market rules/tendencies from the historical quotations.

Otherwise stated, the idea is to understand tendencies between quotations and discover relationships among them - e.g. in 10% of the cases, the exchange rate is high, the ethanol is low, the methanol is high, etc. In order to attain such conclusions, specifying whether such quotation is classified as high or low is crucial. The rule for classification ($class$) of each quotation is defined in equation 5.4, where m stands for the minimum value, M represents the maximum value and mdn is the 50^{th} percentile (also known as Median value).

$$class = \begin{cases} Low, & \text{if } m \leq x_i < mdn \\ High, & \text{if } mdn \leq x_i \leq M \end{cases} \tag{5.4}$$

Further, figure 5.4 illustrates the relevant parameters for the previous equation - the minimum, the median and the maximum values for each quotation. For the sake of clarity and consistency, the applied colours match the ones previously presented on figures 5.1, 5.2 and 5.3.

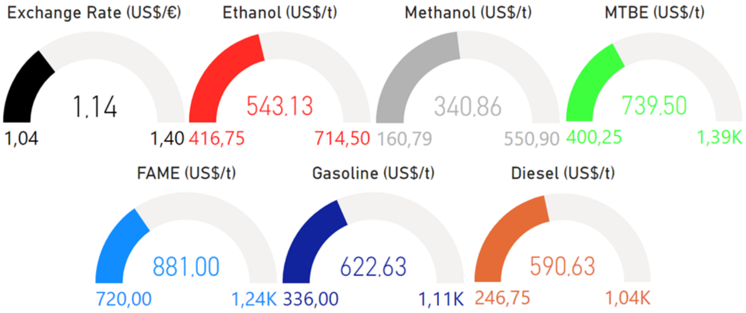


Figure 5.4: Representation of the minimum (on the left), the median (in the middle) and the maximum (on the right) values for each quotation

Through the velocimeter representation of the relevant values (figure 5.4), it is interesting to report that in all 7 quotations, the $High$ classification interval is always bigger than the Low interval. This happens since the median value is always lower than the mid point of the min-max interval.

Further, focusing on establishing quotations' relationships, the author built a probability tree diagram. This type of diagram is a way of representing a sequence of events (in this case, combining $High$ and Low events for all quotations). Tree diagrams are particularly useful since they record all possible outcomes in a straightforward manner. Associated with each tree branch, is a probability of occurrence, which, regarding this study, is always 50% - due to the definition of the median value, used to separate the Low and the $High$ branches.

Moreover, since this research requires the study of 7 different quotations, the number of tree branches and, therefore, number of scenarios is $2^7 = 128$. Figure 5.5 illustrates part of the tree diagram - only the first three quotations are illustrated to capture the idea of the real tree diagram due to the actual size of the tree with 128 branches - where ↓ represents Low in opposition to ↑ which stands for $High$.

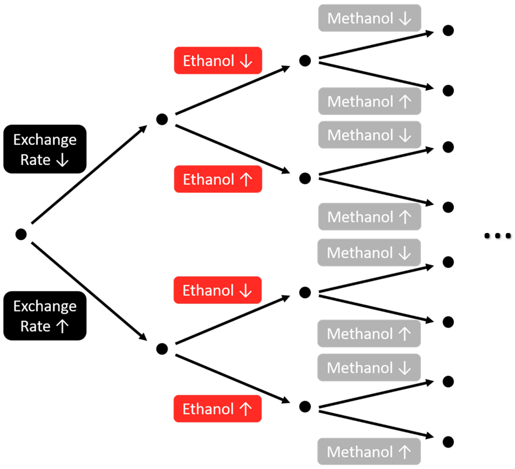


Figure 5.5: Part of the tree diagram.

The tree diagram framework is useful to overcome the barrier of the abstract thinking of quotations' relationships into 128 possible and measurable scenarios which combine the 7 types of quotations.

Thus, the following step is understanding how many of these scenarios are plausible and decide which ones to study in Galp's planning software, based on their frequency of occurrence (considering daily basis occurrences between 2013 and 2019). As a result, the author built an absolute frequency diagram which is illustrated in figure 5.6.

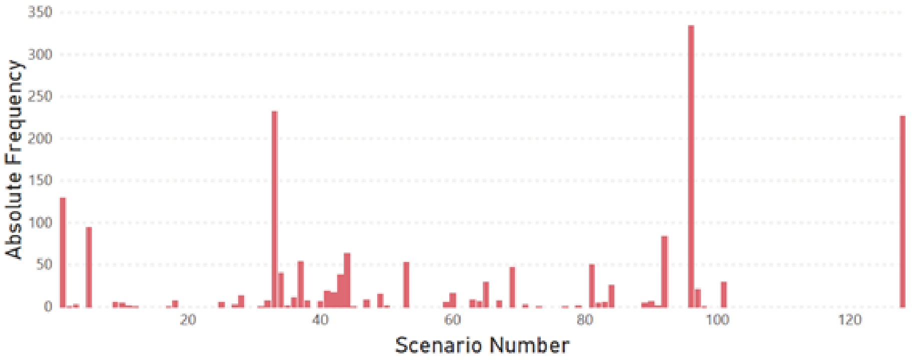


Figure 5.6: Absolute Frequency graph of the 128 scenarios.

Undoubtedly, even without a closer look, the absolute frequency diagram (figure 5.6) clarifies that 3 of the scenarios are the most frequently. Also, on the contrary, it illustrates that several scenarios did not occur at all. In reality, 73 of the scenarios (57%) do not represent a single occurrence (frequency 0). Additionally, there is a total of 110 scenarios (86%) representing less than 1% of the events (individually). In order to capture a broader understanding of the situation, figures 5.7 and 5.8 illustrate the cumulative frequency graph.

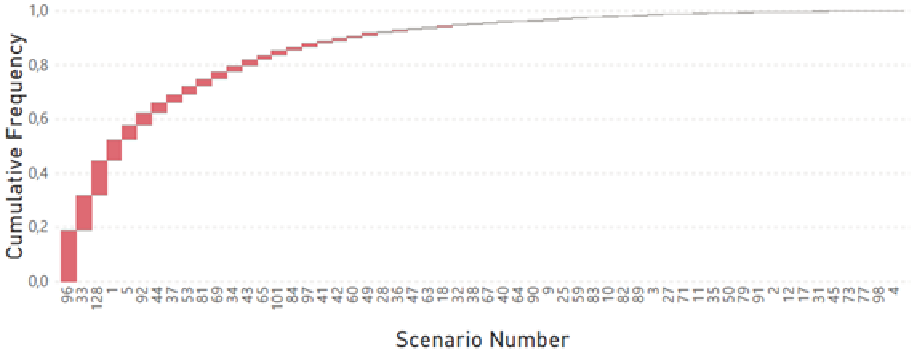


Figure 5.7: Cumulative frequency diagram.

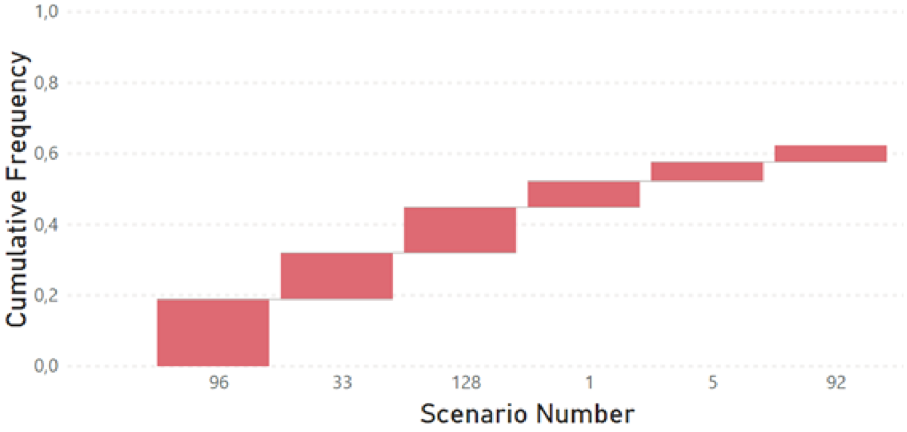


Figure 5.8: A closer look at the cumulative frequency diagram.

To summarise, it is interesting to notice that a little amount of scenarios constitute the majority of the occurrences. This idea is quite vivid from figure 5.7 where the slope is extremely high at the beginning and drastically drops after a few scenarios. Consequently, the author, aligned with Galp's Planning department, decided to study the most frequent 6 scenarios where the number of occurrences exceeds 90. Further, from figure 5.8 (a closer look at the cumulative graph) it is noteworthy that those 6 scenarios (4.7%) have a cumulative frequency of 62.4%.

The 6 most-relevant scenarios are briefly described in table 5.2 where ↑ represents $High$ in opposition to ↓ which stands for Low.

Table 5.2: Overview of the 7 most frequent scenarios.

Scenario Number	Frequency (%)	Exchange Rate (US$/€)	Ethanol (€/m^3)	Methanol (US$/t)	MTBE (US$/t)	FAME (US$/t)	Gasoline (US$/t)	Diesel (US$/t)
96	18,9	↑	↓	↑	↑	↑	↑	↑
33	13,1	↓	↑	↓	↓	↓	↓	↓
128	12,8	↑	↑	↑	↑	↑	↑	↑
1	7,4	↓	↓	↓	↓	↓	↓	↓
5	5,4	↓	↓	↓	↓	↑	↓	↓
92	4,8	↑	↓	↑	↑	↓	↑	↑

By analysing table 5.2 and recapping the beginning of this section, some market tendencies can be withdrawn. It is interesting that Gasoline and Diesel quotations' behaviour follow the same pattern - as previously stated by observing figure 5.2 - although, this time, the author reached the same expected conclusion without explicitly observe those individual behaviours, but by building and exploring the tree diagram to create scenarios. Additionally, it is interesting that the 4 most frequent scenarios are two pairs of opposite situations. In fact, scenario 96 is the exact opposite scenario compared to scenario 33 whereas scenario 128 is the opposite of scenario 1.

Further, also from table 5.2, it is vivid that the MTBE and Methanol quotations, as well as the exchange rate, follow the exact same behaviour as the petroleum-based fuels - diesel and gasoline. Finally, apparently both Ethanol and FAME quotations do not follow other reference prices. This raises an interesting point of debate. Among the 7 reference prices, both FAME and Ethanol are the most important ones for this study, since they are the biofuels. Hence, and taking into consideration that both quotations do not follow the others, trying to understand market insights at the beginning and then come up with scenarios would have been harder and the outcome might have been poorer. Within this approach, the relationship between quotations is somehow irrelevant since the outcome translates those exact relationships.

At this point, the author has narrowed down the 128 scenarios to 6. Although, each of them only possesses qualitative attributes, either $High$ or Low. Since quantitative quotations are required in Galp's downstream planning model, an additional step is required to convert the qualitative information into quantitative inputs. Recapping the author's definition of $High$ and Low (equation 5.4 and figure 5.4), the author decided to use the midpoint of each interval to represent such $Class$.

Finally, it is vivid that different scenarios may have a significant difference from others. Therefore, comparing its results will turn out (in most cases) to be pointless. Hence, the author decided to divide each scenario into 5 scenarios - a baseline scenario + 2 scenarios regarding changes in FAME + 2 scenarios regarding changes in Ethanol. As a result, the 6 scenarios are 6 groups of 5 scenarios where inside each group they can all be compared with their baseline. This idea is also useful for the sensitivity analysis described in section 5.8.

5.6 Output 2/ Input 3

Table 5.3 illustrates the 30 scenarios to be evaluated and tested in Galp's optimisation software. Each group of scenarios has an associated number (related to the previous studied 6 scenarios (see table 5.2)) and points (a), (b), (c) and (d) which represent either the increase (↗) or decrease(↘) in a specific biofuel quotation. In each point, only one change is performed compared to the baseline.

Table 5.3: Scenarios' definition and overview.

Scenario Number	**Exchange Rate (US$/€)**	**Ethanol (€/m^3)**	**Methanol (US$/t)**	**MTBE (US$/t)**	**FAME (US$/t)**	**Gasoline (US$/t)**	**Diesel (US$/t)**
96	1,27	480	446	1065	1063	868	817
(a) ↗ 10% FAME	1,27	480	446	1065	**1169**	868	817
(b) ↘ 10% FAME	1,27	480	446	1065	**957**	868	817
(c) ↗ 10% Ethanol	1,27	**528**	446	1065	1063	868	817
(d) ↘ 10% Ethanol	1,27	**432**	446	1065	1063	868	817
33	1,09	629	251	570	801	479	419
(a) ↗ 10% FAME	1,09	629	251	570	**881**	479	419
(b) ↘ 10% FAME	1,09	629	251	570	**721**	479	419
(c) ↗ 10% Ethanol	1,09	**692**	251	570	801	479	419
(d) ↘ 10% Ethanol	1,09	**566**	251	570	801	479	419
128	1,27	629	446	1065	1063	868	817
(a) ↗ 10% FAME	1,27	629	446	1065	**1169**	868	817
(b) ↘ 10% FAME	1,27	629	446	1065	**957**	868	817
(c) ↗ 10% Ethanol	1,27	**692**	446	1065	1063	868	817
(d) ↘ 10% Ethanol	1,27	**566**	446	1065	1063	868	817
1	1,09	480	251	570	801	479	419
(a) ↗ 10% FAME	1,09	480	251	570	**881**	479	419
(b) ↘ 10% FAME	1,09	480	251	570	**721**	479	419
(c) ↗ 10% Ethanol	1,09	**528**	251	570	801	479	419
(d) ↘ 10% Ethanol	1,09	**432**	251	570	801	479	419
5	1,09	480	251	570	1063	479	419
(a) ↗ 10% FAME	1,09	480	251	570	**1169**	479	419
(b) ↘ 10% FAME	1,09	480	251	570	**957**	479	419
(c) ↗ 10% Ethanol	1,09	**528**	251	570	1063	479	419
(d) ↘ 10% Ethanol	1,09	**432**	251	570	1063	479	419
92	1,27	480	446	1065	801	868	817
(a) ↗ 10% FAME	1,27	480	446	1065	**881**	868	817
(b) ↘ 10% FAME	1,27	480	446	1065	**721**	868	817
(c) ↗ 10% Ethanol	1,27	**528**	446	1065	1063	868	817
(d) ↘ 10% Ethanol	1,27	**432**	446	1065	1063	868	817

5.7 Programming & Testing in Optimisation Software

This section encompasses a brief description of Galp's planning software - GRTMPS, developed by Haverly. Regarding Galp, since GRTMPS was already used in Refining planning, the Downstream Planning Department adapted the model to their needs. As a result, the author did not develop any part of the model but used the software to test the different scenarios. Regarding the model itself, it is noteworthy to mention that it considers numerous inputs such as the 7 mentioned quotations and the complex network of refineries, depots and service stations. Further, bearing in mind that the oil companies are legally compelled to introduce/blend biofuels within refined products in order to meet energetic targets, and since different biofuels have different impacts on the energetic target (non-linear relationship), the optimisation model is a non-linear model. The model aims to maximise results (margins) considering product supply and logistics costs.

As previously stated in chapter 2.7, the Iberian Peninsula comprehends two different paradigms for Galp either in logistics infrastructures or in Galp's market position. Although, there is another difference, between the Iberian countries. The downstream optimisation model is entirely focused on the Spanish market. Due to several rigid and established contracts in Portugal, the downstream supply of Galp in this country does not suffer relevant changes over time and, when it does, the contracts drive the downstream network composition. As a result, this research paper results and its analysis is entirely focused in Spain supply.

The output of the model is a complex network of downstream supply. It provides the optimal connections between refineries, depots and service stations. Finally, it is noteworthy to mention that the model itself might be tested within different time horizons (e.g. annual, monthly, semester, quarterly, etc.) for demand. In order to prevent sharing sensitive data, the author choose one specific time horizon for all the scenarios although it is not explicitly described which one.

5.8 Data-driven Sensitivity Analysis

This section represents the meaningful results of this thesis. Hence, it could be directly divided between each group of scenarios. Although, the author decided to perform such division in an indirect way. For the sake of clarity, this section is divided between segments of the downstream fuel network (see figure 2.6) which, in turn, gather results and information of each group of scenarios. Further, there is also a special emphasis in the Depots themselves where some products are blended and/or bought from other oil suppliers. Therefore, a deeper Depot analysis is also performed for each group of scenarios. The idea beyond this division is turning this analysis in a more fluid one and to avoid the repetition of ideas inside each group of scenarios.

Further, as previously defined, inside each set of scenarios, apart from the baseline, there are two scenarios regarding changes in FAME's quotation ((a) and (b)) and two regarding differences in Ethanol's quotation (c and d). Thus, since FAME is a biodiesel, the author decided to analyse the diesel network when studying changes of FAME. On the contrary, since Ethanol is a biogasoline, the performed analysis and results are related to the gasoline network. Put differently, the results of scenarios a and b are in terms of diesel movement, whereas, scenarios c and d are concerned with gasoline movements. Finally, since the key idea idea is to compare with the baseline, the author presents the baseline itself with the two types of movements. At the end of this chapter, to capture the real impact in the downstream supply costs, it is presented a cost overview analysis of the diferent scenarios.

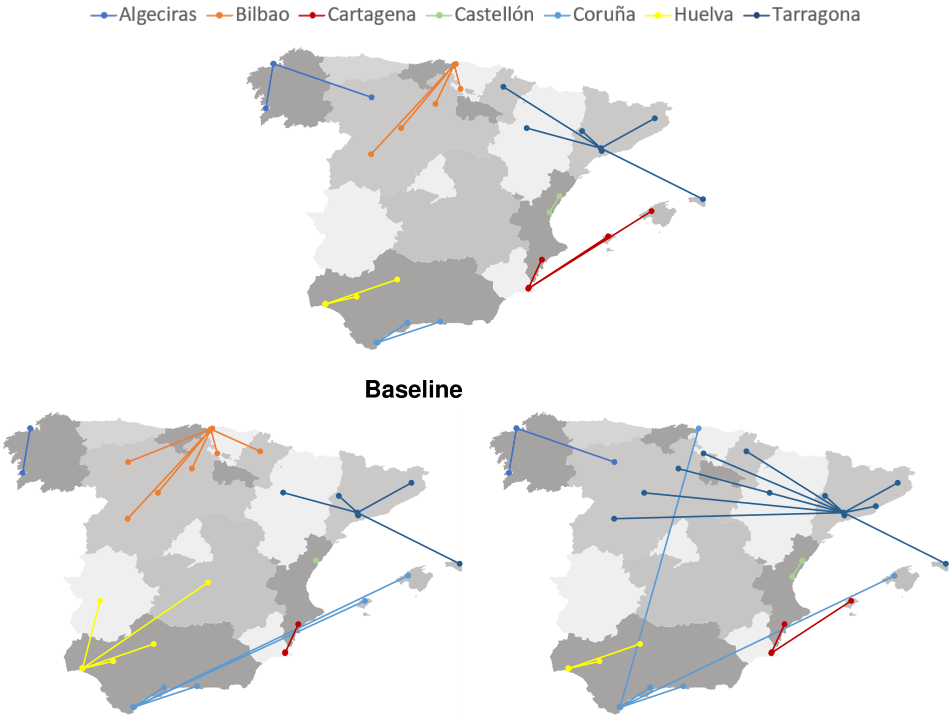
The key idea of this section is to retrieve relevant information about the downstream diesel and gasoline supply network of Galp under different circumstances. Due to the obvious sensitive information of Galp business, the author carefully displays the results in such a way to allow anyone who reads this paper to understand the results and conclusions without exposing Galp's sensitive data.

5.8.1 The 1st segment: From Refineries to Depots

The first part of this analysis focuses on the primary segment of the downstream supply - movements of products from Refineries to Depots. Remembering figure 2.8, the number of Spanish refineries is 8, however, the Puertollano Repsol's refinery is currently closed. Hence, the model only provides optimal networks regarding the 7 available Spanish refineries (Huelva and Algeciras from Cepsa; Castellón from Bp and Coruña, Bilbao, Tarragona and Cartagena from Repsol).

- **Diesel Network**

The results regarding the first segment of the diesel network comprehend two types of information. Firstly, for each group of scenarios (baseline + (a) + (b)) there are three maps (one for each) grouped as one figure illustrating the resulting connections between refineries and several depots. Hence, figures 5.9, 5.10, 5.11, 5.12, 5.13 and 5.14 correspond to the group of scenarios 96, 33, 128, 1, 5 and 92, respectively. Following, in order to get a broader understanding of each refinery's diesel movement, in terms of volume, figures 5.15, 5.16, 5.17, 5.18, 5.19 and 5.20 illustrate the volume of diesel moving out of each refinery, correlating to the group of scenarios 96, 33, 128, 1, 5 and 92, respectively.

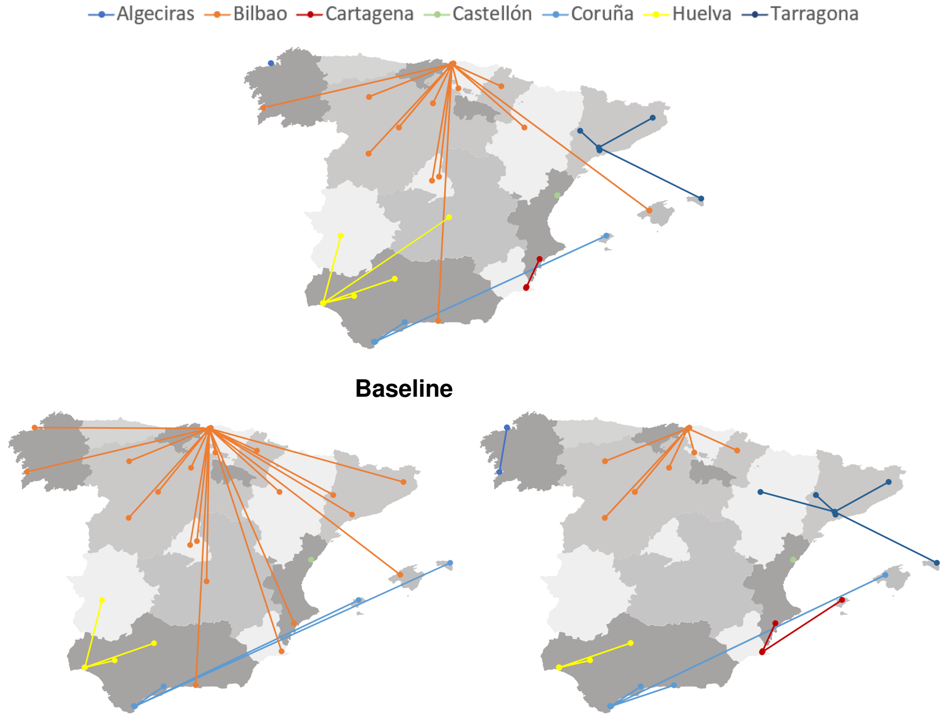


Baseline

(a)

(b)

Figure 5.9: Diesel network (1st segment) regarding scenario 96 baseline, 96 (a) and 96 (b).

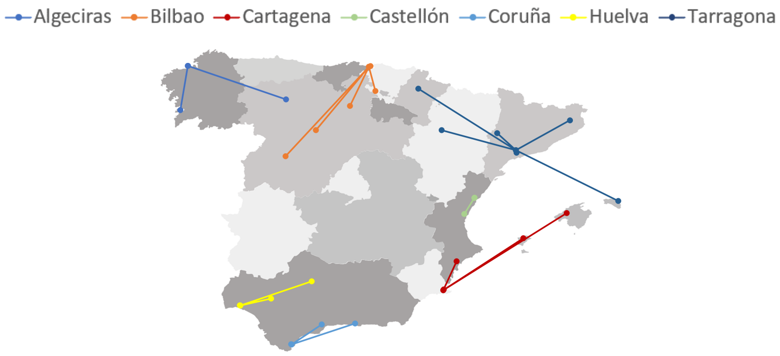


Baseline

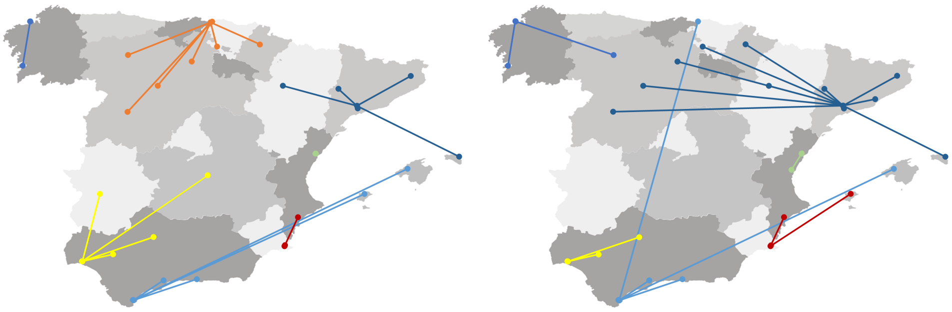
(a)

(b)

Figure 5.10: Diesel network (1st segment) regarding scenario 33 baseline, 33 (a) and 33 (b).

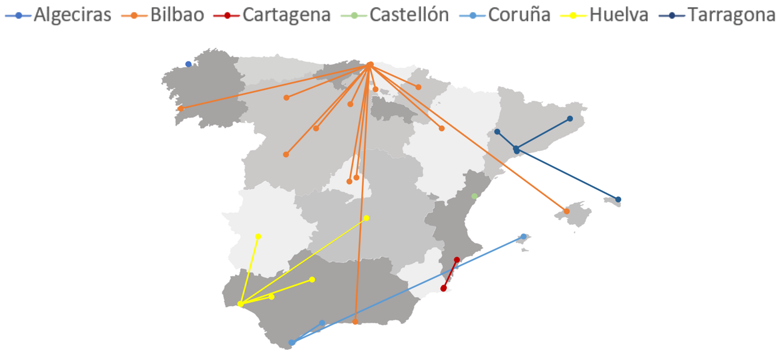


Baseline

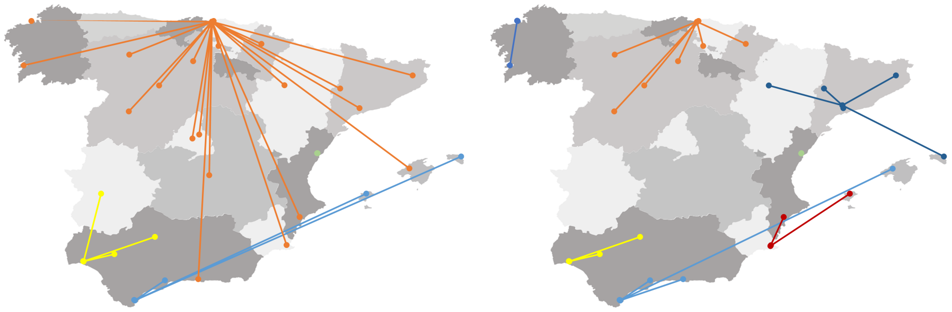


(a) **(b)**

Figure 5.11: Diesel network (1st segment) regarding scenario 128 baseline, 128 (a) and 128 (b).

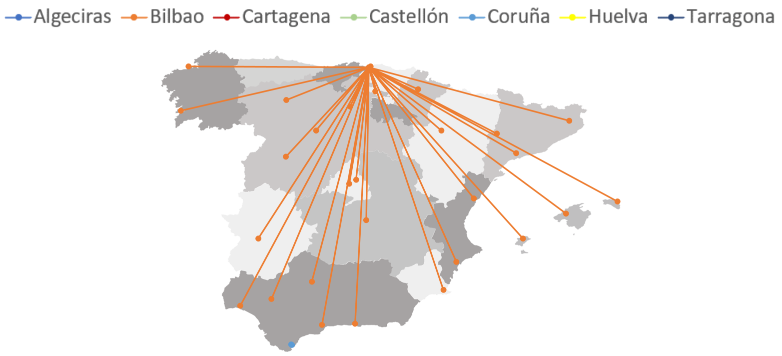


Baseline

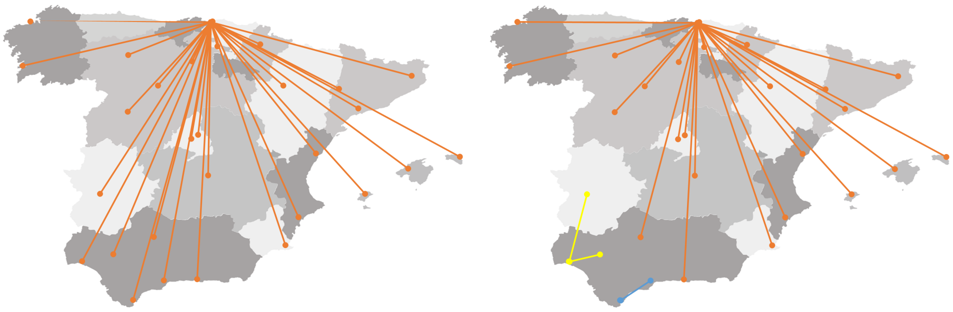


(a) **(b)**

Figure 5.12: Diesel network (1st segment) regarding scenario 1 baseline, 1 (a) and 1 (b).

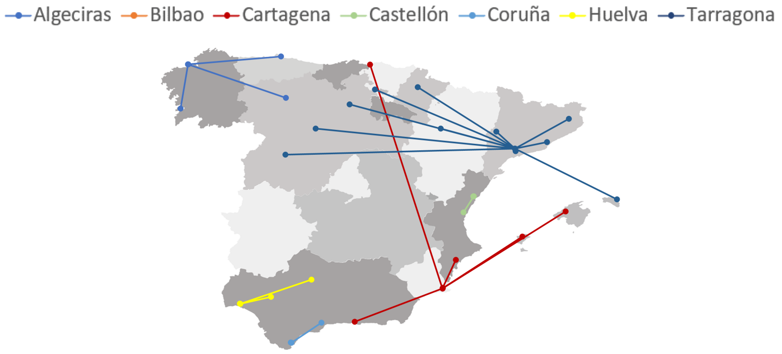


Baseline

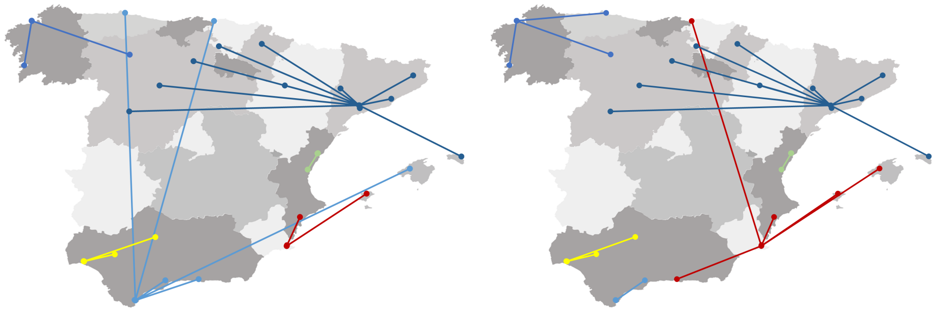


(a) **(b)**

Figure 5.13: Diesel network (1^{st} segment) regarding scenario 5 baseline, 5 (a) and 5 (b).



Baseline



(a) **(b)**

Figure 5.14: Diesel network (1^{st} segment) regarding scenario 92 baseline, 92 (a) and 92 (b).

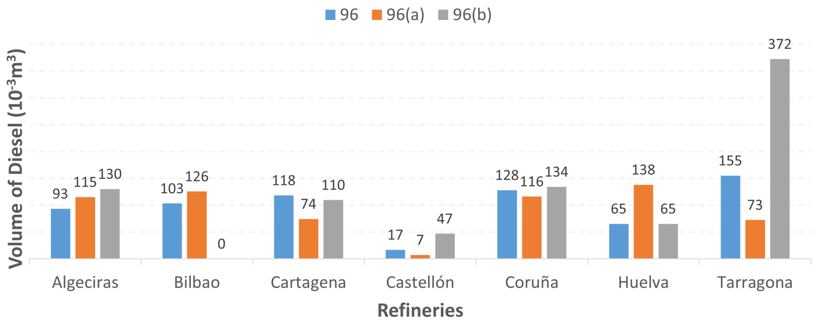


Figure 5.15: Volume of Diesel moving out of Refineries regarding scenario 96 baseline, 96 (a) and 96 (b).

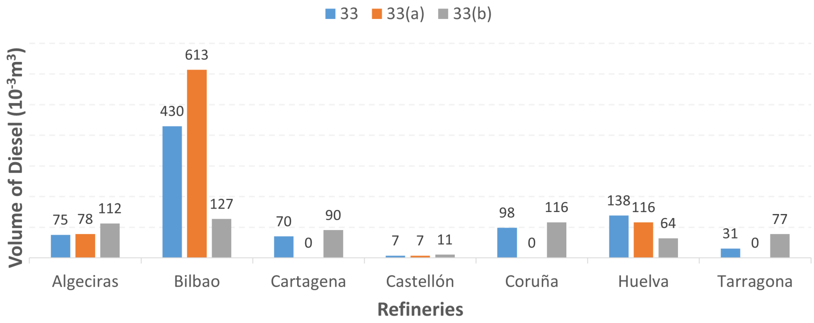


Figure 5.16: Volume of Diesel moving out of Refineries regarding scenario 33 baseline, 33 (a) and 33 (b).

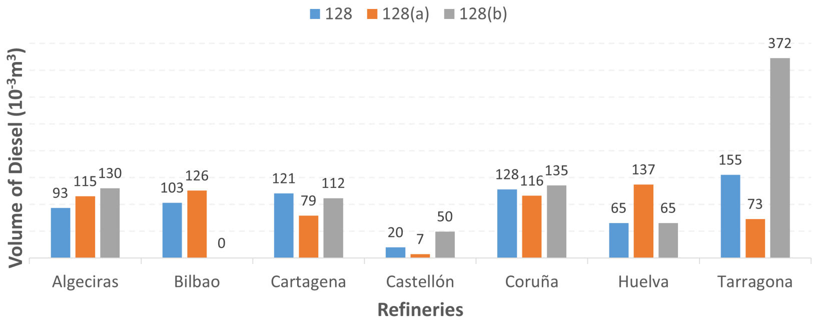


Figure 5.17: Volume of Diesel moving out of Refineries regarding scenario 128 baseline, 128 (a) and 128 (b).

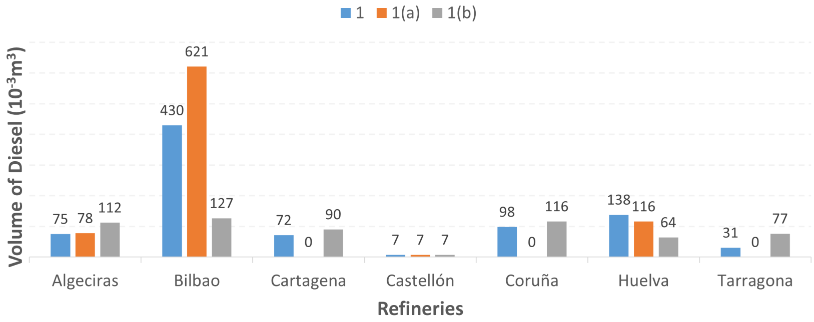


Figure 5.18: Volume of Diesel moving out of Refineries regarding scenario 1 baseline, 1 (a) and 1 (b).

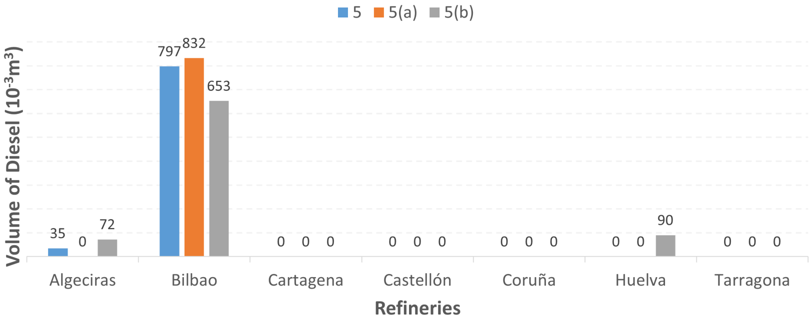


Figure 5.19: Volume of Diesel moving out of Refineries regarding scenario 5 baseline, 5 (a) and 5 (b).

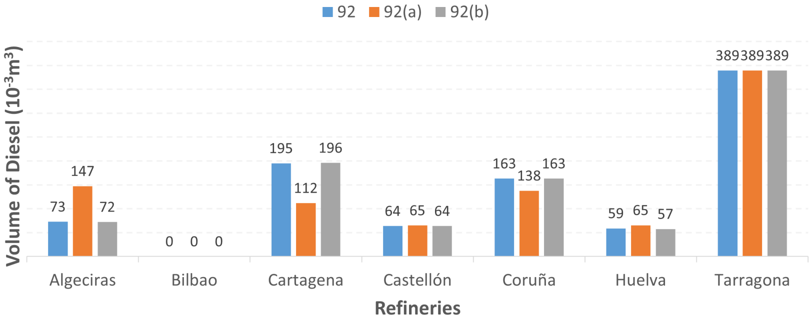


Figure 5.20: Volume of Diesel moving out of Refineries regarding scenario 92 baseline, 92 (a) and 92 (b).

The given results are analysed taking into account two different perspectives. As previously stated, the way each group of scenarios is built allows that all scenarios (a) and (b) may be compared with its baseline scenario since there is only one type of variation. However, it is also possible to compare different groups of scenarios.

In fact, scenario 96 can be analysed alongside scenario 128 since all the inputs are the same except Ethanol's quotation which is higher in scenario 128. Further, the exact same situation happens between scenarios 33 and 1, being the Ethanol's quotation input higher in scenario 33. A slightly different situation occurs between scenarios 1 with 5 and 96 with 92 where all the inputs are equal except FAME's quotation. Actually, between scenarios 1 and 5, FAME's quotation is higher in 5, whereas, between 96 and 92 the same quotation is higher in 96.

Starting the analysis by taking a closer look at scenario 96, from the different networks (figure 5.9) it is vivid that when FAME's quotations drops 10% (scenario (b)), the resulting network does not include Bilbao's refinery. Therefore, the previous Bilbao supplied depots (in the baseline case) are now mainly supplied by another Repsol refinery - Tarragona. Further, considering an increase in FAME's quotation by 10% (scenario (a)), the rearranged network entails a significant difference in Huelva refinery since it now supplies 2 new depots. In fact, analysing figure 5.15, where the volume of diesel moving out of refineries is displayed, those conclusions are supported. Tarragona refinery in scenario 96 (b) distributes 140% more diesel compared to the baseline while Huelva refinery supplies 112% more diesel in scenario 96 (a) compared to the baseline.

Since scenario 96 might be compared with scenario 128, figures 5.11 and 5.17 are now explored. It is worth noting that even though the Ethanol's quotation has increased 31%, the diesel network remains practically the same either in configuration (figure 5.11) or in terms of volumes (figure 5.17). This raises an interesting point of debate - does the ethanol's quotation impact the network?

Further, bearing in mind the raised question, let's observe another comparable pair of scenarios where the same situation might occur. Indeed, by analysing scenarios 33 and 1 altogether (figures 5.10, 5.12, 5.16 and 5.18) the same conclusion is withdraw. In other words, even a totally different input (scenarios 33 and 1 do not have a single equal input compared with scenarios 96 and 128) provided the same results - the diesel network remains practically untouched either in configuration or in terms of volume.

Taking a closer look at the diesel network of scenarios 33 and 1 (figures 5.10 and 5.12) it is noteworthy that when FAME's quotation drops 10%, Bilbao refinery tends to lose its importance. In fact, bearing in mind that FAME's quotation increases from scenario (b) to the baseline and then to scenario (a), the same happens to Bilbao's refinery importance. On the contrary, with the increase of FAME's quotation, Tarragona's refinery loses importance. This idea is also supported by figures 5.16 and 5.18.

Moreover, scenario 5 is a very interesting one. Analysing its diesel network, illustrated by figure 5.13, it becomes clear the Bilbao's refinery importance. In reality, in either the baseline situation or scenarios (a) and (b) it is vivid the orange domination in the map representing the Bilbao's refinery connections. In addition, figure 5.18 captures the same idea and helps drawing another conclusion - the importance of Bilbao's refinery arises when FAME's quotation increases.

Further, a particularly different scenario - 92. Until now, Bilbao's refinery was one of the key points of discussion. Although, in scenario 92, Bilbaos' refinery is not used. Observing figure 5.14, it is interesting to mention that Castellón, Huelva and Tarragona's refineries connections do not suffer any changes in scenarios (a) or (b) compared to the baseline. Figure 5.20 also supports the same idea. Further, analysing both figures combined, the optimal diesel network design for scenarios 92 baseline and 92 (b) is almost the same since only slightly volume differences occur.

Finally, the comparable pairs of scenarios where the input difference was regarding the Ethanol's quotation were already analysed. However, the comparable pairs where the difference stands on the FAME's quotation input are yet to evaluate. Hence, let's observe scenario 1 with 5 and scenario 96 with 92. Firstly, in opposition to what happened between scenarios with Ethanol's variation, these scenarios have significant changes in its network. This outcome was obvious since all the previous analysis inside each scenario (comparing the baseline with scenarios (a) and (b)) was based on FAME's quotation changes.

The only difference between scenarios is the magnitude of that change. Previously, the magnitude was ± 10% compared to the baseline, although, the magnitude of change between these pair of scenarios is 33% (scenario 5/96 baseline has a 33% higher FAME input than scenario 1/92 baseline, respectively). Figures 5.21 and 5.22 provide a broader understanding.

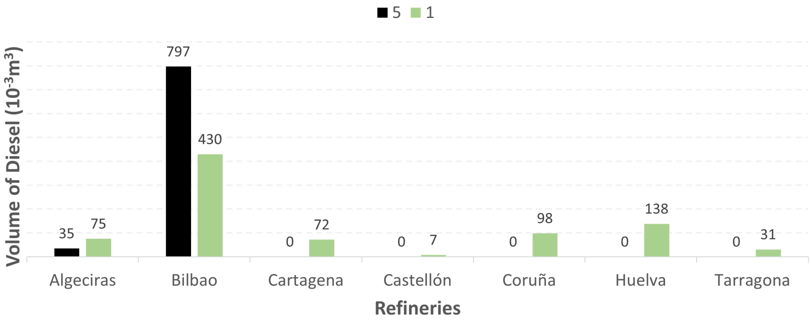


Figure 5.21: Volume of Diesel moving out of Refineries regarding scenario 5 baseline and 1 baseline.

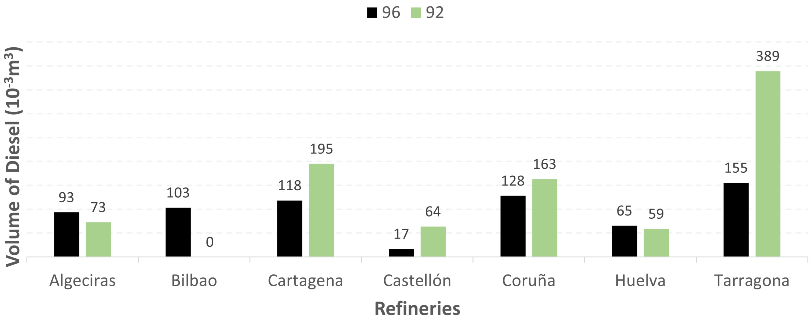
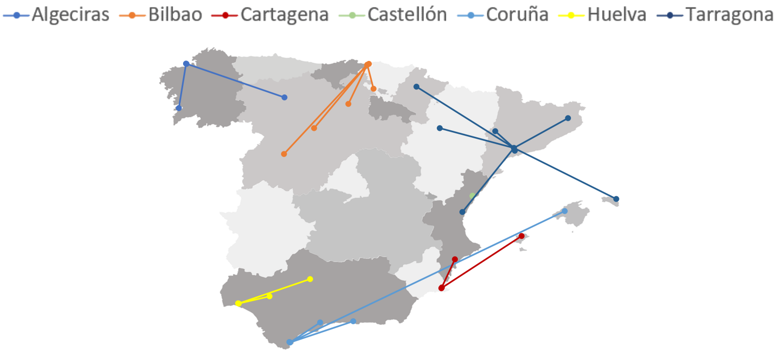


Figure 5.22: Volume of Diesel moving out of Refineries regarding scenario 96 baseline and 92 baseline.

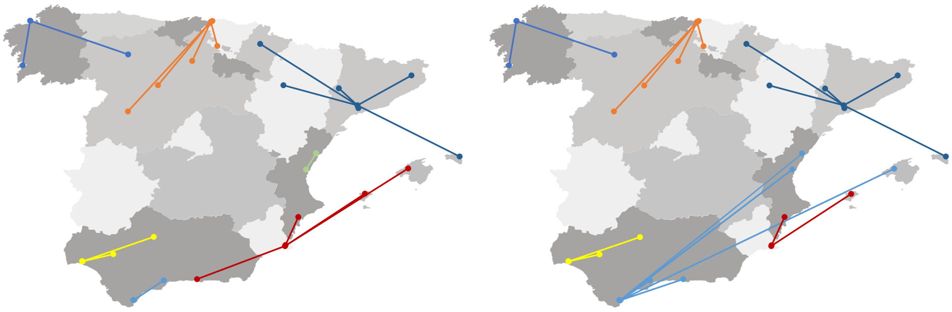
Notwithstanding the greater magnitude of change of FAME's quotation between different scenarios, the same key conclusions can be withdrawn. On one hand, in both cases (figures 5.21 and 5.22) the importance of Bilbao's refinery arises when FAME's quotation increases. On the other hand, the importance of Tarragona's refinery decreases as FAME's quotation increases.

- **Gasoline Network**

In regard to the 1st segment of the gasoline network, the results are also divided between two types of information aligned to what happened in the diesel network. Hence, figures 5.23, 5.24, 5.25, 5.26, 5.27 and 5.28 represent the gasoline network of each baseline and scenarios (c) and (d), correlating to the group of scenarios 96, 33, 128, 1, 5 and 92, respectively. Further, the volume of gasoline moving out of refineries is described in figures 5.29, 5.30, 5.31, 5.32, 5.33 and 5.34 corresponding to the group of scenarios 96, 33, 128, 1, 5 and 92, respectively.

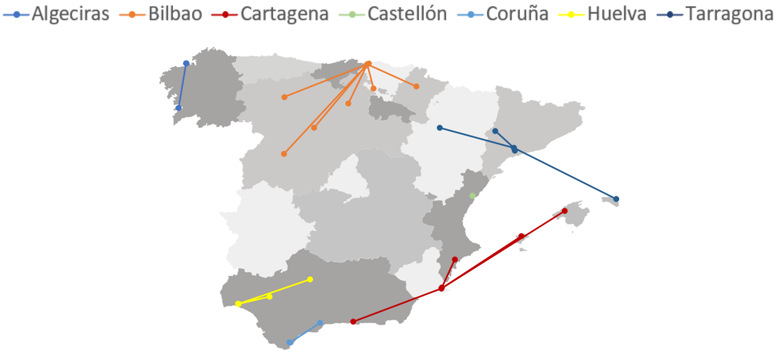


Baseline

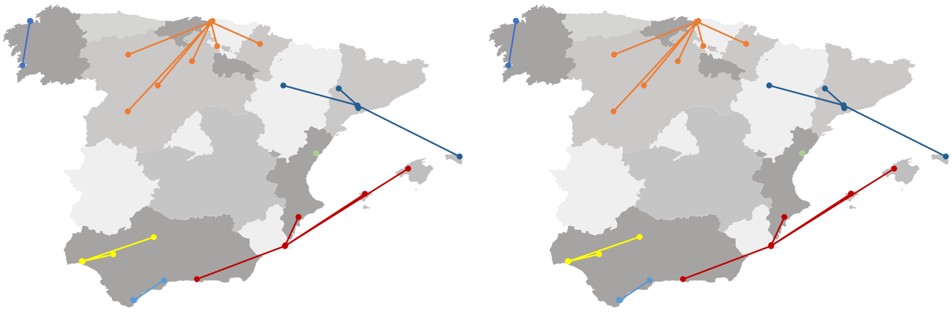


(c) **(d)**

Figure 5.23: Gasoline network (1st segment) regarding scenario 96 baseline, 96 (c) and 96 (d).

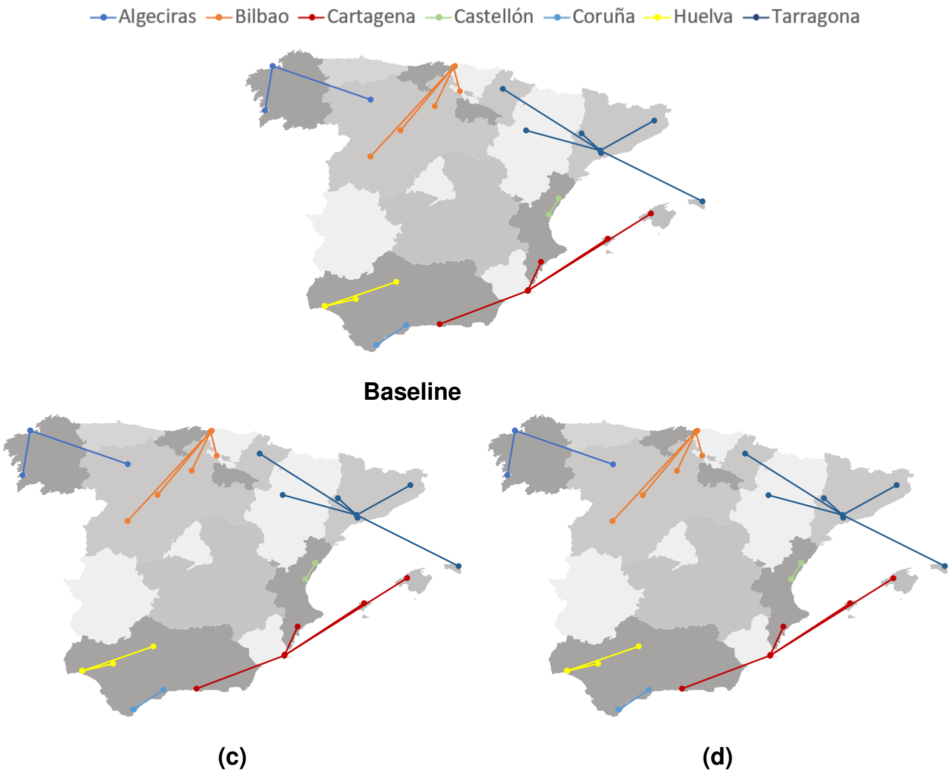


Baseline



(c) **(d)**

Figure 5.24: Gasoline network (1st segment) regarding scenario 33 baseline, 33 (c) and 33 (d).

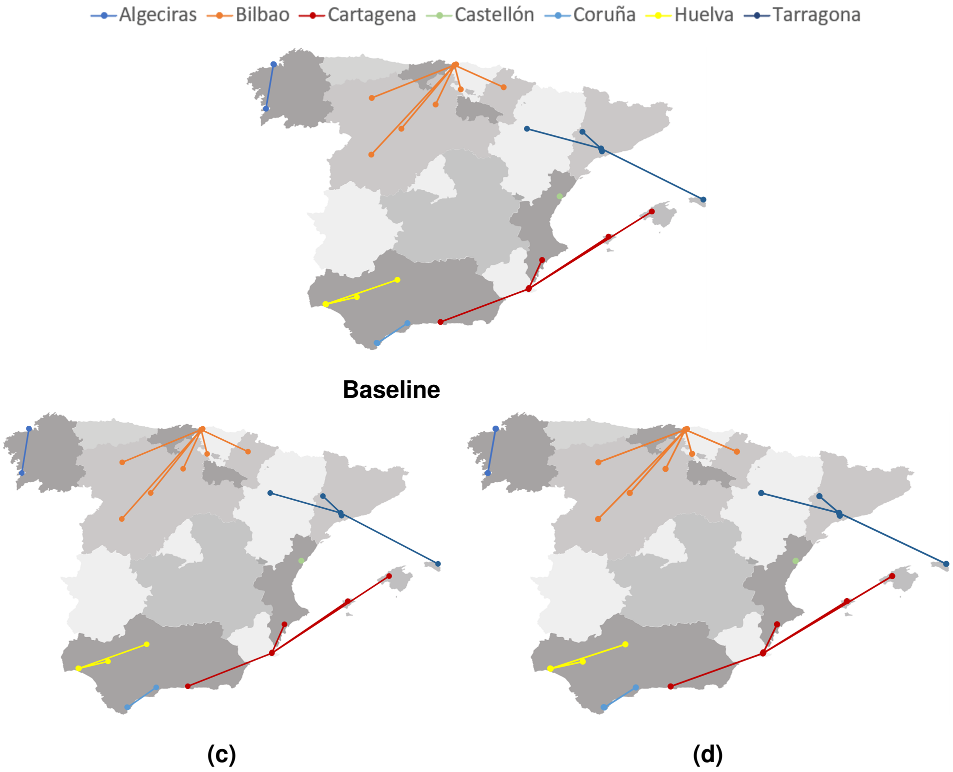


Baseline

(c)

(d)

Figure 5.25: Gasoline network (1st segment) regarding scenario 128 baseline, 128 (c) and 128 (d).

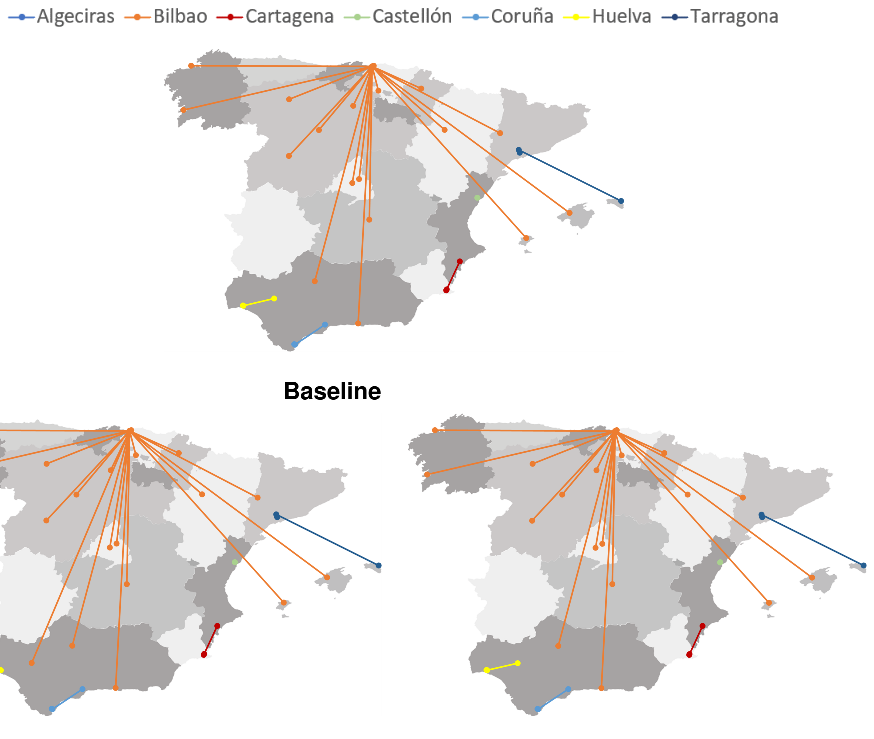


Baseline

(c)

(d)

Figure 5.26: Gasoline network (1st segment) regarding scenario 1 baseline, 1 (c) and 1 (d).

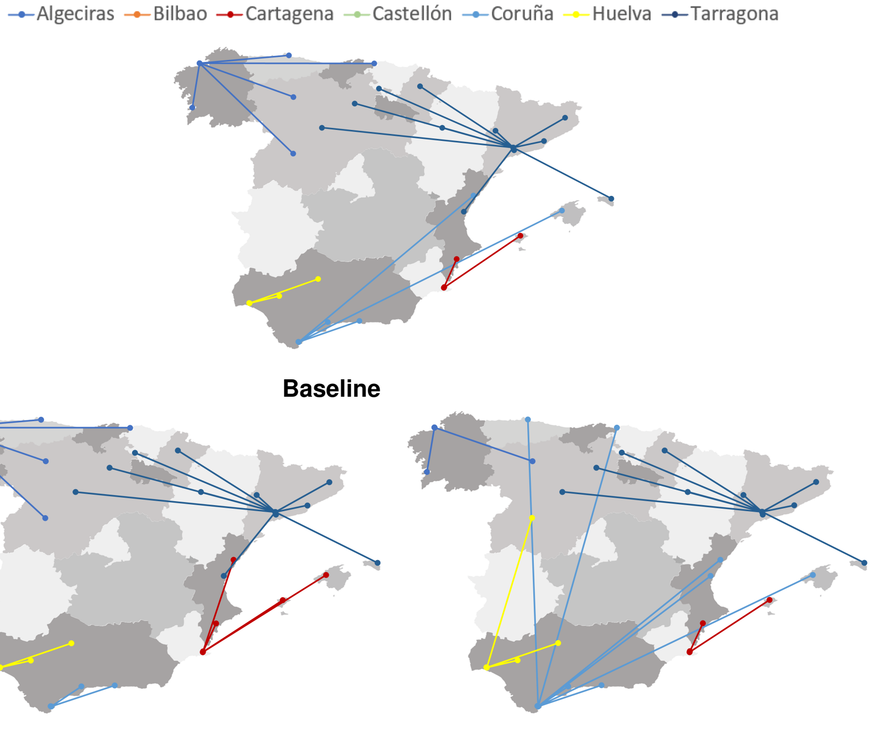


Baseline

(c)

(d)

Figure 5.27: Gasoline network (1st segment) regarding scenario 5 baseline, 5 (c) and 5 (d).



Baseline

(c)

(d)

Figure 5.28: Gasoline network (1st segment) regarding scenario 92 baseline, 92 (c) and 92 (d).

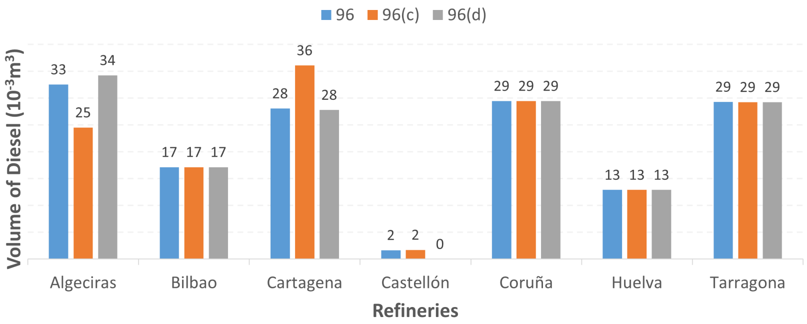


Figure 5.29: Volume of Gasoline moving out of Refineries regarding scenario 96 baseline, 96 (c) and 96 (d).

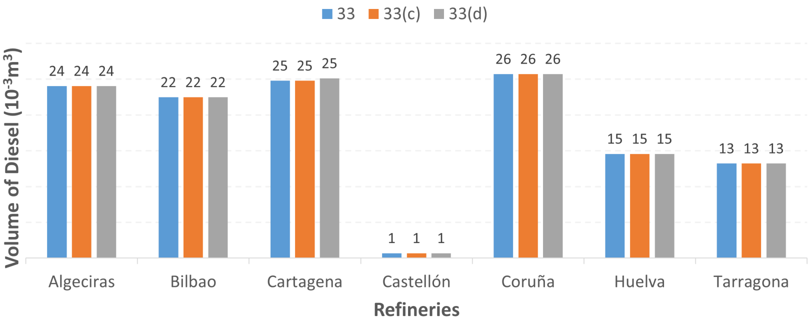


Figure 5.30: Volume of Gasoline moving out of Refineries regarding scenario 33 baseline, 33 (c) and 33 (d).

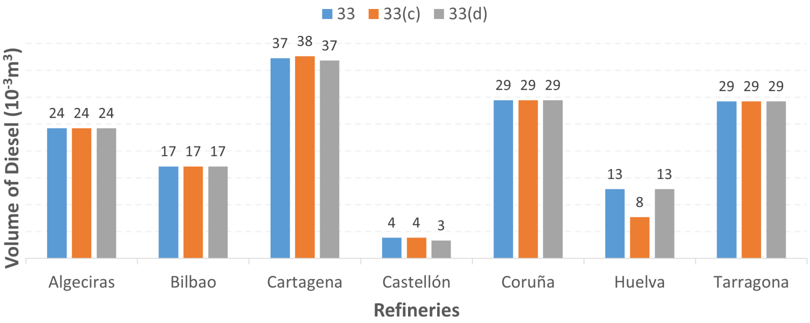


Figure 5.31: Volume of Gasoline moving out of Refineries regarding scenario 128 baseline, 128 (c) and 128 (d).

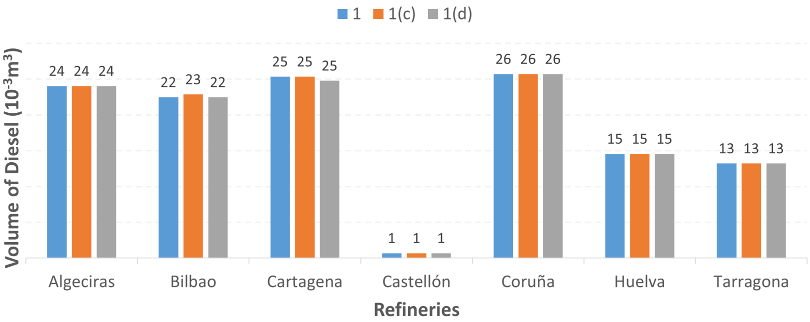


Figure 5.32: Volume of Gasoline moving out of Refineries regarding scenario 1 baseline, 1 (c) and 1 (d).

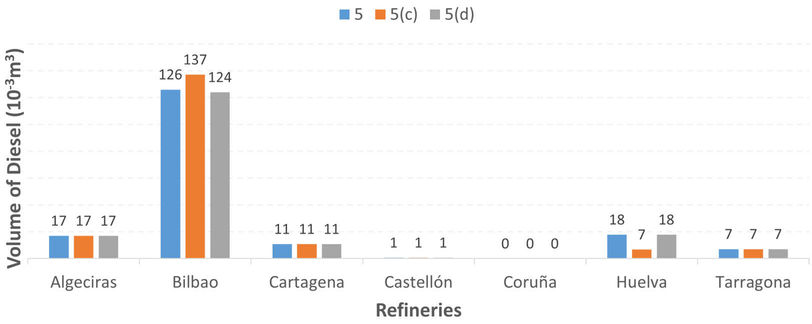


Figure 5.33: Volume of Gasoline moving out of Refineries regarding scenario 5 baseline, 5 (c) and 5 (d).

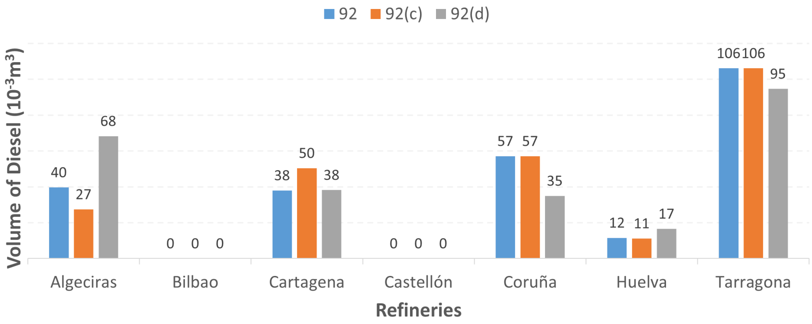


Figure 5.34: Volume of Gasoline moving out of Refineries regarding scenario 92 baseline, 92 (c) and 92 (d).

The given gasoline network results are analysed taking into account the same two different perspectives as the diesel network was - analysis inside a group of scenarios and analysis of comparable pairs of scenarios.

Before a deeper understanding of the gasoline network, it is important to recall a particular result in the diesel network - the diesel network did not suffer relevant changes when only the Ethanol's quotation input varies. This discovery was quite expected since Ethanol, as a biogasoline, should impact the gasoline network and not the diesel network. Although, regarding the gasoline network, the same situation also occurs.

In fact, excluding scenarios 96 and 92, all the scenarios remain almost unchanged with changes in the Ethanol's quotation. By analysing figures 5.24, 5.25, 5.26 and 5.27 it is vivid that changes of ± 10% of Ethanol's quotation comparing to its baseline did not impact the gasoline network. Taking a closer look on figures 5.30, 5.31, 5.32 and 5.33 becomes clear that the volume of gasoline moving out of each refinery did not suffer any relevant change.

Further, even considering scenarios 96 and 92, where the network suffer some changes compared to the baseline (figures 5.23 and 5.28), the volume of gasoline coming out of each refinery did not suffer meaningful changes. Regarding scenario 96 (figure 5.29), comparing the baseline with scenario (c), the relevant difference stands in Algeciras' refinery where the volume of gasoline decreases 24% and in Cartagena's refinery where the volume of gasoline increases 29%. Further, comparing the baseline with scenario (d), the relevant difference is in Castellón's refinery (the least relevant in terms of volume) where the volume drops 100%. On the other hand, regarding scenario 92 itself, there are a few changes, comparing the baseline with scenario (c), in Algeciras and Cartagena's refineries. In Algeciras, there is a drop of 33% of gasoline volume whereas there is an increase of 32% in Cartagena. Finally, regarding scenario 92 (d) compared with 92 baseline, there is an increase of 70% in Algeciras and a decrease of 39% in Coruña. There are also lighter changes in Huelva and Tarragona.

The second part of this analysis is an inter-scenario analysis (between comparable pairs of scenarios). Reinforcing the idea of the light changes derived by the Ethanol's quotation is the analysis between scenarios 96 with 128 and 33 with 1. It is vivid that either the network distribution (figures 5.23 with 5.25 or figures 5.24 with 5.26) either the amount of gasoline (figures 5.29 with 5.31 or figures 5.30 with 5.32) suffer minor changes. On the contrary, changes in FAME's quotation real impact the gasoline network as well. Figures 5.35 and 5.36 provide a broader understanding.

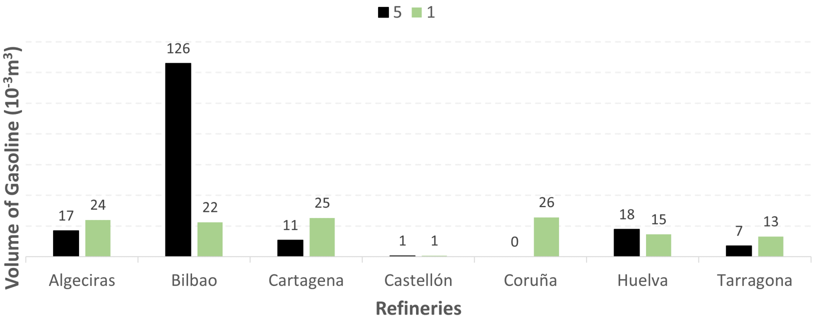


Figure 5.35: Volume of Gasoline moving out of Refineries regarding scenario 5 baseline and 1 baseline.

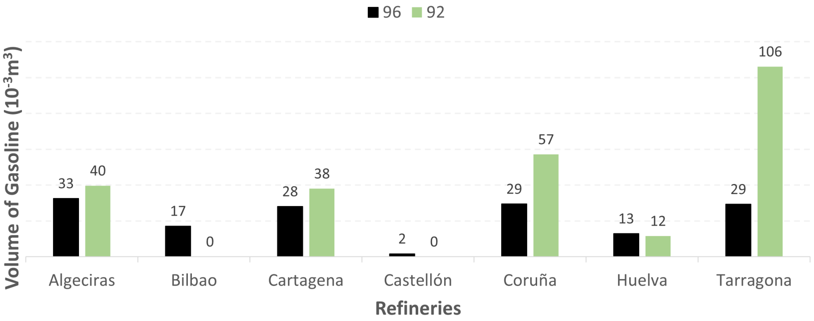


Figure 5.36: Volume of Gasoline moving out of Refineries regarding scenario 96 baseline and 92 baseline.

Notwithstanding this is a gasoline network, the changes of FAME's quotation between different scenarios has quite an impact. It is also interesting that the same key conclusions can be withdrawn. On one hand, in both cases (figures 5.35 and 5.36) the importance of Bilbao's refinery arises when FAME's quotation increases. On the other hand, the importance of Tarragona's refinery decreases as FAME's quotation increases.

5.8.2 A deeper Depot analysis

The second part of this analysis focuses on the connection point between the primary and the secondary segment of the downstream supply - Depots. Remembering figure 2.8, there are various depots spread around Spain that Galp (and, obviously, Galp's competitors) may utilise to fulfil costumer's demand. This analysis will focus on the used depots to store diesel before supplying the service stations.

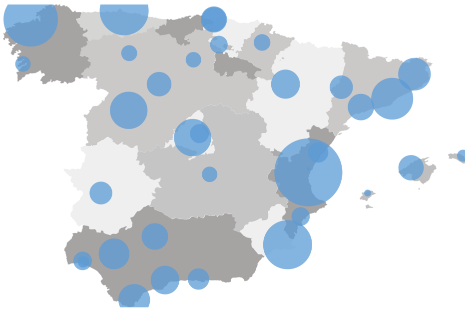
This analysis will be only focused on the diesel network since variations of Ethanol did not significantly impact the gasoline network as outlined in the previous section (remembering that the idea of studying the gasoline network was to analyse changes in Ethanol's quotation). Further, section 5.8.3 describes the similarities between scenarios for the secondary segment of the downstream network where becomes clear that a deeper depot analysis would be pointless.

Apart from the diesel originated from refineries, in order to meet costumers demand, Galp needs to buy diesel in some depots. As a result, the volume of diesel available in each depot is a combination from both inputs. Therefore, figures 5.37, 5.38, 5.39, 5.40, 5.41 and 5.42 illustrate, in groups of three different bubble maps, the importance of each depot in the downstream network corresponding to the group of scenario 96, 33, 128, 1, 5 and 92, respectively. Put differently, the volume of each bubble does not represent the absolute volume of diesel in the depot, but it takes into account the percentage of diesel (in volume) regarding the whole network.

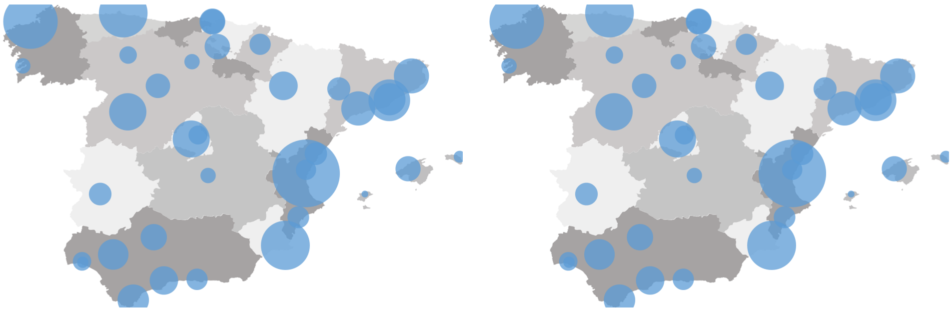
Further, it is illustrated a different depot analysis. Bearing in mind that the number of Depots is, by far, higher than the number of refineries, the way to represent the volume of diesel concerning each depot is different from the previous analysis of refineries. Therefore, aiming at representing each utilised depot, figures 5.43, 5.45, 5.46, 5.48, 5.49 and 5.50 illustrate the variation of diesel's volume of scenarios (a) and (b) compared to its own baseline for group of scenarios 96, 33, 128, 1, 5 and 92, respectively.

In addition, since there are some situations where the variation is not possible to evaluate, the author decided that if the group of scenarios include new depots in some of each own scenarios ((a) or (b)), it should be represented separately. Hence, for scenarios 96 and 128 there is an additional representation of the volume of diesel crossing those particular depots. Figures 5.44 and 5.47 represent those situations.

Finally, it is noteworthy to mention that the author represents each depot by a unique code instead of using the location name of the depot in order to protect Galp's business and sensitive information.

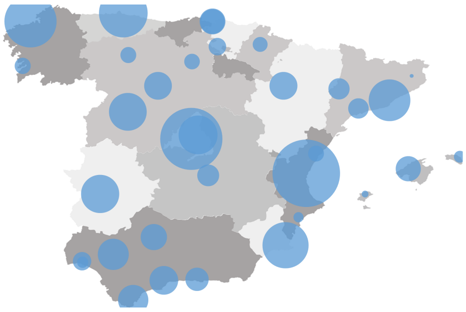


Baseline

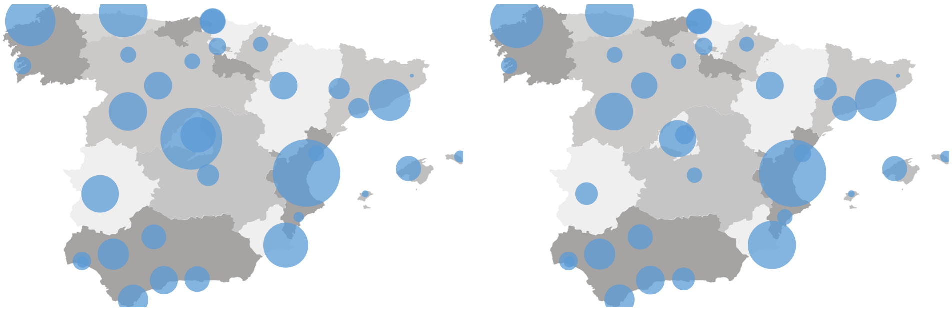


(a) **(b)**

Figure 5.37: Bubble maps representing the volume of diesel, in depots, for scenarios 96 baseline, 96 (a) and 96 (b).

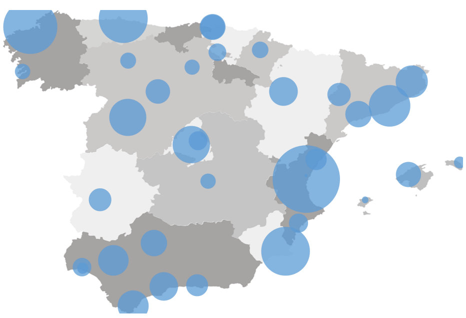


Baseline

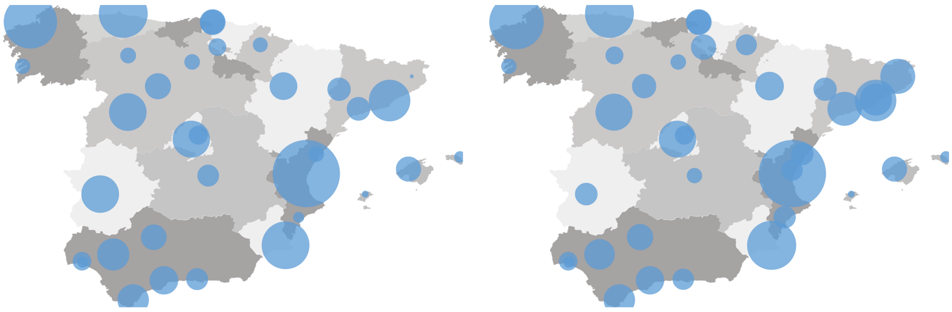


(a) **(b)**

Figure 5.38: Bubble maps representing the volume of diesel, in depots, for scenarios 33 baseline, 33 (a) and 33 (b).

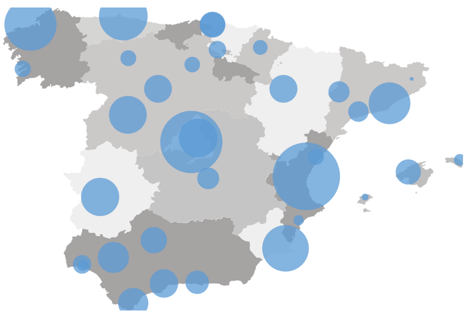


Baseline

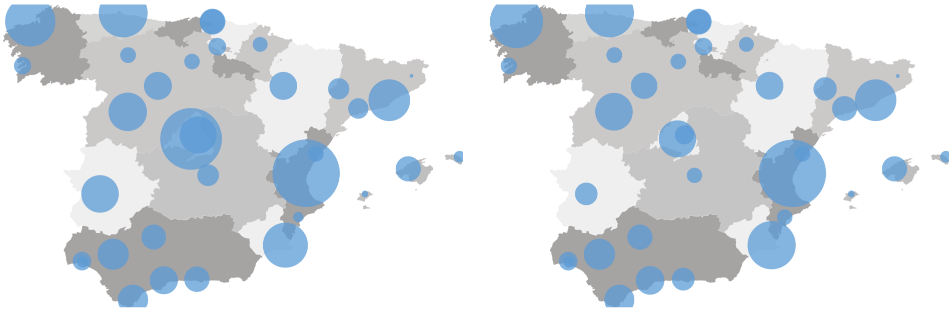


(a) (b)

Figure 5.39: Bubble maps representing the volume of diesel, in depots, for scenarios 128 baseline, 128 (a) and 128 (b).

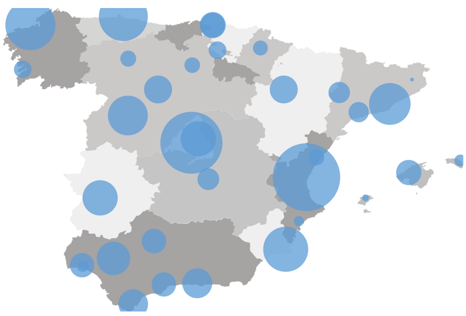


Baseline

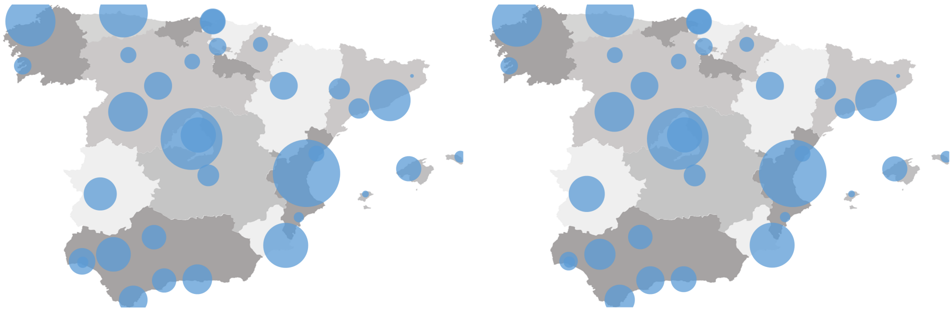


(a) (b)

Figure 5.40: Bubble maps representing the volume of diesel, in depots, for scenarios 1 baseline, 1 (a) and 1 (b).

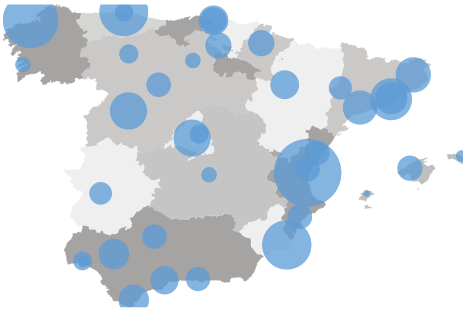


Baseline

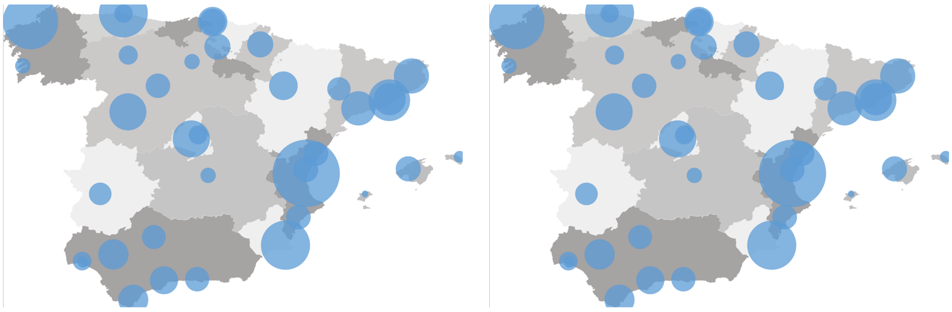


(a) **(b)**

Figure 5.41: Bubble maps representing the volume of diesel, in depots, for scenarios 5 baseline, 5 (a) and 5 (b).



Baseline



(a) **(b)**

Figure 5.42: Bubble maps representing the volume of diesel, in depots, for scenarios 92 baseline, 92 (a) and 92 (b).

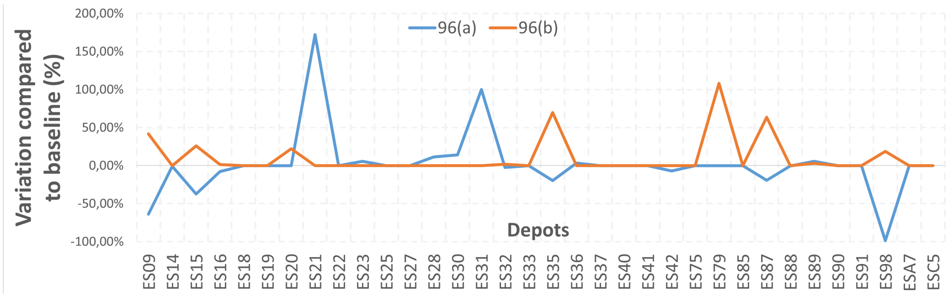


Figure 5.43: Diesel variation (in volume) of scenarios 96 (a) and 96 (b) compared to the 96 baseline scenario.

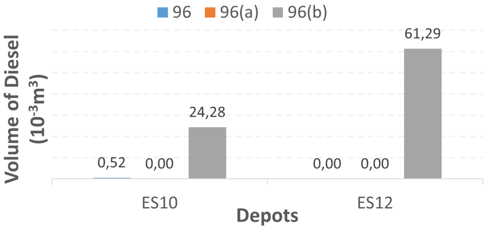


Figure 5.44: Volume of Diesel inside depots regarding scenario 96, 96 (a) and 96 (b).

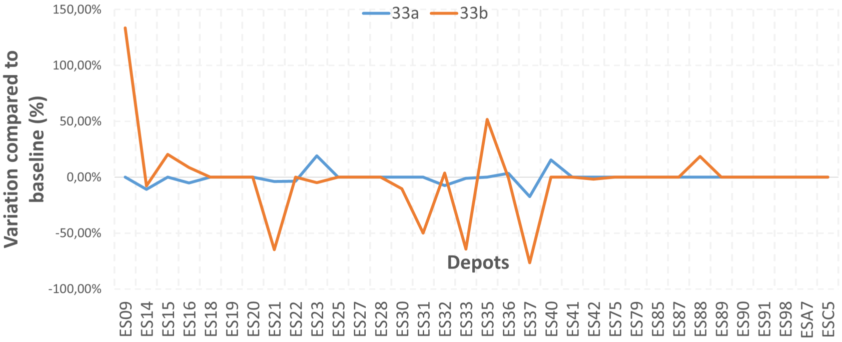


Figure 5.45: Diesel variation (in volume) of scenarios 33 (a) and 33 (b) compared to the 33 baseline scenario.

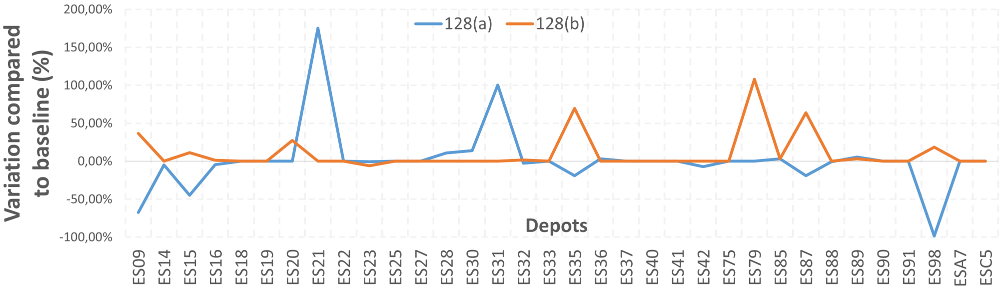


Figure 5.46: Diesel variation (in volume) of scenarios 128 (a) and 128 (b) compared to the 128 baseline scenario.

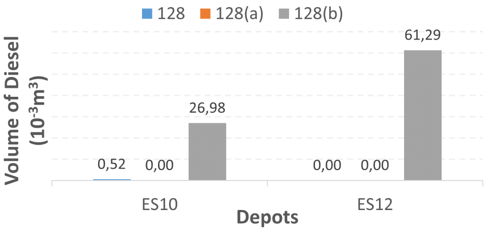


Figure 5.47: Volume of Diesel inside depots regarding scenario 128, 128 (a) and 128 (b).

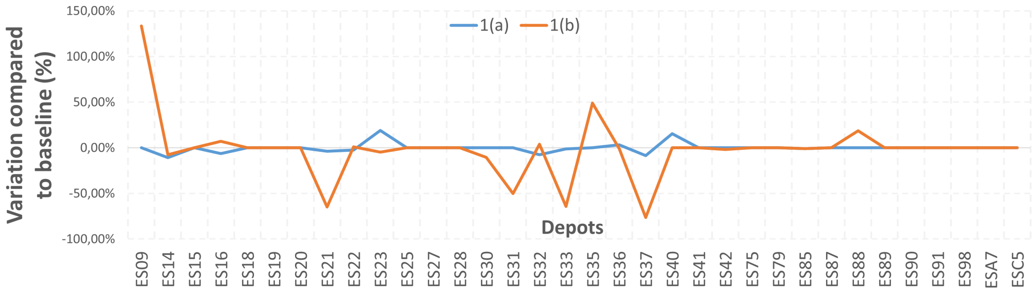


Figure 5.48: Diesel variation (in volume) of scenarios 1 (a) and 1 (b) compared to the 1 baseline scenario.

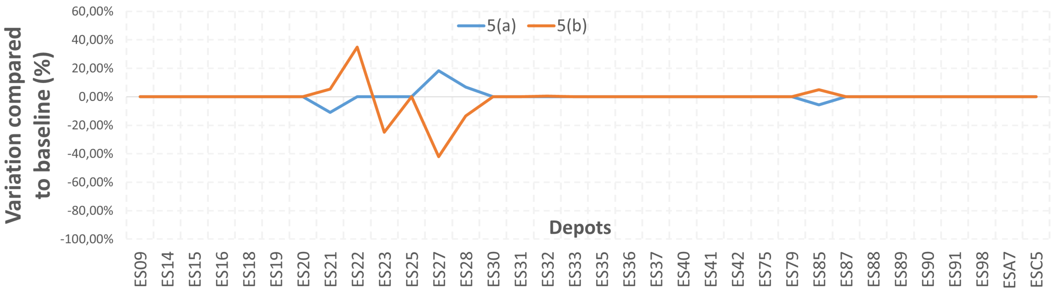


Figure 5.49: Diesel variation (in volume) of scenarios 5 (a) and 5 (b) compared to the 5 baseline scenario.

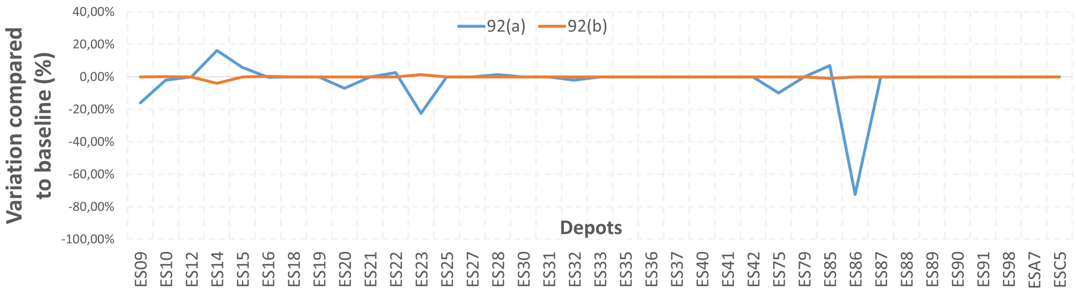


Figure 5.50: Diesel variation (in volume) of scenarios 92 (a) and 92 (b) compared to the 92 baseline scenario.

Starting the results' analysis with the bubble maps (figures 5.37, 5.38, 5.39, 5.40, 5.41 and 5.42) it is interesting that in every scenario, regardless of if it is baseline, (a) or (b), the most relevant depot in the network is located in the east of Spain, near Valencia. Put differently, it is nearby Valencia that is stored more diesel in one single depot. Further, still combing all bubble maps together, it is also visible that another important depot is always located in the northwest of Spain, in Corunã. Hence, regardless the different inputs, the strategic positions of supply are well defined and very distant from one another.

Further, taking a closer look at scenarios 96 and 128 altogether (remembering that the only difference between them is the Ethanol's quotation input), it is important to note that the variation between (a) and (b) compared to each baseline is the same, visible from figures 5.43 and 5.46. Additionally, even the utilisation or not of other depots is very similar between scenarios 96 and 128, illustrated by figures 5.44 and 5.47. Finally, in order to get a broader picture of this situation, figure 5.51 illustrates a comparison between those scenarios in terms of diesel variation inside depots (in volume) between baselines where becomes clear the really low impact of Ethanol in the network (the highest variation, in module, is around 10%).

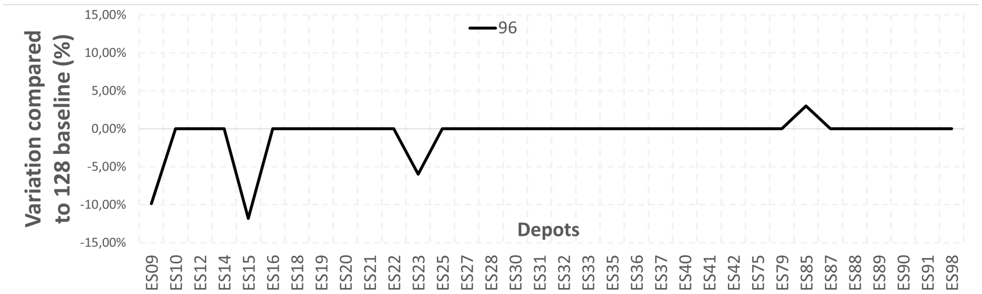


Figure 5.51: Diesel variation inside depots (in volume) of scenario 96 baseline compared to scenario 128 baseline.

In fact, the same conclusion can be withdrawn from the analysis of scenarios 33 and 1, which, in the same way, only diverge in the Ethanol's quotation. Once again, the variation between each baseline with (a) and (b) is the same in both situations (see figures 5.45 and 5.48). Additionally, figure 5.52 provides a broader comparison between both scenarios where it is vivid, again, the low impact of Ethanol's quotation in the network (the highest variation, in module, is around 1,5%).

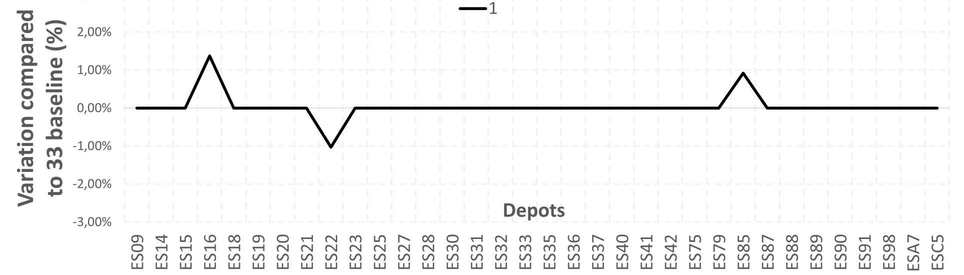


Figure 5.52: Diesel variation inside depots (in volume) of scenario 1 baseline compared to scenario 33 baseline.

On the contrary, it is clear that FAME's quotation has a higher impact in the network. By analysing figures 5.43, 5.45 5.46, 5.48, 5.49 and 5.50 it is vivid that all of them illustrate relevant changes inside each group of scenarios. Put differently, in all groups of scenarios (except in scenario 92) there is a variation of at least 70% compared to each baseline. Not only there is a rearrange in the network. but also, in some cases, there is a need to introduce/exclude different depots compared to the baseline. This situation happens for scenarios 96 and 128 (see figures 5.44 and 5.47).

Finally, aligned with the last idea, the author decided to study the impact of FAME's variation within different comparable scenarios. Hence, figures 5.53, 5.54 and 5.55 illustrate such comparison between scenarios 96 with 92 and 5 with 1 where it is portrayed the high impact in the network - between scenarios 96 and 92 the variation reaches 150% and there are new depots in scenario 92; and between scenarios 5 and 1 the variation reaches 40%.

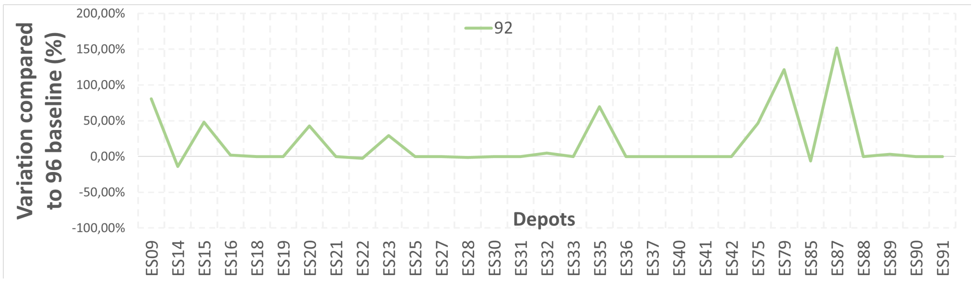


Figure 5.53: Diesel variation inside depots (in volume) of scenario 92 baseline compared to scenario 96 baseline.

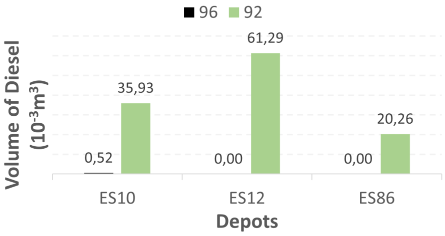


Figure 5.54: Volume of Diesel inside depots regarding scenario 96 and 92.

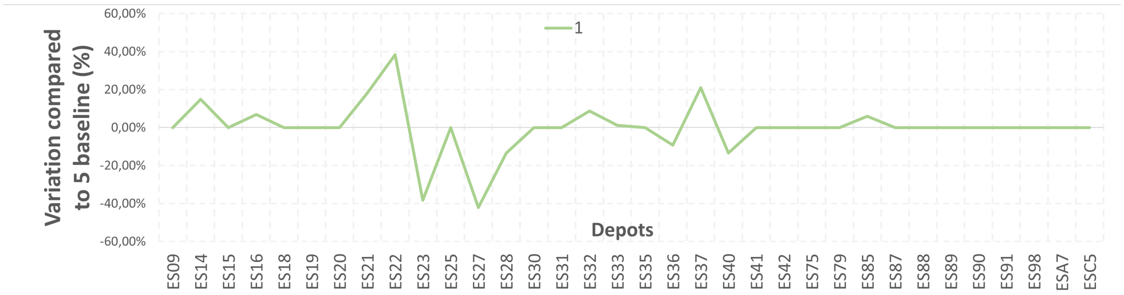


Figure 5.55: Diesel variation inside depots (in volume) of scenario 1 baseline compared to scenario 5 baseline.

5.8.3 The 2nd segment: From Depots to Service Stations

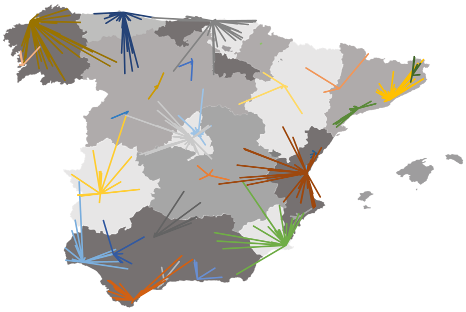
The last part of this analysis focuses on the secondary segment of the downstream supply - movements of products from Depots to Service Stations. From figure 2.8 becomes clear that the number of supply locations escalates comparing to the primary segment. This analysis will focus on both diesel and gasoline networks.

- **Diesel Network**

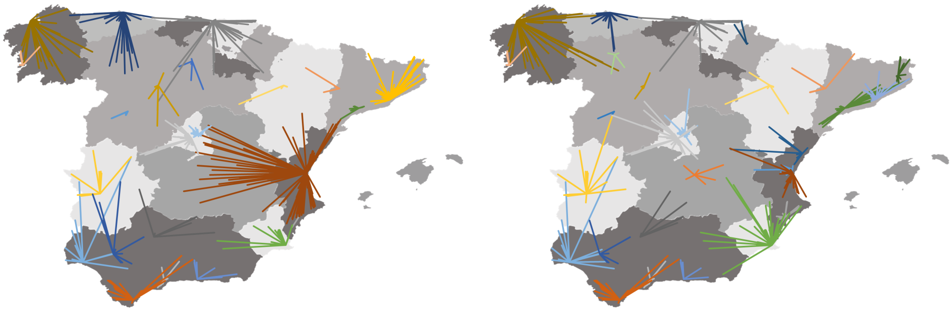
The idea beyond this analysis is to capture a broader view of the different outcomes caused by changes in FAME's quotation. As a result, the connections between Depots and Service Stations are illustrated in figures 5.56, 5.57, 5.58, 5.59, 5.60 and 5.61 regarding the groups of scenarios 96, 33, 128, 1, 5 and 92, respectively.

Align with the previous analysis, both intra-scenario and inter-scenario analysis is conducted. This time, the idea is to visually compare each network map since Service Stations' demand do not change and the different depots are already analysed (see section 5.8.2).

These results follow the exact same tendencies of the ones previously described in sections 5.8.1 and 5.8.2- changes in FAME's quotation cause a higher impact in the diesel network than changes in Ethanol's. Taking a closer look, it is vivid that regardless of the scenario, it is visible some networks changes inside each group of scenarios. Put differently, figures 5.56, 5.57, 5.58, 5.59, 5.60 and 5.61 which represent the baseline and scenarios with changes in FAME's quotation, visually demonstrate changes in all networks configurations. Further, even comparing scenarios 96 with 92 and 1 with 5 - remembering that the only difference is FAME's quotation input - the same conclusion is attained. Finally, on the other hand, comparing scenarios 96 with 128 and 33 with 1, the idea of Ethanol's quotation not impacting the diesel network is confirmed.

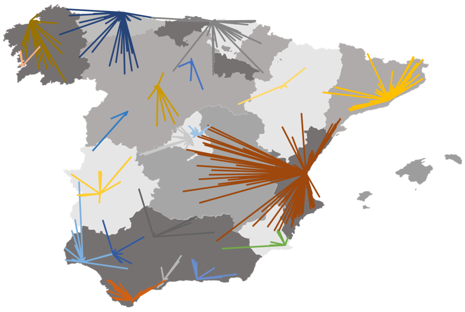


Baseline

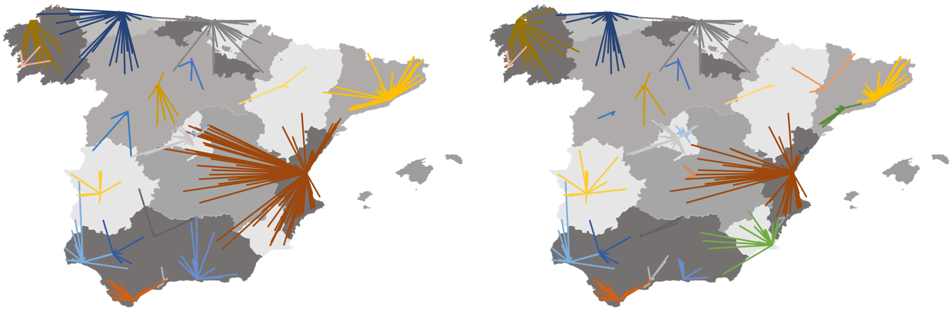


(a) (b)

Figure 5.56: Diesel network (2nd segment) regarding scenarios 96 baseline, 96 (a) and 96 (b).

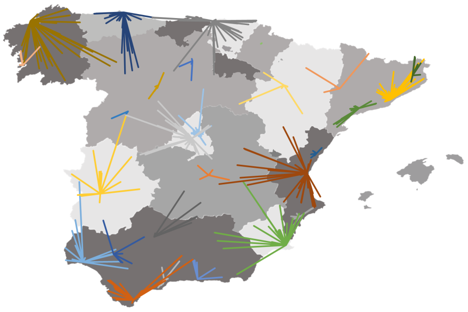


Baseline

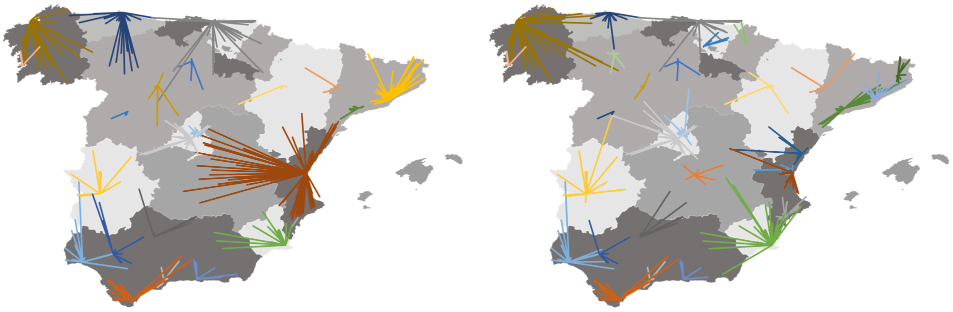


(a) (b)

Figure 5.57: Diesel network (2nd segment) regarding scenarios 33 baseline, 33 (a) and 33 (b).

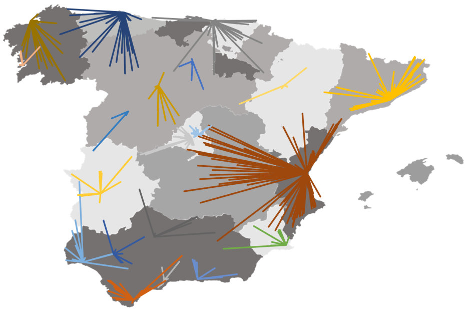


Baseline

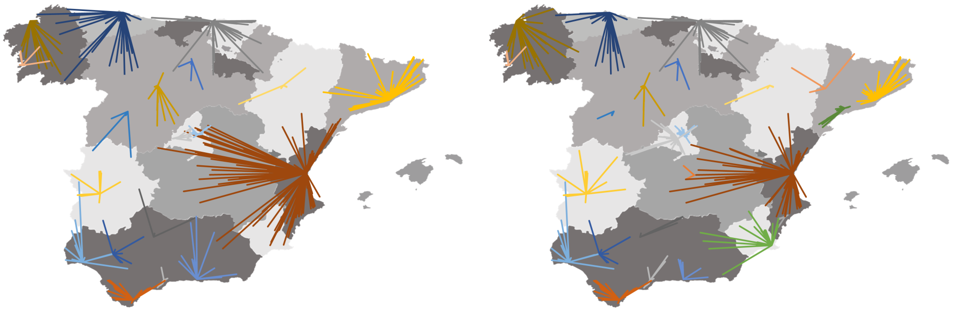


(a) **(b)**

Figure 5.58: Diesel network (2^{nd} segment) regarding scenarios 128 baseline, 128 (a) and 128 (b).

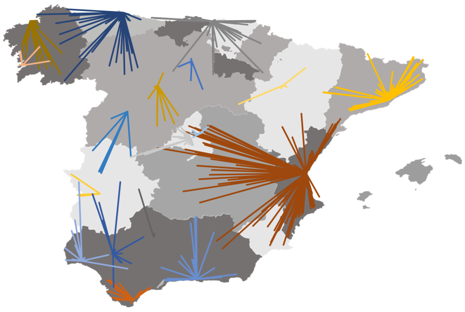


Baseline

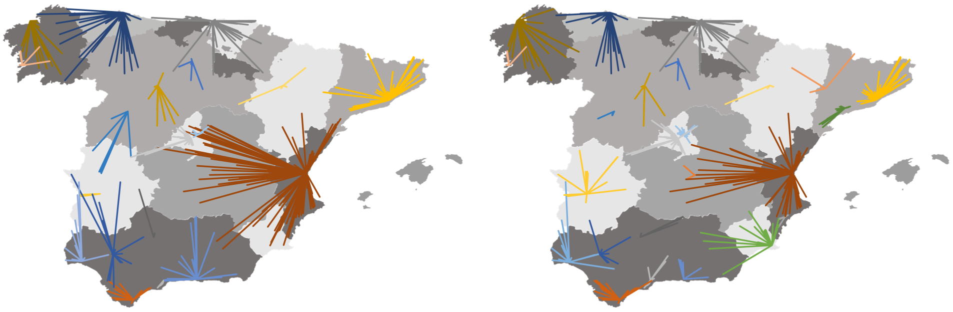


(a) **(b)**

Figure 5.59: Diesel network (2^{nd} segment) regarding scenarios 1 baseline, 1 (a) and 1 (b).

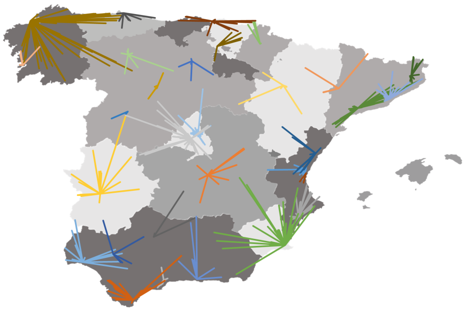


Baseline

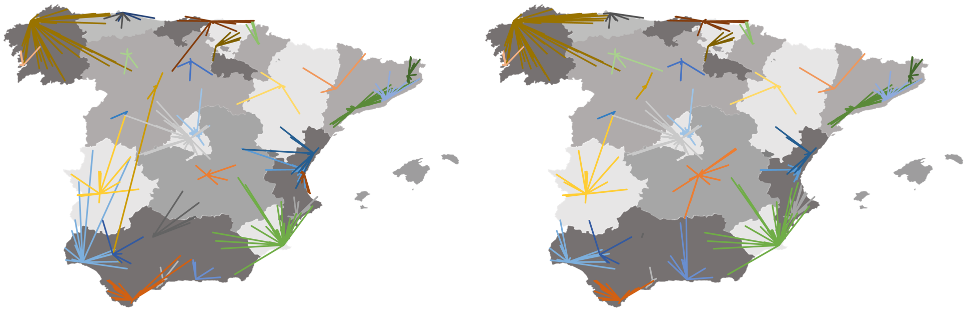


(a) **(b)**

Figure 5.60: Diesel network (2nd segment) regarding scenarios 5 baseline, 5 (a) and 5 (b).



Baseline



(a) **(b)**

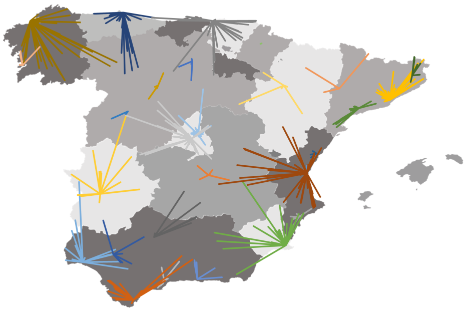
Figure 5.61: Diesel network (2nd segment) regarding scenarios 92 baseline, 92 (a) and 92 (b).

■ Gasoline Network

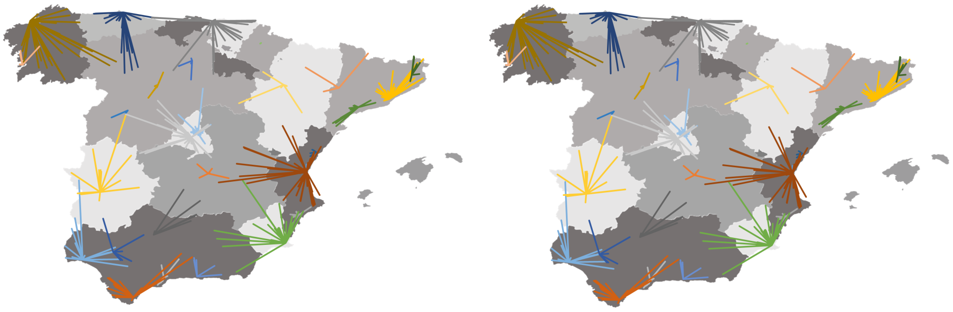
Regarding the secondary segment of the gasoline downstream network, it is crucial to on focus the connections between depots and service stations. Further, within this section, the previous decision of not to deeper explore the depots regarding the gasoline network is justified.

To provide a broader understanding, between scenario 96 and 128 only 6 out of 492 service stations (around 1%) received gasoline from a different depot. Further, even a smaller amount of differences is found between scenarios 33 and 1 where only 4 service stations (less than 1%) were served by different depots. Herein lies the crux of the matter. Remembering that the gasoline network is primarily explored to understand the impact of variations in Ethanol's quotation, it would be irrelevant to address a specific section to illustrate such meaningless impact. On the other hand, comparing the gasoline network between comparable scenarios where FAME's quotation input is different provides different results. In fact, between scenarios 96 and 92 around 40% of the service stations were supplied differently. Additionally, around 14% of the service stations were supplied differently if considered scenarios 1 and 5.

Therefore, due to the similarities of the network with only changes in Ethanol's quotation, this section only provides visual description of the network for scenarios 96, 92, 1 and 5. Figures 5.62, 5.63, 5.64 and 5.65 illustrate the secondary segment of the gasoline network for groups of scenarios 96, 92, 1 and 5, respectively. This way, it is ensured that the similarities are visible through comparing each baseline with scenarios (c) and (d) and the differences between the comparable groups of scenarios.

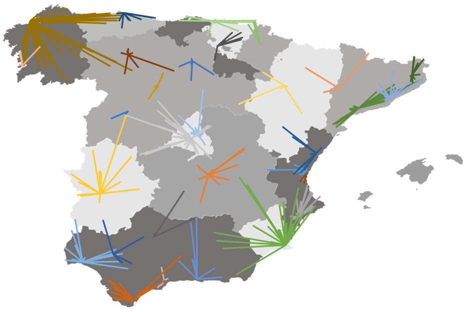


Baseline

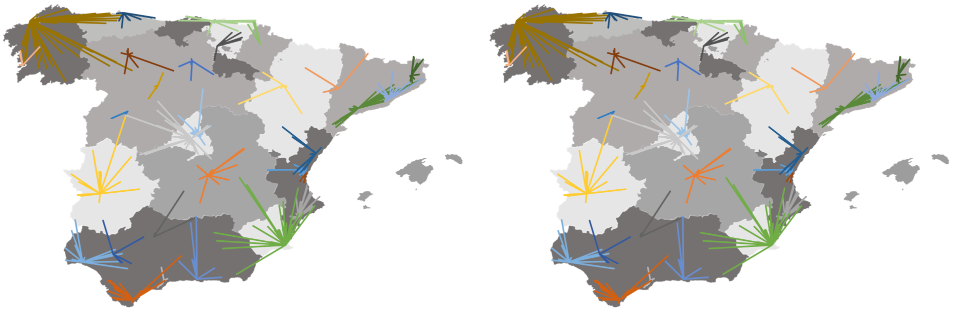


(c) **(d)**

Figure 5.62: Gasoline network (2nd segment) regarding scenarios 96 baseline, 96 (c) and 96 (d).

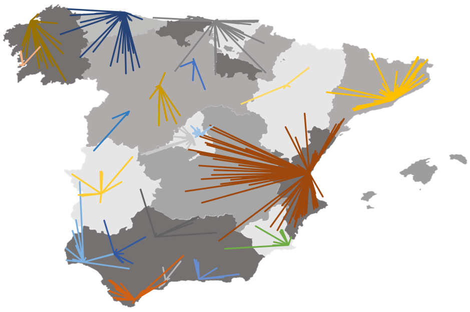


Baseline

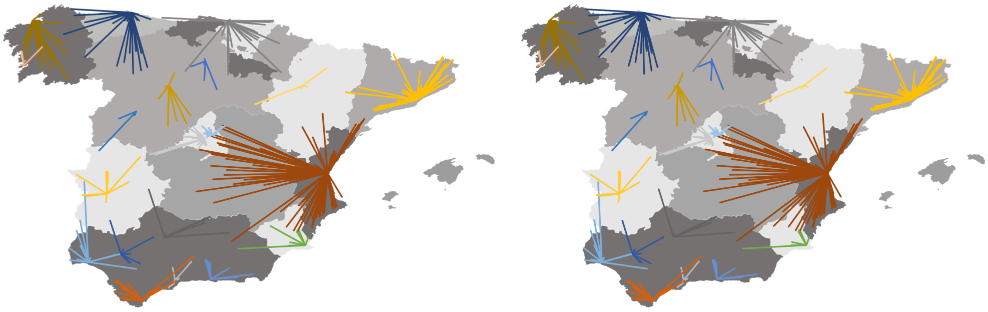


(c) **(d)**

Figure 5.63: Gasoline network (2nd segment) regarding scenarios 92 baseline, 92 (c) and 92 (d).

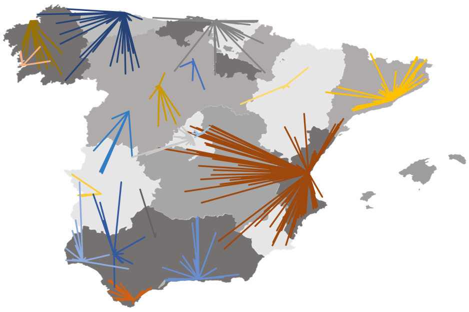


Baseline

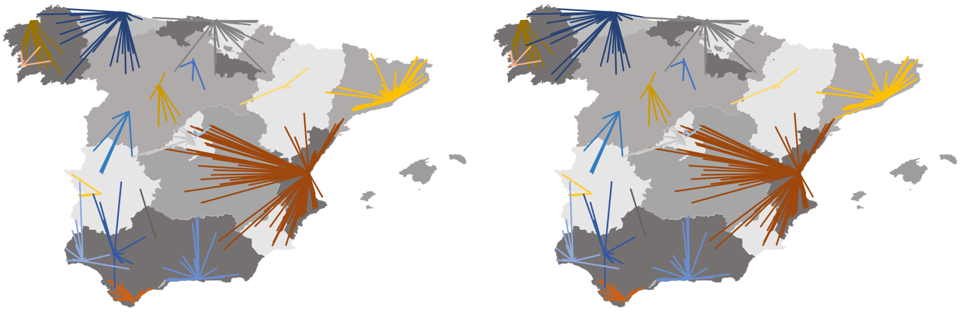


(c) (d)

Figure 5.64: Gasoline network (2nd segment) regarding scenarios 1 baseline, 1 (c) and 1 (d).



Baseline



(c) (d)

Figure 5.65: Gasoline network (2nd segment) regarding scenarios 5 baseline, 5 (c) and 5 (d).

5.8.4 Scenario's impact on Downstream Supply Costs

Finally, table 5.4 portrays the different impacts of each scenario in the Objective Function (total cost of the Downstream Supply) and the Diesel and Gasoline Purchase costs. In order to avoid sharing sensitive data, the value itself of each cost is dully presented without any associate monetary unit. Although, for the sake of consistency, all the results share the same magnitude and monetary unit.

Table 5.4: Overview of Downstream Supply costs per scenario.

Scenario	**Objective Function**		**Diesel Purchase**		**Gasoline Purchase**	
	Value	Variation (%)	Value	Variation (%)	Value	Variation (%)
96	248,24	–	160,51	–	32,85	–
(a) ↗ 10 FAME	249,08	0,34	161,14	0,39	32,85	0,01
(b) ↘ 10 FAME	247,51	-0,29	159,44	-0,67	32,91	0,18
(c) ↗ 10 Ethanol	248,36	0,05	160,51	0,00	32,96	0,35
(d) ↘ 10 Ethanol	248,13	-0,05	160,51	0,00	32,74	-0,35
33	151,42	–	84,78	–	18,88	–
(a) ↗ 10 FAME	151,61	0,13	84,73	-0,06	18,82	-0,30
(b) ↘ 10 FAME	150,98	-0,29	84,98	0,23	18,89	0,07
(c) ↗ 10 Ethanol	151,53	0,07	84,78	0,00	18,98	0,57
(d) ↘ 10 Ethanol	151,31	-0,07	84,78	0,00	18,77	-0,56
128	248,60	–	160,55	–	33,17	–
(a) ↗ 10 FAME	249,44	0,34	161,18	0,40	33,18	0,04
(b) ↘ 10 FAME	247,86	-0,30	159,47	-0,67	33,25	0,22
(c) ↗ 10 Ethanol	248,74	0,06	160,61	0,04	33,25	0,24
(d) ↘ 10 Ethanol	248,45	-0,06	160,51	-0,02	33,06	-0,34
1	151,16	–	84,72	–	18,68	–
(a) ↗ 10 FAME	151,35	0,13	84,65	-0,08	18,66	-0,14
(b) ↘ 10 FAME	150,72	-0,30	84,92	0,24	18,69	0,01
(c) ↗ 10 Ethanol	151,25	0,06	84,78	0,07	18,71	0,12
(d) ↘ 10 Ethanol	151,07	-0,06	84,72	0,00	18,59	-0,53
5	151,53	–	84,70	–	18,40	–
(a) ↗ 10 FAME	151,55	0,01	84,71	0,02	18,27	-0,72
(b) ↘ 10 FAME	151,46	-0,05	84,78	0,10	18,48	0,42
(c) ↗ 10 Ethanol	151,62	0,06	84,78	0,09	18,39	-0,06
(d) ↘ 10 Ethanol	151,43	-0,06	84,69	0,00	18,30	-0,55
92	245,49	–	157,49	–	32,71	–
(a) ↗ 10 FAME	246,89	0,57	158,76	0,81	32,85	0,42
(b) ↘ 10 FAME	244,56	-0,38	156,68	-0,52	32,59	-0,37
(c) ↗ 10 Ethanol	245,60	0,05	157,49	0,00	32,83	0,35
(d) ↘ 10 Ethanol	245,38	-0,05	157,49	0,00	32,59	-0,37

By taking a closer look at table 5.4, it is possible to withdraw some conclusions. Firstly, as expected, in every group of scenarios, scenarios (a) and (c) cause an increase in the total cost (objective function). Put differently, scenarios which portray a quotation increase drive the objective function to an increase. Additionally, it is interesting that in all scenarios (except scenario 5), the variation (in module) regarding the objective function value is bigger for scenarios (a) and (b). This confirms that a variation in FAME's quotation has, typically, a higher impact in the network resulting in additional costs.

Secondly, two more conclusions can be withdrawn from table 5.4. On one hand, it is clear that a variation in ethanol's quotation does not impact the diesel purchase cost, however it does impact the gasoline purchase cost. On the other hand, a variation in FAME's quotation impacts both types of costs. In fact, apart from scenario 5, the impact is more relevant in the diesel purchase cost.

6

Conclusions and Future work

Experts advise that current oil and gas reserves would last merely a few more decades. To outstrip the accelerating energy demand and the reducing of petroleum reserves, fuels such as biodiesel and bioethanol are in the cut-edge of the alternative technologies. Biofuels have been explored as alternative sources to undertake the demanding consumption of conventional fossil fuels, to minimise the economic and environmental impact, and to assure the sustainability for decades.

It is well-established that vehicle transportation essentially depends on petroleum-based fuels such as gasoline and diesel. Thus, an alternative fuel must be technically feasible, economically competitive, environmentally adequate, and easily available. Accordingly, biodiesel and bioethanol blended with either diesel or gasoline play an important role in downsizing pollutant emission levels while meeting national and European legislation.

The downstream planning of fuel distribution is a complex problem, since the number of demand locations escalates when including the primary and secondary segments. The complexity also derives from the fact that unique products are present, with different supply locations and constraints. The goal of this Master Thesis dissertation is to study the Iberian fuel distribution system, taking the perspective of one Iberian player - Galp - and looking into the specific problem of biofuels quotations and its impact in tactical and operational level of Galp's planning while meeting all legal requirements.

The present document starts by providing a synopsis of the downstream planning of fuel distribution. First, a general analysis of the petroleum and biofuel industries is fully presented and, subsequently, the current legislation regarding biofuels introduction is covered in great detail. Further, Galp's structure as a company was described, and its downstream planning in Iberia is portrayed. Thereafter, the roots of this research are presented, and the problem is defined - impact of biofuels quotations in the downstream planning of the company. Herein lies the crux of the matter. Consequently, the literature review presented in the following chapter focus on the scientific researches around planning activities as well as various fuel prices' relationships. From the literature review chapter, becomes explicit that the downstream planning is thoroughly explored, although, to the best of our knowledge, fail to address the integrated planning of operations considering both oil products and biofuels. Therefore, this master dissertation aspires at filling these gaps while answering to the challenge proposed by the Optimisation Planning and Supply department of Galp. Thereafter, the author proposes a methodology to be followed by merging the identified literature gaps and Galp's challenge.

Following the proposed methodology, the relevant results are portrayed. The key results indicate that FAME's quotation has a larger impact in the downstream network compared to the Ethanol quotation's impact. This impact can be understood from different perspectives. Either an impact in the network design or an impact in the downstream supply costs.

Regarding FAME's quotation and its impact on the diesel network, it is noteworthy that the importance of Bilbao's refinery arises when FAME's quotation increases. On the contrary, the importance of Tarragona's refinery decreases as FAME's quotation increases. This raises an interesting point of discussion. Perhaps, a future research might be developed in order to create a framework to predict FAME's quotation. With that basis, Galp could renegotiate some contracts and take a competitive advantage in those refineries.

The impact of FAME's quotation in the network design goes beyond the diesel network and causes changes in the gasoline network as well. On the contrary, Ethanol's quotation does not drive major network rearranges. Finally, the biofuels quotations' impact on the downstream supply cost is also different. On one hand, a variation on FAME's quotation causes a higher impact on the total supply network cost compared to a change in Ethanol's quotation. On the other hand, it is also clear that a variation in ethanol's quotation does not impact the diesel purchase cost whereas a variation in FAME's quotation impacts both diesel and gasoline purchase costs.

It is a great profession. There is the fascination of watching a figment of the imagination emerge through the aid of science to a plan on paper. Then it moves to realisation in stone or metal or energy. Then it brings jobs and homes to men. Then it elevates the standards of living and adds to the comforts of life. That is the engineer's high privilege. (...) The great liability of the engineer compared to men of other professions is that his works are out in the open where all can see them. His acts, step by step, are in hard substance. He cannot bury his mistakes in the grave like the doctors. He cannot argue them into thin air or blame the judge like the lawyers. He cannot, like the politicians, screen his shortcomings by blaming his opponents and hope the people will forget. The engineer simple cannot deny he did it. If his works do not work, he is damned.

— Herbert Hoover, American Engineer
the 31st President of the United States

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