Jet Fuel Distribution System: Lisbon Airport Case Study

A New Pipeline System to Increase Supply Safety and Reliability

Guilherme Barreiros Pereira

Thesis to obtain the Master of Science Degree in

Industrial Engineering and Management

Supervisor(s): Prof. Susana Isabel Carvalho Relvas
Prof. António Manuel da Nave Quintino

Examination Committee

Chairperson: Prof. Tânia Rute Xavier de Matos Pinto Varela
Supervisor: Prof. António Manuel da Nave Quintino
Member of the Committee: Prof. Teresa Sofia Cipriano Gonçalves Rodrigues

April 2021

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.

Declaration

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

Abstract

Crude oil and its products are present in the supply chain of most goods and services and are a key resource in many industries. The transportation sector is a major example of this. Before the pandemic state, crude oil products accounted for 94% of the sector total energy demand. The aviation sector is no exception, as it depends directly on jet fuel to refuel the aircrafts in order to keep flights running as well as the remaining airport operations.

This dissertation will focus on the supply of jet A-1 to Lisbon airport, which was one of the economic activities most affected by the recent hazardous material drivers' strikes. The aim is to study the replacement of the current distribution system with a new pipeline system. Therefore we are faced with a decision-making problem where the final goal is to provide the necessary data and information to the decision makers in order to promote an informed decision of introducing a new pipeline system to replace the current distribution system of jet A-1 via road tankers. To tackle this problem it is developed a methodology which combines an investment analysis, where two decisive parameters of the problem arise, profitability and transport fee. With a Multicriteria Decision Analysis where multiple criteria are considered, including subjective ones.

Considering all the results obtained from the methodology developed, they thoroughly support the replacement of the current system and the investment in a new pipeline system to transport the jet A-1 from CLC to Lisbon airport.

Keywords: Jet Fuel; Oil Pipeline; Investment Analysis; Multicriteria Decision Analysis; MACBETH.

Resumo

O petróleo bruto e os seus produtos refinados estão presentes ao longo da cadeia de abastecimento de vários bens e serviços em diversas indústrias. O sector do transporte é um grande exemplo disso. Visto que, antes da pandemia os produtos do petróleo bruto representavam 94% da energia total utilizada. O sector de aviação não é exceção, uma vez que, depende diretamente do jet para abastecer os aviões e assim garantir que as operações do aeroporto continuem em normalidade.

Esta dissertação foca-se no fornecimento de jet A-1 para o aeroporto de Lisboa, pois este foi uma das atividades económicas mais afetadas com as recentes greves dos motoristas de matérias perigosas. O objetivo passa por estudar a substituição do atual sistema de distribuição por um novo oleoduto. Logo, estamos perante um problema de tomada de decisão onde o objetivo final é proporcionar aos decisores a informação e dados necessários para promover uma decisão informada relativamente à introdução de um novo oleoduto para substituir o atual sistema de distribuição de jet A-1 via camião cisterna. Para solucionar este problema é desenvolvida uma metodologia que combina uma análise de investimentos, onde dois parâmetros decisivos emergem, rentabilidade e taxa de transporte. Com uma Análise de Decisão Multicritério, onde são considerados múltiplos critérios incluindo critérios subjetivos.

Os resultados obtidos a partir da metodologia seguida apoiam por completo a substituição do atual sistema de distribuição e o investimento num novo oleoduto para transportar o jet A-1 da CLC até ao aeroporto de Lisboa.

Palavras-chave: Jet fuel; Oleoduto; Análise de Investimentos; Análise de Decisão Multicritério; MACBETH.

Acknowledgements

I would like to thank to my family for all support they gave me throughout my academic life that culminates in this thesis. I would also like to show my gratitude to my friends, who have always been willing to help me.

I would like to thank to professor Susana Relvas and professor António Quintino for their support and guidance throughout the dissertation, which always advised me in the best way possible for me to achieve the desired results.

Finally, I want to thank all the people which were involved in the development of the dissertation since without them it would not be possible to achieved the desired results. I want to thank in particular Engineer José Manteigas for his continuous support and availability to help me whenever necessary.

TABLE OF CONTENTS

List of Figures

List of Tables

List of Acronyms

AHP - Analytic Hierarchy Process

ANP - Analytic Network Process

B/C ratio - Benefit-Cost Ratio

CAPM – Capital Asset Pricing Model

CBA - Cost-Benefit Analysis

CEA - Cost Effectiveness Analysis

CEPS - The Central European Pipeline System

CLC - Companhia Logística de Combustíveis

COP – Condition of Order Preservation

DAI – Decision Analysis Interview

DAHP – Dynamic Analytic Hierarchy Process

DCF – Discounted Cash Flow

EBIT – Earnings before Interest and Taxes

EIA – Environmental Impact Assessment

EIB - European Investment Bank

EIS – Environmental Impact Study

EM – Eigenvalue Method

ESD – Emergency Shutdown

NPV - Net Present Value

IRR - Internal Rate of Return

IATA - The International Air Transport Association

LDS – Leak Detection System

LPG - Liquefied Petroleum Gas

MAHP – Modified Analytic Hierarchy Process

MCDA - Multicriteria Decision Analysis

MILP - Mixed-Integer Linear Problem

MINLP - Mixed-Integer Nonlinear Problem

MIRR – Modified Internal Rate of Return

QRA - Quantitative Risk Analysis

PI – Profitability Index

SCADA – Supervisory Control and Data System

SML – Security Market Line

SMYS – Specific Minimum Yield Stress

WACC - Weighted Average Cost of Capital

WSN - Wireless Sensor Networks

1. Introduction

1.1 General Context

Despite, the increasing investment in renewable energies, oil still remains the most consumed source of energy (EIA, 2019)

(Figure 1).

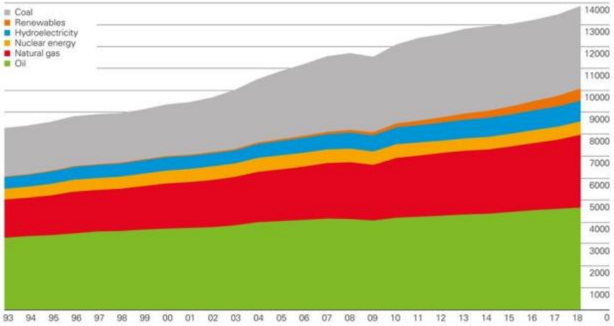


Figure 1 - World Consumption of Fuels in Mtoe (BP, 2019)

Hence, crude oil and its products may be considered as one of the most important resources in our day to day basis. Many countries depend on the inflow of energy to keep their economies working (Moerkerk & Crijns-Graus, 2016). Oil is present in the supply chain of most goods and services. Most companies do not consume directly crude oil, however they consume its refined products such as gasoline, jet fuel, plastics, ink, nylons, among others, somewhere in the value chain (Henriques & Sadorsky, 2011; Moerkerk & Crijns-Graus, 2016).

Before the pandemic state, crude oil products accounted for 94% of total transportation energy demand. The main products being gasoline, diesel and jet fuel (EIA, 2019). This dependency shows how important it is to guarantee their supply to end consumers, since they do not have direct alternatives. The focus of this project will be on the supply of jet fuel to its final destination – i.e. the secondary distribution within the oil supply chain. Jet fuel is the main fuel used in aviation, but it can also be used in other jet turbine applications (Chevron, 2007; McKinsey, n.d.). Therefore, if there is lack of supply, economies will suffer since air transport supports both economic growth and prosperity trough tourism and trade (IATA, 2019a). Both tourism and trade will be negatively impacted due to flight cancelation and the impossibility of transport goods by air, respectively.

The event of an airport running out of fuel is unusual. However, in recent years Portugal has been dealing with socio-political problems which have affected the distribution of oil refined products via road tankers. In 2019, two strikes of hazardous goods truck drivers took place as a form of protest about their contractual conditions. This led to a full stop in the distribution of oil refined products to points of sale. In the most recent one, minimum services were not fulfilled, consequently airports and emergency gas stations were not supplied as they should have been.

Lisbon airport was one of the affected, with only one canceled flight and six delayed. However, these events showed how fragile the current system can be if there are no drivers available. Consequently, the Portuguese government felt the need to study alternatives to the current distribution system.

1.2 Objectives

The aim of this master dissertation is to study the introduction of a new pipeline system to replace the current distribution system of jet A-1 via road tankers to Lisbon's Airport. This study combines two different methods, a Multicriteria Decision Analysis (MCDA) and an investment appraisal with the main goal of providing the necessary data and information to the decision makers in order to promote an informed decision on whether to replace the current distribution system or not. The investment appraisal is key to give us information on economic indicators which are key for this decision where profitability and transport fee are highlighted, while the MCDA allows us to consider multiple and subjective factors, such as environmental and social aspects. This methodology allows us to tackle the three key dimensions of the problem, economic, environmental and social, hence providing the necessary information for the decision-making process.

These techniques follow a socio-technical approach where the inclusion of the stakeholders involved in the problem in study is a key part in order to give consistency to the results obtained and guarantee transparency in the decision-making process.

1.3 Research Methodology

The project's research methodology can be split into three major parts, accordingly to how the thesis' content is divided and to the information and data needed in each chapter.

In the first part, regarding the characterization of both current and alternative distribution systems the research was mainly based on information from official sources. These included, companies' websites, documents and reports, newspapers and energy reports. Also, data was gathered from meetings, which took place in Companhia Logística de Combustíveis (CLC), with its engineers and managers, through unstructured discussions.

On the other hand, for the second part, an intensive literature research related with oil pipeline industry was conducted. For this purpose, different keywords were used: jet fuel, jet fuel pipeline, oil pipeline, pipeline versus truck, distribution systems, oil pipeline project, pipeline projects, investment analysis, cost-benefit analysis, multicriteria decision analysis, analytic hierarchy process, MACBETH, risk assessment. Those words were written down in several scientific databases (Google Scholar, ScienceDirect, ResearchGate, IEEExplore and SpringerLink), which provided several scientific papers, books and other reference types about these topics. Those documents were analyzed in detail in order to extract information in order to answer to two main research questions: i) What has been the focus of authors studies in the oil pipeline industry, in recent yeas and ii) How have been studied recent pipeline projects have been studied in terms of economic, social and environmental dimensions and which methodologies have been applied to tackle these problems. Apart from all the documents encountered in these databases with the mentioned keywords, several others were found from the references of the papers collected from the keyword search.

In the third part, where the methodology to tackle the problem at hand will be developed, besides the information and data we were able to collect from the literature, a large portion of what was additionally gathered, like unit costs and decision makers points of view and judgements, were obtained from individual interviews with the different individuals included on the development of the thesis methodology. This is further detailed in chapter 4.

1.4 Dissertation Structure

The dissertation document structure is divided into seven main chapters. Table 1 presents an overview of these chapters.

Table 1- Dissertation Structure

Chapter	1	2	3	4	5	6	7
Content	**Introduction:** 1 - General Context 2 - Objectives 3 – Research Methodology 4 – Project's Structure	**Case Study:** 1 – Jet Fuel 2 – Jet A-1 to Lisbon Airport Supply Chain 3- Alternative Supply Chain System 4 – Problem Definition	**Theoretical Background:** 1 - Pipeline Systems 2 – Pipeline Design 3 – Decision Making Analysis 4 – Investment Analysis	**Input Data Collection and Treatment:** 1 – Pipeline System Characterization 2 – Multicriteria Model 3 – Investment Analysis	**Methodology Development:** 1 – Multicriteria Model (MACBETH) 2 – Investment Analysis	**Discussion on Results & Limitations**	**Conclusion & Future Work**
Pages	1-3	4-13	14-45	46-62	63-74	75-78	79-80

2. Problem definition: Jet supply to Lisbon Airport

The goal of this chapter is to characterize the problem so that in the end we are able to clearly define it. Thus the chapter will initially comprise a general overview about jet fuel and a characterization of jet supply chain to Lisbon airport with a focus on the current distribution system via road tanker and its participants. Then the main causes that triggered the study of an alternative system to replace the current one are analyzed and this alternative system is identified. In the final section the problem is clearly defined, as well as, all the key aspects that need to be considered to study it.

2.1 Jet Fuel

Jet fuel is one of the most important products produced from the process of refining crude oil, alongside gasoline and diesel. It is mainly used in the transportation sector, being the principal fuel used in aircrafts, but it can also be used in other jet turbine applications (Chevron, 2007; McKinsey, n.d.).

Since the commercial jet industry began its growth there are several different types of jet fuel for different uses and markets. These different types of jet fuel can be distinguished by its smoke point (a measure of the tendency of a fuel to emit smoke when burned in a jet turbine), flash point (a measure of the temperature at which a fuel forms a potentially ignitable mixture of hydrocarbon and air) and freeze point (the temperature at which a fuel starts to form solid crystals) (McKinsey, n.d.; Wei et al., 2019; Yang et al., 2019). Therefore, there are four main grades of jet fuel:

- Jet A - Is the standard grade used within the United States by domestic and international airlines. It is a kerosene grade fuel and it has a minimum flash point of 38°C and a maximum freezing point of -40°C.
- Jet A-1 - Is the standard grade used in international commercial aviation. Because not only it is a kerosene grade fuel which suits most turbine engine aircraft, but also has a lower freezing point of -47°C when compared to Jet A, which makes it more appropriate to be used in long international flights.
- Jet B - Is a wide-cut type fuel. Despite not being as commonly used has other types of jet fuels, it is important for countries with very cold climates. It is mainly used in northern Canada and Alaska where its lower freeze point and higher volatility are an advantage.
- TS-1 - Is the standard grade available in Russia and CIS region. It is a kerosene type fuel and it has a minimum flash point of 28°C and a maximum freezing point of -50°C.

All these different grades of jet fuel have been used throughout the years in a large number of flights. The International Air Transport Association (IATA) reported that during 2018 there were 46.1 million flights with a total of 4.4 billion passengers. To this number we could still add the flights needed for the amount of cargo transported, which was reported of being 64 million tones to markets around the world. IATA also forecasts that over the next two decades the number of passengers will double (IATA, 2019a). These will have a direct impact in global jet fuel consumption, which according to the U.S. Energy Information Administration (EIA) will have the highest increase rate from all liquid transportation fuels trough 2050. EIA predicts that from 2018 to 2050, jet fuel consumption will more than double (EIA, 2019). Despite these statistics representing growth in the aviation industry they are worrying for the industry due to environmental and economic factors. Currently, aviation industry represents approximately 2% of total CO_2 emissions every year due to jet fuel use (Chuck & Donnelly, 2014; Yang et al., 2019). On the economical side, fuel cost still represents one of the largest portion of the worldwide airline industry operational costs, accounting for 23.5% in 2018 (Chuck & Donnelly, 2014; IATA, 2019b; Wei et al., 2019). The impact of the continuous increase in demand of jet fuels can be huge because it can lead to increase in both CO_2 emissions and fuel prices. Therefore, the search for alternatives to the current used jet fuels has been the main focus of all the stakeholders involved in the aircraft industry, including aircraft and engine manufacturers, oil companies, airline companies, governments and researchers. More precisely the study of bio-jet fuels have been the major interest in the industry, since it is seen as the best alternative to the current jet fuels because its use could decrease the dependence on fossil fuels and also reduce CO_2 emissions (Chuck & Donnelly, 2014; Wei et al., 2019; Yang et al., 2019). In order to be a viable substitute bio-jet fuels need to have specific characteristics to ensure they are safe, reliable and compatible with current mechanical systems and at the same time being cost competitive with other existing jet fuels (Chuck & Donnelly, 2014; Yang et al., 2019). Despite many potential biofuels being proposed in the academic literature, the grades of jet fuel presented previously are the ones that are still being used.

The type of jet fuel is a key factor in this project, since some technical components of the new infrastructure in study depend directly from the physical and chemical characteristics of the fuel. Currently, jet A-1 is the grade of jet fuel supplied to the Lisbon airport and it is the one that it is going to be considered throughout the dissertation. Nevertheless, it is important to keep in mind that the appearance of a new viable bio-jet fuel could happen in the near future.

2.2 Jet A-1 to Lisbon Airport: Supply Chain Structure

The jet A-1 supply chain to Lisbon airport is illustrated below (Figure 2). If compared to other oil products' supply chain the differences are minimal. It only differs on the last movement of the jet fuel to the airport which needs to be done via a single fuel grade dedicated system (API, 2014) whereas for diesel and gasoline it is done simultaneously to gas stations. When they arrive to their destination, they are deposited into the respective storage tanks and quality tests are performed, before they can be available to be consumed.

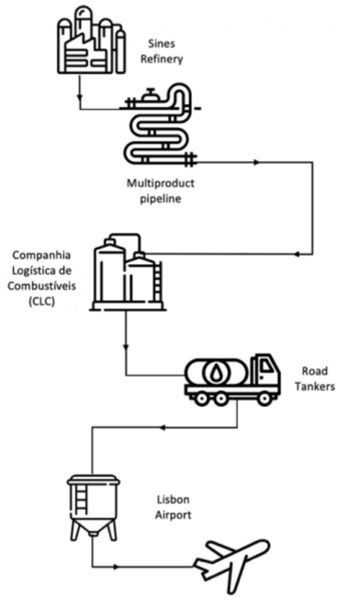


Figure 2- Jet A-1 Supply Chain

The supply chain of jet A-1 is divided into five main phases. It does not include the exploration phase common to the general supply chain of jet, since Portugal imports all the crude oil used in its refineries. Hence, the imported crude oil is refined in Sines refinery in order to produce jet A-1 and other crude oil products. Then, jet is transported alongside the other crude oil products via a multiproduct pipeline to Companhia Logística de Combustíveis (CLC), an intermediary storage facility. Besides being responsible for the storage CLC is also the company which operates the multiproduct pipeline. Then, the distribution to Lisbon airport is done via single load road tankers, which are loaded in CLC. As mentioned above and contrary to what happens in the multiproduct pipeline, this final movement of jet A-1 cannot be made simultaneous with the other products, due to its specific characteristics. When jet A-1 arrives at the airport is stored in the existing tanks where it settles and the quality is tested afterwards. Subsequently, aircrafts can be fueled via an hydrant servicer vehicle connected to an underground hydrant system, or via an aviation refueller. From this phases we can already identify four main actors in this supply chain which have their interest in the problem in study, these are oil companies (product owners), CLC (possible operator of a new transportation system), TIEL – Transportes e Logística, S.A. (transportation company) and ANA (company responsible for airport management)

In the following section, the secondary transportation phase, where jet is transported from CLC to airport, is going to be explained in detail since it is the one relevant for the problem in study. Additionally, its main problems and impacts on the stakeholder mentioned above are identified.

2.2.1 Secondary Transportation: Road tankers

Secondary transportation is the final movement of the oil refined products to points of sale, such as gas stations, airports, industries. As well as in primary transportation, secondary transportation can be done via road, pipeline, rail, barge (river) and ship (sea).

The distribution of jet A-1 to Lisbon airport is done via road tankers. The carriers are contracted by the oil companies trough outsourcing contracts. The loading of the road tankers is done in CLC facilities as mentioned above. Meaning that everyday trucks loaded with jet A-1 leave CLC facilities, in Aveiras de Cima, in direction to Lisbon airport, in Portela. Each truck completes more than one trip per day: it loads in CLC, then unloads at the airport and returns to load again. The route they take is via highway A1, hence it can be considered for the trip CLC – Airport – CLC a distance of approximately 120km (Figure 3).

Figure 3- Road tankers Route

According to data provided by CLC in 2019, 1 319 024 m^3 of jet A-1 left its facilities in direction to Lisbon airport, transported by a total of 36 828 road tankers. Table 2 and Table 3 display the greenhouse gas emissions generated by these trucks in 2019. They include the emission of CO_2, CO, NO_x and other particles. To compute these emissions it was considered that road tankers have an average diesel consumption of 0.25 L/km and that each truck travels 120 km per trip, as mentioned above.

Table 2- Road tankers CO2 Emissions in 2019

Pollutant	Factor (kg/L	Emission per Trip (kg)	Emissions in 2019
CO2	2.67	80.10	2 949 923

(Commercial Fleet, 2020)

Table 3- Road tankers Emissions in 2019

Pollutant	Emission Factor (g/km)	Emission per Trip (kg)	Emissions in 2019
CO	2.35	0.28	10 385
NOx	3.37	0.40	14 893
Particles	0.13	0.02	575

(Kouridis et al., 2018)

As shown by the results the CO_2 emissions are largely superior when compared to the other pollutants. However, it is crucial to consider all pollutants in this analysis because all have impact in both the environment and in human health. Therefore, the possibility of reducing the emissions generated by the current distribution system is key factor for the stakeholders involved.

Additionally to the environmental impacts, there are other general concerns related with road distribution via road tankers. These include: delay in supply and public health safety. The first associated with the dependency on the highway which suffers from frequent traffic jam as well as the risk of highway unavailability in extreme situations. The second associated with the risk of accident, with road tanker, which can cause severe impacts to thousands of citizens which have to travel daily in that highway. Moreover, the general public complain about the mobility constraints and traffic caused by the hundreds of road tankers which travel daily in the highway (ECO Sapo, 2020; The Portugal News, 2019).

2.2.2 Discussion about the current distribution system

Besides the general concerns about the distribution of dangerous goods via road tankers, Portugal, in recent years, has been dealing with socio-political problems which have affected the distribution of oil refined products via road tankers. Dangerous goods drivers have expressed their displeasure to the Portuguese government about their contractual conditions, demanding for changes in salary, working time and contract extension. These complaints led the drivers to strike as a form of protest, stopping completely the distribution of oil refined products to points of sale. In 2019, two strikes by drivers of dangerous materials took place, the first from the 15th to 18th of April and the second from the 12th to 18th of August.

In the last one, minimum services were not fulfilled, consequently airports and emergency gas stations were not supplied as they should have been. The Portuguese government had to declare state of energy emergency, and the use of military support was necessary to satisfy the requirements until the strike was called off. In September another strike was announced by the Sindicato Nacional dos Motoristas de Matérias Perigosas (SNMMP) from the 7th to 22nd, but ended up being cancelled. This is a situation that leaves the government in constant state of alarm, due to the socio-economic consequences an event like these already caused and could cause in the future.

In the perspective of jet A-1 supply the most recent event did not had an impact as bad as it could have been, with only one canceled flight and six delayed in Lisbon airport since airlines have the possibility to fuel its aircrafts in other international airports (Sábado, 2019). However, it showed how fragile the current supply system is if there is unavailability of road tankers to deliver jet A-1. If an event like this happens in larger proportion, not only the number of flights cancelled will increase but also other airport services will be impacted since the number of passengers will decrease. Airlines could even lose interest into fueling their aircrafts in Lisbon airport and search for alternative airports for that purpose. All these consequences would cause great economic impact to all stakeholders, where it can be included oil companies, airlines, ANA and even the country since tourism as high impact on its economy.

Consequently, the Portuguese government practically felt obligated to look into alternative distribution channels that could mitigate the risk of jet A-1 not being supplied to Lisbon airport. This alternative is further analyzed in the next section.

2.3 Alternative supply system for jet A-1

As previously mentioned, there are five main modes of transportation to move oil refined products, which are road, pipeline, rail, barge (river), ship (sea). Following the recent events and the existing high uncertainty of something of that kind happening again, there is a need to study alternatives to the current supply of jet A-1 via road. This section will be divided into two parts. Firstly, it will be presented some jet A-1 distribution systems in European countries as example of alternatives to the Lisbon airport case, which will include the supply system of Porto airport. Secondly, the alternative that is being considered by the Portuguese government will be approached in detail, including what impact it will make on the stakeholders of jet A-1 supply chain.

2.3.1 Examples of jet A-1 distribution system in European airports

As mentioned above there is a variety of modes to transport oil products which is reflected throughout Europe. The first example of this is the large amount of pipeline systems spread across Europe that transport the different oil products from the refineries until the final customer. An important part of these systems is the supply of jet A-1 to several European airports.

The first example of one of these systems is in Spain where the CLH Group operates a pipeline network composed by several oil pipelines with a total length of more than 4,000 kilometers, which is complemented by vessels and road tankers. The company pairs the pipeline network with a storage capacity of more than 8 million cubic meters, spread through 40 storage facilities and 28 airport facilities all over the country (CLH, 2020) .These infrastructures are available to any oil operator in Spain under the same conditions. Additionally, CHL Aviación is the company of the CLH Group responsible for the jet fuel management. Therefore, it manages the 28 airport storage facilities operating in the main airports in Spain. The company takes advantage from the pipeline network to fuel them, since the storage plants and airports are connected through this network ensuring a reliable and flexible supply of jet fuel.

Another example is The Central European Pipeline System (CEPS), the CEPS is comprised by a cross-border pipeline, with a total length of 5314 km capable of transporting the equivalent of approximately 1100 trucks, 24 hours a day, 365 days a year over an average distance of 385 km, and also with a storage system, with 35 depots and a capacity of over 1 million m^3 of oil products, most of them also equipped with truck/rail loading isles. This system used to supply only NATO's depots and military airbases (*CEPS*, 2008) but nowadays also supplies non-military depots, refineries, sea ports and airports, throughout the countries it is present on (Capiau, 2010). This pipeline system has two major benefits, not only frees up the roads but also reduces emissions and environmental impacts (NATO, 2020). The CEPS has six member nations, France, Belgium, Netherlands, Luxembourg, Germany and United States, but it is only physically present in France, Belgium, Netherlands, Luxembourg and Germany. Jet fuel is one of the main fuels which the CEPS transports and store, due to its importance for military aviation but also for non-military clients (*CEPS*, 2008). The system supplies significant amount to civilian airports, but more important is the main supplier to major international airports such as, Schiphol, Findel, Frankfurt, Koln-Bonn, Zaventem and Zurich. The CEPS guarantees the delivery of over 50% of jet fuel all these airports while for some of them ensures up to 90-100% of supply.

A final example of a pipeline which supplies an airport is Porto's airport jet A-1 distribution system that can be seen as the best example since it can be directly compared to the one existing to supply Lisbon airport. In this system the fuel is supplied to the airport directly from Matosinhos refinery via a pipeline. Thus and contrary to what happened in Lisbon airport, the dangerous goods drivers' strike caused no problems in the Porto airport operations. The existence of a pipeline allows oil companies to have their own channels to supply the airport without depending on second parties which they have little to no control of.

Additionally an example can be given for a different type of supply system. Recently in Hungary in the city of Budapest, a project funded by the European Commission, beginning in 2015 was developed where the main objective was to connect the railway line Budapest-Arad to the multi-modal hub at Budapest Airport. The project consisted in two deeds:

- Upgrade the existing single-track railway link from the main line R100A Budapest-Arad to a new rail transshipment area of Budapest Airport
- Re-routing and partial extension of the service road which connects the logistics areas with one another and with the passenger terminal

On the long run, this project will not only stimulate local growth but also allow shifting traffic from road to rail. Therefore having great influence on traffic on regional roads and on the impact of the airport on the environment (European Commission, 2015).

Table 4 below gives a summary of the different distribution system and a comparison with the current Lisbon distribution system.

Table 4- Comparison between distribution systems

Type of Distribution System	Examples	Comparison to the current Lisbon distribution system
Pipeline	Spain The CEPS Porto	1 - Reduce road traffic which reduces emissions and environmental impacts 2 - More reliable and flexible supply of jet fuel 3 - Took advantage of already existing pipeline infrastructures 4 - Have their own channels to supply the airport without depending on second parties on which they less control
Railway	Budapest	1- Reduce road traffic which reduces emissions and environmental impacts 2- Took advantage of already railway infrastructures near the airport

2.3.2 Pipeline to supply jet A-1 to Lisbon airport

The development of a new pipeline system to supply jet A-1, that will connect CLC directly to Lisbon airport, is projected by the Portuguese government, as the best fitted alternative to mitigate some of the risks of the current distribution system. Rail could have been considered together with the pipeline, but the lack of existing rail infrastructure near Lisbon's airport makes it unfeasible. Whereas for the pipeline, there is the possibility of using an already existing water pipe channel, which will theoretically allow decreasing the project costs.

As it was possible to analyze via the examples of distribution systems presented, pipeline is the leading transportation mode for jet A-1 used in Europe. Despite having high initial costs and being limited in terms of route, pipeline is safer and has less environmental impacts while being the most cost efficient mode of transportation (Capiau, 2010; Pootakham & Kumar, 2010; Strogen et al., 2016).

Accordingly, the introduction of a pipeline into the supply chain of jet A-1 to Lisbon airport could possibly be the solution to mitigate the main problems related to hazardous materials road tankers. It will eliminate the need of daily travelling of road tankers between CLC and Lisbon airport, consequently it will not only increase security and mobility of A1 highway users but also decrease traffic and emissions of CO_2, NO and other particles. However, this is just added value since the primary goal of introducing this new pipeline system is to increase the security of supply of jet A-1 to Lisbon airport. The fact that the Porto airport has not suffered any impact from the dangerous goods drivers' strike showcases that the pipeline system can be a solution to achieve this goal.

However, this new potential system cannot be seen as the perfect solution that will solve all existing problems. There are still some obstacles and uncertainties that need to be considered.

It is still uncertain if the existing water pipe channel can be used or not, therefore both cases need to be considered. If the existing water pipe is used, the most important issue is that there is a big difference between transporting water and transporting a hazardous material like jet A-1, because of the difference between their physical and chemical characteristics. The impacts that a spillage of jet A-1 can have on public health and on the environment are considerably higher than the ones caused by a spillage of water. Consequently, the infrastructures and the route of the water pipe need to be studied. In the case of the infrastructures it is necessary to analyze if they can be tailored to transport a liquid with jet A-1 characteristics. If so, which changes need to be made is the first question to be answered. In the case of the route, it must be scrutinized if it passes through areas which a jet fuel pipeline cannot go through. Thus, as for the infrastructures, adaptations to the route might be indispensable. On the other hand, if the water pipe cannot be used it will be necessary to build all the infrastructures from scratch which will lead to a larger investment costs than expected. Other important consideration is that a pipeline system will never mitigate all risks, since it has its own risks. Even, if any problem occurs, either at the Sines refinery or at CLC which can disrupt the supply of jet A-1, the pipeline will not be able to solve it. Therefore, an increase of storage capacity at the Lisbon airport might be a good infrastructure investment alongside the new pipeline system. It will increase the safety stock of jet A-1 at the airport, assuring that there is enough jet fuel for the aircrafts while the problem is being solved.

Correspondingly, the new pipeline system will cause several changes and impacts to the jet A-1 supply chain to Lisbon airport and to its stakeholders. Some of them could be the difference between the new system being viable or not, therefore they are presented in Table 5.

Table 5- Impacts on Stakeholders

Stakeholders	Impacts
CLC	Integrate into its operations the distribution of jet A-1 to airport 🟢 High initial investment 🔴
Dangerous goods owners/drivers	Loss of jobs since road tankers will be substituted by the pipeline 🔴 Obsolete Jet Fuel fleet 🔴
Oil companies	Mitigate the main risks existent with the current distribution system 🟢 Change in transport fee charged 🟢 / 🔴
ANA	Increase reliability of supply 🟢 Build new infrastructures to allow the supply via pipeline (high cost) 🔴 Increase storage capacity 🟢
Portuguese government	Decrease socio-economic instability impacts 🟢 Potential financial support to the investment 🔴 Reduction of CO_2 emissions, which goes in line with the country’s duties 🟢

🔴 - Negative 🟢 - Positive

CLC will be one of the main stakeholders impacted by the development of a new pipeline system to supply Lisbon airport. The company is on the front line to be responsible not only for developing the project, but also to operate the new pipeline system when finished. Which means it will integrate into its functions the transportation of jet A-1 to the airport, however an high initial investment from the company will be necessary. In the case of the dangerous goods drivers it could cause greater dissatisfaction since they can lose their job. If this dissatisfaction lead drivers to planning new strikes, it might have great impact on other products distribution which will remain to be transported by truck. The oil companies, ANA and the Portuguese government could be the main beneficiaries of introducing the pipeline into the jet A-1 supply chain, since it could solve some of the greatest problems these stakeholders have been facing with the current distribution system.

2.4 Problem definition

As showcased throughout this chapter, this dissertation arises from the need to study the introduction of a new pipeline system to supply jet A-1 to Lisbon airport to replace the current distribution system via road tankers. The main goal is to develop a methodology that will allow us at the end of the dissertation to provide to the decisions makers the necessary information and data about the problem so that they are able to make an informed decision on whether to go through or not with this new pipeline system project. However, this is a complex problem because it is at the same time a capital budgeting decision, for the company which will be investing in this new system, and a social interest project because it can have great impact to society in a social and environmental dimension. Our goal is not to focus on only one of these dimensions but rather on all three so the information gathered to support the decision-making will comprise economic, environmental and social factors.

The economic dimension brings up two decisive parameters of the problem, profitability and transport fee which is the fee charged to oil companies for the transportation of jet A-1 from CLC to Lisbon airport. Regarding profitability, it has to be guaranteed for the investor company, which will be considered for the purposes of our study CLC, so that the investment on this project is attractive. In terms of transport fee, it can be identified as the main economic decisive factor of this problem because if the transport fee required to guarantee the investment profitability is higher than the current charged for the transportation via road tankers, oil companies would continue to ship the product via road tanker as it will be cheaper thus making the pipeline system needless in an economic perspective. So, the only way the investment is beneficial for both parts is if the transport fee decreases while guaranteeing CLC's profitability. However, in case this does not happen if the Portuguese government considers the new system essential for national interest, it can subsidize the project to overcome those problems. This is where the environmental and social dimension are as important as the economic one, because if the introduction of the new pipeline system leads to environmental and social benefits, like decrease in air pollutant emission, decrease social instability and increase reliability of supply it can be enough to make the Portuguese government to consider the new system essential for national interest and as mentioned above it the project is developed independently of the results of the economic analysis.

Additionally to this key decision factors, an in depth characterization of both systems, current and new, is necessary. This characterization will allows to gather essential information and data, like costs, air pollutant emissions, decision makers objectives and worries, etc., that will enable the development of our study where all the aspects mentioned above are tackled. Furthermore, since the information regarding the new pipeline system is scarce we will be developing a preliminary study on its design where some key components will be identified like diameter, wall thickness, route, etc.

In the following chapters all these points will be addressed, starting with the literature review and the theoretical background, where the methodology of the dissertation will be identified, then the data collection and treatment and finally the development of the methodology and results analysis.

3. Theoretical Background

The goal of this chapter is to expose the existing theoretical and scientific literature which will act as a supportive basis for solving the problem under study. Therefore, it will be divided into four main topics. In section 3.1 it will be presented the work that has been developed in the past years about pipeline systems, focusing on refined crude oil products systems. In section 3.2, the pipeline system characterization is presented, including the pipeline design and project planning. In section 3.3 the main decision-making analysis methods are presented with a focus on multicriteria decision analysis (MCDA) and the MACBETH method. Finally, section 3.4 focus on investment analysis where the main techniques to support capital budgeting decisions are presented, mainly the net present value (NPV) method with special attention on determining the project cash flows, estimating the WACC and sensitivity analysis.

3.1 Pipeline systems

Pipeline systems play a very important role in petroleum industry since they are the main method of transportation for both crude oil and its refined products. Its cost-effectiveness due to having lower costs for large volumes over long distances is the key reason for pipeline being chosen over other transportation modes (Herrán et al., 2010; MirHassani et al., 2013; Zhigang et al., 2016). The initial investment associated with the construction of a new pipeline system is high, hence its operating costs is where the difference is made because they are very low when compared to other transportation modes such as rail and road tankers (Herrán et al., 2010)., Therefore, the development of optimization models for the scheduling associated with the transportation process of crude oil and its derivatives via pipeline have been one of the focus of many authors over the years (Herrán et al., 2010; Relvas et al., 2006). The main objective of pipeline scheduling is to find an optimal sequence of batches that will allow the delivering of products at the right time, quantity and location with minimum operational costs (MirHassani et al., 2013).

3.1.1 Scheduling optimization models for pipeline systems

Pipeline scheduling problems have been studied over the years via different types of models, including heuristic algorithms (Zhigang et al., 2016) and Mixed-Integer Linear Problem (MILP) or Mixed-Integer Nonlinear Problem (MINLP) models. The MILP or MINLP are the most common found in the literature and are categorized into two groups: discrete and continuous models. Rejowski and Pinto first work was the development of a MILP model to tackle the problem of oil products distribution from one refinery to multiple distribution centers, in which both time and pipeline volume had a discrete representation (Rejowski & Pinto, 2003). Later the same authors studied a continuous time MINLP model for both multiproduct pipeline scheduling and hydraulic operation (Rejowski & Pinto, 2008). When compared to their previous work, this one achieved better results. A different approach to the same problem was taken by Cafaro and Cerdá. These authors developed a continuous-time and pipeline volume MILP model to address the scheduling of a multiproduct pipeline transporting different refined crude oil products from a single refinery to multiple distribution centers (Cafaro & Cerdá, 2004). The authors improved their previous work by adding to their model formulation multiple delivery due dates (Cafaro & Cerdá, 2008). MirHassani and Fani extended Cafaro and Cerdá latest model to tree structure pipelines (MirHassani & Fani Jahromi, 2011). Relvas et al. also explored a continuous model but for a multiproduct pipeline which connects one refinery to one distribution center (Relvas et al., 2006). Additionally, to the problems tackled by other authors, they also focused on inventory management at the distribution center, taking into consideration daily client information and the need of a minimum settling period. In later work by the same authors, variable flow rates and pipeline stoppages were also considered in the modeling. A new procedure was developed in order to obtain updated schedules in case unexpected events take place (Relvas et al., 2007).

The studies presented above related with pipeline scheduling problems represent the primary work developed on this topic. However, in recent years there have been other authors which have been focusing on it. Dimas et al. also proposed a MILP formulation to model the simplest problem of scheduling, a straight pipeline connecting a single-source to a single-destination (Dimas et al., 2018). The problem of connecting a single-source to multiple destinations have been approached based on MILP (Chen, Zuo, et al., 2017; Zaghian & Mostafaei, 2015), MINLP (Cafaro et al., 2015; Rejowski & Pinto, 2008), heuristics (Zhang et al., 2017), and decomposition strategies (Meira et al., 2018). Still, for straight pipeline systems problems, there is the multiple-sources to multiple-destinations (Castro & Mostafaei, 2017; Chen, Wu, et al., 2017). Other more complex pipeline systems topologies have been studied, such as tree-like (Liao et al., 2019; Taherkhani, 2018) and mesh-like (Magatão et al., 2015; Polli et al., 2017).

The pipeline scheduling problem is merely operational, therefore it is studied and applied only for already existing pipeline systems. Hence, this topic can be relevant in a later stage, when the system is already constructed, in order to understand if the new pipeline system can affect the scheduling of the already existing multiproduct pipeline. However, for this stage of the project which is focused on the strategic side the scheduling falls outside the objectives.

3.1.2 Risk assessment and monitoring systems of pipeline systems

Besides the scheduling problem tackled in the previous section, there is another main problem related with oil products pipeline systems approached in the literature, which is the risks associated with these systems and the possible consequences for public health and environment in case of accident. About this topic, authors focus on two main points: i) some study methodologies for risk assessment related with pipeline accidents, whereas ii) other explore the monitoring of oil pipeline systems which includes the analysis of potential mitigation systems.

Pipeline systems are designated as the safest mode of transportation for hazardous materials, essentially due to the low incidence of both spills and accidents (Bonvicini et al., 2014; Ramírez-Camacho et al., 2017). However, the risks related with pipeline operations are high since the impacts it can cause to the environment and public health, in case of accident, are massive (Fra & Dziubin, 2006; Ramírez-Camacho et al., 2017). Therefore, the possibility of it happening cannot be ignored, considering the millions of kilometers of pipeline extension existing around the world (Bonvicini et al., 2014; Ramírez-Camacho et al., 2017). This is recognized by both industry and public agents which seek to maintain high safety standards for these system through the development of various regulatory approaches worldwide (Bonvicini et al., 2014).

Quantitative Risk Analysis (QRA) techniques applied to pipelines have been studied and improved throughout the years by several researchers (Gharabagh et al., 2009; Han & Weng, 2011). Bonvicini et al. explored a quantitative risk analysis model to study the environmental risks related to spillage from onshore pipelines. They defined specific environmental indexes where the risk of soil and groundwater contamination were expressed in both physical and economic terms (Bonvicini et al., 2014). The authors believe that the proposed methodology is a step towards a better comprehension of risk management associated to onshore pipelines (Bonvicini et al., 2014). Ramírez-Camacho et al. took a qualitative technique approach to assess the risks associated with pipeline systems (Ramírez-Camacho et al., 2017). The authors developed an historial analysis about onshore pipeline accidents based on the data of 1063 accidents which ocurred in several countries (Ramírez-Camacho et al., 2017). The authors noticed that third party activities, essentialy excavation machinery, was the most frequent cause for accidents in onshore pipelines. However, they state that pipeline systems are the safest mode of transportation when compared to the other existing ones (Ramírez-Camacho et al., 2017). An even different approach was taken by Fra and Dziubin to tackle the same problem. The authors proposed a methodology which comprises both qualitative and quantitative techniques, which offers the capability of fully assess the risks related to pipelines systems (Fra & Dziubin, 2006). In the case of their study, it focused on long pipelines and from it they comprehended that the environmental hazard assessment needs an individual approach to each specific case, essentially due to the different ecosystem each pipeline are located in (Fra & Dziubin, 2006). Strogen et al. studied the problem in a different prespective (Strogen et al., 2016). They present a methodology not only to evaluate the externality profile of all oil products transportation modes, which includes externalitites such as environmental, public health, and safety impacts. But also to appraise new infrastructure projects against existing ones and other alternatives. Consequently, all externalities considered by the authors were monetized based on estimates from the economics literature. Overall and accordingly to other authors, pipeline is the best fitted to transport hazardous materials, however the authors highlight on how much superior pipeline system are when compared to other modes, in terms of public health burdens (Strogen et al., 2016).

As mentioned previously, the frequency of accidents in pipeline systems is low. However the possibility of occurrence can never be ignored. Hence, the study and development of new monitoring frameworks and new mitigation systems for oil pipelines have been one of the topics of attention for researchers. In recent years, the concerns related with pipeline systems goes beyond corrosion and operational errors, threats from terrorism and cyber-attacks are the most concerning ones (Eze et al., 2017). Wireless Sensor Networks (WSN) is cosidered one of the most fitted ways to monitor and aquire data from a pipeline system, due to its low costs, flexibility and efficiency (AL-Kadi et al., 2013; Yu & Guo, 2012). AL-Kadi et al. explored four different solutions for pipeline leak monitoring using WSNs: magnetic induction based, continuous pressure monitoring, underground to above ground radio propagation and wireless signal networks (AL-Kadi et al., 2013). While, Yu and Guo proposed an algorithm for efficient pipeline data collection based on sensor node line deployement strategy and data fusion strategy in WSN (Yu & Guo, 2012). Both authors affirmed that despite WSN already being efficient in leak detection there is still future work to do in order to futher improve the systems in study and increase even more its performance (AL-Kadi et al., 2013; Yu & Guo, 2012).

3.1.3 Discussion on Pipeline Literature

An overview of the pipeline literature has been given in this section, where the main focus goes to the optimization of pipeline scheduling as well as to the assessment and monitoring of pipeline systems risks. The objective of this dissertation falls outside of these topics because they concentrate mainly on the operational dimension of pipeline systems, whereas our goal is to gather the necessary information to support a strategic decision of introducing a new pipeline systems. This includes an intitial study of system's design, developing a decision support system methodology and an investment analysis, so that we can tackle all crucial dimensions of the problem. Therefore, the following sections will be dedicated to these three topics where their theoritical background will be presented in the context of our problem.

3.2 Pipeline Design

The first key concept related with pipeline design is the design life. Design life corresponds to the period for which the design basis is planned to remain valid (ISO 13623, 2009). Generally, the design of crude oil products pipeline systems considers a lifetime span of between 20 to 25 years (Angelini, 2011). However, it is expected that the system will last more than these years, but a new design study will be necessary to evaluate its condition and guarantee its security.

According to the International Standard (ISO 13623, 2009) requirements , the coverage and detail of the pipeline design must be sufficient to demonstrate that the integrity and serviceability can be maintained during the design life. Therefore, the pipeline design characteristics will be selected in accordance with good engineering practice and pipe flow theory. Methods of analysis may be based on analytical, numerical or empirical models, or a combination of these methods.

In the following sections the main objective is to determine pipeline design characteristics, pipe diameter, wall thickness and pump horsepower. To do that, we need to consider the various elements that impact the design process, for example, fluid characteristics ,route, loads.

3.2.1 Characterization of the Fluid

Prior to focus the attention on actual pipeline design, it is necessary to have a deep knowledge about the fluid which is being moved. There is a significant difference between moving water and crude oil refined products, which are hazardous materials. Not only they have different physical and chemical characteristics, but also the impacts which an accident in an oil refined products distribution system could cause in both human health and environment are irreversible when compared to a water distribution system. Therefore, the safety measures for this type of products need to be much more restrict. The table 6 categorizes fluids based on the hazard potential with respect to public safety.

Table 6 -Classification of fluids with respect to potential hazard to public safety (ISO 13623, 2009)

Category A	Non-flammable, water-based fluids
Category B	Flammable and/or toxic fluids that are liquids at ambient temperature and at atmospheric pressure conditions. Typical examples are oil and petroleum products. Methanol is an example of a flammable and toxic fluid.
Category C	Non-flammable fluids that are non-toxic gases at ambient temperature and atmospheric pressure conditions. Typical examples are nitrogen, carbon dioxide, argon and air.
Category D	Non-toxic, single-phase natural gas.
Category E	Flammable and/or toxic fluids that are gases at ambient temperature and at atmospheric pressure conditions and are conveyed as gases and/or liquids. Typical are hydrogen, natural gas (not otherwise covered in category D), ethane, ethylene, liquefied petroleum gas (such as propane and butane), natural gas liquids, ammonia and chlorine.

Jet A-1 is the fluid that will be transported in the pipeline system in study. Therefore, it should be placed in Category B since it is a crude oil product. This part will be dedicated to its chemical and physical characteristics which will be key on the pipeline design phase. To characterize this type of products there are five principal basic properties: melting point, flash point, flammability, density and viscosity. In the Table 7, these and other basic physical and chemical properties of jet A-1 are displayed.

Table 7 - Jet A-1 chemical and physical characteristics (Moses, 2011; NESTE, 2019)

Properties	JET A-1
Appearance	Liquid
Odor	Hydrocarbons
Melting Point	≤ -47°C
Flash Point	≥ 40°C
Upper flammable/explosive limit	0,6%
Lower flammable/explosive limit	6%
Relative Density (kg/L @15°C)	0,775 - 0,840
Viscosity (mm2/s @ 15°C)	1.75 - 2
Initial boiling point and range	170 - 300 °C
Vapour Pressure (kPa @ 38°C)	2
Vapour Density	> 3
Solubility	Poor water-solubility
Explosive Properties	Not considered to be explosive

All these properties have to be taken into consideration when designing the new pipeline system. Properties such as density and viscosity will have impact on the required pump horsepower and consequently will influence the pipe size as well. These properties are not only important to consider in the design phase but also when the pipeline is in operation. There are for example certain levels of temperature and pressure that have to be maintained in order to ensure that the product is kept in liquid state. The vapor pressure of a fluid is the pressure at which the fluid will boil at ambient temperature. Therefore, if the fluid pressure reaches values lower than the fluid vapor pressure, local boiling will occur and gas bubbles will form within the fluid. When this fluid goes through the pump, the pressure within the fluid will increase leading to the gas bubbles to collapse creating vibrations which will cause damage on the pipeline system and the pump, this effect is called cavitation (Brennen, 2014).

3.2.2 Pipeline Characteristics and Components

Route Selection

Route is one of the most crucial elements of a pipeline system because it impacts and is impacted not only the design but also construction, operation and maintenance. The main goal of route selection is to select the route that minimizes costs. However, it is not possible to select the shortest path between the origin and delivery points because there are several factors that need to be considered. According to the International Standard, the factors that should be included in the route selection process are:

- Safety of the public, and personnel working on or near the pipeline;
- Protection of the environment;
- Other properties and facilities;
- Third-party activities;
- Geotechnical, corrosivity and hydrographical conditions;
- Requirements for construction, operation and maintenance;
- National and/or local requirements;
- Future exploration.

Additionally, route and soil surveys must be carried out to identify and locate accurately the significant geographical, geological, geotechnical, corrosivity, topographical and environmental features, and other facilities such as other pipelines, cables and obstructions, than can influence the pipeline route selection.

When selected there are some elements of the route, such as length, elevation profiles and crossings that will influence the pipeline design mainly the pump horsepower.

Loads

Loads are another key element which impacts the pipeline design, mainly the strength design. The loads taken into account are the ones that can cause or contribute to pipeline failure or loss of serviceability. These are classified as:

- Functional; or
- Environmental; or
- Construction; or
- Accidental.

Functional loads include the loads arising from the intended use of the system (weight of the pipeline, including components and fluid, and the loads due to pressure and temperature) as well as the residual loads from other sources (pre-stressing, residual stresses from installation, soil cover, external hydrostatic pressure, marine growth, subsidence and differential settlement, frost heave and thaw settlement, and sustained loads from icing). Environmental loads, as the name suggests, arise from the environment, it includes hydrodynamic loads, earthquake loads, soil and ice loads, road and rail traffic, fishing and mining. Construction loads include the loads for installation and commissioning. Accidental loads are the ones suffered by the pipeline under unplanned but possible circumstances.

Strength Requirements

The strength design objective is to guarantee that the pipeline will support all the loads that could be applied to it throughout its design life.

Calculation of stresses

In pipeline systems there are three different stresses:

- Circumferential stress (Hoop stress);
- Longitudinal stress;
- Radial stress.

The circumferential stress, σ_{hp}, due to fluid pressure only (hoop stress), is the largest stress in the pipe. Also, it is the hoop stress which allow us to compute the required pipe wall thickness. Using the thin wall approximation, where D_o/t_{min} needs to be greater than 20, the hoop stress is defined through Equation (1).

$$\sigma_{hp} = (p_{id} - p_{od}) \times \frac{D_o}{2t_{min}} \quad (1)$$

where

p_{id} is the design pressure;

p_{od} is the maximum external hydrostatic pressure;

D_o is the nominal outside diameter;

t_{min} is the specified minimum wall thickness.

Then, the maximum hoop stress due to fluid pressure can be determined in accordance with Equation (2):

$$\sigma_{hp} \leq f_h \times \sigma_y \quad (2)$$

where

f_h is the hoop stress design factor (ISO 13623, 2009);

σ_y is the specified minimum yield strength (SMYS) at the maximum design temperature.

Therefore, it is possible to rearrange Equation 1, in order to allow us to compute the required pipeline wall thickness that will guarantee there is no mechanical failure due to the fluid pressure, for diameter and design pressure identified.

Crossings/ Other Activities

Besides the loads applied on the pipeline there are other factors that influence the definition of the pipeline protection requirements and cannot be measured by the equations presented above. These factors are:

- Possible effects of pipeline damage on public safety and the environment;
- Possible effects of interference from other activities;
- National requirements for public safety and the protection of the environment.

Some examples of activities that need to be considered are other land users, traffic, cultivation, installation of drainage, construction of building and work on roads, railways, waterways and military exercises. Consequently, additional protection measures might be needed such as cover, increased wall thickness, markers and marker tape, mechanical protection, controlling access to pipeline route, or a combination of these measures. For example, if the pipeline goes through a densely populated area it might be required a pipeline wall thickness greater than the one determined by the methodology presented above.

Pipeline Cover

The cover depth is a characteristic of the pipeline which depends solely on the location. Table 8 displays the correlation between minimum cover depth for pipelines and location. Cover depth must be measured from the lowest possible ground surface level to the top of the pipe, including coating and attachments.

Table 8 - Minimum cover depth for pipelines on land (ISO 13623, 2009)

Location	Cover Depth [a] (m)
Areas of limited or no human activity	0.8
Agricultural or horticultural activity [b]	0.8
Canal, Rivers [c]	1.2
Roads and railways [d]	1.2
Residential, industrial, and commercial areas	1.2
Rocky ground [e]	0.5

a Special consideration for cover may be requires in areas with frost heave.
b Cover shall not be less than the depth of normal cultivation.
c To be measured from lowest anticipated bed.
d To be measured from bottom of the drain ditches.
e The top of pipe shall be at least 0.15 m below the surface of the rock

Section Isolation Valves/ Pressure Control Valves

Section isolation and pressure control valves will be installed at the beginning, at the intermediate sections and at the end of the pipeline. These valves are one of the essential components of the system because they allow for:

- Operation and maintenance
- Control of emergencies
- Limiting potential spill volumes

Thus, they are not only key for the normal operation of the system, but also, to minimize the impacts of any accident that can occur in the system.

Pigging

Pipeline pigging is one the activities included in pipeline's routine maintenance. Pipeline pigging involves the use of devices known as pigs which performs various cleaning, maintenance, inspection, dimensioning, process and pipeline testing operation on both new and existing pipelines. This process is normally performed without the need of stopping the flow of the product in the pipe. Generally, pigs are cylindrical or spherical to aid movement and efficient cleaning. The pigging process starts by inserting the pig into a pig launcher and then through applying flow under pressure to the rear of the device it will move into the pipeline. Throughout its movement through the pipe, the pig scraps and removes debris existing in the pipe. A pig catcher is located at the end of the pipe to capture the pig when it finishes the process. This pig catcher is isolated via a shut-off valves guaranteeing that the pig is safely removed. Pipeline pigging ensures that the pipe is clean and clear, hence continuing to deliver optimum performance (inline, n.d.).

Pipeline pigging will have influence on the pipe's design due to pig's specific characteristic. For example, the process does not work for every valve. Two most common piggable valves are through conduit valves and trunnion mounted ball valves (Tiger Valve Company, 2020).

Corrosion Management/ Cathodic Protection

Corrosion is one of the key problems suffered by the pipeline system which can cause failures and/or loss of operability. Therefore, it is necessary that the pipe has an external coating which can prevail throughout the pipe's design life. Usually, 3 Layer Polyethylene corrosion resistant coating is the one applied to the external surfaces of the pipe. This coating system is adequate to operating temperatures up to 50ºC during the pipe design life.

Alongside the application of an external coating, the application of a cathodic protection is an essential part of the pipeline system in order to minimize corrosion. Cathodic protection is a electrochemical technique which makes the metal surface the cathodic side of an electrochemical cell. It connects an external anode to the metal to be protected and passes a direct current between them so that the metal becomes cathodic, preventing the metal surface corrosion (Abriox, 2019).

Leak Detection Systems

The main purpose of leak detection systems (LDS) is to support pipeline controllers in detecting and localizing leaks.

The current leak detection methods generally used are (Geiger, 2012):

- Pressure Leak Detection – The software measures the actual pressure and flow in each pipeline section and compares them with the expected values. In case of discrepancy a possible leak is reported as well as its location is indicated in the batch tracking display.
- Volume Batch Leak Detection – The volume entering and the volume exiting the pipeline is permanently compared. When the discrepancy exceeds the threshold value of error, an alarm is generated.

Safety and Control Systems/Communication System

In terms of safety and control, it requires two systems: a control (SCADA) and a safety one (ESD).

Supervisory Control and Data Acquisition (SCADA) is a computer-based data communication system that monitors, processes, transmits and displays pipeline data for the pipeline controller. Generally, a pipeline LDS collects data like flow, pressure, temperatures, etc, which is generated by a SCADA system (Geiger, 2012).

The Emergency Shut Down (ESD) system is designed to control the existing emergency shutdown valves of the system. Therefore, allowing manual or remote closure of these valves isolating pressure and flow during a overpressure situation, like a leak or rupture. The main goal of the ESD system is to minimize the loss of containment and impacts of the incident.

Pressure Tests

Lastly, prior to being put into operations the pipeline must be pressure-tested in order to evaluate its strength and leak-tightness. If the results do not meet the requirements of the International Standard, the pipeline shall be repaired and retested.

3.2.3 Pipeline Dimensioning

Now that most of the elements of a pipeline system that impact its design were approached, we will focus on pipeline dimensioning which will include all the theoretical background to determine the most economic pipe diameter and the wall thickness that is in line with safety measures.

Diameter Definition

The pipeline diameter has great influence on both capital and exploration costs. Higher diameter pipes are higher priced and also require more expensive infrastructures and take longer to install. On the other hand, the pumping costs rapidly decrease as the pipe diameter rises. For a fixed flow rate, a higher diameter will require less velocity, head losses will be lower and consequently less pump horsepower will be necessary. Therefore, there is a trade-off between these costs for the needed flow rate of product (Schaschke, 1998). The main goal is to determine a diameter which will give the minimum total costs based on this trade-off. To do that we study several pipe sizes for which we build a graph with a curve for both capital and energy costs, as well as, a curve for the total cost. The minimum point of the total cost curve showcases the economic diameter (Hanesian & Perna, 1994; Kowalski & Wernik, 2014).

The first element that influences the pipe size is the amount of fluid that needs to be transported. Therefore, primarily it is necessary to define the necessary flow rate for the entirety of the pipeline lifetime. The flow rate will not be constant since the demand of jet A-1 can fluctuate over time. Hence, the pipeline size has to account for these fluctuations and will be directly dependent on the maximum demand of jet A-1, during the pipeline lifetime.

On contrary to road tankers, where it is easier to contract extra vehicles if more capacity is needed, in a pipeline system its size is fixed, therefore it has a maximum capacity of product that can be transported. If we need to increase the flow rate for a fixed diameter, it is necessary to increase the flow velocity. However, there is a point where this velocity cannot be increased because the pipe has a maximum internal pressure it can resist. Therefore, flow velocity is another key element of a pipeline system, but there are some considerations to be made when defining it such as:

- Maximum internal pressure of the pipe;
- Head losses which could lead to an excessive electricity cost;
- Existing elevation profiles on the pipe route;
- Pipeline wear (erosion, corrosion, cavitation).

All these factors are constraints for determining flow velocity, which at the end will also have impact in the pipe size.

Firstly, the yearly flow rate (Q) for the system's lifetime has to be estimated based on the demand of jet, because this is what will influence the flow velocity, then the head losses and ultimately the required horsepower which allows the computation of the energy cost. The energy costs will vary each year depending on the growth rate of jet demand. Therefore, the yearly energy costs have to be estimated based on the flow rate required in each year, so that the total energy costs during the system's lifetime can be estimated. This total energy costs will be a key part on the selection of the most economic diameter.

Once obtained the yearly flow rates in each diameter, the flow velocity (V) is estimated for each one, from $\mathrm{V}=\frac{\mathrm{Q}}{\mathrm{A}}$ with $A = \pi\left(\frac{D}{2}\right)^2$ (M. White, 2017). However, related to the constraints mentioned above, there is another consideration regarding flow velocity, which is the velocity limit in pipeline systems. This limit is imperative due to pipe's internal pressure and wear that will be caused to it. API recommend practice 2003 states that flow velocity in a pipe should never exceed 7 m/s (API, 2016). However, in general for pipeline systems like the one in study velocities are not higher than 3,5 m/s. For example, the multiproduct pipeline which connects Sines refinery to CLC runs with velocities between 1 m/s and 1,5 m/s. Pipeline systems with flow velocity higher than the usual 3,5 m/s will suffer a more rapid degradation (erosion, corrosion, cavitation) and can even undergo an internal pressure that can surpass the maximum internal pressure the pipe can resist. This could mean that an extra pump station or the use of drag reducers might be indispensable. Since a certain value of flow velocity might be crucial to surpass elevations existent throughout the pipe route.

Drag reducers are high molecular weight polymers which are used to reduce the frictional pressure loss ratio in crude oil, refined fuel and aqueous pipelines. In general drag reducers are used in pipeline systems to tackle the following problems (Marawan, 2004):

- Throughput improvement
- Power optimization
- By passing intermediate pump stations
- Batch management
- Scheduled maintenance
- Shortening barge download time
- Peal shaving
- Operating pressure reduction

In short, drag reducers will help to minimize the flow turbulence, which will allow reducing velocity for the same flow rate, reducing the head losses in the system and in the end reducing the energy costs. However, companies that commercialize drag reducers are aware of its benefits and sometimes charge prices that would not be attractive when compared to the possible reduction in energy cost. It is necessary to analyze the trade-off between drag reducers' price and energy cost reduction to make the best decision in both economic and technical point of view.

However, for this study these possibilities are not going to be considered, we are considering a system with only one pump station.

Now that the flow velocity has been discussed, the next phase is to estimate the head losses and from it the pump horsepower. To enable it, first it is necessary to compute the number of Reynolds (Re) and ε/D, in order to attain the pipe friction factor (f). With f it is then possible to estimate the head losses (h_f). The Bernoulli equation enables the determination of head increase across the pump (h_p). Lastly, the pump horsepower (Pot) can be estimated (White, 2017).

The Reynolds number (Re) is directly related with the fluid flow behavior. The name Reynolds is in honor of Osborne Reynolds, a British engineering professor, which showed in 1883 that the transition depended on the parameter determined through Equation (3) (White, 2017).

$$Re_d = \frac{\rho V d}{\mu} = \frac{V d}{\upsilon} \qquad (3)$$

where

ρ	is the fluid density;
V	is the velocity;
υ	is the fluid viscosity;
d	is the pipe diameter.

This equation will allow to compute the Reynolds number taking into account the transition from laminar flow to turbulent flow.

For the ε/D factor, ε is the roughness of the pipe (m) which has the value of approximately 0,046 for commercial steel pipes (Mccoy & Rubin, 2008).

The dimensionless parameter f is named after Henry Darcy, a French engineer that established the effect of roughness on pipe resistance, as the *Darcy friction factor.* In 1800, it was discovered by Coulomb that surface roughness has effect on friction resistance. Great differences were observed on both laminar and turbulent flow. In the first one the effect is negligible while in the second one it is substantial (White, 2017).

To tackle the problem of the transitionally rough range, Colebrook combined the smooth wall (Equation 4) and fully rough (Equation 5) relations into an interpolation Equation (6) (M. White, 2017):

$$\frac{1}{f^{1/2}} = 2.0\ \log(Re_d\, f^{1/2}) - 0.8 \quad smooth\ wall \tag{4}$$

$$\frac{1}{f^{1/2}} = -2.0\ \log\frac{\varepsilon/d}{3.7} \quad fully\ rough \tag{5}$$

$$\frac{1}{f^{1/2}} = -2.0\ \log\left(\frac{\varepsilon/d}{3.7} + \frac{2.51}{Re_d\, f^{1/2}}\right) \quad Colebrook \tag{6}$$

This equation was plotted in 1944 by Moody, into what is most likely the most famous and useful chart in fluid mechanics, the *Moody chart* for pipe friction (Annex A). It is accurate to $\pm$15 percent over the full range shown in the chart. It gives the values of both laminar and turbulent pipe friction taking into consideration the roughness effects. All types of problems related to pipe flow can be solved by using the chart or by using the Colebrook eq. trough iteration or a direct solver. Haaland proposed an explicit formula (Equation 7) that can be used when only a calculator is available, which only varies less than 2 percent from Colebrook's Equation (6) (M. White, 2017).

$$\frac{1}{f^{1/2}} \approx -1.8\ \log\left[\frac{6.9}{Re_d} + \left(\frac{\varepsilon/d}{3.7}\right)^{1.11}\right] \tag{7}$$

Therefore, the Haaland equation is generally the one used to compute f.

The pipe head loss (h_f) represents the change in height of the hydraulic grade line (HGL), from an incompressible steady flow between two sections of an inclined pipe. In 1850, a German professor named Julius Weisbach showed how the head loss can be useful for pipe flow problems. In a modern textbook he published about hydrodynamics he proposed the following correlation Equation (8) (M. White, 2017):

$$h_f = f \frac{L}{d}\frac{V^2}{2g} \quad (8)$$

where

h_f is the pipe head loss;

L is the pipe length;

V is the velocity;

g is the gravitational acceleration.

By using the Bernoulli equation between the inlet and outlet of the pipe, with a pump we get Equation (9):

$$\left(\frac{p}{\rho g} + \frac{V^2}{2g} + z\right)_1 = \left(\frac{p}{\rho g} + \frac{V^2}{2g} + z\right)_2 + h_f - h_p \quad (9)$$

where

p is the pressure of the fluid;

z is the vertical height of the system;

ρ is the fluid density;

g is the gravitational acceleration;

Since $v_1 = v_2 \approx 0$ and $p_1 = p_2$, solve for the pump head we get Equation (10):

$$h_p = z_2 - z_1 + h_f = z_2 - z_1 + \frac{fL}{d}\frac{V^2}{2g} \quad (10)$$

With the head loss across the pump, h_p, to determine the required horsepower we use Equation (11)

$$Pot = \rho g Q h_p \quad (11)$$

where

Pot is the pump horsepower;

Q is the flow rate;

h_p is the head loss.

Now that the yearly required pump horsepower for each diameter is known, it is possible to compute the corresponding yearly energy costs. Then, along with the capital costs associated with each sized pipe, the overall costs can be computed. Allowing a comparison between all the diameters considered. With the main objective of not only analyzing the trade-offs between energy and capital costs, but also of choosing the most economic diameter for the pipeline system.

The capital costs include the pipe price and its installation, which should be obtained from the constructor. In the case of energy costs, first it required to know the energy unit price (€kWh). Then, the total energy cost can be computed considering the pump horsepower required each year. Finally, the total costs can be computed and the most economic diameter is selected.

Wall Thickness Definition

Alongside the pipe diameter, wall thickness is the other physical characteristic of the pipe that enables us to choose which one will be ordered to suppliers. By solving Equation 1 for wall thickness and considering, $\sigma_{hp} \leq f_h \times \sigma_y$, we get Equation (12):

$$t_{min} = \frac{p_{id}\, D_o}{2(f_h \times \sigma_y)} \quad (12)$$

Note that the external hydrostatic pressure, p_{od}, is not considered. The pipeline in study is onshore, therefore the external pressure exerted by the soil is not significant when compared to the external pressure exerted by water in offshore pipelines. Additionally, this will allow us to get a higher value for the pipe wall thickness which increases the system's safety.

To determine t_{min}, the design factor, f_h, is given from a table and depends only on the pipeline location (ISO 13623, 2009). The specified minimum yield stress (SMYS), σ_y, is also given from a table and depends on the pipe material (M. A. El-Reedy, 2015). From these two parameters hoop stress, σ_{hp}, can be computed. Then, the pipe diameter is determined via the procedure presented previously. Lastly, the internal design pressure, p_{id}, is directly related with the head losses throughout the pipe computed when pipe diameter is defined.

All the key elements for an initial characterization of a pipeline system were identified and explained. The main goal was to obtain vital information about the pipeline system components and design which we will have to identify and determine for the system in study.

3.3 Decision Making Analysis

3.3.1 Decision Making Analysis methods

There are several methods applied to decision-making problems where the methodologies based on economic principles are highlighted. Which include two main approaches cost-benefit analysis (CBA) and cost effectiveness analysis (CEA) (EIB, 2013; Spackman, Dogson, Pearman, & Lawrence, 2000).

Cost-benefit analysis (CBA) has been used worldwide for several years. It is one of the most commonly accepted and applied method for project appraisal for large-scale investments in the public sector (Jones et al., 2014; Nickel et al., 2009; Tudela et al., 2006). There are even many entities, comprising governments and funding agencies, that make CBA a requirement for project approval, in order to choose the project which offers the most efficient resource allocation (Beukers et al., 2012; EIB, 2013; European Commission, 2014; Jones et al., 2014). Generally, CBA target is translating into monetary values the overall costs and benefits of alternative projects, allowing the comparison between different projects, based on the same unit of measurement (Beukers et al., 2012; Jones et al., 2014; Tudela et al., 2006).

Cost effectiveness analysis (CEA) is an economic evaluation method which is very similar to CBA but there is an essential factor which distinguish them. In a CEA costs are also measured in monetary units but on contrary to CBA, benefits are measured in non-monetary quantitative terms (EIB, 2013; Karlsson & Johannesson, 1996; TheWorld Bank, 2004). Therefore, CEA is the main economic evaluation method used in healthcare (Garber & Phelps, 1992; George et al., 2001; Karlsson & Johannesson, 1996), since many physicians agree that it is not correct putting a monetary value on a health outcome (Garber & Phelps, 1992). Typically, in CEA the health outcomes are measured in life-years saved, surrogate clinical endpoints or Quality Adjusted Life Year (QALY), which is the common measured used (Garber & Phelps, 1992; George et al., 2001; Karlsson & Johannesson, 1996). In general, CEA evaluates each alternative in terms of the ratio of incremental cost per unit of incremental health outcome. Therefore, alternatives can be compared with the main goal of maximizing the health effects for a given budget (Garber & Phelps, 1992; Karlsson & Johannesson, 1996). Sectors such as energy, solid waste, water and wastewater where benefits are also difficult to measure monetarily, CEA can be a more fitted method to be applied instead of CBA (EIB, 2013).

Despite being used worldwide there are some cases when the outputs of a project are difficult to measure monetarily where CBA and CEA are not the best fitted methodology to be applied (EIB, 2013). Additionally, there have been some authors which have been criticizing CBA over past few years. Criticism related to its decision-making process (Jones et al., 2014), its process (Beukers et al., 2012), it monetizes non-market goods (Mackie & Preston, 1998), the openness of the interpretation of its results (TheWorld Bank, 2004), its scrutiny by the public (Tudela et al., 2006), its need for completeness and correctness (Annema et al., 2007), its lack of being understood (Jones et al., 2014), its ethics (Wee, 2007) and its discounting of long-term environmental consequences (Ludwig et al., 2005).

Multicriteria decision analysis (MCDA) is a technique to support decision-making problems which appears as an alternative to CBA and CEA (EIB, 2013; Tudela et al., 2006). Despite also being based on economic principles, the main difference between MCDA and the other methods is that it considers both quantitative and qualitative criteria whereas the other methods only consider quantitative criteria (Tudela et al., 2006; Yedla & Shrestha, 2003). Consequently, it is a method which is better fitted for sectors where benefits are difficult to be measured monetarily such as education, urban and regional development (EIB, 2013). There are various techniques for developing a MCDA: Multi attribute utility theory, REGIME, ADAM type, Electre and Promethee outranking procedures, goal programming, Analytic Network Process (ANP), Analytic hierarchy process (AHP) and MACBETH (Spackman et al., 2000; Tudela et al., 2006).

Considering the dissertation goal where all key dimensions, economic, environmental and social must be tackled, MCDA method is the one which more in line with it. The method allow us to consider multiple and subjective criteria, qualitative and quantitative, where economic, environmental and social aspects are all included, whereas in the other methods the need to monetize and discount environmental and social consequences is not suitable to obtain the information we intend for supporting the decision-making. Therefore, an in-depth description of MCDA method theoretical background is given in the next section.

3.3.2 Multicriteria Decision Analysis

MCDA is a technique to support decision-making problems, where there are several criteria under consideration, which sometimes are contradictory to each other and have different importance (Baltussen & Niessen, 2006; Beria et al., 2012; Tudela et al., 2006). In this type of problems the decision process becomes so complex that makes it impossible for the decision maker to fully understand the problem in study (Phillips & Bana e Costa, 2007). Therefore, MCDA goal is to guide the decision maker in the process of judging the multiple criteria and evaluating the alternatives, in order to promote informed decisions (Belton & Stewart, 2002).

Before judging the multiple criteria and evaluating the alternatives, there is an essential phase of the MCDA method which is the problem structure. In this phase, the project's areas of interest are identified and different points of view are accessed, with the goal of identifying the project's objective and evaluation criteria. These must be in accordance with the stakeholders' objectives and with the strategic values of the companies involved. Ensuring that the decision maker considers all the necessary factors when evaluating the alternatives in study (Beria et al., 2012; EIB, 2013; R. Keeney & Raiffa, 1976). A common mistake is focusing only on criteria which facilitate the distinction between alternatives, taking to a second plan the companies' goals. However, in MCDA alternatives are evaluated through a global score which is determined based on the performance of each alternative in each criterion. Hence, alternatives must be seen as means to reach companies' goals and not as a basis to identify criteria, this is called "value-focused thinking" (R. Keeney, 1992).

The construction of a value tree is a very useful tool in multicriteria model structuring, because it is one of the best instruments to visually represent the problem's objectives, by decomposing them into areas of interest and subobjectives. The visual representation given by the value tree helps the process of identifying evaluation criteria, since it gives to decision makers and facilitator an additional tool to think about the problem (C. A. Bana e Costa et al., 1999). Hence, the identified criteria are generally organized into groups or areas of concern.

The objectives identified from the stakeholders, comprise the higher levels of the value tree. Then, the evaluation criteria identified from decision makers' worries and opinions, are introduced. These criteria can be hierarchically organized where main criteria are at the higher levels in the value tree and sub-criteria, which are ramifications of the main criteria, are placed at inferior levels (Edwards et al., 2007). The evaluation criteria defined have to be consensual, independent, exhaustive, mensurable, non-redundant, operational and concise, to enable the construction of descriptors (Beinat & Bana e Costa, n.d.).

When constructed, the value tree should be presented and discussed with decision makers to check if any change is needed and if not validate it.

Once evaluation criteria are identified and the value tree constructed, the final phase of problem structuring is to operationalize criteria by constructing descriptors for each criterion (Beinat & Bana e Costa, n.d.). A descriptor of impacts is an ordered set of quantitively or qualitatively plausible impact levels of a criterion, with the goal of measuring to what degree an alternative satisfies that criterion. The levels of the descriptor have to comply with the condition of being rank-ordered in term of their relative attractiveness, resulting in an ordinal preference scale, enabling us to distinguish from two alternatives which one is more attractive once their impacts have been assessed. This preference is only valid for the criterion in consideration, so it is called “partial” attractiveness (Beinat & Bana e Costa, n.d.).

Defining the descriptors is a process which involves both facilitator and decision makers, where each criterion is clarified, and the descriptors are defined precisely and methodically in a plausible domain. Descriptors have to be intelligible, mensurable and operational.

A descriptor can be classified as quantitative or qualitative, discrete or continuous and direct, indirect or constructed (Beinat & Bana e Costa, n.d.). A direct descriptor directly reflects effects, whereas an indirect descriptor indicate causes more than effects. A descriptor is constructed when neither a direct nor an indirect attribute is appropriate for a criterion. This correlates to criteria which have an intrinsically subjective nature or there is lack of information about it (Beinat & Bana e Costa, n.d.).

The impacts of options on each criterion should be described as objectively as possible. A more objective appraisal of the impacts, give us a better understanding, consequently they are less ambiguous and the model will be better accepted (C. Bana e Costa et al., 2008). Therefore, continuous and quantitative descriptors are better than discrete and qualitative ones. Also, direct and indirect descriptors are preferable to constructed ones. However, as mentioned above this type of descriptors might be necessary, which in some cases can compromise the intelligibility of the model.

Throughout the process of constructing descriptors some redundancies or new criteria can be found. If this is the case the model structure must be revised, showcasing the iterative nature of the model.

When constructing the criteria descriptors, it is recommended to delineate two reference levels, one that represents the idea of a “good” option and the other a “neutral” option. The “good option”, that generally has a partial score of 100, represents a level of unquestionable attractiveness. Whereas the “neutral option” , that generally has a partial score of 0, hence is neither attractive nor unattractive (Beinat & Bana e Costa, n.d.). These two reference levels allow us to launch the discussion on the next phases of the methodology in a more natural way.

Then the wide range of options and criteria identified are measured based on scoring, ranking and weighting instead of being measured in monetary value as in CBA (Beria et al., 2012; EIB, 2013). Trough decision makers’ preferences in each criterion a function value is obtained which alongside with the criterion weight coefficients, results in a global score for each alternative (Belton & Stewart, 2002). These global scores allow us to make a direct comparison between alternatives. There are three main value measurement approaches to compute them, outranking method, goal model and additive method (Thokala & Duenas, 2012). The outranking method is bases itself on the concept of dominance. In this method the criterion weight represents the importance which that criterion has on the decision-making of judging that an alternative is as good or better than other (Belton & Stewart, 2002; Thokala & Duenas, 2012). Goal model is a type of linear programming, based on the concept of goal achieving. In goal programming, the objective function is based on the goals which need to be met, so that any deviation from these goals is penalized. The objective is then to minimize these penalties. Also goals are ordered by priority level related to its importance, so that the penalties vary depending on the goal importance (Tamiz et al., 1998; Thokala & Duenas, 2012). Considering a set of evaluation criteria $E_i, i = 1, \dots, n$ and their appropriate performance descriptors $X_i, i = 1, \dots, n$, a performance profile of a bid x, can be defined as $(x_1, \dots, x_n)$, where x_i is a specific performance level of X_i. The additive model (Equation 13) allow us to compute a global score of bid x.

$$v(x_1, \dots, x_n) = \sum_{i=1}^{n} w_i v_i(x_i) \quad with \quad \sum_{i=1}^{n} w_i = 1, w_i > 0$$

$$and \begin{cases} v_i(x_i^+) = 100 \\ v_i(x_i^0) = 0 \end{cases} for\ i = 1, \dots, n \qquad (13)$$

where v is the overall value score of bid x that measures its global attractiveness, $v_i, i = 1, \dots, n$ are single-attribute value functions; $x_i^+ and\ x_i^0, i = 1, \dots, n$ are, respectively, the “good” and “neutral” reference performance levels defined for each performance descriptor $X_i, i = 1, \dots, n$, and $w_i,, i = 1, \dots, n$ are scaling constants referred as the weights of the criteria. The global score represents the contribution of each alternative on the criteria identified, reflecting the decision makers preferences. Therefore, an alternative A is preferable to alternative B when v_A is higher than v_B.

The additive model is the most common to compute the alternatives global scores due to its transparency, simplicity and ease of use. The MCDA methodologies which base themselves in the additive model have a more arduous structure process because it needs to comply with specific conditions, however they give the decision makers a clearer and more transparent view of the problem. Because their goal is to make the decision makers reflect about the problem in order to fully understand their priorities and the different perspectives of all the parts involved (Belton & Stewart, 2002; Thokala & Duenas, 2012). Whereas, the outranking method is too complex for decision makers to fully understand it which could lead to poor results. And, the goal model demands criteria to be evaluated quantitatively, hence being unfitted for problems which need to consider subjective criteria (Belton & Stewart, 2002).

The process of building a multicriteria model is not an exact science because from the identification of criteria to weighting and scoring them it is mostly based on the perspectives and preferences of decision makers. Therefore, the decision support process comprises a socio-technical approach. The technical dimension includes the development of the model to analyze and solve the problem. And the social dimension includes the involvement of the decision makers and the stakeholders (Spackman et al., 2000).

Generally, decision support processes with a constructive approach, use decision conferences to connect both social and technical dimensions (C. Dias & Tsoukiàs, 2003) alongside with initial individual interviews which are vital for model structuring. However, prior to the interviews it is necessary to identify which stakeholder(s) should be approached in order to gather the information in need to build the model. To do that we have to take two considerations.

Firstly, that the problem in study includes different companies with different interests. Secondly, that within the company there could be different perspectives related with the areas of work. The goal is to identify a diverse group of individuals with different perspective and background in order gather information from all areas of interest related with the problem (Keeney, 1994).

Thus, the individual interviews approach allow us, at an initial phase of the model, to have access to different points of view of the problem, gather what are the main concerns, objectives and problems in the perspective of each stakeholder. Not only that, this tool promotes the sharing of knowledge and ideas which contribute for adding value to the model. Individual interviews guarantee that every part involved express their opinion about different topics of discussion, while we can collect essential information for structuring the model and also for preparing the decision conferences which are performed later in the process. Generally, semi structured interviews with pre-defined questions are best fitted in this type of problems where the sample group is diverse (Barriball & While, 1994). These type of interviews allow for more in-depth conversations about topics where the people involved are more comfortable so that we can gather new information and knowledge about it, and not only their opinions (Barriball & While, 1994). On the other hand, making interviews based on pre-defined questions facilitate the analysis and the comparison of the answers given by the different participants (Leech, 2002).

The individual interviews can be divided into three main goals:

- Validate the information gathered to date, includes problem objective, concerns, areas of interest, stakeholder involved, etc.;
- Identify evaluation criteria and their descriptors;
- Gather information for planning decision conferences.

Therefore, the pre-defined questions must in line with these goals.

Decision conferences are meetings with the decision makers and a neutral facilitator, where all the phases of the methodology are approached, and the model is constructed throughout. The information gathered from individual interviews is discussed and validated, and the weighting and scoring phase begins, where decision makers' judgments will be elicited. The main goal of these conferences is to promote a discussion between the decision makers, where different perspectives, information and knowledge are shared, giving value and consistency to the model (Phillips & Bana e Costa, 2007). Another important aspect is that everyone involved have access to the model while it is being built, as well as, the results obtained, which contributes for the transparency and credibility of the process (Spackman et al., 2000). However, despite a decision conference can be done in one day, it generally lasts two or three working days which is a constraint due to stakeholders busy timetable. Therefore, an alternative approach for involving stakeholders is decision analysis interview (DAI), where facilitated meetings and personal computer-aided interviews are developed (Marttunen et al., 2015). The first phase of the DAI is in line with the individual interviews approach presented above with the goal of having access to different points of view of the problem, gather what are the main concerns, objectives and problems in the perspective of each stakeholder. The second phase where the preferences and judgements of the decision makers are elicited is done via a personal computer-assisted interview, where the decision analyst uses the MCDA software to obtain a set of preference models reflecting each stakeholders perspective. Throughout this process it is important that the decision analysist documents the interviewees' argumentation and reasoning behind their judgements. The final phase of the DAI is the synthesis of the results and recommendations, since this process produce a large amount of info from the several interviews done with each stakeholder (Marttunen et al., 2015).

When the end results are attained they must be tested for robustness trough a sensitivity analysis (EIB, 2013). Also they must be approved by the decision makers involved in the process, because there could be some final adjustments to be made in order fully replicate their objectives and opinions (Marks et al., 2013).

These tools are be key to successfully achieve the social dimension of the process, as well as, give robustness and quality to the model. Hence, the socio-technical approach of the decision support process is accomplished.

Now that an in-depth overview of both MCDA and decision support process was presented, its application in the petroleum pipeline industry is detailed further below. Despite not being very large there are some authors which explored it.

Pipeline project Multicriteria Decision Analysis

The Analytic Hierarchy Process (AHP) is the most common multi-criteria method applied in the petroleum pipeline industry. AHP developed by Saaty (Saaty, 1977), is one of the most used and renowned multi-criteria techniques (Beria et al., 2012; Tudela et al., 2006). The AHP is described as the decomposition of a complex decision-making process into a hierarchical structure. Where the main objective is located at the top. In the second level are located the secondary criteria. Following these criteria could be other subcriteria. The hierarchy can be composed by several subcriteria levels until it reaches the penultimate level of the hierarchy. At the bottom level of the hierarchy are located the discrete options under consideration (Beria et al., 2012; Dey, 2006; Tudela et al., 2006). When criteria and sub-criteria are identified a set of weights is needed to proceed with the method. The weights will represent the relative importance of the criteria, subcriteria and attributes belonging to a specific nest in the hierarchy. These weights are estimated from pairwise comparison matrices, for each nest in the hierarchy (Saaty, 2008) (Saaty, 2008). Once weights are estimated, the hierarchical structure is collapsed, following a folding back procedure. Every alternative under study will have a final weight. These final weights are used to rank these alternatives, in order to support the decision-making process (Tudela et al., 2006).

Authors apply AHP for several purposes for risk assessment (Dawotola et al., 2009; Dey, 2004), for route selection (Dey & Gupta, 2001; Nataraj, 2005; Nonis, Varghese, & Suresh, 2007) and also for project evaluation (Dey, 2006).

On the topic of risk assessment, Dawotola et al. proposed a combined AHP and Fault tree Analysis (FTA) to support the design , construction, inspection and maintenance policy of oil and gas pipelines by proposing an optimal selection strategy based on probability of failure and consequences of failure (Dawotola et al., 2009). Dey used the AHP to the factors that influence failure on specific segments and analyzes their effects by determining probability of occurrence of these risk factors (Dey, 2004). When constructing the hierarchical structure both authors considered the same criteria and subcriteria. Criteria considered were corrosion, external interference, structural defects, operational error and other. In the case of the subcriteria: internal and external corrosion (Corrosion), third party activities and sabotage (External interference), construction and material defects (Structural defects), human error and equipment failure (Operational error).

On the topic of route selection, Nonis et al. proposed a methodology of a combined Geographic Information System (GIS) and AHP. The GIS can automatically develop a pipeline route considering the several factor which influence the routing process. However, it cannot derive the relative preferences of these different factors. Consequently, AHP is applied to solve this problem (Nonis et al., 2007). Dey & Gupta proposed an AHP to quantitatively analyze strict governments stipulations, expansion capability, the chances of pipeline failure, and along with other factors, with the main goal of solving a optimal pipeline route problem (Dey & Gupta, 2001). Nataraj also proposes AHP as a tool to evaluate geophysical, environmental, political, economic and regulatory factors to help the decision-making in pipeline routing problems (Nataraj, 2005). P. Dey & Gupta and Nararaj used the same criteria in their study, which included length, operability, maintainability, approachability, construcability and environmental friendliness. P. Dey & Gupta considered for the third level the following subfactors: route diversion, hydraulic gradient and augmentation possibility (Operability), corrosion, piferage and third party activities (Maintainability), nearness to railway/highway and terrain characteristics (Approachability), statutory clearance, mobilization, construction and availability of power and water (Constructability). Nonis et al. had to adapt the AHP in order to combine it with GIS, so the factors they selected were: avoid areas with steep slopes, avoid both road, railway and river crossings, but proximity to the roads should be high, avoid prohibithed areas, avoid reserved forest areas, avoid areas with high land cost and avoid unfavourable soil type.

Lastly on the topic of pipeline project evaluation, Dey proposed the application of the AHP to analyze projects with respect to market, technicalities, and social and environment impact, with the main goal of helping the selection of best possible project (Dey, 2006). The hierarchical structure developed by the author is composed by five levels, which include the criteria in level II and both level III and IV with subcriteria. Some of these criteria and subcriteria considered by the author in this study are the same from previous his studies presented above related with risk assessment and route selection, since they are both key factor for project evaluation and selection.

Although the AHP method has been applied by several authors for different purposes in the petroleum pipeline industry, there are some authors which point out some inconsistencies related with its methodology. Belton and Gear state that *there is a degree of imprecision in the specification of what factors should be taken into account when determining the weight*. Because of the ambiguity inherent to what the decision maker recognizes as weight. In their study the authors carefully chose the data so that there was no ambiguity on what weight meant. Therefore, concluding that the root of inconsistency in Saaty's method is the normalization factor (Belton & Gear, 1983). Bana e Costa and Vansnick address a problem concerning the meaning of the priority vector derived from the principal eigenvalue method used in AHP. The authors goal was to prove that the AHP priority vector does not satisfy the Condition of Order Preservation (COP). They concluded that the principal eigenvalue method (EM) used in AHP has a serious fundamental weakness which leads to inconsistencies in the model (C. A. Bana e Costa & Vansnick, 2008).

In response to the lack of consistency in the AHP method, two new methodologies derived by it were proposed the Modified AHP (MAHP) method (Donegan et al., 1992) and the Dynamic AHP (DAHP) method (González-Prida et al., 2012).

Moreover, MACBETH, the Measuring Attractiveness by Categorical Based Evaluation Technique, emerges as an alternative to AHP (Spackman et al., 2000). MACBETH is an interactive multi-criteria decision support approach. However, contrary to numeric methods like Direct Rating and Bisection Method, where the decision maker have to express quantitative judgments to construct value functions, the MACBETH approach uses qualitative judgments of differences in attractiveness in order to generate value functions (C. Bana e Costa et al., 2011). Since giving quantitative judgements can be a difficult task for the decision maker due to not being intuitive to express preferences with numbers (C. Bana e Costa et al., 2008; von Winterfeldt & Edwards, 1996), MACBETH'S approach solves this problem. That is one of the main reasons alongside the inconsistencies found by some authors for choosing MACBETH instead of AHP, which is from the literature the main method used in petroleum pipeline projects.

3.3.3 MACBETH

The implementation of the MACBETH method is done via M-MACBETH software application, which not only includes all the necessary tools to build the multicriteria model, but also functionalities to interactively analyze the sensitivity and robustness of the model's results. These tools are used for the structuring phase, to build value tree and criteria's descriptors, as well as, for ranking, scoring and weighting, and at the end to obtain alternatives' global scores.

Next, the process of determining criteria's value functions and weights in MACBETH method via M-MACBETH software is presented.

MACBETH introduces seven qualitative categories, which are used by decision makers to do a pairwise comparison between options , no difference, very weak, weak, moderate, strong, very strong and extreme. These are used to fill in a judgment matrix like the one in Figure 4.

	B2	Good	B1	B3	Neutral
B2	no	weak-mod	moderate	strong	Neutral ong
Good		no	very weak	strong	strong
B1			no	moderate	moderate
B3				no	very weak
Neutral					no

Consistent judgements

Figure 4 - M-MACBETH judgement matrix

Determination of Value Functions

By filling the judgement value function matrix the value function can be determined from the software. The judgements are obtained from the decision makers by asking to them questions like "What is the difference in attractiveness between an alternative with a B2 performance level and an alternative with a B1 performance level, knowing that they have the same performance in all other criteria?". This question must be answered with a MACBETH qualitative judgement. However, when each qualitative judgment is elicited, it is required to verify the consistency of the judgements thereto made by the decision maker. If any inconsistency is found the M-MACBETH gives suggestions to solve it, thus it guarantees the model's consistency. Once we get a consistent judgement matrix the M-MACBETH software estimates a value function based on the decision makers' qualitative judgements, giving a score to the different performance levels which demonstrates the magnitude of difference between levels. However, these are not final scores as they need to be validated by the decision maker that can make some adjustments. Hence, the decision maker has to compare the extents of the intervals between the proposed scores. If any adjustment is necessary, it has to be done one level at a time within a range compatible with the judgments previously provided. If the adjustment goes outside this range, judgments might need to be revised. The aim of this process is to quantify the relative attractiveness of the options on an interval measurement scale.

Determination of weights

When value functions are attained for every criterion, the next stage is to weight those criteria, so as to permit the calculation (via an additive model) of the alternatives' global scores (C. A. Bana e Costa & Chagas, 2004). The criteria weights are also called weighting coefficients are determined via the M-MACBETH software by the following procedure. Firstly, we have to consider the neutral and good levels determined previously and a hypothetical option which is neutral in every criterion. Then we ask the decision makers "how much a swing from neutral to good in criterion A increase its overall attractiveness". Like in determining value functions, the decision makers respond with a MACBETH qualitative judgement. This question is asked for every criterion until the last column of the judgement weighting matrix (Figure 5) is complete. From this, the software derives an incomplete ranking of the swings, which the decision makers needs to validated and then order it by the most attractive swing to the least attractive, thereby changing the order of the criteria in the matrix (Figure 6). The second part of this procedure consists in to elicit from the decision makers qualitative judgements regarding the difference of attractiveness between swings. It begins with the comparison between the most attractive swing to the second most attractive swing, i.e. asking "how much more attractive is a swing from neutral to good in criterion A than in criterion B?". This process is repeated row-by-row from left to right, until the matrix is completed. Like in the value function matrix the software checks consistency automatically. Then the M-MACBETH creates the weighting scale (Figure 6), which once more has to be validated by the decision makers and can be adjusted within a certain range (C. A. Bana e Costa & Chagas, 2004).

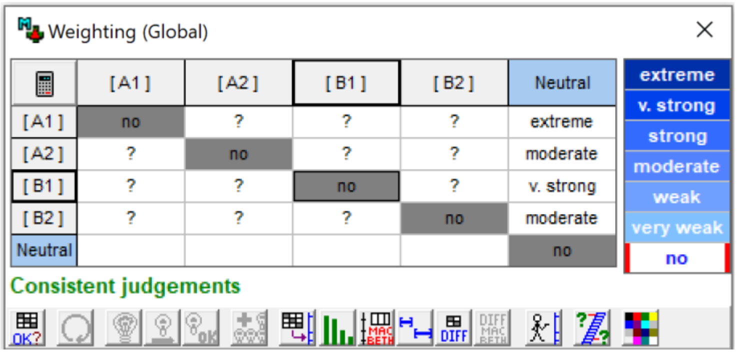


Figure 5 - Qualitative judgements for the swings

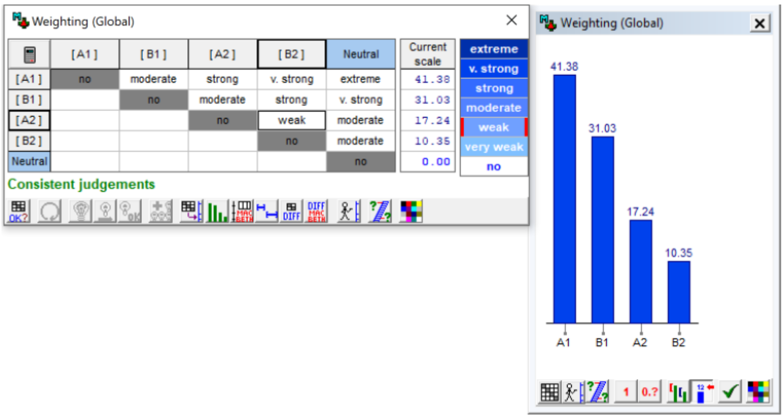


Figure 6 - Weighting judgements and scale

Global scores and sensitivity analysis

With the value functions and weights determined for each criterion, alongside the full characterization of each alternative considered, the M-MACBETH software computes a global score for each of them, via the additive model (Equation 13), which allow us to find the most fitted alternative accordingly with the decision makers judgements.

This software, as mentioned previously, allow us to perform a sensitivity analysis where we can see how a change in any of the weights, within the allowed interval, would affect the overall scores of the alternatives. The software also provides the profile of each alternative, where it showcases the contribution of a criterion in the global score, as well as, the differences between two alternatives, where it showcases the differences of scores between alternatives in each criterion (C. A. Bana e Costa & Chagas, 2004).

3.4 Investment Analysis

An investment is the allocation of funds for a period of time with the goal of deriving future gains that will compensate the investor for (1) the time the funds are committed, (2) the expected rate of inflation during that time period, and (3) the uncertainty of the future payments. The "investor" can be an individual, a government, a pension fund, or a firm. This definition is suitable for all different types of investments, like capital investments done by firms or investments by individuals in stocks, bonds, commodities or real estate (Reilly & Brown, 2011). In the context of the dissertation we will be focusing on firms investments.

Capital budgeting is the name gives to the process of planning and managing firm's long-term investments. The financial manager target is to identify investment opportunities on assets that will generate more cash flows for the firm than its costs (Ross, Westerfield, & Jordan, 2015). Generally, the types of investment opportunities depend on the nature of the firm's business. For example, in our problem the opportunity of investing in a new pipeline system emerged, hence CLC is faced with an important capital budgeting decision on whether to introduce the new pipeline system which will lead to an expansion in their operations.

3.4.1 Investment Analysis Techniques

In corporate finance there are several techniques used to analyze potential investments in order to support capital budgeting decisions, these include (Fabozzi & Drake, 2009; Ross et al., 2015):

1. Net present value (NPV);
2. Payback period;
3. Discounted payback period;
4. Internal rate of return (IRR);
5. Modified internal rate of return (MIRR);
6. Profitability index (PI).

The net present value method, the profitability index, the internal rate of return and the modified internal rate of return are named as discounted cash flow (DCF) techniques because they are characterized by discounting the future cash flows to the present at an interest rate which reflects the degree of uncertainty associated with this future cash flows (Fabozzi & Drake, 2009). The NPV method and the IRR are described in detail below as they are the ones relevant for the problem in study.

Net Present Value

The net present value method begins by estimating all future cash inflows and outflows that we expect the project to produce (Ross et al., 2015). Only when this is done we are able to estimate NPV as the difference between the present value of the future cash flows and the cost of the initial investment (Equation 14).

$$NPV = \sum_{t=1}^{N} \frac{CF_t}{(1+r)^t} - I \quad (14)$$

where CF_t, are the cash flows in which cash inflows are positive values of CF_t and cash outflows are negative value of CF_t, in a given period t. r represents the firm's required rate of return (cost of capital) at which the cash flows are discounted. I represents the initial investment costs. A positive NPV means that the investment increases company's value, hence the project should be accepted. A negative NPV means that the investment decreases company's value, hence the project should be rejected. A NPV equal to zero means that there is no change in company's value, hence is indifferent to accept or reject the project. The NPV allows us to understand how much value an investment creates to the company therefore if we have to select between two different investment we should chose the one with higher NPV because it is the one which will create more value.

Internal Rate of Return

The internal rate of return (IRR) of an investment is the discount rate that makes the NPV equal to zero. The IRR is the rate that solves Equation 15

$$NPV = 0 = \sum_{t=1}^{N} \frac{CF_t}{(1+IRR)^t} - I \qquad (15)$$

The IRR represents what is earned, on average, per year with the investment. Therefore, if the IRR is greater than the cost of capital (minimum acceptable rate of return) the project should be accepted. if the IRR is smaller than the cost of capital the project should be rejected accepted. if the IRR is equal to the cost of capital is indifferent to accept or reject the project. An important aspect to notice in IRR is that it can lead to incorrect decisions when comparing mutually exclusive investments because not always the one with the highest return is the best one. In this cases, we should compare them via NPV because it represents the value created, therefore the best investment is the one with higher NPV since is the one which maximizes owners' wealth (Fabozzi & Drake, 2009; Ross et al., 2015).

The remaining techniques, payback period and discounted payback period, as their name indicates follow a payback criteria instead of the discounted cash flow criteria to analyze investments.

Payback period

The payback period represents the time it takes to recover the initial investment cost. The process of identifying the payback period is simple, basically the accumulated cash flows of the project are computed, the year when the accumulated cash flows hits or exceeds the initial investment cost that year is the payback period. For example, if in year 2 of project X the accumulated cash flows hits or exceeds the initial investment, the payback period of project X is two years. There is not a clear rule for which project's length Is the best, but generally a shorter payback period is better. However, this leads to an advantage for investments with high initial cash flows which can lead to misleading information on the value created by the investment. Therefore, it is mostly used for an initial screening of minor investments, since for investments in assets with a long lifetime it cannot be used.

Discounted Payback Period

The discounted payback period is similar to the payback period but the discounted payback period uses discounted cash flows. Therefore, the process of identifying the discounted payback period is exactly the same but firstly cash flows are discounted and only then the accumulated discounted cash flows are computed. The discounted payback period is the year where accumulated discounted cash flows hit or exceed the initial investment.

Despite considering the time value the discounted payback period still has most of the same problems identified for the payback period, mainly the one that both cannot be used for investments in assets with long lifetime.

Now that the main investment evaluation techniques were defined, the NPV is the only one that satisfies four key criteria to support capital budgeting decisions:

- Consider all future incremental cash flows from the project;
- Consider the time value of money;
- Consider the uncertainty associated with future cash flows;
- Have an objective criterion by which to select a project (including mutually exclusive projects).

The NPV method is the one that will guide the financial manager into the investment that maximizes wealth, so when it is possible to compute it should always be used to make their decision. Usually, as there is the possibility of poor estimates, financial managers make use of several techniques since they will provide them additional information to support the results given by the NPV method (Fabozzi & Drake, 2009; Ross et al., 2015).

The NPV method has two key aspects, estimation of cash flows and determination of the firm's required rate of return, which will be approached in detail next.

3.4.2 Project's Cash Flows

Beginning with cash flows in investment analysis the first and most important step on this topic is to identify which cash flows are relevant. This relevant cash flows are called incremental cash flows because they are characterized by being increments to the company's current cash flows. So, the incremental cash flows for investment analysis consist of any and all changes in the company's future cash flows that are direct consequence of taking the investment (Ross et al., 2015). An evident and key consequence from this definition is that any cash flows that exists regardless of whether or not the investment is undertaken is not relevant and should not be considered.

In project evaluation, cash flows from assets are divided into three components, operating cash flow, capital spending and net working capital, and project cash flow can be compute via (Equation 16):

$$\begin{aligned} \text{Project cash flow} = {} & \text{Project operating cash flow} \\ & - \text{Project change in net working capital} \\ & - \text{Project capital spending} \end{aligned} \tag{16}$$

Where project operating cash flows is defined by (Equation 17):

Operating cash flow = Earnings before interest and taxes (17)
+ Depreciation
- Taxes

The earnings before interest and taxes (EBIT) includes sales, variable costs, fixed costs and depreciation, which need to be identified and computed so that we are able to calculate the operating cash flow.

The project capital spending consists in the initial investment that the firm has to make in year zero on fixed assets. The net working capital consist in an additional investment from the company to pay any expenses that can arise during the project and is represented by the balance between accounts receivable and accounts payable. Only when these three components are identified and computed we are able to calculate the NPV.

3.4.3 WACC

Regarding the required return, it leads to another vital concept in investment analysis that is the weighted average cost of capital (WACC). The WACC represents the cost of capital for a company as a whole, so it can be interpreted as the overall return the company need to earn from its assets so that it is able to maintain its stock value. In investment appraisal WACC is the firm's required return that should be used to discount future cash flows (Reilly & Brown, 2011; Ross et al., 2015). The WACC concept considers that the firm's capital structure is a mixture of debt and equity and that these have different costs associated to them, so the firm's cost of capital reflects both its cost of debt and its cost of equity (Ross et al., 2015). This is all included in the formula to compute the WACC (Equation 18).

$$WACC = R_E \times \frac{E}{E+D} + R_D \times (1-t) * \frac{D}{E+D} \quad (18)$$

where

R_E is the cost of equity;
R_D is the cost of debt;
E is the market value of firm's equity;
D is the market value of firm's debt;
E + D is the total market value of firm's financing;
$\frac{E}{E+D}$ is the percentage of financing that is equity;
$\frac{D}{E+D}$ is the percentage of financing that is debt;
t is the firm's tax rate.

The market value of firm's equity, E, is calculated by multiplying the number of shares outstanding by the price per share. The market value of firm's debt, D, is divided into long-term and short-term debt. The first one is calculated by multiplying the market price of a single bond by the number of bonds outstanding. Whereas, the short-term debt is estimated via the book values since it should be similar to the market value. Regarding the cost of debt, R_D, it represents the returns the firm's creditors demand on new borrowing which can be observed directly or indirectly as the interest rate the firm must pay on new borrowing and this can be obtained from financial markets. An important thing to pay attention is that we must look at the yield on debt in the current marketplace and not when the bonds were issued. Lastly, the cost of equity, R_E, which is the most complex variable on the topic of cost of capital, because there is no direct way of knowing the return that the firm's stakeholders require on their investment. Consequently there is a need to estimate it and there is two main approaches to do it, the dividend growth model approach and the security market line (SML) approach which involves the capital asset pricing model (CAPM). We are only going to approach in detail the second one because in general the SML & CAPM approach is useful in a wider variety of circumstances (Ross et al., 2015).

The security market line (SML) is the name called to the line used to describe the relationship between systematic risk and expected return in financial markets (Reilly & Brown, 2011; Ross et al., 2015).

It is known that, if we always receive what we expect, the investment would be considered risk-free, hence the risk associated to investments comes from unexpected events which we have to consider when we determine the expected return. However, these unexpected events are divided into two types. The systematic risks which influence a large number of assets, each to a greater or lesser extent. And the unsystematic risks which influence a single asset or a small group of assets, however through diversification this type of risk can be mostly eliminated (Ross et al., 2015). Therefore we are only going to consider the unsystematic risks which is exactly the focus of the SML.

From the SML we can derive Equation 19 which represents the capital asset pricing model (CAPM).

$$E(R_i) = R_f + \left[E(R_M) - R_f\right] \times \beta_i \tag{19}$$

The CAPM showcases that the expected return for a specific asset depends on three factors:

1. The time value of money, measured by the risk-free rate, R_f, which represents the earnings from just waiting for the money, without taking any risk;
2. The reward for bearing systematic risk, measured by the risk premium, $E(R_M) - R_f$, where $E(R_M)$ is the expected market return. The risk premium represents the reward for bearing an average amount of systematic risk;
3. The amount of systematic risk, measured by β_i which is the amount of risk present in a particular asset or portfolio, relative to that in an average asset.

The CAPM can be used to estimate the cost of equity by rewriting Equation 19 in the following way (Equation 20):

$$R_E = R_f + \left[R_M - R_f\right] \times \beta_E \tag{20}$$

Where R_E is the required return on the stock by the stakeholder, hence representing the cost of equity. In order to compute R_E, firstly the risk premium, $R_M - R_f$, and the amount of systematic risk, β_E, have to be estimated. The risk premium ca be estimated based on historical data on market returns (Ross et al., 2015). In term of β_E, by definition an average asset has a beta of 1.0 relative to itself, an asset with a beta of 0.50 has half has much systematic risk as an average asset and an asset with a beta od 2.0 has twice as much. Generally, beta coefficients for publicly traded companies is commonly available, however when this is not the case it can also be estimated by using historical data via Equation 21.

$$\beta_E = \frac{cov(R_E, R_M)}{var(R_M)} \tag{21}$$

Where R_E and R_M are estimated based on historical data.

Taking all this information into consideration the SML approach alongside the CAPM have two important advantages over the dividend growth model approach, it explicitly adjusts for risks and can be applied to all companies. The only drawback from this approach is the need to estimate both the risk premium and the beta coefficient but this is something that is similar to the need of estimating the growth model in the dividend growth model approach.

The procedure to estimate all variables needed for computing the WACC is now presented. Therefore, we presented all the theoretical background behind the components to apply the NPV method and with it the necessary information to develop an investment analysis to support capital budgeting decisions. However throughout this chapter it was mentioned that various components of the method need to be estimated which can lead to some inaccuracies on the results obtained. Therefore a tool generally used to test the robustness and consistency of the results obtained is scenario analysis specifically sensitivity analysis.

The general idea behind sensitivity analysis is to freeze all variable except one and with that to study how sensitive the estimate of NPV is to changes in that particular variable. If the NPV estimate is very sensitive to small changes in a specific variable it means that the forecasting risk associated with that variable is high. Consequently we have to pay more attention to that variable and a further market research might be necessary to decrease its risk (Ross et al., 2015).

3.5 Chapter Conclusions

In the first section of this chapter it became clear that the focus of authors in the last couple of years was on pipeline system's operations, specifically optimization of scheduling and security and control systems. This was expected because new pipeline system projects are not that common since they consist in a high initial investment cost and also because there is already a vast number of pipeline systems all over the world. Therefore the focus is on improving their cost-efficiency, safety and security with the goal of enlarging its competitive advantage against the alternative transportation methods. Taking this into consideration, the goal of this dissertation falls outside this focus because our problem motivation is to support the strategic decision of replacing the current system via road tanker with a new pipeline system. Thus our research focused on the existing methodologies to approach this type of decision-making problems.

From the literature review and theoretical background presented in this chapter, we could not reach any consensus among authors on what method is the best fitted to evaluate this type of decision-making problems.

Considering the dissertation goal where all key dimensions, economic, environmental and social must be tackled, MCDA method is the one which more in line with it. The method allow us to consider multiple and subjective criteria, qualitative and quantitative, where economic, environmental and social aspects are all included, whereas in the other methods the need to monetize and discount environmental and social consequences is not suitable to obtain the information we intend for supporting the decision-making. Additionally, in MCDA there is a big involvement of decision makers which gives consistency to the results obtained and guarantee transparency in the decision-making process. Therefore, MCDA method was the one selected to be applied to support our decision-making problem.

However, despite MCDA allowing us to consider multiple criteria, qualitative and quantitative, from all vital dimensions for the decision-making, including economic, environmental and social, it is still essential to develop an investment appraisal since this new pipeline project is considered as a capital budgeting decision for CLC. In this appraisal we are going to evaluate both scenarios, with (pipeline system) and without (road tankers) the project, in order to provide to decision makers additional information on the problem's economic dimension regarding the profitability and other decisive economic factors, mainly transport fee, which we are unable to extract from the MCDA. Hence, the combination of this information with the one attained from the MCDA tackles all the necessary topics to promote an informed decision.

In the investment appraisal we will be using the net present value method, where the project selected is the one which maximizes the NPV generated for the company. The discount rate in both scenarios will be the WACC of the company which is considered the investor, in this case will be the operator of both systems, where for road tankers is TIEL and for the pipeline system is CLC. The WACC will be computed via the procedure presented previously, where the cost of equity will be estimated by using the SML & CAPM approach because it was stated that it is useful in a wider variety of circumstances and it considers the risk involved in the investment.

Taking all this information into consideration the methodology which will be developed is different from the existing techniques, as it will be a combination of a MCDA, where the MACBETH method will be used, with an investment appraisal, where the NPV method will be used but where the transport fee will also be a decisive economic factor as it was identified in section 2.4. In the next chapter all the data and information required to develop this methodology will be collected, analyzed and treated.

4. Input Data Collection, Analysis and Treatment

The goal of this chapter is to collect, analyze and treat all the necessary data and information that will enable us to develop all the methods proposed in order to solve the problem in study. Additionally, an essential part of this chapter is that throughout it the sources for all data will be referenced. The chapter is divided into three sections: i) Pipeline characterization, ii) Multicriteria Model, iii) Investment appraisal.

4.1 Pipeline System Characterization

This section of this chapter consists on gathering all necessary data for initial characterization of the pipeline system, mainly focused on its design and the tasks needed to develop this type of projects, considering the topics approached in section 3.2.

4.1.1 Pipeline Design

The objective of this initial study regarding the pipeline design is to gather information that will be necessary for the development of both multicriteria model and investment appraisal, some information is already known and will be obtained directly from the stakeholders involved, mainly CLC, or from literature about pipeline systems, this includes route, materials and equipment. However other aspects like pipe diameter and wall thickness are yet to be known therefore we will determine them according to the procedures presented in section 3.2.

Pipeline's Lifetime

For the purposes of our study it was considered a design life for the pipeline system of 20 years, where the first year is for the construction project and the remaining are for the pipeline operation. However, as mentioned in section 3.2 it is expected that the system will continue to operate beyond the 20 years of lifetime considered.

Material

The material selection was based on Galp's manual of procedures where the company displays the different pipe classes used in its activities. BA3 is the one used for general hydrocarbons, hence being the best fitted for jet A-1. Via the pipe class, we are able to identify the pipe's material, which is API 5L-B (ISO 3183, 2019).

Route Selection, Crossings & Pipeline Cover

Route selection is a key part on pipeline's design because it will impact some of its features, like wall thickness, due to the strict safety measures a pipeline has to comply with. However, as it is not yet decided if the existing water pipe channel is going to be used the route is yet to be defined. The only information we gathered is that it is going to connect CLC with Lisbon's airport, with is a length of approximately 50 km, and that its main crossing will be the Loures river. Therefore, from Table 8 we can define a pipeline cover of 1.2 m throughout all its length.

System's components

In terms of its key components the system will be composed by:

- Three pumps, where one will have a speed variator which will enable changing the flow rate accounting for the variation in jet A-1 demand. The need for three pumps has two main reasons. If the operating pump gets broken while its getting fixed, operation cannot stop thus there is a need for a backup pump to continue the operation. The other reason is in case the speed variator gets broken the other two pumps will definitely be able to provide the necessary power to continue the system operation while the speed variator is getting fixed. In this industry, the extra pump is chosen over the extra speed variator due to the high cost of the latter.
- Emergency shutdown valves and sectioning valves;
- Two most common piggable valves are through conduit valves and trunnion mounted ball valves (Tiger Valve Company, 2020), thus any of them can be used;
- A 3 Layer Polyethylene corrosion resistant coating, equal to the one applied in CLC's multiproduct pipeline, will be applied to the external surfaces of the pipe. This coating system is adequate to operating temperatures up to 50ºC during the pipe design life. Alongside it a cathodic protection will be applied;
- The LDS applied to the new pipeline system should be similar to the one existing in the multiproduct pipeline, in order to take advantage of the already existing infrastructures in CLC;
- In terms of safety and control, the new system will also require systems similar to the ones of the already existing multiproduct pipeline. Similarly, the supervision and operation of the pipeline will be made from the control room already existing in Aveiras (CLC).

Diameter Definition

As mentioned above the dimensions of the new pipeline system are still unknown, however we are able to collect the necessary data to make a preliminary dimensioning of the system which will include selecting the most economic pipe diameter and pipe wall thickness that will ensure system's strength requirements. This preliminary dimensioning of the system will provide us with essential information for developing both the multicriteria model and investment appraisal, mostly because it will enable us to compute the system's costs which otherwise we would not be able to do.

Starting with selecting the most economic pipe diameter, it will be characterized by a study between five different diameter sizes, 6, 8, 10, 12 and 14 inches, where the one selected will be the one with the least total cost (capital cost + total energy cost).

In this process there is several data that needs to be collected, which includes chemical characteristics of the fluid, physical characteristics of the pipe, amount of jet A-1 transported and flow rate, unit cost for pipe and labor for each diameter and energy unit cost,

Firstly, chemical characteristics of the fluid and physical characteristics of the pipe are presented (Table 9). Density, ρ, and viscosity, ν, of the fluid, are found in Table 7. Duration of construction, pump efficiency, η, length, L, and ΔH (maximum elevation profiles) were provided to us by CLC.

Table 9 - Fixed parameters (1) (Mccoy & Rubin, 2008)

Parameters	Value
ρ (@15ºC) [kg/m³]	840
ν (@15ºc) [mm²/s]	2
ε [mm]	0.046 (1)
L [km]	50
ΔH [m]	430
η	60%
Pipe construction duration [years]	1

Regarding jet A-1 transported, in 2019, 1 320 000 m³ of jet A-1 were carried from CLC to Lisbon airport, however due to the current pandemic only thirty percent of that amount was carried in 2020 which corresponds to 396 000 m³ of jet A-1. This thirty percent come mainly from the distribution of goods via airplane since the number of commercial flights for people, who usually travel due to work or tourism, is currently very low. CLC expects that the amount of jet transported will recover to similar amounts as in 2019, in about 4 years i.e. in 2024.

Table 10 displays the expected amount of jet A-1 to be shipped in the following 20 years, where year 1 represents the year the system starts operating.

Table 10- Transported Jet A-1 per year

Year	Annual growth rate of Jet A-1 consumption	Transported Jet A-1 [m³]	Transported Jet A-1 with safety gap of 20% [m³]
Year 0 (2020)	-70,00%	396 000	475 200
Year 1	30,00%	514 800	617 760
Year 2	50,00%	772 200	926 640
Year 3	50,00%	1 158 300	1 389 960
Year 4	20,00%	1 389 960	1 667 952
Year 5	3,00%	1 431 659	1 717 991
Year 6	3,00%	1 474 609	1 769 530
Year 7	3,00%	1 518 847	1 822 616
Year 8	3,00%	1 564 412	1 877 295
Year 9	3,00%	1 611 345	1 933 614
Year 10	3,00%	1 659 685	1 991 622
Year 11	3,00%	1 709 475	2 051 371
Year 12	3,00%	1 760 760	2 112 912
Year 13	3,00%	1 813 583	2 176 299
Year 14	3,00%	1 867 990	2 241 588
Year 15	3,00%	1 924 030	2 308 836
Year 16	3,00%	1 981 751	2 378 101
Year 17	3,00%	2 041 203	2 449 444
Year 18	3,00%	2 102 439	2 522 927
Year 19	3,00%	2 165 512	2 598 615
Year 20	3,00%	2 230 478	2 676 573

As we can see from Table 10, in 2021, it is expected that the amount of jet A-1 transported to begin its recovery, but only in the following two years is that this recovery will be more pronounced with a growth of fifty percent in both years. As mentioned previously, in year 4, the amount shipped is already close to the quantities transported before the pandemic. This is mainly due to an expected increase in tourism which was the main sector that contributed to the growth of the aviation industry in Portugal. For the following years, we considered a constant growth of 3% since the growth will be more stable and not as abrupt as in the first four years. Additionally, to guarantee the security of supply of jet A-1 to Lisbon airport, a safety margin of 20% was considered to counteract factors such as:

- Time that jet fuel needs to settle in the storage tanks when arrives at the airport;
- Time for developing the indispensable quality tests;

- Maintenance of the pipeline;
- Problems in the refinery or in CLC.

Now that the yearly jet demand is known, we are able from the procedure explained in section 3.2.1 to compute the yearly required pump horsepower for each diameter. Even before analyzing the costs, from the data obtained throughout this procedure we had to exclude the 6” sized diameter because from a certain quantity of jet transported the flow velocity in the pipe surpassed the usual maximum of 3,5 m/s, mentioned in section 3.2. Meaning that for this size the pipe would suffer a more rapid degradation and even can put into danger its safety leading to an internal pressure higher to what the pipe can resist. Therefore, the costs were only computed for the remaining sizes in study, 8”, 10”, 12” and 14”.

Beginning with energy costs, the energy unit cost considered was the one charged for industry purposes, 0.137 €/kWh (PORDATA, 2020). Table 11 showcases the computed total energy costs during the 20 years of lifetime, for each diameter taking into account the required horsepower values obtained.

Table 11- Total Energy Cost (€) for each diameter

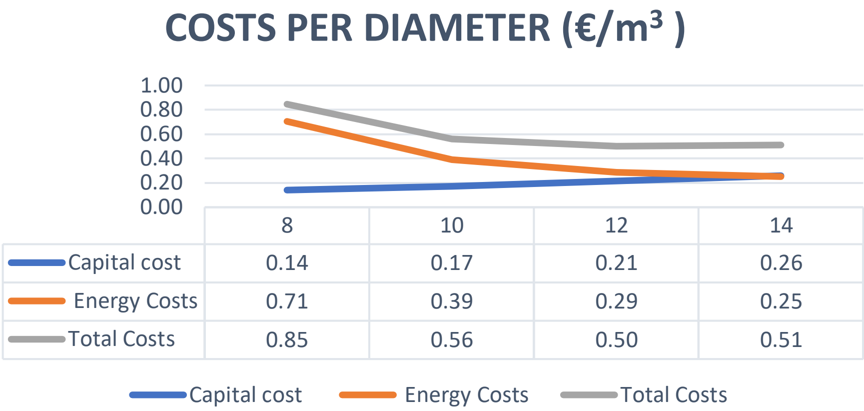
Diameter (inches)	Total Energy cost (€)
8	28 000 000
10	15 500 000
12	11 400 000
14	10 000 000

Table 12 showcases the unit costs for pipe and labor for each diameter in study. These unit costs were obtained through data from CLC’s current and previous projects.

Table 12 - Capital costs (€)

Diameter (inches)	Pipe unit cost (€/m)	Pipe cost (€)	Labor unit cost (€/day)	Labor cost (€/day)	Capital cost (€)
8	60	3 000 000	7 000	2 600 000	5 600 000
10	80	4 000 000	7 500	2 800 000	6 800 000
12	110	5 500 000	8 000	3 000 000	8 500 000
14	140	7 000 000	9 000	3 300 000	10 300 000

Now that we estimated both energy and capital costs we are able to compute the total costs for each diameter, however to be able to compare them we computed the costs in €/m^3 so that they are all on the same unit (Figure 7).



	8	10	12	14
Capital cost	0.14	0.17	0.21	0.26
Energy Costs	0.71	0.39	0.29	0.25
Total Costs	0.85	0.56	0.50	0.51

Figure 7 - Capital cost, Energy cost and Total cost

The first outcome that can be drawn is that in fact the increase in capital costs is much lower than the decrease in energy costs. Therefore, the trade-off between capital and energy costs, for the flow rate considered, favors the larger diameter pipes. The 8" diameter, despite having lower capital costs, is straight away excluded from being an option due to its unsustainable energy costs. When comparing the remaining pipe sizes, the 12" diameter is the one that incur in lower total costs, 0,50 €/m^3. However the difference to both the 10" and 14" diameter is considerably small, since they incur in 0,56 €/m^3 and 0,51 €/m^3 respectively. Meaning that all sizes are well fitted for the system however the 12 " is preferable not only because it has lower total costs, but also, when comparing with the 10" diameter it gives an higher margin for transporting higher amounts of jet in a long-term perspective and the 14" would be too large so the additional capital cost are avoidable. In conclusion, the 12" diameter is selected as the most economic diameter.

Wall Thickness

Alongside the pipe diameter, wall thickness is the other physical characteristic of the pipe that enables us to choose which one will be ordered to suppliers, it is computed via Equation 12. To determine t_{min}, the design factor, f_h, is given from a table and depends only on the pipeline location (0,67) (ISO 13623, 2009). The specified minimum yield stress (SMYS), σ_y, is also given from a table and depends on the pipe material. In this case, we are considering, API 5L-B, which give us a σ_y= 35 000 psi (M. A. El-Reedy, 2015). From these two parameters we compute hoop stress, σ_{hp}, 23 450 psi. The pipe diameter is 12 inches as determined above. Lastly the internal design pressure, p_{id}, is directly related with the head losses throughout the pipe computed when pipe diameter is defined. Table 13 summarizes all these parameters.

Table 13 - Parameter to compute Wall Thickness

Parameter	Value
Design Pressure, p_{id} (psi)	348.33
Outside Diameter, D (inches)	12.75
Specified Minimum Yield Strength, σ_y (psi)	35 000
Hoop Stress Design Factor, f_h	0.67
Hoop Stress, σ_{hp} (psi)	23 450

Via Equation 12 it was determined that the minimum pipe wall thickness required is equal to 0.20 inches (5.13 mm). To determine the nominal wall thickness, we need to add to the minimum pipe wall thickness, the corrosion allowance which is 1.6 mm for the pipe class selected obtained from Galp's manual of procedures.

However, just like the pipe diameter there are only specific wall thickness sizes that are produced. In this case, each pipe diameter is associated with several schedule numbers which represent a wall thickness. Generally, these values are given through tables where we can find the pipe wall thickness for various pipe sizes. In the table, we need to search for a wall thickness equal or greater than the computed above, for a pipe size of 12 inches. We considered the STD schedule therefore the nominal pipeline wall thickness is equal to 9.53 mm (engineersedge, n.d.).

Pipe Design Summary

From the pipeline system preliminary dimensioning and design study presented throughout this section we were able to identify or estimate key characteristics. A summary of those characteristics is showcased in Table 14.

Table 14 - Pipe Design Summary

Characteristics	Definition
Pipe Class	BA3
Material	API 5L-B
Diameter (inches)	12
Wall Thickness with CA (mm)	6.73
Nominal Wall Thickness (mm)	9.53

4.1.2 Pipeline System Project Planning

Alongside pipeline design and dimensioning, in this initial phase a preliminary project planning will be developed, with the main goal of displaying the main tasks of a pipeline project. They are split into seven main groups, routing, project, licensing, procurement, construction, testing and start operation. This plan will serve as control tool throughout the project, guaranteeing that all activities are going as planned. For our dissertation this planning will be key in order to guarantee that all costs from each phase are considered when computed. Therefore, a simple form of a Gantt chart is developed. Also, it is important to emphasize that this type of projects is developed as turnkey projects. Therefore, there will be a contracted company which will have the responsibility of developing the project and delivered it ready to begin operations.

This contract will have a defined budget and different clauses agreed by both parts which can lead to deviations from the initial budget agreed. Hence, CLC will contract a specialized firm that will be fully responsible for the project and has to deliver the pipeline system ready to begin its operations.

Hence, it will develop the tasks showcased on the Gantt chart (Annex B). The duration of the tasks is based on data regarding previous projects CLC has developed, therefore there could be some inaccuracies.

Routing is the first task to be performed. Various potential pipe layouts which connect CLC to Lisbon airport are analyzed. The main goal is to choose the route with minimum pipe extension. However it is subject to some constraints. These constraints include environment, territorial, crossings (roads, water lines, etc.), public health, safety, legal requirements and engineering and construction requirements. When the final pipe layout is defined, it gives crucial information for the project phase, such as land elevations and pipe laying depths which can impact pipe's diameter and wall thickness.

The project phase is divided into eight specialties, civil, mechanical process, electrical, instrumentation, control, safety and security and HAZOP. Despite some decisions in this phase being dependent on the final pipe layout, there are some preliminary studies that can be made and hence the two phases can be done simultaneously. Firstly, a draft project is developed where initial values for the pipe design, like diameter and wall thickness, are estimated, as well as, construction processes and pipeline's safety and security systems are identified, approximately to what we presented in the previous section. The draft project serves as a support tool for the Environmental Impact Study (EIS). The EIS is an analysis developed by the project promoter, of the environmental impacts resulting from the construction and operation of the facility. Then the draft project alongside the EIS, are crucial for the project licensing. However, for a pipeline project it is necessary to subject it to and Environmental Impact Assessment (EIA) procedure, prior to the licensing and approval of the project.

When all licensing is acquired and the project is approved, the actual project is developed. The estimates and decisions made previously in the draft project are adjusted in conformance with the feedback given by the ministry. Additional safety measures might be necessary, like increasing the pipe wall thickness or of the cover depth in some pipe sections. At the end of this phase the pipe's design must be fully defined, such that the procurement phase can begin. In this phase all the needed materials and equipment for construction must be ordered. But first market enquires and then negotiations with suppliers are required. These could take up to three months depending on the number of suppliers and on their flexibility. Despite, existing commercial sizes for both pipe diameter and wall thickness, there are other elements which do not have as much supply due to their specifications. Then orders must be placed taking into account the beginning of the construction phase because there is some equipment which is not needed right at the beginning, like pumps which are only installed when the pipe is already assembled. Hence, orders should be schedule considering the constructors necessities. When the construction work is finished, tests are required. Firstly, safety and security systems and control systems are tested to guarantee that everything is working as expected. Lastly, the mechanical tests are performed. If any adjustments are done, tests are repeated until everything is as required to begin operation.

4.2 Multicriteria Model

This section will focus on the process of collecting and processing all the necessary information to build the multicriteria model which will serve as a basis for decision-making. As mentioned in section 3.3 the multicriteria model construction is an iterative and didactic process, which follows a constructive socio-technical approach. In this phase of data collection the process's social dimension takes a major part. The inclusion of decision makers is vital and it is from them that we are able to gather the majority of information we need. This includes both the structuring phase and ranking, weighting and scoring phase. In the first one, decision makers' objectives and concerns allow us to identify the model's evaluation criteria, as well as, its descriptors. In the second phase, the integration of decision makers' is indispensable because without their judgements we are not able to determine criteria's value functions and weights and consequently the model cannot be finished.

In the following sections, the procedures followed to gather the necessary information and data in both phases are presented in more detail, as well as, the information we were able to collect from it.

4.2.1 Model Structuring

The data used in model structuring phase was obtained from a mixture of literature on the topic with semi-structured individual interviews we developed, with pre-defined questions, with each decision maker. The reasoning behind us opting for semi-structured interviews is that despite having pre-defined questions we have flexibility to approach more specific subjects according to each the decision maker area of expertise. Decision makers were selected considering what was mentioned in section 3.3.2.

In the problem in study there are three groups of stakeholders. Firstly, CLC which is the company responsible for the logistics of storing the jet A-1 and in this thesis is considered as the company which will be responsible of operating the new pipeline system. Then, oil companies, including Galp, Repsol, BP and OZ, which are the companies that own the jet A-1 and sell it to airlines. Lastly, ANA which is the company responsible for managing Lisbon's airport. Hence, we interviewed at least one individual from each one of these groups. In cases where we found it was relevant for the model more than one individual from different areas of work were interviewed.

The group which took part on the model structuring phase and which we made an individual interview with, was composed by the following individuals:

- Operations manager at CLC;
- Head of aviation at Galp, connected with the business of selling jet to airlines;
- Airport Operations Coordinator at Galp;
- Director at Galp, connected with various environmental projects in the company.

The interview starts with general questions about the problem in study focusing on stakeholders' concerns and objectives regarding the distribution system of jet A-1. Also, in this first stage of the interview we seek to validate the stakeholders involved and to identify new individuals that we can approach to add value to the model. To finalize the first stage of the interview and connect it to the next one, related with the evaluation criteria, we ask about the problem areas of interest which were mainly used in the literature to evaluate this type of problem.

The questions used in the interviews are showcased below in Table 15. Occasionally, additional questions might be necessary in order to get a better understating of topics discussed throughout the interview.

Table 15 - Question for individual interviews

1	What are your main concerns regarding the current distribution system of jet A-1 via road tanker?
2	What would be your main goals to be achieved if the current system is replaced by a new pipeline system?
3	What are the main drawbacks of introducing the new pipeline system to supply jet A-1 to Lisbon's airport?
4	This project involves different stakeholders. To build this model I will approach CLC, petroleum companies (Galp) and ANA. There is any other stakeholder I should approach that would add value to the model?
5	From the literature I identified that this type of problem is usually evaluated considering four areas of interest, economic, environmental, risk and social. Do you agree with these areas? Is there any other area that should be added?
6	From 1 to 5 which level of relevance you assign to the following factors used to appraise jet A-1 distribution systems: CO_2 emissions; operational costs; investment costs; transport fee; system's flexibility; system's efficiency; risks for reliability of supply; risks for public and environment safety; risks for infrastructures and assets security; public acceptance; city councils acceptance; traffic of road tankers on public roads; Where 1 corresponds to strongly disagree 2 disagree 3 to no opinion 4 to agree and 5 to totally agree.
7	Besides the factors mentioned above, what additional ones must be considered in the decision-making of choosing the best fitted distribution system to supply jet A-1 to Lisbon airport?
8	Is there any other topic that was not approached in this interview but that you think could be important on the decision of replacing or not the current distribution system with a new pipeline system?

The initial questions (1 to 3) of the interview, despite having the goal of beginning the conversation, they also allow us to identify stakeholders' objectives, which serve as a basis to identify and define the evaluation criteria. The identification of these criteria is not a simple process because it depends on the interpretation of the facilitator. However, the questions developed have the goal to facilitate this process, by focusing on the importance that each decision maker gives to each issue or objective identified. Therefore, question 6 aims to collect the relevance that each stakeholder give to criteria previously adopted in the literature, in similar problems, in order to minimize the risk of omitting relevant factors and to check if they should be included in the model. Also, depending on the interviewee area of work, questions related with some criteria's descriptors can be done. Moreover, question 4 intends to identify new individuals with different perspectives which can add value to the model. Question 5 is in line with question 6 since it intends to validate information that as gathered from the literature regarding the areas of interest in this type of problems.

To finalize the interview, a question related with the stakeholder availability for the decision conferences is asked, with the goal of gathering information to plan them. Moreover, throughout the entirety of the interview relevant information about each stakeholder is collected which is key to plan the decision conferences.

Something that is important to notice about these question is that since our objective with the proposed methodology is to consider not only the economic factor but also the environmental and social factors, all defined questions are open to discussion on these three topics. Furthermore there is no questions focused on identifying alternatives because in this study they are already defined.

Model Structuring Data Treatment

We based the model structuring data treatment in the existing literature related with the application of multicriteria evaluation methods to problems similar or close to the one we are studying. The majority of authors considered four main areas of interest to evaluate this type of problems, economic, environmental, risk and social (Dey, 2006; Sittipolkul, 2016; Sólnes, 2003). Economic includes operation costs and investment costs. Environmental includes CO_2 emissions and noise pollution. Risk includes infrastructures and assets safety, people and environmental security and reliability of supply. Lastly, social includes public acceptance (Dey, 2006; Sittipolkul, 2016; Sólnes, 2003).

Regarding the individual interviews, despite agreeing to the areas of interest identified in the literature decision makers also acknowledged the operational aspect of the system as an additional key area to be considered when evaluating it.

Then we identified what are their main concerns regarding the current distribution system and what are the goals they want to reach from replacing the current distribution system of jet A-1 via road tanker with a new pipeline system. The key goal pointed out from all parts was the guarantee of supply of jet A-1 to Lisbon's airport, in the right quantities at the right time. This objective goes in line with the main reason that led us to evaluate an alternative to the current distribution system of jet A-1 that was the uncertainties in terms of reliability and security of supply, due to the recent drivers strikes. Moreover, the different parts showed different perspectives and concerns regarding the distribution system of jet A-1. From CLC point of view, the focus was on the safety and security of the system, due to the health, environmental and socioeconomic impacts an accident in the system can cause. Also, highlighted that social approval could be one of the main constraints of introducing the new pipeline system. From oil companies (Galp) point of view the focus was on the transport fee charged for the transportation of jet A-1, the introduction of a new pipeline system can lead to an increase in this fee which can have impacts on the company's business due to the low margins existent in selling jet A-1 to airlines. Also, on the topic of economic factors, highlighted that the costs associated with the pipeline project might make it unfeasible to replace the current system.

The main concerns and objectives gathered from the interviews with the different stakeholders are summarized below:

- Guarantee the supply of jet A-1 to Lisbon's airport, in the right quantities at the right time;
- Maintain or decrease the transport fee charged to oil companies, to maintain market competitivity;
- How energy efficient is the process of transporting the jet A-1;
- Guarantee public safety;
- Decrease environmental impacts;
- Ensuring that alternative distribution methods exist, in case any problem occurs in the distribution system in place;
- Public and city councils approval;
- Amount of subsystems/tasks existing in the process of transporting the jet A-1 (complexity of the system).

In the next phase we identified which are the main characteristics of a distribution system which contribute for reaching these objectives. Therefore, by focusing on the relevance that each decision maker gives to each parameter of the system, which we retrieved from question 6 of the interview, it leads to the identification of the evaluation criteria. Their answers were in line with the objectives and concerns mentioned before. Therefore, we identified environmental impact, economic assessment, social impact, system's operations and risk assessment, as the main areas of concern.

The topic of **environmental impact** considers all the impacts on the environment caused by the distribution systems during its operation. However, despite noise pollution being a key impact which is considered in the EIA, from the interviews we could conclude that it could be neglected for the purposes of the model, since the decision makers only gave major relevance to air pollutants emissions, due to their impacts in both climate change and public health.

The topic of **economic assessment** considers all the economic concerns associated with the distribution system. Despite the relevance given to both operational and investment costs, it was concluded that the transport fee parameter already includes both these costs. Because the transport fee is computed by having investment and operational costs as a basis, in order to guarantee the company's earnings. Additionally on this topic, energy efficiency was highlighted in the interviews. Energy efficiency consists on using less energy to perform the same task. Hence, a more efficient transportation method is the one where for the same quantity of jet transported the amount of energy used is lower. This is a factor which is also connected with the topic of environment, less energy used less environmental impacts. For the purposes of the model we are evaluating energy efficiency in terms of energy consumption, i.e. the energy consumed from each method to transport the same amount of jet A-1.

The topic of **risk assessment** comprises safety, security and supply reliability. Thus it considers the impacts the distribution system's hazards can have on people, environment, assets and supply. Hence, tackling the concerns related with supply reliability, health and environmental safety and assets and infrastructures safety.

The topic of **social impact** is characterized by the social implications coupled with the different distribution systems. This includes public and city councils acceptance, since in some cases this type of projects are not well seen from the general public due to their risks and potential impacts on environment and on people's health. Moreover on this topic, the employment factor was identified due to the impacts that the change to a pipeline system can have on it.

The topic of **system's operation** tackles the areas of concern related with distribution system's operation. The two parameters highlighted in the interviews regarding the system's operation are also related with the area of risk. The first one, is the existence of alternatives to the distribution system in place which are capable of guaranteeing the supply of jet A-1 in case any type of problem occurs which is evaluated by the number of modes available to transport Jet A-1. The second one, is the amount of subsystems existent in the process of transporting the jet A-1, the more subsystems the process has the greater the risk of any problem occurring.

All this information and data collected, from literature and individual interviews, will serve as a basis to identify and define evaluation criteria, build the value tree and criteria's descriptors, and characterize the alternatives in study, which will be presented in the next chapter.

4.2.2 Ranking, Scoring, Weighting

Generally, this phase is developed via decision conferences where all decisions makers are present. The goal is to promote discussion between them so that in the end we can collect consensual judgments. However, in our case this was not possible not only due to unavailability of all decision makers, but also due to the confidentiality agreements each decision maker have with their company. Therefore, we developed an approach similar to the DAI where personal computer-assisted interviews were done with each decision maker. In those interviews we followed the procedure presented in section 3.3.3 to obtain decision makers' judgements, with the goal of filling all judgment matrixes, so that we are able to determine both criteria's value functions and weights via the M-MACBETH software.

Since, the procedure was done individually for each decision maker it led us to obtain different judgement matrixes for each one of them. Therefore all the data gathered had to be analyzed and treated in order to obtain a final matrix for each criterion's value function, as well as, one for criteria weighting. Despite, in most of the cases there was a general consensus between decision makers judgments, there were some cases where different points of view emerged. In these cases, it our responsibility to analyze the information gathered throughout all the interviews and select the judgment which is in line with it. Additionally, it was important to consider the area of specialty of the decision maker because they are more comfortable with certain criteria and that can be a deciding factor on the final judgment.

In the end, all this data collected regarding decision makers judgements will be used in the M-MACBETH software allowing us to obtain alternatives' global scores and provide decision makers in depth data for an informed decision.

4.3 Investment Analysis

This section focuses on gathering all information and data required to develop the investment analysis on the possibility of replacing the current distribution system via road tanker with the new pipeline system. Therefore as mentioned in section 3.5, we have two scenarios the one without the project (road tanker scenario) and the one with the project (pipeline system scenario). This section will be divided into two parts one for each scenario, where all the data necessary to implement the NPV method will be presented, with focus on each scenario cash flows and WACC. As mentioned in section 3.4 project's cash flows are divided into three components operating cash flow, capital spending and net working capital, and the WACC includes company's equity and debt market value, cost of debt and cost of equity.

In the following sections, all these components will be identified and/or computed for each scenario, the assumptions that we needed to made will be justified and all the sources from where we collected the data will be presented.

4.3.1 Road tankers Scenario

Firstly, it is important to obtain information regarding the road tanker operation which will facilitate the identification and estimation of the cash flows. Additionally, it is important to notice that we are considering only one road tanker because the cash flows are equal for the entire fleet and for the purposes of this study our goal is to compute the NPV and transport fee in €/m^3 so that we have the tools to compare both scenarios. From CLC we gathered that in each shift a road tanker does 3 trips, CLC – Lisbon Airport – CLC, of 120km each, where it transports 35 m^3 of jet A-1 in each one. The truck does 2 shifts per day with one different driver for each shift. Each driver works 8 hour per day, 6 days per week, 24 days per month.

With this information we are able to identify the first key characteristic prior to the cash flows which is the service life of a road tanker. The average lifetime of a truck is 8 to 12 years (Meszler et al., 2018). Considering that the truck does 6 trips per day of 120 km (3 in each shift), we estimate that it will travel 207 360 km per year. Thus for this study we considered that the road tanker will have a service life of 10 years, meaning that it has a lifetime travel of approximately 2.07 million km which is above the average but it is still an acceptable value for this type of trucks (Meszler et al., 2018).

Now that we identified the lifetime to be considered in the analysis, the next phase is to identify and/or estimate the scenario cash flows. We will start by the capital spending component and then we will approach the operational cash flows. The capital spending in this scenario only includes the purchase cost of the road tanker which is divided into two components the truck tractor and the jet A-1's tank , which is different from the ones which are used to transport diesel and gasoline because it has no compartments (Table 16) (Killcar, 2014).

Table 16 - Capital spending in road tanker scenario

Component	Purchase Price (€)
Truck Tractor with ADR and 420 hp	85 000
Jet A-1's tank	75 000

Once obtained the capital spending, the next step is to identify and/or estimate the operational cash flows, these include operational costs and revenues.

The operational costs can be divided into two categories, vehicle-based and driver-based (Murray & Glidewell, 2019). In Table 17 below all relevant operational costs from each category will be identified. The table is divided into four columns on for identification of the cost, one for its unit value, one for any assumptions made to estimate it and one for the source.

Table 17 - Operational costs

Vehicle-based			
Cost	**Unit Value**	**Assumptions**	**Source**
Fuel	1.25 €/L	15 cents discount from the current diesel price, 1.40 €/L	(DGEG, 2021)
Repair and Maintenance	0,09 €/km		(Murray & Glidewell, 2019)
Insurance	0,04 €/km		(Murray & Glidewell, 2019)
Tires	0,03 €/km		(Murray & Glidewell, 2019)
Tolls	11.70 €/trip		(Via Verde, 2021)
Driver-based			
Cost	**Unit Value**	**Assumptions**	**Source**
Salary	31 487 €/year	This yearly salary includes extra hours, night shifts and weekend shifts	(Carvalho, 2019)
Health insurance	60 €/month		(Médis, n.d.)
Fixed and administrative	10 000 €/year	Assumed as an additional costs for administrative services	

In terms of the revenues, they are estimated by the following formula, transport fee (€/m^3) x amount of jet transported (m^3), thus we have to determine these two components. Because the actual transport fee charged is a confidential value, CLC provided us the average price in the industry which is of 3.90 €/m^3 of jet transported in each trip (120 km). Regarding the amount of product transported, it was already mentioned above which is of 35 m3 per trip thus each truck transports 60 480 m3 per year. Lastly, we obtain a revenue of 235 872 €/year.

Identified and estimated all relevant cash flows, we now shift our focus to the WACC of the investing firm. In this analysis we are considering, TIEL – Transportes e Logística, S.A. , as the investing firm because it is one of the major companies operating in the sector of transporting hazardous materials in Portugal, and is currently the company responsible for the transportation of jet A-1 to Lisbon airport (Tiel, n.d.).

As mentioned above, to determine a firm's WACC we have to gather data on the following parameters, company's equity and debt market value, cost of debt and cost of equity. Beginning with the company's equity and debt market value, we obtain them from TIEL's financial data from 2019 and are showcased in Table 18.

Table 18 - TIEL's Equity and Debt market

Parameter	Value (€)
Equity market value	4 815 377
Debt market value	14 901 561

From it, we estimate a percentage of financing that is equity and a percentage that is debt of 24% and 76%, respectively.

The cost of debt was also obtained from TIEL's financial data from 2019 and based on its debt structure is equal to 3.50%. Whereas the cost of equity has to be estimated and as mentioned in section 3.5 it will be estimated via the CAPM method, RE = rF + [ß x (rM - rF)]. All data required to compute the cost of equity is showcased in Table 19, including assumptions made and their source.

Table 19 - Data to estimate cost of debt and cost of equity

Parameter	Value	Assumptions	Source
Risk-free rate (r_F)	0.001%	Portugal one-year government bonds	(World Governement Bonds, 2021)
Expected market return (r_M)	0.27%	Based on PSI-20 index	(Jornal de Negócios, 2021)
Beta coefficient (ß)	1.11	Beta coefficient used in trucking sector	(Damodaran, 2021)

Given this data and the tax rate of 21% applied in Portugal (Autoridade Tributária e Aduaneira, 2020), we can estimate both cost of debt and equity and finally TIEL's WACC (Table 20).

Table 20 - TIEL's Cost of Debt, Cost of Equity and WACC

Variable	Estimative
Cost of Debt (R_D)	3.50%
Cost of Equity (R_E)	0.001% + (1.11 x (0.27 – 0.001)) = 0.30%
WACC	24% x 0.30% + 76% x 3.50% x (1 – 21%) = 2.16%

So we obtained a WACC of 2.16% for TIEL which is considerably low meaning that now is a good time for the company to invest. We now have gathered all the information and data necessary to compute the NPV for the road tanker scenario, which will be done in the next chapter. In the next section, the same procedure will be developed for the pipeline system scenario.

4.3.2 Pipeline System Scenario

Starting with the information and data we were able to collect from the initial characterization of the pipeline system and also from CLC, which will be important to identify and compute scenario's cash flows. Regarding its operation, the system will provide a continuous supply of jet A-1 because restarting the system would be inefficient due to the energy needed to switch on the pumps. Therefore, the system will have a flow rate that guarantees that the tanks in the airport have the required amount to fulfill the demand plus the safety stock at any time. In terms of its dimensioning and components all the necessary information about the pipeline system was presented in section 4.1 and it will be referred to whenever used.

Like for the road tanker scenario, the first parameter to be identified is the lifetime considered. The pipeline system lifetime was already identified, thus we also considered for the investment analysis a lifetime of 20 years.

Focusing now on identifying and/or estimating the scenario cash flows we will start with the capital spending and then with the operational cashflows as before. The capital spending in this scenario consists on the total costs to develop the pipeline project considering all the tasks identified in section 4.1.2. This costs are divided into two categories, the material and equipment cost and the labor cost. Table 21 showcases the unit and total costs of the main costs associated with the development of a project for new pipeline system. All information about these costs was provided directly from CLC and it is based on data from their former and current projects. Considering the values obtained the capital spending adds up to approximately 10.64 million €.

Table 21 - Capital spending unit costs

Material and Equipment			
Cost	**Unit Value**	**Total cost (€)**	**Assumptions**
Pipe	110 €/m	5 500 000	12" diameter, 9.53mm wall thickness and 50 km
Pump	180 000 €/pump	940 000	The system will have three pumps
Speed variator for pump	400 000 €/speed variator	400 000	Only needed for one pump
Valves	50 000 €/valve	300 000	The system will have six valves
Cathodic protection	900 000 €	900 000	Includes its application
Labor			
Cost	**Unit Value**	**Total Cost (€)**	**Assumptions**
Workforce	8000 €/day	3 000 000	Workforce of ten welders, pipe fitters, steel fitters, management team, specialists and a quality and safety controller - one year construction work

Once obtained the capital spending, the next step is to identify and/or estimate the operational cash flows, these include operational costs and revenues.

The operational costs in a pipeline system includes, the maintenance and repair, and other operational costs, and the energy costs. The maintenance and repair, and other operational costs were estimated based on Sines-CLC pipeline cost. We extracted from CLC's 2019 financial report, the operational costs the company had had from the transportation via pipeline which were approximately 2.3 million € (CLC S.A., 2019). Considering the Sines-CLC pipeline has a length of 147 km we computed the unit operational costs, in €/km, which gave approximately 15 667 €/km. Lastly, considering the pipeline in study has a length of 50 km we estimated thw maintenance and repair, and other operational costs of 783 333 €/year. Additionally, we considered that the pipeline would have an increase degradation rate throughout the years, so the maintenance and repair, and other operational costs will have a yearly growth rate of 0,5% to account to this. Regarding the energy costs, the procedure to compute them is exactly the same as the one developed for the selection of the most economic diameter. Via the forecasted amount of jet A-1 transported each year (Table 10), the pipe flow rate and consequently the required pump horsepower, for a 12" diameter pipe, can be compute for each year. Lastly, the yearly energy cost can be computed considering the energy unit cost for industry purposes of 0.137 €/kWh (PORDATA, 2020).

In terms of the revenues, they are estimated by the following formula, transport fee (€/m^3) x amount of jet transported (m^3), thus we have to determine these two components. In this scenario case the transport fee is unknown therefore we had to estimate it. The procedure developed to estimate it has two main steps. The first one was to ask CLC, "as the investing firm what is the required rate of return it wants to attain from the investment in the pipeline system?", where the answer given by the firm was a required return of 11%. The second step is to estimate based on the investment cash flows what is the transport fee which needs to be charged so that a required return of 11% is obtained. Via this procedure we are able to obtain the transport fee which CLC will need to charge to oil companies in order to obtain the return on investment it wants, this will be presented in the next chapter. In terms of the amount of jet transported it depends on its yearly demand (Table 10), consequently the revenue in this case will vary each year depending on this demand, contrary to what happened in the other scenario where the amount of jet transported per truck is fixed.

Identified and estimated all relevant cash flows, we now shift our focus to the WACC of the investing firm. In this analysis we are considering CLC as the investing firm because it is one of the major logistic companies in Portugal in the sector of hazardous materials and already has a large experience with operating the Sines-CLC pipeline. Additionally, one of the goals of this dissertation is to support CLC's capital budgeting decision of investing or not in this new pipeline system.

As mentioned above, to determine a firm's WACC we have to gather data on the following parameters, company's equity and debt market value, cost of debt and cost of equity. Beginning with the company's equity and debt market value, we obtain them from CLC's financial data from 2019 and are showcased in Table 22.

Table 22 - CLC's Equity and Debt market value

Parameter	Value (€)
Equity market value	15 765 099
Debt market value	150 550 771

From it, we estimate a percentage of financing that is equity and a percentage that is debt of 9% and 91%, respectively.

Additionally from CLC's financial data from 2019 we can obtained the company's cost of debt and based on its debt structure is equal to 0.50%. Regarding the cost of equity, all data required to compute it is showcased in Table 23, including assumptions made and their source. The procedure followed is the same as the one presented for the road tanker scenario.

Table 23 - Data to estimate cost of debt and cost of equity

Parameter	Value	Assumptions	Source
Risk-free rate (r_F)	0.001%	Portugal one-year government bonds	(World Governement Bonds, 2021)
Expected market return (r_M)	0.27%	Based on PSI-20 index	(Jornal de Negócios, 2021)
Beta coefficient (ß)	0.74	Beta coefficient used in utility companies	(Damodaran, 2021)

From this data we can estimate the cost equity and lastly CLC's WACC (Table 24).

Table 24 - CLC's Cost of Debt, Cost of Equity and WACC

Variable	Estimative
Cost of Debt (R_D)	0.50 %
Cost of Equity (R_E)	0.001% + (0.74 x (0.27 – 0.001)) = 0.20%
WACC	9% x 0.20% + 91% x 0.50% x (1 – 21%) = 0.38%

So we obtained a WACC of 0.38% for CLC which is considerably low meaning that, as for TIEL, now is a good time to invest. With all the data we were able to gather throughout this sections we now have all the necessary elements to compute the NPV for both scenarios and also the transport fee for the pipeline system scenario which will enable us to analyze if the investment in the new pipeline system is attractive for both CLC and oil companies. That procedure and its results will be presented in the next chapter.

5. Methodology Development

5.1 Multicriteria Model

From all the data and information collected, which was presented in chapter 4, we are now able to build the multicriteria model and applying to the M-MACBETH software. Throughout this chapter all parts of the multicriteria model built via the data collected will be presented, as well as, its respective representation in M-MACBETH. This includes model structuring, ranking, scoring and weighting, and global scores and sensitivity analysis.

5.1.1 Model Structuring

Model structuring begins with the construction of the value tree. From the data we built the following value tree (validated by the decision makers) (Figure 8), where the bold and red text represents the evaluation criteria identified.

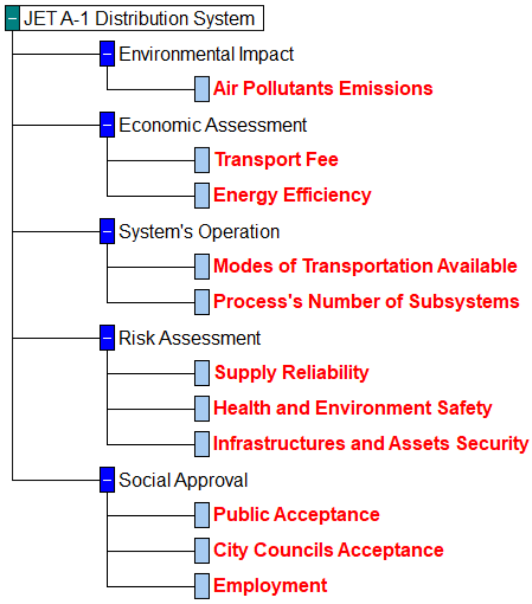


Figure 8 - Value tree. The red nodes correspond to the evaluation criteria.

Further to the construction and validation the value tree, the next stage is to operationalize the evaluation criteria identified by building descriptors for each one of them. As mentioned in chapter 3, it is essential to define for each criterion two reference levels, “good”, which represents a level of unquestionable attractiveness and “neutral” which represents a level neither attractive nor unattractive. These levels are fundamental for criteria weighting. Therefore, we gave them special attention so that they were well defined. An example of a descriptor is given below for criterion “Supply Reliability” the remainder are displayed in Annex C .

- **Supply Reliability**

This criterion seeks to evaluate the level of risk of the distribution system’s hazards, which impact the jet A-1 supply reliability. By developing a risk assessment through the risk matrix approach we obtain the risk ratings for each of the hazards considered. Therefore, for the “Supply Reliability” criterion we built a qualitative constructed descriptor based on the risk ratings of the hazards studied in the risk assessment (Figure 9). In the risk matrix approach we assess hazard's severity of consequences and its frequency, where we assign a numerical score to each one from 1-5. Finally, the risk level corresponds to the product between the scores of severity and frequency. Depending on the value obtained risks are evaluated as critical (25-16), high (15-8), medium (3-6), low (1-2). For supply reliability we considered the following hazards:

- Driver´s strike
- Explosion
- Theft, vandalism and sabotage
- Rupture – fire and toxic cloud/ loss of containment to groundwater
- Leak due to corrosion - loss of containment to groundwater
- Road accident

Performance levels:

- +	Qualitative level	Short
1	Only low rated risks	Low
2	At least one medium	Medium
3	At least one high rated risk	High
4	At least one critical rated risk	Critical

Figure 9 - Qualitative constructed descriptor for criterion "Supply reliability". ***Caption: Blue level*** *– " Neutral" reference level;* ***Green level*** *– "Good" reference level*

Alternatives Definition

The final stage of model structuring is to define the alternatives which will be studied and determine their performances in each criterion. The alternatives were previously defined since the main objective of this thesis is to study the possibility of introducing a pipeline system to supply jet A-1 to Lisbon's airport to replace the current distribution system via road tanker. Therefore, we have two options, which will be evaluated trough the multicriteria model: i) keep the current system or ii) replace it with a new pipeline system.

When building the value tree we identified and defined the model's evaluation criteria. Additionally, that process allow us to identify what additional data we needed to gather regarding each alternative, in order to evaluate them via the multicriteria model. This additional data was mostly to support the information obtained from the individual interviews and to complete it when necessary, hence we resort to data from literature, which was always checked and discussed with the decision makers.

Beginning with quantifying the air pollutant emissions for each system, we resort to the literature in order to obtain the emission factors associated with each transportation method (referenced in Table 25). Via the emission factors, the air pollutants emissions were computed in kg/m^3 considering the amount of jet A-1 transported.

In the case of the transport fee, the values identified were the same as the ones obtained in section 4.3 where the data for investment analysis is presented. Therefore, for the current system is the average price in the industry which is of 3.90 €/m3 of jet transported in each trip (120 km). In the new pipeline system case, we obtained the transport fee through the procedure already explained in the same section, for an required return of 11%, which was identified by CLC as the minimum acceptable profitability they seek for the investment in the new system.

Regarding the risk assessment developed with the objective of evaluating supply reliability, people and environment safety and infrastructures and assets security, we followed the risk matrix methodology (Annex D), which was based on both decision makers' perspectives and historical data. This historical data is gathered from both literature and stakeholders. Regarding criterion "supply reliability" we have one main risk related with the road tankers due to the recent drivers' strikes therefore we get a medium level risk (minor severity and credible frequency). Also in relation with road tankers but for the "Health and environmental safety" criterion, an important risk considered is road accidents. In Portugal, there was only one case of road accident where there was one fatality (Lima, 2008). Hence we considered it has medium level risk (major severity and unlikely frequency). For “Infrastructures and Assets Security” there is no meaningful risk associated with road tankers therefore we evaluated as a low risk. For the pipeline system the main risk is associated with theft and third party activities (Cech et al., 2020), with two cases of spillage already registered in Portugal due to robbery attempts (Rodrigues, 2016, 2017). This risk affects both “Health and environmental safety” and “Infrastructures and Assets Security” criteria. For the first one due to pipeline systems being equipped with advanced security and control systems the impacts to both people and environment are negligible, hence we evaluated it as a low-level risk (negligible severity and unlikely frequency). However for the second criterion the impacts are greater due to the costs incurred to fix the system, hence we evaluated as a medium level risk (major severity and unlikely frequency). For “supply reliability” criterion the same logic as “Health and environmental safety” can be done therefore we evaluated as a low rated risk.

All other characteristics, related with qualitative criteria, were defined from discussions and data gathered from the different decision makers which are experts and have large experience in the area and work daily with this type of systems.

Therefore, for criterion “modes of transport transportation available” in the case of the current system there is “Only one mode of transporting jet A-1” since transporting jet A-1 via road tanker is the only available option. Whereas, in the case of the new pipeline system there will be “Two modes of transporting jet A-1” the current one via road tanker and the new one via pipeline. Hence if the pipeline system has to stop for any reason, there will be road tankers available to supply the jet A-1 while the system is down.

For criterion “number of subsystems”, in the case of the current system it has “Multiple simple subsystems” since the distribution via road tanker includes several simple subsystems, like inset the hose into the road tanker then fill it with jet A-1, then when it arrives to Lisbon airport unload the road tankers. Despite being simple the number of tasks processed on an ongoing basis accumulates risks in the process. In the case of the new system it has “Multiple complex subsystems” since the pipeline system is composed by several complex components like valves, pumps, control system, cathodic protection, communication system, etc. If any malfunction is found in one of these components the whole system will be obligated to stop.

For criterion “Public acceptance” there is more subjectivity associated to it. In the case of the current system it was considered a neutral public acceptance because despite some part of the public which complain about the mobility constraints and traffic caused by the hundreds of road tankers which travel daily in the highway, there is mostly an indifference to this. In the case of the new pipeline system it was considered a partial public approval because in one side we will have people who support it due to the environmental benefits and also see it as the solution to the problems occurred due to the driver’s strikes, whereas in the other side we will have some people which will be against it due to the fear of explosion and its potential impacts.

For criterion “City councils acceptance” also has some subjectivity associated to it but mostly because there is still a lack of information regarding the new pipeline system. Even so, in the case of the current system it was considered a city councils approval because the road tankers have been operating for several years and there was never opposition or search for alternatives from the city councils. In the case of the new pipeline system, despite the lack of information it was considered a city councils approval because it will lead to a decrease in air pollutant emissions which will help them reach their goals.

Table 25 showcases the characterization of both alternatives in each criterion.

Table 25 – Alternatives' table of performances *(1)* (Galp, 2018) *(2)* (Jaramillo & Muller, 2016) *(3)* (Soares, 2009)

Evaluation Criteria	Current system	New pipeline system
Air pollutants emissions	2.3 kg/m^3 (1) (2)	0.56 kg/m^3 (3)
Transport fee	3.90 €/m^3	1.67 €/m^3
Energy efficiency	8 kWh/m^3	2.08 kWh/m^3
Modes of Transportation Available	1	2
Number of subsystems	Multiple simple	Multiple complex
Supply reliability	Medium risk	Low risk
Health and environmental safety	Medium risk	Low risk
Infrastructures and Assets Security	Low risk	Medium risk
Public acceptance	Neutrality	Partial Approval
City councils acceptance	Approval	Approval
Employment	0	40

5.1.2 Ranking, Scoring and Weighting

When the model structuring is finalized, by validating both the value tree and the descriptors, the next phase is to construct the criteria's value functions, as well as, determine their weights, in order to enable us to compute the global score of each of the options considered.

Determination of Value Functions

From the individual interviews approach mentioned in chapter 4 we collected each decision maker judgements on the pairwise comparison between performance levels in terms of their difference in attractiveness, in order to fill out the judgement value function matrix of each criterion. However, because the process of collecting decision makers' judgements was done through individual interviews instead of decision conferences, it was inevitable that for some pairwise comparisons different judgements were elicited. In these cases, we took advantage of a MACBETH's tool which is the possibility of selecting more than one category to measure the difference in attractiveness between levels. When this was not possible it was the facilitator responsibility to analyze the information collected from the interviews and select the judgment which better reflects the decision makers perspectives. From this procedure we obtain a final matrix for each criterion that best reflects the judgements elicited from the decision makers. Figure 10 showcases an example of the final value function matrix obtained for the "Supply Reliability" criterion.

	Low	Medium	High	Critical
Low	no	mod-strg	v. strong	vstrg-extr
Medium		no	mod-strg	strg-vstr
High			no	mod-strg
Critical				no

Consistent judgements

Figure 10 - Judgement Value Function Matrix for criterion "Supply Reliability"

As shown in Figure 10, the M-MACBETH software evaluates the judgements' consistency throughout the process and if any inconsistency is found it suggest ways to solve it which were discussed with the decision makers whenever necessary. Only when a consistent judgements matrix is obtained the software is capable to compute the criterion's value function.

When obtained from the M-MACBETH software the value functions were validated by the decision makers and adjustments were made where necessary (Figure 11).

Figure 11 - Interval Scale for criterion "Supply Reliability" obtained from M-MACBETH

Figure 11 displays the interval scale for criterion "Supply Reliability" obtained from M-MACBETH which reflects the judgments elicited by the decision makers. The interval scale was validated without any adjustments since the decision makers agreed with the scores obtained for each performance level.

Determination of weights

The next step is to determine the weight for each criterion. Again the data collected previously enabled us to fill the judgement weighting matrix (Figure 12). As was the case for the value functions, whenever different judgements were elicited by decision makers the same process was taken. With this data the M-MACBETH creates the weighting scale, which once more has to be validated by the decision makers and can be adjusted within a certain range (Figure 13).

	[TF]	[SR]	[HES]	[APE]	[EE]	[IAS]	[CCA]	[SUB]	[MT]	[PA]	[E]	[all lower]
[TF]	no	very weak	very weak	weak	moderate	moderate	strong	strong	strong	strong	vstrg-extr	extreme
[SR]		no	very weak	weak	moderate	moderate	strong	strong	strong	strong	vstrg-extr	extreme
[HES]			no	weak	moderate	moderate	strong	strong	strong	strong	vstrg-extr	extreme
[APE]				no	very weak	moderate	moderate	strong	strong	strong	v. strong	v. strong
[EE]					no	weak	moderate	moderate	strong	strong	v. strong	positive
[IAS]						no	weak	weak	strg-vstr	strong	strg-vstr	strg-vstr
[CCA]							no	weak	strong	strg-vstr	strg-vstr	strong
[SUB]								no	moderate	strong	strong	strong
[MT]									no	moderate	strong	mod-strg
[PA]										no	weak-mod	moderate
[E]											no	weak
[all lower]												no

Consistent judgements

Figure 12 - Judgement Weighting Matrix

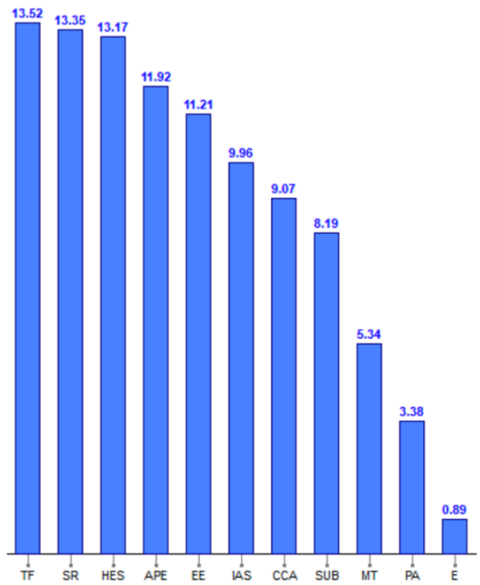


*Figure 13 - Criteria's Weights Histogram obtained from M-MACBETH. **Caption: TF** – Transport fee; **SR** - Supply reliability; **HES** – Health and environmental safety; **IAS** – Infrastructures and assets safety; **APE** - Air pollutants emissions; **SUB** – Process's number of subsystems; **EE** – Energy efficiency; **CCA** – City councils acceptance; **PA** – Public acceptance; **E** – Employment; **MT** – Modes of transportation available.*

From the individual interviews it was consensual that criteria "Transport fee", "Supply reliability" and "Health and environmental safety" have the most important swings and the difference in attractiveness between them was almost none as showcased by their weights, 13.52, 13.35 and 13.17 respectively. The same can be said for criterion "Employment" but in the opposite way, since it was consensual that this criterion has the least important swing, hence having the lowest weight, 0.89.

The determination of criteria's weights is the final phase of constructing the multicriteria model. We now have the available data to compute the alternatives' global scores and analyze which criteria have the biggest influence on the decision-making process, as well as, to develop a sensitivity analysis to understand how a variation in their weights can change the results obtained.

5.1.3 Global scores and Sensitivity analysis

Finalized the construction of the multicriteria model we are now able to obtain alternatives´ global scores from M-MACBETH software, which uses the value functions and weights determined previously and through an additive model computes each alternative's global score considering its performance in each of the evaluation criteria. These global scores are shown in Figure 14.

Figure 14 - Overall Thermometer

From these we can analyze that the option of replacing the current system with a new pipeline system has a much higher global score (104.38) than the option of keeping the current system as it scored (-0.9). The negative value obtained for the current system alternative global score is due to its performance in criteria “Air pollutants emissions” and “Modes of transportation available” which are below the “neutral” reference level. Which is in line with decision maker points of view since the current emissions are above acceptable and currently there is only one transportation mode available thus putting the supply of jet A-1 in danger as it happened with the road tanker drivers' strikes where there were no alternatives.

Additionally, the M-MACBETH software is equipped with tools which showcase the evaluation criteria that had the greatest impact in this difference and which allow us to perform a sensitivity analysis, allowing us to do a more in-depth analysis of the results obtained. Figure 15 presents one of M-MACBETH’s tools (differences profiles), it exhibits the weighted difference in performance in each criteria between alternatives, as well as, the overall difference (105.28). We can analyze that the pipeline option has a better performance in seven criteria whereas the road tanker option only in three criteria. Besides having a better performance in more criteria it is also important to notice that these include the ones with higher weights, “transport fee”, “supply reliability" and "health and environmental safety", hence contributing to the big difference in the global scores presented above (Figure 14). However, we can see that the main evaluation criterion that contribute for this difference is "air pollutants emissions" with a weighted difference of 35.97. Followed by the "transport fee" criterion with a weighted difference of 25.77 (Figure 15).

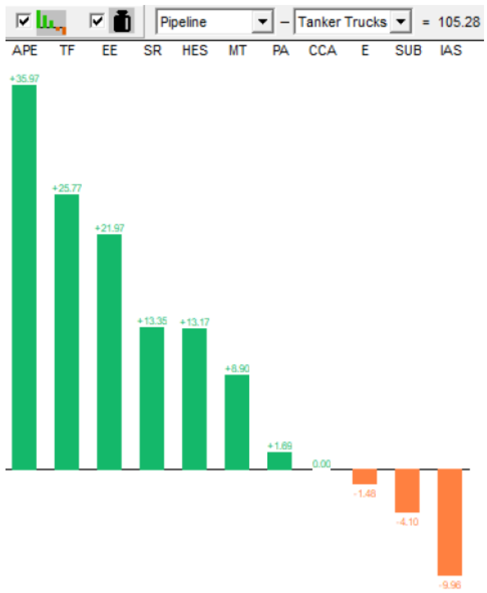


Figure 15 - Options' differences profiles

Then, the software also has the capability of developing a sensitivity analysis where it showcases for each criteria how varying the criterion weight from 0 to 100 influence the overall scores and which is the weight that makes the road tanker option more attractive than the pipeline option. However, in this case due to the really big difference between alternatives' overall scores the necessary weight variations in order to make the road tanker option more attractive are unrealistic because they are too large. Hence, confirming that the criteria´s weights correctly reflect the decision makers preferences.

5.2 Investment Analysis

In this section we will make use of all the information and data presented in section 4.3 to develop the investment appraisal for both scenarios, where the NPV is estimated and analyzed. However, in this analysis this indicator will not be enough to support the capital budgeting decision to be faced by CLC of investing or not in a new pipeline system to supply jet A-1 to Lisbon airport. Therefore, an additional decisive economic factor for this problem will be the potential transport fee charged to oil companies for the transportation via pipeline. Because, if CLC has to charge oil companies a transport fee higher than the one currently charged for the transportation via road tankers to reach the required return on the investment, oil companies would choose to continue to ship the product via road tankers as it is cheaper for them, and thus the pipeline system would be needless, considering merely the economic dimension of the problem. Hence, the goal of this section is to answer two main questions. Firstly, "Considering the pipeline project's cash flows the transport fee charged to reach the required return of 11%, identified in section 4.3, is lower than the one currently charged in the road tanker scenario?". And if yes, "Considering the road tanker scenario cash flows can TIEL compete with CLC's transport fee while maintaining its business profitable?". If the answer to the first question is no, the investment on the new pipeline system is not beneficial for CLC and oil companies, thus it should not go through considering solely the economic dimension of the problem.

5.2.1 Pipeline System Scenario & Transport Fee

Beginning with the first question, the transport fee for the pipeline system scenario was estimated by developing the procedure presented in section 4.3.2, therefore accounting for all the scenario's cash flows and the required return of 11%, we obtained the result showcased in Table 26. The whole procedure and respective calculations are presented in Annex E.

Table 26 – Estimative of pipeline system scenario transport fee and comparison with current transport fee

Scenario	Transport fee (€/m^3)
Pipeline System	1.67
Road tanker	3.90

This result clearly supports CLC to proceed with the investment in the new pipeline system because the transport fee charged will be decreased hence being more attractive for oil companies which will be able to decrease the costs it currently has with the transportation of the jet to Lisbon airport. The savings in transportation costs that oil companies are able to achieve with this change in mode of transportation will balance the initial investment that is required to introduce this new supply system showcasing how beneficial this investment could be. In this process more information on the investment was obtained (Tale 27).

Table 27 - Pipeline system scenario economic indicators

Indicator	Value
NPV	32.89 €/m^3
Payback period	10 years

We obtained, as expected, a positive NPV meaning that the investment increases company's value. Also, the 10-year payback period means that CLC will recover the initial investment cost on the pipeline system in exactly half of the lifetime considered for it.

5.2.2 Road tanker Scenario & Sensitivity Analysis

Despite all indicators being favorable to accept and go through with the investment in the new pipeline system there is additional relevant information regarding the road tanker scenario which can influence the results obtained above. This is related with the second question raised because TIEL will see this new system as a threat to its business of transporting jet A-1, thus there is the possibility for the company to negotiate and give better conditions to oil companies which can lead to a change in the results and conclusions made previously. Hence, in this section the investment appraisal for the road tanker scenario in TIEL's perspective will be presented and a sensitivity analysis will be developed with the goal of studying how competitive can TIEL be in relation to CLC in terms of the transport fee charged.

From the data gathered in section 4.3.1 regarding the scenario's cash flows and WACC (0.97%) we obtained the following results (Table 28). The whole procedure and respective calculations are presented in Annex E.

Table 28 - Road tanker scenario economic indicators

Indicator	Value
NPV	5.81 €/m^3
IRR	33 %

These results showcase that for a transport fee of 3.90 €/m3 the jet A-1 shipping business has been giving TIEL a great return on its investment. Additionally, it showcases that the company has a considerable margin to charge a cheaper fee while maintaining its business profitable. Therefore, the next stage is to develop the sensitivity analysis mentioned above where some variables will be diverse, however instead of just studying its impact on the NPV we will also study the impact on the transport fee. The main goal is to analyze if TIEL is able to decrease the current transport fee charged to a value lower than the one obtained above for the pipeline system scenario while maintaining its business profitable. In order to estimate the new values of transport fee, we will follow the same procedure developed for the pipeline system scenario, thus it will be assumed that TIEL'S minimum required return on the investment is 11%, as considered for CLC.

Throughout the process of identifying and computing the road tanker scenario cash flows we came to the conclusion that the most impactful variable is the amount of trips the truck performs per shift because the increase in revenue from it its larger than the additional operational costs. Additionally, we identified the diesel cost as a key variable which alongside the number of trips can make a real change in the results obtained. Therefore, in the sensitivity analysis developed we varied the number of trips per shift and the diesel price (Table 29). An important aspect to notice is that we cannot study more than four trips per shift because drivers can only drive a maximum of 10 h per day (European Union, 2021). Thus considering each trip of 120 km takes approximately two hours and fifteen minutes including the jet loading and unloading, plus the obligatory rest time of 30 minutes between trips, consider more than four trips per shift is completely unfeasible. Considering the changes in both variables and the required return of 11%, we obtained the following result (Table 29). The whole procedure and respective calculations are presented in Annex E.

Table 29 - Sensitivity analysis on number of trips per shift and diesel cost

Parameter	Base Scenario	Sensitivity Analysis
Number of trips per Shift	3	4
Diesel Cost (€/L)	0.25	0.15
Result		
Transport Fee (€/m³)	3.90	2.29

This result showcases that despite TIEL'S considerable margin to charge a cheaper fee while maintaining its business profitable as we saw in the initial results it is insufficient, even in more favorable conditions, to compete with the transport fee obtained for the pipeline system scenario. In this last result of the sensitivity analysis, we even obtained a transport fee much closer to that one but nevertheless the introduction of the new pipeline system will be more beneficial for oil companies as it will lead to minimize their transportation costs. Something that we can also conclude from these results is that even if TIEL attempts to optimize even more its current jet shipping business via road tanker in terms of its operation and costs it will always be difficult to compete with a new pipeline system since this type of systems are considered as the most cost effective to transport oil products (Herrán et al., 2010; MirHassani et al., 2013).

The results obtained throughout this section strengthen the conclusions elicited in the previous section for CLC to accept and go through with the investment in the new pipeline system because now we are able to add that there is no possibility for TIEL to charge a cheaper transport fee which would compromise CLC's investment without jeopardizing its own business.

6. Results Discussion and Limitations

6.1 Results Discussion

The combination of MCDA with an investment appraisal, enabled us to develop an overall appraisal to the project where all relevant aspects to the problem in study were tackled. We were able to focus not only on the capital budgeting decision for CLC via the investment analysis, where profitability and transport fee are the deciding factors, but also with the MCDA consider other factors, mainly subjective ones, which are difficult to introduce in an investment appraisal but have a big weight in the decision-making process of an investment of this type which involves important environmental and social aspects.

Beginning by discussing the MCDA, including both the multicriteria construction process and its results, the first aspect which is important to notice is its socio-technical dimension. The inclusion of decision makers in the building process of the multicriteria model is crucial because it facilitates that in the end the built model is clear and transparent to everyone. Since the procedure developed has the capability of clearly reflecting decision makers preferences in the model, thus generating confidence in the results obtained.

Regarding the results of the multicriteria model we obtained a global score for pipeline (104.38) way higher than for road tankers (-0.90). Revealing that the pipeline system is more fitted to transport the jet A-1 than the current system considering the decision makers judgements on the evaluation criteria identified for the study. Also, we found that decision makers considered "transport fee", "supply reliability" and "health and environmental safety" as the most important evaluation criteria for the problem in study, since they were the criteria with higher weights, 13.52, 13.35 and 13.17, respectively. However, from M-MACBEHT's difference profiles tool the three main evaluation criteria that contribute for the big difference in alternatives' overall scores are "air pollutants emissions", "transport fee" and "energy efficiency", in particular the first one with a weighted difference of 35.97. The main reason for that is because a pipeline system not only leads to a considerable reduction in air pollutant emissions, from 2.3 kg/m^3 (road tankers) to 0.56 kg/m^3 (pipeline). But also, leads to a considerable reduction in energy consumption, from 8 kWh/m^3 (road tankers) to 2.08 kWh/m^3 (pipeline). This emphasizes the importance that this more subjective aspects have on the decision-making process of this problem, supporting the reason why we developed this methodology. Lastly, we developed a sensitivity analysis to the results obtained via a M-MACBETH tool, which showcased that there was not any realistic variation to any criteria weight which changed the results. Confirming that the criteria weights obtained correctly reflect the decision makers preferences, thus sustaining the results obtained that the pipeline system is better suited to transport the jet A-1 than the current system, considering alternatives' performances and decision makers' judgements in the evaluation criteria selected.

Alongside supply reliability and transport fee which were tackled in the MCDA, the project's profitability was another decisive factor mentioned in the dissertation's problem definition hence supporting the methodology developed and the need of combining the results of MCDA with an investment analysis, where profitability and also transport fee were studied.

Generally, the NPV is the method used to support the decision of accepting an investment and also to choose between different possible investments however in this problem's case using the NPV is not enough to accept or reject the investment in the new pipeline system, because oil companies have a big say in this decision. The only way they would accept this change is if the transport fee charged to ship the jet A-1 to Lisbon airport decreases. Therefore the results obtained from the investment analysis focused on answering the two questions raised in section 5.3. , "Considering the pipeline project's cash flows the transport fee charged to reach the required return of 11%, identified in section 4.3, is lower than the one currently charged in the road tanker scenario?". And if yes, "Considering the road tanker scenario cash flows can TIEL compete with CLC's transport fee while maintaining its business profitable?".

The answer for the first question is yes since we obtained a required transport fee of 1.67 €/m^3 for the new system so that CLC can achieve its required return on the investment of 11%, which is cheaper than the one currently charged to oil companies of 3.90 €/m^3. This result supports the decision of CLC going through with the investment in a new pipeline system since it will be beneficial for the two parties involved in the business, CLC will be able to reach the required return they perceive for this investment and oil companies will be able to decrease its current transportation costs.

The answer to the second question is no because the minimum transport fee we were able to reach with our sensitivity analysis on the road tanker scenario was of 2.29 €/m^3. This sensitivity analysis complemented an increase in the number of trips a truck can do per day and also an additional discount in diesel prince, but even in this more favorable conditions the investment in the new pipeline system is still more beneficial to oil companies. This showcases that even if TIEL attempts to optimize even more its current jet shipping business via road tanker in terms of its operation and costs it is difficult for the company to compete with a pipeline system by charging to oils companies a more attractive fee without compromising the profitability of the business.

Aggregating all the results obtained from the methodology developed they thoroughly support the replacement of the current supply system with a new pipeline system considering the three key dimensions identified, economic, environmental and social. The main worries mentioned in the problem definition of this dissertation were the high investment costs associated with this type of project as well as the possibility of an increase in transport fee which would turn off the oil companies from this change. However, the results obtained from both the MCDA and the investment analysis showcased that despite the expected high investment cost, in its operations the pipeline system is more efficient than the current system in almost every key aspect, yearly costs, energy consumption, emissions and even risk, both in terms of supply and safety. Thus, leading to improvements in all dimensions, economic with the decrease in the transport fee charged, environmental with the decrease in air pollutant emissions and social with the decrease in risk, showcasing how beneficial this change can be to the stakeholders involved. The results obtained throughout this dissertation not only give reasoning to why the majority of European airports are supplied via pipeline, as presented in section 2.3.1, but are also in line with the information found in the literature which referred the pipeline systems as the most efficient mode of transporting oil products. However, as also mentioned in the literature this only applies for cases where large amounts of product are transported. This brings up a vital aspect to analyze which is, if the demand of jet A-1 continues at the same level it currently stands due to the pandemic state it is most likely that the transportation via road tanker is better and should be maintained. However, as it was shown from the results obtained, from a certain level of demand the pipeline system is undoubtably the best fitted method to transport the jet A-1 from CLC to Lisbon Airport.

A final remark, following the topic of the product demand, is that the results obtained from the methodology developed are only fitted if the Lisbon airport system remains the same during the lifetime considered. It is known that the Portuguese government would like to expand the current Lisbon airport system with the introduction of a new airport which would support the current airport in Portela. However, this possibility was not considered in our study due to the large uncertainty related with that topic. Despite that we are aware that the decision makers have to take that possibility into account in their decision because the introduction of a new airport would completely change the results we obtained in our study mainly due to the decrease on the amount of jet to be transported to Portela airport. A system with a 12 inch pipe diameter like the one we considered in our study would no longer be efficient because it would be too large for the amount of product transported. Thus, if the new pipeline system project and the investment on it are done, there will need to be a guarantee from the Portuguese government to the investing firm that the Lisbon airport system or the amount of product transported remains the same so that the system is still profitable.

6.2 Limitations

Throughout the development of the dissertation we were faced with some limitations that led us to adapt some aspects of the procedure we initially planned. In this section these limitations will be identified and explained in detail.

Firstly, in the characterization of the new pipeline system we were not able to go into much detail because there is a lot of information about it which still raw, since it is in a phase where stakeholders are still discussing if it should be done and how it should be done thus there are many uncertainties surrounding it. Leading us to focus mostly on the components which were key for our problem like the diameter and wall thickness.

Regarding the MCDA, despite the inclusion of the decision makers being a vital part to its procedure, this inclusion is a complex and difficult process which led to some problems along the way and to some constraints in our model. Firstly, we were not able to interview every stakeholder that we intended, mainly someone from ANA (airport perspective) and someone from an environmental organization (due to the environmental implications involved in this type of project). Secondly, as mentioned in section 4.2.2 , we were not able to do decision conferences to obtain the decision makers judgments, due to limitations imposed by the pandemic state and personal agendas. Meaning that everything was done via individual interviews and there was not any discussion between decision makers on their perspectives. Additionally, since it was the first time all decision makers used MACBETH some stages of the process were not simple, mainly determining criteria's weights because of the difficulty in understanding the concept of swing. However, the capabilities of M-MACBEHT software, like being able to use more than one qualitative judgement and confirming judgements consistency every time a judgment is elicited while giving suggestion on how to solve the inconsistencies, helped to simplify and facilitate the process.

Lastly, we faced some limitations on the gathering of data regarding some parameters. Primarily, the data we obtained initially regarding the demand of jet A-1 was completely compromised due to the pandemic state. In 2020, the demand of jet A-1 suffered a large decreased and it is still unclear when airports will be fully operational, thus the values used for future demand have a lot of uncertainty associated with them. Taking this into considerations, we used data of what CLC expects will be the demand in future years as they anticipate that demand will return to the same values of 2019 in about 4 years and then a constant growth as it was the case before the pandemic state. Finally, due to the confidentiality or scarce actual information on some parameters we had to use the average values from the industry, for example the road tankers transport fee. And for some cases they had to be estimated from the average values of the industry like the maintenance and insurance costs on road tankers and maintenance and repair, and other operational costs on the pipeline, which were estimated based on the Aveiras-CLC pipeline costs. Additionally regarding the topic of gathering information, in some cases we had to use certain methodologies to obtain the information we needed, where unfortunately we were not able to go into much detail since they were not the focus of this dissertation. One of this cases was the risk matrix approach used to characterize both alternatives in the risk criteria of the multicriteria model. This approach was not studied in as much detail as it could have been, however a complete study on the system's risks must be done in the future where more data is considered. The same can be applied to the more technical side regarding the pipeline characterization and dimensioning where we just focused on the parameters necessary for our study but this topic can and should be in the future studied in more detail.

Despite these limitations we were able to overcome them and achieve the goals proposed in the beginning of this dissertation. However, this leaves some gaps and improvements that can be done in future works in order to obtain even more robust results, these future works will be mentioned in the next section.

7. Conclusion & Future Work

The introduction of a new pipeline system to replace the current distribution system of jet A-1 to Lisbon airport is a complex problem due to the involvement of multiple stakeholders with different goals and worries and also because of the implications this change can make to the industries involved. Therefore, the dissertation's methodology combined an investment analysis and a MCDA and fulfilled its goal of gathering the necessary information and data to promote an informed decision.

In the MCDA, we were able to develop a consistent multicriteria model composed by all problem's key criteria and which reflected decision makers perspectives. From it, decision makers identified the economic and risk criteria, "transport fee", "supply reliability" and "health and environmental safety", as the most important. Additionally, in the ones that had more impact on the difference between alternatives, the environmental criteria, "air pollutants emissions" and "energy efficiency" are highlighted, where the first one had the highest weighted difference between alternatives of 35.97. Accordingly, the results obtained from the multicriteria model constructed showcased a clear advantage for the new pipeline system alternative when compared to the current distribution system, since the overall scores were of 104.38 and -0.90, respectively. Thus, despite the limitations we faced throughout this process we were able to obtain robust results and achieve our goal of including social and environmental aspects in the decision making analysis.

In the investment analysis, we analyzed both profitability and transport fee because they were identified in problem definition as the two key economic factors for the decision-making process. Profitability in operator's (investor) perspective and transport fee in user's (oil companies) perspective. We evaluated both scenarios, the one without the project (road tanker scenario) and the one with the project (pipeline system scenario). Despite the results showcased that the investment is profitable in both scenarios, the transport fee of 1,67 €/m^3 in the pipeline system scenario is clearly more favorable for the user than the one currently charged of 3.90 €/m^3. Additionally, we developed a sensitivity analysis to study the competitiveness of the road tanker scenario in terms of transport fee. The results showcased that even in more favorable conditions the minimum transport fee obtained was of 2.29 €/m^3 meaning that the pipeline system scenario is still more beneficial for oil companies. Thus, the capital investment on a new pipeline system to supply jet A-1 to Lisbon airport should be accepted since it economically benefits both parties interested.

In conclusion, the combining results of both methods thoroughly support the decision of replacing the current distribution system with a new pipeline system to supply jet A-1 to Lisbon airport. The results consistently showcased that the pipeline system outperforms the transportation via road tankers mainly due to its higher operational efficiency which leads to a decrease in energy consumed, air pollutant emission and transport fee. Additionally, it mitigates the risk of drivers' strike while being the safest mode of transportation equipped with advanced safety and control systems. This proves what we found in the literature regarding the pipeline system being the most fitted mode of transporting large quantities of oils products.

Future work

We had some limitations throughout the application of the methodology, has already stated in chapter 6, mainly related with its social dimension and the difficulty to obtain specific data on some matters. Therefore for future work we suggest the following. Decrease uncertainties associated with some parameters of both alternatives. Mainly in the new pipeline system where there is a lack of information on some design characteristics like route. When this information is available alongside with specialized studies on matters like environment, mechanical, civil, risk, etc., consistency and robustness of both models can be improved. Additionally, in the MCDA the addition of airport's (ANA) and an environmental organization perspectives to the model, which we were not able to obtain, could be relevant because they are two perspectives which can have a significant impact on the decision-making.

Finally, the next step is to gather all decision makers, which we were not able to do via the decision conferences, in order to discuss the results obtained, understand if there is any final necessary adjustments and lastly make use of the information gathered to support their decision.

References

Abriox. (2019). Just What is Cathodic Protection? Retrieved October 12, 2020, from Just What is Cathodic Protection? website: https://www.abriox.com/just-what-is-cathodic-protection/

AL-Kadi, T., AL-Tuwaijri, Z., & AL-Omran, A. (2013). Wireless Sensor Networks for Leakage Detection in Underground Pipelines: A Survey Paper. *Procedia Computer Science*, *21*, 491–498. https://doi.org/https://doi.org/10.1016/j.procs.2013.09.067

Angelini, F. (2011). Economic Analysis of Gas Pipeline Projects. *JASPERS Knowledge Economy, Energy and Waste Division*, (July), 1–10.

Annema, J., Koopmans, C., & Wee, B. (2007). Evaluating Transport Infrastructure Investments: The Dutch Experience with a Standardized Approach. *Transport Reviews - TRANSP REV*, *27*, 125–150. https://doi.org/10.1080/01441640600843237

API. (2014). MAINTENANCE AND DELIVERY. In *Energy Institute* (2nd ed.). London: Energy Institute.

API. (2016). *Protection Against Ignitions Arising Out of Static , Lightning , and Stray Currents*. Washington DC.

Autoridade Tributária e Aduaneira. (2020). *Sistema Fiscal Português - Taxas Aplicáveis*.

Baltussen, R., & Niessen, L. (2006). Priority setting of health interventions: the need for multi-criteria decision analysis. *Cost Effectiveness and Resource Allocation*, *4*(1), 14. https://doi.org/10.1186/1478-7547-4-14

Bana e Costa, C. A., & Chagas, M. P. (2004). A career choice problem: An example of how to use MACBETH to build a quantitative value model based on qualitative value judgments. *European Journal of Operational Research*, *153*(2), 323–331. https://doi.org/https://doi.org/10.1016/S0377-2217(03)00155-3

Bana e Costa, C. A., Ensslin, L., Cornêa, É. C., & Vansnick, J.-C. (1999). Decision Support Systems in action: Integrated application in a multicriteria decision aid process. *European Journal of Operational Research*, *113*(2), 315–335. https://doi.org/https://doi.org/10.1016/S0377-2217(98)00219-7

Bana e Costa, C. A., & Vansnick, J.-C. (2008). A critical analysis of the eigenvalue method used to derive priorities in AHP. *European Journal of Operational Research*, *187*(3), 1422–1428. https://doi.org/https://doi.org/10.1016/j.ejor.2006.09.022

Bana e Costa, C., De Corte, J.-M., & Vansnick, J.-C. (2011). *Chapter: MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique)*. https://doi.org/10.1002/9780470400531.eorms0970

Bana e Costa, C., Lourenço, J., Chagas, M., & Costa, J. (2008). Development of Reusable Bid Evaluation Models for the Portuguese Electric Transmission Company. *Decision Analysis*, *5*, 22–42. https://doi.org/10.1287/deca.1080.0104

Barriball, K., & While, A. (1994). Collecting data using a semi-structured interview: a discussion paper. *Journal of Advanced Nursing*, *19 2*, 328–335.

Beinat, E., & Bana e Costa, C. (n.d.). *Model-structuring in public decision-aiding*.

Belton, V., & Gear, T. (1983). On a short-coming of Saaty's method of analytic hierarchies.

Omega, *11*(3), 228–230. https://doi.org/https://doi.org/10.1016/0305-0483(83)90047-6

Belton, V., & Stewart, T. (2002). *Multiple Criteria Decision Analysis: An Integrated Approach*. Kluwer Academic Publishers.

Beria, P., Maltese, I., & Mariotti, I. (2012). Multicriteria versus Cost Benefit Analysis: A comparative perspective in the assessment of sustainable mobility. *European Transport Research Review*, *4*, 137–152. https://doi.org/10.1007/s12544-012-0074-9

Beukers, E., Bertolini, L., & Te Brömmelstroet, M. (2012). Why Cost Benefit Analysis is perceived as a problematic tool for assessment of transport plans: A process perspective. *Transportation Research Part A: Policy and Practice*, *46*(1), 68–78. https://doi.org/https://doi.org/10.1016/j.tra.2011.09.004

Bonvicini, S., Antonioni, G., Morra, P., & Cozzani, V. (2014). Quantitative assessment of environmental risk due to accidental spills from onshore pipelines. *Process Safety and Environmental Protection*, *93*, 31–49. https://doi.org/10.1016/j.psep.2014.04.007

BP. (2019). *BP Statistical Review of World Energy Statistical Review of World*.

Brennen, C. E. (2014). *Cavitation and Bubble Dynamics* (1st ed.). New York: Cambridge University Press.

C. Dias, L., & Tsoukiàs, A. (2003). On the constructive and other approaches in Decision Aiding. *Proceedings of the 57th Meeting of the EURO MCDA Working Group*.

Cafaro, D. C., & Cerdá, J. (2004). Optimal scheduling of multiproduct pipeline systems using a non-discrete MILP formulation. *Computers & Chemical Engineering*, *28*(10), 2053–2068. https://doi.org/https://doi.org/10.1016/j.compchemeng.2004.03.010

Cafaro, D. C., & Cerdá, J. (2008). Dynamic scheduling of multiproduct pipelines with multiple delivery due dates. *Computers & Chemical Engineering*, *32*(4), 728–753. https://doi.org/https://doi.org/10.1016/j.compchemeng.2007.03.002

Cafaro, V. G., Cafaro, D. C., Méndez, C. A., & Cerdá, J. (2015). MINLP model for the detailed scheduling of refined products pipelines with flow rate dependent pumping costs. *Computers & Chemical Engineering*, *72*, 210–221. https://doi.org/https://doi.org/10.1016/j.compchemeng.2014.05.012

Capiau, T. (2010). *An economic analysis of pipeline transport in Flanders An economic analysis of pipeline transport in Flanders*. Universiteit Gent.

Carvalho, P. S. (2019, August 23). Um motorista ganha 1.558 euros limpos. Apenas 35% é salário base. *Um Motorista Ganha 1.558 Euros Limpos. Apenas 35% é Salário Base*. Retrieved from https://eco.sapo.pt/2019/08/23/um-motorista-ganha-1-558-euros-limpos-apenas-35-e-salario-base/

Castro, P. M., & Mostafaei, H. (2017). Product-centric continuous-time formulation for pipeline scheduling. *Computers & Chemical Engineering*, *104*, 283–295. https://doi.org/https://doi.org/10.1016/j.compchemeng.2017.04.023

Cech, M., Davis, P., Gambardella, F., Haskamp, A., & Huidobro Barrio, I. (2020). *Performance of European cross-country oil pipelines*. Brussels.

CEPS. (2008).

Chen, H., Wu, C., Zuo, L., Diao, F., Wang, L., Wang, D., & Song, B. (2017). Optimization of Detailed Schedule for a Multiproduct Pipeline Using a Simulated Annealing Algorithm and Heuristic Rules. *Industrial & Engineering Chemistry Research*, *56*. https://doi.org/10.1021/acs.iecr.6b04745

Chen, H., Zuo, L., Wu, C., Wang, L., Diao, F., Chen, J., & Huang, Y. (2017). Optimizing detailed schedules of a multiproduct pipeline by a monolithic MILP formulation. *Journal of Petroleum Science and Engineering*, *159*, 148–163. https://doi.org/https://doi.org/10.1016/j.petrol.2017.09.036

Chevron. (2007). *Aviation Fuels - Technical Review*.

Chuck, C. J., & Donnelly, J. (2014). The compatibility of potential bioderived fuels with Jet A-1 aviation kerosene. *Applied Energy*, *118*, 83–91. https://doi.org/https://doi.org/10.1016/j.apenergy.2013.12.019

CLC S.A. (2019). *Relatório de Gestão & Contas 2019*. Retrieved from http://www.clc.pt/DocsCLC/2020/RC2019.pdf

CLH. (2020). CLH. Retrieved March 11, 2020, from https://www.clh.es/index.cfm?lang=sp

Commercial Fleet. (2020). Carbon Footprint Calculator. Retrieved April 10, 2020, from https://www.commercialfleet.org/tools/van/carbon-footprint-calculator

Damodaran, A. (2021). Betas by Sector (US). Retrieved February 5, 2021, from Betas by Sector (US) website: http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/Betas.html

Dawotola, A., Gelder, P. H. A. J. M., & Vrijling, J. (2009). Risk Assessment of Petroleum Pipelines using a combined Analytical Hierarchy Process - Fault Tree Analysis (AHP-FTA). *7th International Probabilistic Workshop*. Delft.

Dey, P. K. (2004). Decision support system for inspection and maintenance: a case study of oil pipelines. *IEEE Transactions on Engineering Management*, *51*(1), 47–56. https://doi.org/10.1109/TEM.2003.822464

Dey, P. K. (2006). Integrated project evaluation and selection using multiple-attribute decision-making technique. *International Journal of Production Economics*, *103*(1), 90–103. https://doi.org/https://doi.org/10.1016/j.ijpe.2004.11.018

Dey, P. K., & Gupta, S. (2001). Feasibility analysis of cross-country pipeline projects: A quantitative approach. *Project Management Journal*, *32*. https://doi.org/10.1177/875697280103200407

DGEG. (2021). Preço dos Combustíveis. Retrieved February 5, 2021, from http://www.precoscombustiveis.dgeg.pt/pagina.aspx?f=2&cn=62796281AAAAAAAAAAAAAAAA&regniu=7747&regformid=5044&regestagioid=5188&regnumprocesso=31455463&regtipo=S&regbloco=7747&regrespostaid=31455495&posicionar=&g7745n0nrec=50

Dimas, D., Murata, V. V, Neiro, S. M. S., Relvas, S., & Barbosa-Póvoa, A. P. (2018). Multiproduct pipeline scheduling integrating for inbound and outbound inventory management. *Computers & Chemical Engineering*, *115*, 377–396. https://doi.org/https://doi.org/10.1016/j.compchemeng.2018.04.025

Donegan, H. A., Dodd, F. J., & McMaster, T. B. M. (1992). A New Approach to AHP Decision-

Making. *Journal of the Royal Statistical Society. Series D (The Statistician)*, *41*(3), 295–302. https://doi.org/10.2307/2348551

ECO Sapo. (2020). Abertas candidaturas para oleoduto de abastecimento ao aeroporto de Lisboa. Retrieved April 15, 2020, from https://eco.sapo.pt/2020/02/17/abertas-candidaturas-para-oleoduto-de-abastecimento-ao-aeroporto-de-lisboa/

Edwards, W., F. Miles Jr., R., & von Winterfeldt, D. (2007). *Advances in Decision Analysis: From Foundations to Applications*. https://doi.org/DOI: 10.1017/CBO9780511611308

EIA. (2019). *International Energy Outlook 2019*. Washington DC.

EIB. (2013). *The Economic Appraisal of Investment Projects at the EIB*.

El-Reedy, M. A. (2015). *3 - Offshore Structures' Loads and Strength* (M. A. B. T.-M. S. D. C. El-Reedy, Ed.). https://doi.org/https://doi.org/10.1016/B978-0-08-099987-6.00003-9

engineersedge. (n.d.). Standard Pipe Schedules. Retrieved October 28, 2020, from https://www.engineersedge.com/pipe_schedules.htm#Related

European Commission. (2014). *Guide to Cost-Benefit Analysis of Investment Projects*. https://doi.org/10.2776/97516

European Commission. (2015). *Connection of the railway line Budapest- Arad to the multi-modal hub at Budapest Airport*. Brussels.

European Union. (2021). Trabalhadores do transporte rodoviário. Retrieved February 12, 2021, from Trabalhadores do transporte rodoviário website: https://europa.eu/youreurope/business/human-resources/transport-sector-workers/road-transportation-workers/index_pt.htm#globan-dropdown-2r2j43xmqw4

Eze, J., Nwagboso, C., & Georgakis, P. (2017). Robotics and Computer – Integrated Manufacturing Framework for integrated oil pipeline monitoring and incident mitigation systems. *Robotics and Computer Integrated Manufacturing*, *47*(November 2016), 44–52. https://doi.org/10.1016/j.rcim.2016.12.007

Fabozzi, F. J., & Drake, P. P. (2009). *Finance: Capital Markets, Financial Management and Investment Management*. Wiley.

Fra, M., & Dziubin, M. (2006). Aspects of risk analysis associated with major failures of fuel pipelines. *Journal of Loss Prevention in the Process Industries*, *19*, 399–408. https://doi.org/10.1016/j.jlp.2005.10.007

Galp. (2018). *Rotulagem de Energia Elétrica 2018*. Retrieved from https://casa.galp.pt/sites/default/files/faqs/rotulagem_energia_eletrica_2018_0.pdf

Garber, A., & Phelps, C. (1992). Economic Foundations of Cost Effective Analysis. *National Bureau of Economic Research, Inc, NBER Working Papers*.

Geiger, G. (2012). *Principles of Leak Detection*.

George, B., Harris, A., & Mitchell, A. (2001). Cost-Effectiveness Analysis and the Consistency of Decision Making. *PharmacoEconomics*, *19*(11), 1103–1109. https://doi.org/10.2165/00019053-200119110-00004

Gharabagh, M. J., Asilian, H., Mortasavi, S. B., Mogaddam, A. Z., Hajizadeh, E., & Khavanin, A. (2009). Comprehensive risk assessment and management of petrochemical feed and product transportation pipelines. *Journal of Loss Prevention in the Process Industries*, *22*(4), 533–539. https://doi.org/https://doi.org/10.1016/j.jlp.2009.03.008

González-Prida, V., Barberá, L., Viveros, P., & Crespo, A. (2012). Dynamic Analytic Hierarchy Process: AHP method adapted to a changing environment. *IFAC Proceedings Volumes*, *45*(31), 25–29. https://doi.org/https://doi.org/10.3182/20121122-2-ES-4026.00005

Han, Z. Y., & Weng, W. G. (2011). Comparison study on qualitative and quantitative risk assessment methods for urban natural gas pipeline network. *Journal of Hazardous Materials*, *189*(1), 509–518. https://doi.org/https://doi.org/10.1016/j.jhazmat.2011.02.067

Hanesian, D., & Perna, A. (1994). *Estimation of Optimum Pipe Diameter and Economics for A Pump and Pipeline System*.

Henriques, I., & Sadorsky, P. (2011). The effect of oil price volatility on strategic investment. *Energy Economics*, *33*(1), 79–87. https://doi.org/https://doi.org/10.1016/j.eneco.2010.09.001

Herrán, A., de la Cruz, J. M., & de Andrés, B. (2010). A mathematical model for planning transportation of multiple petroleum products in a multi-pipeline system. *Computers & Chemical Engineering*, *34*(3), 401–413. https://doi.org/https://doi.org/10.1016/j.compchemeng.2009.11.014

IATA. (2019a). *Annual Review 2019*.

IATA. (2019b). *Economic Performance of the Airline Industry*.

inline. (n.d.). What is Pipeline Pigging? Retrieved October 12, 2020, from What is Pipeline Pigging? website: https://www.inlineservices.com/resources/what-is-pigging/

ISO 13623. (2009). *Petroleum and natural gas industries — Pipeline transportation systems. ISO 13623:2009.* Geneva, Switzerland.

ISO 3183. (2019). *Petroleum and natural gas industries — Steel pipe for pipeline transportation systems.ISO3183*. Geneva: International Organization for Standardization.

Jaramillo, P., & Muller, N. Z. (2016). Air pollution emissions and damages from energy production in the U.S.: 2002–2011. *Energy Policy*, *90*, 202–211. https://doi.org/https://doi.org/10.1016/j.enpol.2015.12.035

Jones, H., Moura, F., & Domingos, T. (2014). Transport Infrastructure Project Evaluation Using Cost-benefit Analysis. *Procedia - Social and Behavioral Sciences*, *111*, 400–409. https://doi.org/https://doi.org/10.1016/j.sbspro.2014.01.073

Jornal de Negócios. (2021). Cotações PSI-20. Retrieved January 15, 2021, from https://www.jornaldenegocios.pt/cotacoes

Karlsson, G., & Johannesson, M. (1996). The Decision Rules of Cost-Effectiveness Analysis. *PharmacoEconomics*, *9*(2), 113–120. https://doi.org/10.2165/00019053-199609020-00003

Keeney, R. (1992). *Value-Focused Thinking: a path to creative decisionmaking*. Harvard University Press.

Keeney, R. L. (1994). Establishing research objectives to address issues of climate change. *Socio-Economic Planning Sciences*, *28*(1), 1–8. https://doi.org/https://doi.org/10.1016/0038-0121(94)90020-5

Keeney, R., & Raiffa, H. (1976). *Decisions with multiple objectives: preferences and value tradeoffs*. Wesley.

Killcar, S. (2014, November). Big rigs, big costs. *FleetOwner Magazine*. Retrieved from https://www.fleetowner.com/industry-perspectives/trucks-at-work/article/21691504/big-rigs-big-costs

Kouridis, C., Samaras, C., Hassel, D., Mellios, G., Mccrae, I., Hickman, J., … Geivanidis, S. (2018). *Methodology for the calculation of exhaust emissions*.

Kowalski, M., & Wernik, J. (2014). Economic pipe size selection by using graphical method. *Chemical Engineering Transactions*, *39*, 835–840. https://doi.org/10.3303/CET1439140

Leech, B. L. (2002). Asking questions: Techniques for semistructured interviews. *PS - Political Science and Politics*, *35*(4), 665–668. https://doi.org/10.1017/S1049096502001129

Liao, Q., Castro, P., Liang, Y., & Zhang, H. (2019). Computationally Efficient MILP Model for Scheduling a Branched Multiproduct Pipeline System. *Industrial & Engineering Chemistry Research*, *58*. https://doi.org/10.1021/acs.iecr.8b06490

Lima, L. (2008, November 18). Camião cisterna arde na A1. *Camião Cisterna Arde Na A1*. Retrieved from https://www.dn.pt/arquivo/2008/camiao-cisterna-arde-na-a1-1135823.html

Ludwig, D., Brock, W., & Carpenter, S. (2005). Uncertainty in Discount Models and Environmental Accounting. *Ecol Soc*, *10*. https://doi.org/10.5751/ES-01586-100213

M. White, F. (2017). *Fluid mechanics* (8th ed.). McGraw-Hill Education.

Mackie, P., & Preston, J. (1998). Twenty-one sources of error and bias in transport project appraisal. *Transport Policy*, *5*(1), 1–7. https://doi.org/https://doi.org/10.1016/S0967-070X(98)00004-3

Magatão, S., Magatão, L., Jr, F., & Arruda, L. (2015). Novel MILP Decomposition Approach for Scheduling Product Distribution through a Pipeline Network. *Industrial & Engineering Chemistry Research*, *54*. https://doi.org/10.1021/ie5046796

Marawan, H. (2004). Pipeline Drag Reducers. *Prospects of Oil, Gas and Petrochemical Industries in the Arab Region: Opportunities and Challenges, Volume 1 and Volume 2*, 1534. Retrieved from http://inis.iaea.org/search/search.aspx?orig_q=RN:40079292

Marks, L., Weatherly, H., & Mason, A. (2013). Prioritizing investment in public health and health equity: What can commissioners do? *Public Health*, *127*. https://doi.org/10.1016/j.puhe.2013.01.027

Marttunen, M., Mustajoki, J., Dufva, M., & Karjalainen, T. (2015). How to design and realize participation of stakeholders in MCDA processes? A framework for selecting an appropriate approach. *EURO Journal on Decision Processes*, *3*, 187–214. https://doi.org/10.1007/s40070-013-0016-3

Mccoy, S. T., & Rubin, E. S. (2008). An engineering-economic model of pipeline transport of CO 2 with application to carbon capture and storage. *International Journal of Greenhouse Gas Control*, *2*, 219–229. https://doi.org/10.1016/S1750-5836(07)00119-3

McKinsey. (n.d.). Jet fuel | McKinsey Energy Insights.

Médis. (n.d.). Simular Seguro Médis. Retrieved February 5, 2021, from https://www.medis.pt/simulador/

Meira, W. H. T., Magatão, L., Relvas, S., Barbosa-Póvoa, A. P., Neves, F., & Arruda, L. V. R. (2018). A matheuristic decomposition approach for the scheduling of a single-source and multiple destinations pipeline system. *European Journal of Operational Research*, *268*(2), 665–687. https://doi.org/https://doi.org/10.1016/j.ejor.2018.01.032

Meszler, D., Delagado, O., Rodríguez, F., & Muncrief, R. (2018). *European Heavy - Duty Vehicles : Cost-Effectiveness of Fuel- Efficiency Technologies for Long - Haul Tractor - Trailers in the 2025 – 2030 Timeframe*. Washington DC.

MirHassani, S. A., Abbasi, M., & Moradi, S. (2013). Operational scheduling of refined product pipeline with dual purpose depots. *Applied Mathematical Modelling*, *37*(8), 5723–5742. https://doi.org/https://doi.org/10.1016/j.apm.2012.11.009

MirHassani, S. A., & Fani Jahromi, H. (2011). Scheduling multi-product tree-structure pipelines. *Computers & Chemical Engineering*, *35*(1), 165–176. https://doi.org/https://doi.org/10.1016/j.compchemeng.2010.03.018

Moerkerk, M., & Crijns-Graus, W. (2016). A comparison of oil supply risks in EU, US, Japan, China and India under different climate scenarios. *Energy Policy*, *88*, 148–158. https://doi.org/10.1016/j.enpol.2015.10.015

Moses, C. (2011). *Properties of Russian Jet Fuels*.

Murray, D., & Glidewell, S. (2019). *An Analysis of the Operational Costs of Trucking : 2019 Update*. Virginia.

Nataraj, S. (2005). Analytic Hierarchy Process as a decision-support system in the petroleum pipeline industry. *Issues in Information Systems*, *6*.

NATO. (2020). Central Europe Pipeline System (CEPS) Programme. Retrieved March 12, 2020, from https://www.nspa.nato.int/en/organization/ceps/ceps.htm

NESTE. (2019). *SAFETY DATA SHEET Aviation Jet Fuel JET A-1 (JETA1)* (Vol. 1).

Nickel, J., Ross, A. M., & Rhodes, D. H. (2009). Comparison of Project Evaluation Using Cost-Benefit Analysis and Multi- Attribute Tradespace Exploration in the Transportation Domain. *Second International Symposium on Engineering Systems*, 1–13.

Nonis, C., Varghese, K., & Suresh, K. (2007, September). Investigation of an AHP Based Multi Criteria Weighting Scheme for GIS Routing of Cross Country Pipeline Projects. In *24th International Symposium on Automation & Robotics in Construction*. https://doi.org/10.22260/ISARC2007/0066

Phillips, L. D., & Bana e Costa, C. A. (2007). Transparent prioritisation, budgeting and resource allocation with multi-criteria decision analysis and decision conferencing. *Annals of Operations Research*, *154*(1), 51–68. https://doi.org/10.1007/s10479-007-0183-3

Polli, H., Magatão, L., Magatão, S., Jr, F., & Arruda, L. (2017). Collaborative Approach Based on Heuristic Algorithm and MILP Model To Assignment and Sequencing of Oil Derivative Batches in Pipeline Networks. *Industrial & Engineering Chemistry Research*, *56*. https://doi.org/10.1021/acs.iecr.6b03516

Pootakham, T., & Kumar, A. (2010). A comparison of pipeline versus truck transport of bio-oil.

Bioresource Technology, *101*(1), 414–421. https://doi.org/https://doi.org/10.1016/j.biortech.2009.07.077

PORDATA. (2020). Preços da electricidade para utilizadores domésticos e industriais (Euro:ECU). Retrieved February 2, 2021, from https://www.pordata.pt/Europa/Preços+da+electricidade+para+utilizadores+domésticos+e+industriais+(Euro+ECU)-1477

Ramírez-Camacho, J. G., Carbone, F., Pastor, E., Bubbico, R., & Casal, J. (2017). Assessing the consequences of pipeline accidents to support land-use planning. *Safety Science*, *97*, 34–42. https://doi.org/https://doi.org/10.1016/j.ssci.2016.01.021

Reilly, F. K., & Brown, K. C. (2011). *Investment Analysis & Portfolio Management* (10th ed.). Cengage Learning.

Rejowski, R., & Pinto, J. M. (2003). Scheduling of a multiproduct pipeline system. *Computers & Chemical Engineering*, *27*(8), 1229–1246. https://doi.org/https://doi.org/10.1016/S0098-1354(03)00049-8

Rejowski, R., & Pinto, J. M. (2008). A novel continuous time representation for the scheduling of pipeline systems with pumping yield rate constraints. *Computers & Chemical Engineering*, *32*(4), 1042–1066. https://doi.org/https://doi.org/10.1016/j.compchemeng.2007.06.021

Relvas, S., Matos, H. A., Barbosa-Póvoa, A. P. F. D., Fialho, J., & Pinheiro, A. S. (2006). Pipeline Scheduling and Inventory Management of a Multiproduct Distribution Oil System. *Industrial & Engineering Chemistry Research*, *45*(23), 7841–7855. https://doi.org/10.1021/ie060309c

Relvas, S., Matos, H., Barbosa-Povoa, A., & Fialho, J. (2007). Reactive Scheduling Framework for a Multiproduct Pipeline with Inventory Management. *Industrial & Engineering Chemistry Research - IND ENG CHEM RES*, *46*. https://doi.org/10.1021/ie070214q

Rodrigues, J. C. (2016, June 26). Ladrões furam oleoduto para levar gasóleo. *Ladrões Furam Oleoduto Para Levar Gasóleo*. Retrieved from https://www.cmjornal.pt/portugal/detalhe/ladroes_furam_oleoduto_para_levar_gasoleo

Rodrigues, J. C. (2017, April 25). Furam oleoduto para levar gasóleo. *Furam Oleoduto Para Levar Gasóleo*. Retrieved from https://www.cmjornal.pt/portugal/detalhe/furam-oleoduto-para-levar-gasoleo

Ross, S. A., Westerfield, R. W., & Jordan, B. D. (2015). *Fundamental of Corporate Finance* (11th ed.). McGraw-Hill Education.

Saaty, T. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, *15*(3), 234–281. https://doi.org/https://doi.org/10.1016/0022-2496(77)90033-5

Saaty, T. (2008). Decision making with the Analytic Hierarchy Process. *Int. J. Services Sciences Int. J. Services Sciences*, *1*, 83–98. https://doi.org/10.1504/IJSSCI.2008.017590

Schaschke, C. (1998). *Fluid Mechanics: Worked Examples for Engineers - IChemE*. Inst of Chemical Engineers UK.

Sittipolkul, M. N. (2016). *Comparative Study of Crude Oil Transportation*. Faculty of Engineering, Chulalongkorn University.

Soares, C. D. (2009). *Environmentally Harmful Subsidies: Identification and Assessment*. 1–26.

Sólnes, J. (2003). Environmental quality indexing of large industrial development alternatives using AHP. *Environmental Impact Assessment Review*, *23*(3), 283–303. https://doi.org/https://doi.org/10.1016/S0195-9255(03)00004-0

Spackman, M., Dogson, J., Pearman, A., & Lawrence, P. (2000). *"Multi-Criteria Analysis Manual."* NERA Publications.

Strogen, B., Bell, K., Breunig, H., & Zilberman, D. (2016). Environmental , public health , and safety assessment of fuel pipelines and other freight transportation modes. *APPLIED ENERGY*, *171*, 266–276. https://doi.org/10.1016/j.apenergy.2016.02.059

Taherkhani, M. (2018). An MILP approach for scheduling of tree-like pipelines with dual purpose terminals. *Operational Research*. https://doi.org/10.1007/s12351-018-0400-7

Tamiz, M., Jones, D., & Romero, C. (1998). Goal programming for decision making: An overview of the current state-of-the-art. *European Journal of Operational Research*, *111*, 569–581. https://doi.org/10.1016/S0377-2217(97)00317-2

The Portugal News. (2019). Fuel pipeline for Lisbon airport an "excellent decision." Retrieved April 15, 2020, from https://www.theportugalnews.com/news/fuel-pipeline-for-lisbon-airport-an-excellent-decision/49869

TheWorld Bank. (2004). *Monitoring and evaluation: Some tools, methods and approaches.* Washington DC.

Thokala, P., & Duenas, A. (2012). Multiple Criteria Decision Analysis for Health Technology Assessment. *Value in Health*, *15*(8), 1172–1181. https://doi.org/https://doi.org/10.1016/j.jval.2012.06.015

Tiel. (n.d.). Transportes e Serviços. Retrieved February 5, 2021, from http://www.tiel.es/pt-pt/transporte/

Tiger Valve Company. (2020). What Types of Valves Are Piggable.

Tudela, A., Akiki, N., & Cisternas, R. (2006). Comparing the output of cost benefit and multi-criteria analysis: An application to urban transport investments. *Transportation Research Part A: Policy and Practice*, *40*(5), 414–423. https://doi.org/https://doi.org/10.1016/j.tra.2005.08.002

Via Verde. (2021). Calculador de Percursos. Retrieved February 5, 2021, from https://www.viaverde.pt/particulares/ferramentas/calculador-percursos

von Winterfeldt, D., & Edwards, W. (1996). *Decision analysis and behavioral research*. Cambridge University Press.

Wallenius, J., Dyer, J., Fishburn, P., Steuer, R., Zionts, S., & Deb, K. (2008). Multiple Criteria Decision Making, Multiattribute Utility Theory: Recent Accomplishments and What Lies Ahead. *Management Science*, *54*, 1336–1349. https://doi.org/10.1287/mnsc.1070.0838

Wee, B. (2007). Rail Infrastructure: Challenges for Cost–Benefit Analysis and Other ex ante Evaluations. *Transportation Planning and Technology - TRANSPORT PLANNING TECHNOL*, *30*, 31–48. https://doi.org/10.1080/03081060701207995

Wei, H., Liu, W., Chen, X., Yang, Q., Li, J., & Chen, H. (2019). Renewable bio-jet fuel production for aviation: A review. *Fuel*, *254*, 115599.

https://doi.org/https://doi.org/10.1016/j.fuel.2019.06.007
World Governement Bonds. (2021). Portugal Government Bonds - Yields Curve. Retrieved February 5, 2021, from http://www.worldgovernmentbonds.com/country/portugal/
Yang, J., Xin, Z., He, Q. (Sophia), Corscadden, K., & Niu, H. (2019). An overview on performance characteristics of bio-jet fuels. *Fuel*, *237*, 916–936. https://doi.org/https://doi.org/10.1016/j.fuel.2018.10.079
Yedla, S., & Shrestha, R. M. (2003). Multi-criteria approach for the selection of alternative options for environmentally sustainable transport system in Delhi. *Transportation Research Part A: Policy and Practice*, *37*(8), 717–729. https://doi.org/https://doi.org/10.1016/S0965-8564(03)00027-2
Yu, H., & Guo, M. (2012). An efficient oil and gas pipeline monitoring systems based on wireless sensor networks. *2012 International Conference on Information Security and Intelligent Control*, 178–181. https://doi.org/10.1109/ISIC.2012.6449735
Zaghian, A., & Mostafaei, H. (2015). An MILP model for scheduling the operation of a refined petroleum products distribution system. *Operational Research*, 1–30. https://doi.org/10.1007/s12351-015-0212-y
Zhang, H., Liang, Y., Liao, Q., Wu, M., & Yan, X. (2017). A hybrid computational approach for detailed scheduling of products in a pipeline with multiple pump stations. *Energy*, *119*, 612–628. https://doi.org/https://doi.org/10.1016/j.energy.2016.11.027
Zhigang, D., Yongtu, L., Qiang, G., Qiao, X., Haoran, Z., & Guoxi, H. (2016). An automatic detailed scheduling method of refined products pipeline. *2016 12th IEEE International Conference on Control and Automation (ICCA)*, 816–823. https://doi.org/10.1109/ICCA.2016.7505379

Annex A

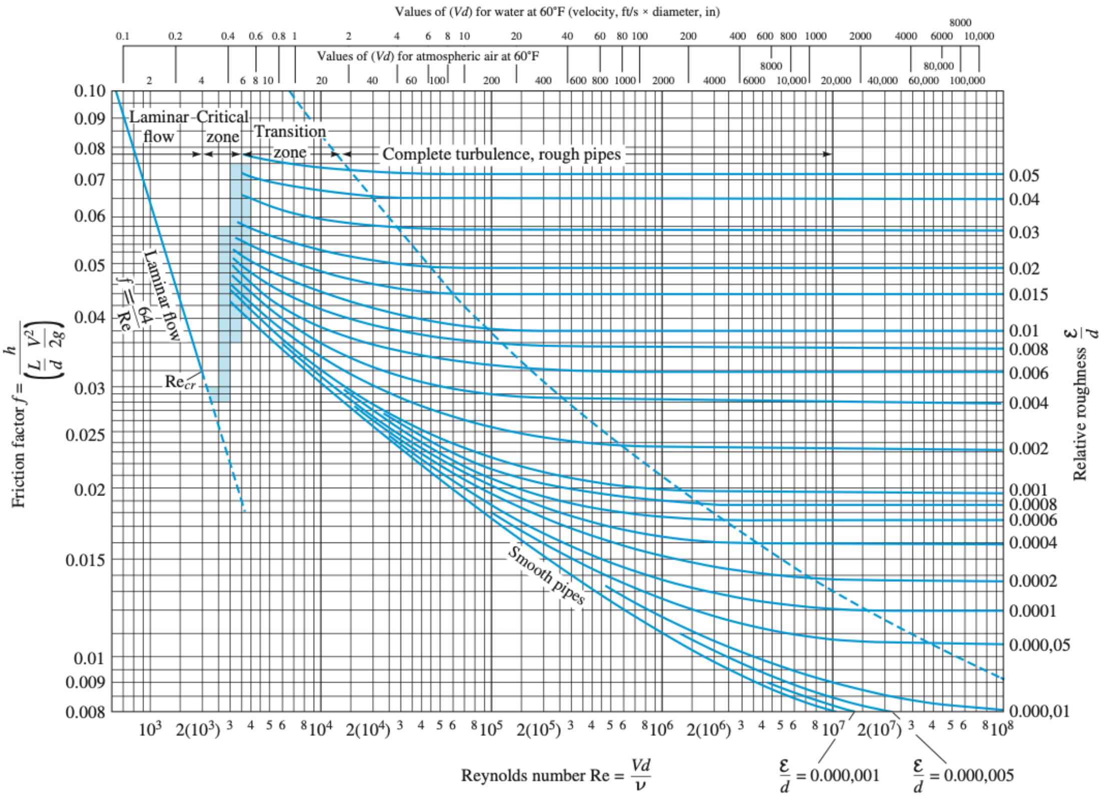


Figure A1 - The Moody Chart for pipe friction with smooth and rough walls (M. White, 2017)

Annex B

Gantt Chart

PROJECT START DATE	01/09/20
PROJECT END DATE	31/01/23

TASK	DURATION (MONTHS)	START DATE	END DATE
Routing	3	01/09/20	30/11/20
Public Safety	2	01/09/20	31/10/20
Environment Protection	2	01/09/20	31/10/20
Route and soil surveys	2	01/09/20	31/10/20
Final route	1	31/10/20	29/11/20
Project	10	01/10/20	31/07/21
Civil	3	01/10/20	31/12/20
Mechanical	8	01/10/20	31/05/21
Process	6	01/11/20	30/04/21
Electricity	5	01/03/21	31/07/21
Instrumentation	5	01/03/21	31/07/21
Control	8	01/11/20	30/06/21
Safety and Security	8	01/11/20	30/06/21
HAZOP	8	01/11/20	30/06/21
EIA	2	01/12/20	31/01/21
Licensing	4	01/02/21	31/05/21
Location	1	01/02/21	28/02/21
Industrial	4	01/02/21	31/05/21
Environmental	3	01/03/21	31/05/21
Construction	2	01/03/21	30/04/21
Procurement	7	01/06/21	31/12/21
Market Enquiries	1	01/06/21	30/06/21
Negociations with Suppliers	3	01/07/21	30/09/21
Orders	3	01/10/21	31/12/21
Construction	12	01/11/21	31/10/22
Components/Equipment Inspection	2	01/11/21	31/12/21
Pipe Assembly	8	01/11/21	30/06/22
Safety and Control Systems	5	01/05/22	30/09/22
Pump Assembly	3	30/06/22	29/09/22
Survey	1	30/09/22	29/10/22
Construction Records	1	30/09/22	29/10/22
Testing	2	01/11/22	31/12/22
Safety and Security	1	01/11/22	30/11/22
Control	1	01/11/22	30/11/22
Mechanical	1	01/12/22	31/12/22
Start Operation	1	01/01/23	31/01/23

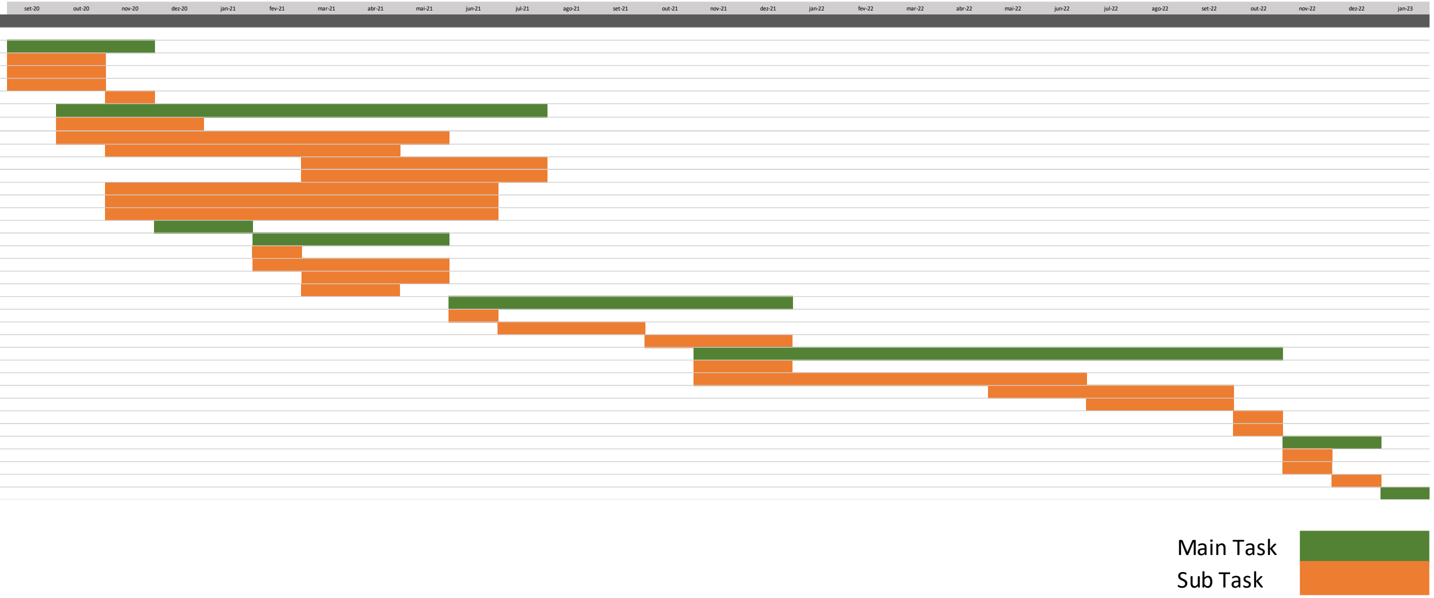


Figure B1 - Gantt Chart for a Pipeline Project

Annex C

Descriptors

- **Air pollutants emissions**

This criterion evaluates air pollutant emissions which are produced from the transportation of jet A-1 from CLC to Lisbon's airport. These include CO, CO_2, HC, N_2O, NO_x and particulate matter. Hence, the descriptor built is based on the emissions of these pollutants throughout the process of distributing the jet A-1. It is a quantitative descriptor measured in kg/m^3 of jet transported (Table C1).

Table C1 - Quantitative descriptor for criterion "air pollutants emissions"

N1 (Good)	Decrease 50%
N2 (Neutral)	Decrease 25%
N3	2.3 kg/m^3

- **Transport Fee**

This criterion considers the transport fee charged to the oil companies for the transportation of jet A-1 from CLC to Lisbon's airport. This fee should be as smaller as possible, because the jet A-1 business deals with low margins, hence a rise in the transport fee will lead to a loss of competitiveness in relation with other European airports. Therefore for this criterion it was built a quantitative descriptor showcased in Table C2, with the fee in €/m^3.

Table C2 - Quantitative descriptor for criterion "transport fee"

N1(Good)	Decrease 30%
N2 (Neutral)	Current transport fee
N3	Increase 10%

- **Energy Efficiency**

This criteria considers the energy consumed to transport the jet A-1 from CLC to Lisbon airport. This will showcase how energy efficient the transportation method is, a more efficient method is the one where for the same quantity of jet transported the energy consumed is lower. The descriptor built is a quantitative descriptor based on the energy costs in kWh/m^3 (Table C3).

Table C3 - Quantitative descriptor for criterion "energy efficiency"

N1	Decrease 75%
N2 (Good)	Decrease 50%
N3 (Neutral)	8 kWh/m^3

- **Modes of Transportation Available**

This criterion seeks to evaluate the existence of alternative distribution methods to guarantee the supply of jet A-1 to Lisbon's airport, in case any problem occurs in the distribution system in place. Therefore, we are considering the number of existing modes to transport the jet

A-1. So the following descriptor (Quantitative Descriptor) was built based on number of ways existent to supply the jet A-1 to Lisbon's airport (Table C4).

Table C4 - Quantitative descriptor for criterion "system's alternatives"

N1 (Good)	More than two modes of transporting jet A-1
N2 (Neutral)	Two modes of transporting jet A-1
N3	Only one mode of transporting jet A-1

- **Process's number of subsystems**

This criterion evaluates the number of subsystems existent in the process of transporting the jet A-1 from CLC to Lisbon's airport. This criterion considers that the more subsystems the process has and the more complex they are, greater is the risk of any problem occurring in it. Alongside the number of subsystems we are also considering how complex they are, i.e. if it is necessary to have a specialist in order to perform the task it is considered as a complex subsystem. For example, the distribution via road tanker involves several subsystems which are simple since it does not require a specialist to perform the tasks involved in it. The descriptor built (Qualitative Constructed Descriptor) for this criterion is presented below (Table C5).

Table C5 - Qualitative constructed descriptor for criterion "process's number of subsystems"

N1 (Good)	Single simple subsystem
N2	Single complex subsystem
N3 (Neutral)	Multiple simple subsystems
N4	Multiple complex subsystems

- **Public and Environment Safety**

This criterion seeks to evaluate the level of risk of the distribution system's hazards, which impact public and environmental safety. Like for the Supply Reliability criterion the risk assessment was used as a tool to build a qualitative constructed descriptor for this criterion (Table C6). In the risk matrix approach we assess hazard's severity of consequences and its frequency, where we assign a numerical score to each one from 1-5. Finally, the risk level corresponds to the product between the scores of severity and frequency. Depending on the value obtained risks are evaluated as critical (25-16), high (15-8), medium (3-6), low (1-2). For public and environmental safety we considered the following hazards:

- Explosion
- Rupture – fire and toxic cloud/ loss of containment to groundwater
- Leak due to corrosion – loss of containment to groundwater
- Road accident

Table C6 - Qualitative constructed descriptor for criterion "public and environmental safety"

N1 (Good)	Only low rated risks
N2 (Neutral)	At least one medium rated risk
N3	At least one high rated risk
N4	At least one critical rated risk

- **Infrastructures and Assets Security**

This criterion seeks to evaluate the level of risk of the distribution system's hazards, which impact infrastructures and assets security. Like for the Supply Reliability and Public and Environment Safety criteria the risk assessment was used as a tool to build a qualitative constructed descriptor for this criterion (Table C7). In the risk matrix approach we assess hazard's severity of consequences and its frequency, where we assign a numerical score to each one from 1-5. Finally, the risk level corresponds to the product between the scores of severity and frequency. Depending on the value obtained risks are evaluated as critical (25-16), high (15-8), medium (3-6), low (1-2). For infrastructures and assets security we considered the following hazards:

- Theft, vandalism and sabotage
- Explosion
- Rupture – fire and toxic cloud/ loss of containment to groundwater

Table C7 - Qualitative constructed descriptor for criterion "infrastructures and assets security"

N1 (Good)	Only low rated risks
N2 (Neutral)	At least one medium rated risk
N3	At least one high rated risk and medium
N4	At least one critical rated risk and high

- **Public Acceptance**

Despite all the safety and control measures applied in the transportation of an hazardous material like jet A-1, there is always some complaints about it from the general public due to the impacts it can have on public health and the environment in case of accident. Therefore, the Public Acceptance criterion considers the approval from the public in relation to the distribution system to supply jet A-1. A qualitative constructed descriptor was built and is presented below (Table C8).

Table C8 - Qualitative constructed descriptor for criterion "public acceptance"

N1 (Good)	Public approval
N2	Partial public approval
N3 (Neutral)	Public neutrality
N4	Public disapproval

- **City Councils Acceptance**

Before being able to put a distribution system of an hazardous material in operation, it necessary to obtain authorization from the city councils from the councils from which the system will go through due to its risks. Hence, this criteria seeks to evaluate the city councils approval in relation to the distribution system to supply jet A-1. A qualitative constructed descriptor was built and is presented below (Table C9).

Table C9 - Qualitative constructed descriptor for criterion "city councils acceptance"

N1 (Good)	City council approval
N2	City council disapproval

- **Employment**

This criterion evaluates the impacts that each distribution system will have on employment, throughout the lifetime considered. The descriptor built is a quantitative descriptor based on the number of dismissals (Table C10).

Table C10 - Quantitative descriptor for criterion "employment"

N1 (Good)	0
N2 (Neutral)	20
N3	Number of drivers which will dismissed with the pipeline system

Annex D

Risk Matrix

	Consequences				Frequency of Ocurrence				
Severity	People Health	Environmental Impact	Impact on supplier (Asset Loss/Infrastructure Damage)	Impact on final customer (shortage of jet A-1)	Rare (1)	Unlikely (2)	Credible (3)	Likely (4)	Frequent (5)
Catastrophic (5)	Multiple fatalities	Spill > 10 000 m3 / Irreversable consequences	Loss > 50M €	Obligated to stop all operations	5	10	15	20	25
Major (4)	One fatality or Multiple LWDC	Spill > 1000 m3 / Thousands of years to reverse consequences	Loss > 50M €	Obligated to stop most operations	4	8	12	16	20
Moderate (3)	Single LWDC or multiple RWDC	Spill > 150 m3 / Hundreds of years to reverse consequences	Loss 100k € - 5M €	Obligated to stop some operations	3	6	9	12	15
Minor (2)	Single RWDC or multiple minor injuries	Spill > 30 m3 / Few years to reverse consequences	Loss 100k € - 100k €	All safety stock used to offset shortage supply	2	4	6	8	10
Negligeble (1)	Minor injury	Spill < 30 m3 / Controllable spill	Loss < 10k €	Enough safety stock to offset shortage of supply	1	2	3	4	5

Risk Rating	Scoring	
	From	To
Critical	25	25
High	12	20
Medium	5	10
Low	1	4

Figure D1 - Risk Matrix for assessing both alternatives hazards

Annex E

Parameters	
Truck cost	85 000 €
Tank cost	75 000 €
Investment	160 000 €
Life time	10
Market Residual Value	16 000 €
Days of work per month	24
Hours of work per day	8
Max hours of work	12
Salary per year (includes extra hours)	31 487 €
Trips per shift	3
Shifts per day	2
Jet A-1 transported per year (m3)	60 480
Transport fee (/m3)	3,90
Revenue	235 872 €
Diesel price	1,25 €
Diesel cost	64 800 €
Insurance	4 147 €
Maintenance	9 331 €
Tires	2 074 €
Tolls	70 €
Salary	77 459 €
Health insurance	720 €
Fixed and administrative costs	10 000 €
Total Costs	168 601 €
IRC	21%
WACC	**2,16%**

	Ano 0	Ano 1	Ano 2	Ano 3	Ano 4	Ano 5	Ano 6	Ano 7	Ano 8	Ano 9	Ano 10
Investment	(160 000) €										
Revenue		235 872 €	235 872 €	235 872 €	235 872 €	235 872 €	235 872 €	235 872 €	235 872 €	235 872 €	235 872 €
Residual Value											12 640 €
Op. Costs		168 601 €	168 601 €	168 601 €	168 601 €	168 601 €	168 601 €	168 601 €	168 601 €	168 601 €	168 601 €
Amotization		16 000 €	16 000 €	16 000 €	16 000 €	16 000 €	16 000 €	16 000 €	16 000 €	16 000 €	16 000 €
Op. Result		51 271 €	51 271 €	51 271 €	51 271 €	51 271 €	51 271 €	51 271 €	51 271 €	51 271 €	63 911 €
Taxes		10 767 €	10 767 €	10 767 €	10 767 €	10 767 €	10 767 €	10 767 €	10 767 €	10 767 €	13 421 €
Liquid op. Result		40 504 €	40 504 €	40 504 €	40 504 €	40 504 €	40 504 €	40 504 €	40 504 €	40 504 €	50 489 €
Op. Cash Flows	(160 000,00) €	56 503,87 €	56 503,87 €	56 503,87 €	56 503,87 €	56 503,87 €	56 503,87 €	56 503,87 €	56 503,87 €	56 503,87 €	66 489,47 €

NPV	351 298,29 €
NPV (€/m3)	5,81 €
IRR	33%

Figure E1 - Economic appraisal for road tankers scenario

Parameters	
Investment	10 640 000 €
Life time	20
Market Residual Value	532 000 €
Length (km)	50
Op. Maint. Cost Sines-CLC Pipeline (€/km)	15 667
Jet A-1 transported per year (m3)	
Transport fee (€/m3)	1,67
Revenue	1 033 564 €
Energy Costs	
Op. , Maintenance and Repairs	783 333 €
Total Costs	
IRC	21%
WACC	0,38%

	Ano 1	Ano 2	Ano 3	Ano 4	Ano 5	Ano 6	Ano 7	Ano 8	Ano 9	Ano 10	Ano 11	Ano 12	Ano 13	Ano 14	Ano 15	Ano 16	Ano 17	Ano 18	Ano 19	Ano 20
Jet A-1 transported per year (m3)	617 760	926 640	1 389 960	1 667 952	1 717 991	1 769 530	1 822 616	1 877 295	1 933 614	1 991 622	2 051 371	2 112 912	2 176 299	2 241 588	2 308 836	2 378 101	2 449 444	2 522 927	2 598 615	2 676 573
Energy Costs	143 138 €	221 612 €	354 153 €	444 772 €	462 118 €	480 337 €	499 486 €	519 628 €	540 829 €	563 162 €	586 705 €	611 541 €	637 763 €	665 469 €	694 765 €	725 767 €	758 599 €	793 398 €	830 310 €	869 493 €
Op. , Maintenance and Repairs	783 333 €	787 250 €	791 186 €	795 142 €	799 118 €	803 113 €	807 129 €	811 165 €	815 221 €	819 297 €	823 393 €	827 510 €	831 648 €	835 806 €	839 985 €	844 185 €	848 406 €	852 648 €	856 911 €	861 196 €
Total Costs	926 471 €	1 008 862 €	1 145 339 €	1 239 914 €	1 261 236 €	1 283 450 €	1 306 615 €	1 330 793 €	1 356 050 €	1 382 459 €	1 410 098 €	1 439 052 €	1 469 411 €	1 501 275 €	1 534 750 €	1 569 952 €	1 607 005 €	1 646 046 €	1 687 221 €	1 730 689 €

		Ano 0	Ano 1	Ano 2	Ano 3	Ano 4	Ano 5	Ano 6	Ano 7	Ano 8	Ano 9	Ano 10	Ano 11	Ano 12	Ano 13	Ano 14	Ano 15	Ano 16	Ano 17	Ano 18	Ano 19	Ano 20
Investment		(10 640 000) €																				
Revenue			1 033 564 €	1 550 346 €	2 325 519 €	2 790 622 €	2 874 341 €	2 960 571 €	3 049 388 €	3 140 870 €	3 235 096 €	3 332 149 €	3 432 114 €	3 535 077 €	3 641 129 €	3 750 363 €	3 862 874 €	3 978 760 €	4 098 123 €	4 221 067 €	4 347 699 €	4 478 130 €
																						420 280 €
Op. Costs			926 471 €	1 008 862 €	1 145 339 €	1 239 914 €	1 261 236 €	1 283 450 €	1 306 615 €	1 330 793 €	1 356 050 €	1 382 459 €	1 410 098 €	1 439 052 €	1 469 411 €	1 501 275 €	1 534 750 €	1 569 952 €	1 607 005 €	1 646 046 €	1 687 221 €	1 730 689 €
Amotization			532 000 €	532 000 €	532 000 €	532 000 €	532 000 €	532 000 €	532 000 €	532 000 €	532 000 €	532 000 €	532 000 €	532 000 €	532 000 €	532 000 €	532 000 €	532 000 €	532 000 €	532 000 €	532 000 €	532 000 €
Op. Result			(424 907) €	9 483 €	648 180 €	1 018 708 €	1 081 105 €	1 145 121 €	1 210 773 €	1 278 078 €	1 347 047 €	1 417 690 €	1 490 016 €	1 564 025 €	1 639 718 €	1 717 088 €	1 796 124 €	1 876 809 €	1 959 118 €	2 043 021 €	2 128 478 €	2 215 441 €
Taxes			- €	1 992 €	136 118 €	213 929 €	227 032 €	240 475 €	254 262 €	268 396 €	282 880 €	297 715 €	312 903 €	328 445 €	344 341 €	360 589 €	377 186 €	394 130 €	411 415 €	429 034 €	446 980 €	465 243 €
Liquid op. Result			(424 907) €	7 492 €	512 062 €	804 779 €	854 073 €	904 646 €	956 511 €	1 009 681 €	1 064 167 €	1 119 975 €	1 177 112 €	1 235 580 €	1 295 378 €	1 356 500 €	1 418 938 €	1 482 679 €	1 547 703 €	1 613 986 €	1 681 498 €	1 750 198 €
Cash Flows		(10 640 000,00) €	107 092,54 €	539 491,90 €	1 044 062,09 €	1 336 779,42 €	1 386 073,20 €	1 436 645,71 €	1 488 510,98 €	1 541 681,26 €	1 596 166,76 €	1 651 975,38 €	1 709 112,39 €	1 767 580,11 €	1 827 377,51 €	1 888 499,85 €	1 950 938,19 €	2 014 678,92 €	2 079 703,23 €	2 145 986,47 €	2 213 497,59 €	2 702 478,32 €
Cash Flows Acummulated		(10 640 000,00) €	(10 532 907,46) €	(9 993 415,56) €	(8 949 353,47) €	(7 612 574,05) €	(6 226 500,85) €	(4 789 855,14) €	(3 301 344,15) €	(1 759 662,89) €	(163 496,13) €	1 488 479,25 €	3 197 591,64 €	4 965 171,75 €	6 792 549,27 €	8 681 049,12 €	10 631 987,31 €	12 646 666,23 €	14 726 369,46 €	16 872 355,94 €	19 085 853,52 €	21 788 331,84 €
NPV	20 320 483,06 €																					
NPV (€/m3)	32,89 €																					
IRR	11%																					

Figure E2 - Economic appraisal for pipeline scenario

Parameters	
Truck cost	85 000 €
Tank cost	75 000 €
Investment	160 000 €
Life time	10
Market Residual Value	16 000 €
Days of work per month	24
Hours of work per day	8
Max hours of work	12
Salary per year (includes extra hours)	31 487 €
Trips per shift	4
Shifts per day	2
Jet A-1 transported per year (m3)	80 640
Transport fee (/m3)	2,29
Revenue	184 945 €
Diesel price	1,15 €
Diesel cost	39 744 €
Insurance	7 949 €
Maintenance	15 898 €
Tires	3 577 €
Tolls	94 €
Salary	77 459 €
Health insurance	720 €
Fixed and administrative costs	10 000 €
Total Costs	155 440 €
IRC	21%
WACC	**2,16%**

	Ano 0	Ano 1	Ano 2	Ano 3	Ano 4	Ano 5	Ano 6	Ano 7	Ano 8	Ano 9	Ano 10
Investment	(160 000) €										
Revenue		184 945 €	184 945 €	184 945 €	184 945 €	184 945 €	184 945 €	184 945 €	184 945 €	184 945 €	184 945 €
Residual Value											12 640 €
Op. Costs		155 440 €	155 440 €	155 440 €	155 440 €	155 440 €	155 440 €	155 440 €	155 440 €	155 440 €	155 440 €
Amotization		16 000 €	16 000 €	16 000 €	16 000 €	16 000 €	16 000 €	16 000 €	16 000 €	16 000 €	16 000 €
Op. Result		13 505 €	13 505 €	13 505 €	13 505 €	13 505 €	13 505 €	13 505 €	13 505 €	13 505 €	26 145 €
Taxes		2 836 €	2 836 €	2 836 €	2 836 €	2 836 €	2 836 €	2 836 €	2 836 €	2 836 €	5 491 €
Liquid op. Result		10 669 €	10 669 €	10 669 €	10 669 €	10 669 €	10 669 €	10 669 €	10 669 €	10 669 €	20 655 €
Cash Flows	(160 000,00) €	26 669,16 €	26 669,16 €	26 669,16 €	26 669,16 €	26 669,16 €	26 669,16 €	26 669,16 €	26 669,16 €	26 669,16 €	36 654,76 €

NPV	85 583,37 €
IRR	11%

Figure E3 - Sensitivity analysis road tankers scenario – 4 trips per shift and 1,15 €/L diesel cost