DEPARTAMENT OF
ENVIRONMENTAL SCIENCES AND ENGINEERING

FILIPE MIGUEL PAULA FRANQUINHO
BSc in Environmental Engineering

PUBLIC TRANSPORT INFRASTRUCTURES IMPACT ON GREENHOUSE GAS EMISSIONS

CASE STUDIES IN THE METROPOLITAN AREAS OF LISBON AND PORTO

INTEGRATED MASTER IN ENVIRONMENTAL ENGINEERING
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Public Transport Infrastructures Impact on Greenhouse Gas Emissions:
Case Studies in the Metropolitan Areas of Lisbon and Porto

Aos Pais e ao João.

ACKNOWLEDGMENTS

It Is from a bitter-sweet perspective that I write this chapter. I cannot lie that I am closing one of the most beautiful chapters I have had so far, but at the same time, I am perfectly aware of what I will miss out on these last five years. I must confess that I did not choose Environmental Engineering as my first option when arriving at FCT NOVA. However, I am glad that It was where I ended up. I could not have chosen a better Institution and significant to graduate from. FCT NOVA gave me a friend group that I can now call family who are responsible for incredible adventures and experiences throughout such a wonderful journey, and it impacted the person I am today. To all ULTRAS FCT (André, Duarte, Bernas 15, Zé Bernas, Pica, Pi, Manel, Rita, Bea, Pipa, Mafalda and Nono) and especially RXP members, you will always be in my heart. Also, to my closest friend group: Saragoça, Tomás, Rui and Bia, thank you from the bottom of my heart for all the support you gave me not only during university but throughout every challenge I have ever come across. I would also like to thank all my family, who have unconditionally supported me all my life and to whom I will be forever grateful.

Recently, I thank Prof. Francisco Ferreira, who played a big part in this final stage of my academic journey and helped and supported me during these last few months.

Nothing in life is to be feared, it is only to be understood. Now is the time to understand more, so that we may fear less (Marie Curie).

ABSTRACT

Car traffic significantly impacts the environment, particularly through greenhouse gases emissions, and human health, requiring immediate action. We must develop strategies to reduce individual road transport and increase public transport users, despite difficulties such as large investments, commuter behaviour or urban planning constraints. We need to fulfil environmental agreements such as the European Green Deal.

This dissertation evaluates the role of investments in reducing emissions from cars. It assessed a total of ten Environmental Impact Assessment reports (EIAR) from public transport mobility projects in Lisbon and Porto's metropolitan areas over the period of 2000 and 2023. From all assessed projects eight were extensions of already existing projects, while two of them are completely new ones gathering a total investment of more than two billion euros. An assessment of the total emission savings forecasted by the studies only sum up to around fifty thousand tons of CO_2 per year, which corresponds to 0.29% of the emissions com-ing from the transport sector, reducing 0.70% and 0.37% locally in Lisbon and Porto respec-tively. A comparison between up-to-date occupancy and forecasted used in selected metro lines in Lisbon, show that the rate is still below or well below the forecasted numbers.

The proposed solutions focused mainly in three main dimensions: municipalities, companies and private commuters. Although actions such as an improved performance of the transport systems or enhancing pedestrian and cycling infrastructure are crucial, we must shift commuter behaviour to avoid car use through limited availability of car parking spaces, com-pany-based measures like teleworking, free public transport passes offer, or workplace shut-tles. These findings underscore the urgent need to reverse these outcomes and make public transport a more attractive alternative to private car use.

Keywords: Greenhouse emissions reduction, Public transport, Road transport; Environmental Impact Assessment, Metropolitan Areas of Lisbon and Porto

Resumo

O tráfego automóvel impacta severamente o meio ambiente, particularmente através da emissão de gases de efeito de estufa, e a saúde humana, exigindo uma ação urgente. É essencial desenvolver estratégias para reduzir o transporte rodoviário individual e aumentar o número de utilizadores de transportes públicos, apesar de desafios como custos de investimento, o comportamento dos passageiros e as limitações do planeamento urbano. Além disso, é necessário cumprir os compromissos ambientais, como o Pacto Ecológico Europeu.

Esta dissertação avalia o papel dos investimentos efetuados na área da mobilidade na redução das emissões provenientes dos automóveis. Foi analisado um total de dez Estudos de Impacte Ambiental (EIA) de projetos de mobilidade pública nas áreas metropolitanas de Lisboa e Porto, realizados entre 2000 e 2023. Do total de projetos avaliados, oito correspondem a extensões de projetos já existentes enquanto dois eram completamente novos, envolvendo um investimento total superior a dois mil milhões de euros. A avaliação das poupanças totais de emissões previstas pelos estudos totaliza apenas cerca de cinquenta mil toneladas de CO_2 por ano, o que corresponde a 0,29% das emissões provenientes do setor dos transportes, reduzindo localmente 0,70% e 0,37% em Lisboa e Porto, respetivamente. Uma comparação entre a ocupação atualizada e as previsões de utilização em linhas de metro selecionadas em Lisboa revela que a taxa de utilização ainda está abaixo ou muito abaixo dos números previstos.

As soluções propostas concentraram-se principalmente em três dimensões: municípios, empresas e passageiros privados. Embora ações como a melhoria do desempenho dos sistemas de transporte ou o reforço das infraestruturas para peões e ciclistas sejam cruciais, é necessário mudar o comportamento dos passageiros para evitar o uso de automóveis, através da limitação da disponibilidade de lugares de estacionamento, medidas empresariais como o teletrabalho, a oferta de passes gratuitos para transportes públicos ou *shuttles* corporativos. Estes resultados destacam a necessidade urgente de reverter estas situações e tornar o trans-porte público uma alternativa mais atrativa ao uso de automóveis particulares.

Keywords: Redução de gases de efeito de estufa, Transporte público, Transporte rodoviário, Avaliação de Impacte Ambiental, Áreas metropolitanas de Lisboa e do Porto

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ACRONYMS

APA	Agência Portuguesa do Ambiente
EIA	Environmental Impact Assessment
EIAR	Environmental Impact Assessment Report
EIS	Environmental Impact Statement
EU	Eurpean Union
GHG	Greenhouse Gases
IMT	Instituto da Mobilidade e dos Transportes
INE	Instituto Nacional de Estatística
IPCC	Intergovernmental Pannel for Climate Change
NECP	National Energy and Climate Plan
UNFCCC	United Nations Framework Convention on Climate Change

1

INTRODUCTION

1.1 Introduction

In recent decades, climate change has been one of the most relevant topics worldwide within the area of sustainability. Greenhouse gases (GHG) emissions have been rising, and we have been struggling to meet the major goal of the Paris Agreement, which is to keep global warming under 2ºC when compared to preindustrial levels, preferably under 1.5ºC (UNFCCC, 2015). Carbon dioxide (CO_2) has the biggest share of GHG emissions and this pollutant's levels have been rising, despite worldwide claims and efforts to reduce them. Furthermore, it is crucial to underline that anthropogenic activity is the main driving force to increase GHG concentration.

One of main contributors of CO_2 emissions globally is the transportation sector, with a share of 20%, of which 75% is due to road transport. Thus, the importance of tackling emissions coming from this sector (Ritchie, 2020). Public transport emerged as one of the main solutions to reduce car traffic. However, people's willingness to adopt public transport has their main travelling mean depends on several factors: physical environmental factors, sociodemographic, economic, psychological, and environmental factors (Burian et al., 2018).

By acknowledging the importance of public transport in reducing car use, we must now understand how to incorporate and finance public transport projects to maximize their efficiency in reducing GHG emissions and how these projects will impact the environment.

Environmental impact Assessment (EIA) unfolded has a powerful tool to evaluate project's future impacts in the environment, including large public transportation projects (IISD, 2024). The main component of an EIA, and the one that we will focus throughout this thesis is the Environmental Impact Assessment Report (EIAR). The EIAR outlines the significant environmental impacts resulting from the implementation of a project. However, various challenges persist in the effective application of EIAs, including a reliable prediction of the public transport infrastructure use, limited commitment from project proponents and political considerations, often centred on balancing environmental concerns with economic development objectives (Morgan, 2012).

The use of public transport infrastructure is a function of several factors such as availability, price, frequency, and comfort. However, part of the daily commuters that can use a car, will balance these factors to decide what would be their preference. For reducing car traffic, as a benefit for several environmental components from air quality to greenhouse mitigation or noise abatement, besides lowering congestion and benefiting the quality of life in cities, many measures have been developed. While some policies are intended to move users away from private car (Push Policies), Pull Policies are designed to attract users towards public transport (Kuss & Nicholas, 2022). From an European perspective, the "100 climate-neutral cities by 2030 - by and for the citizens" where the primary goal is to create innovation hubs across the whole continent to help achieving climate neutrality by 2050 , along with a just transition for all parties (Krogh Andersen & Jordan, 2020). At a national scale, the "RoadMap for Carbon Neutrality 2050" (currently being revised for 2045), comprising the country's long-term strategy, aligned with the European Green Deal's goals (Portuguese Government, 2019) have been two of the backbone instruments to determine several actions on transport policies. The National Energy and Climate Plan 2030 (currently under revision) is also a shorter-term decisive instrument. The impacts of policies in highly populated areas are particularly relevant due to their impact both at the regional level and the national level.

1.2 Objectives and Structure

This thesis aims to explore more deeply the barriers and challenges associated with the decarbonization of the transport sector and the reliability of the estimations of emission's reductions predicted by Environmental Impact Assessment Studies in large public transport infrastructure investments in the Metropolitan Areas of Lisbon and Porto in Portugal. It assesses the accuracy of an Environmental Impact Assessment, more precisely, the forecasted numbers present in Environmental Impact Assessment Reports. By doing so, we are in the position to understand how these tools can contribute to a more reliable prediction of GHG savings, especially carbon dioxide.

Triggering a modal shift away from private cars and towards public transport is the main foundation of an effective GHG reduction. Most project's EIARs make a prediction of how many passengers they expect to move away from private cars; however, we ask ourselves how accurate these predictions are. Thus, to assess their accuracy we evaluated several public transport projects within the timeframe between 2000 and 2023 and compared them (when applicable) to updated occupancy and emission data aiming to look for discrepancies between claimed and observed results.

Furthermore, the present study also aims to identify the main policies and measures to implement in Portugal to encourage a modal shift away from private car, a critical measure for reducing CO_2 emissions. The present thesis comprises five main chapters, organized as it follows:

I. **Introduction:** In this chapter a general overview of the topics discussed in the thesis is presented, more precisely what is the current state of the art of climate change worldwide and the importance of targeted policies to tackle increasing private car use.
II. **Literature Review:** Here, extensive research was done on literature regarding the major topics of the current study. We will delve deeper into climate change, not only on the global panorama, but also on a European and national levels, where the transportation sector plays a crucial role in mitigating GHG emissions, especially carbon dioxide; the role EIAs play in urban transportation projects, giving an overview of what EIAs are and how they help assessing future impacts done by projects and, finally, we will take a deeper look at policies and measures taken worldwide to trigger a modal shit away from private car and towards public transport.
III. **Methodological Approach:** This chapter describes the processes used throughout the thesis. Here, we examine the steps taken while retrieving the data from EIARs and how the data was processed and compared to current usage level and proxies.
IV. **Results & Discussion:** The findings of the present study are presented here, where we compare the data obtained from the Environmental Impact Assessment Report with current data from public transport occupancy levels in the infrastructures studied and road traffic data from direct measurement or proxies like fuel consumption. Furthermore, a critical analysis of the result takes place, suggesting improvements and concluding on the current state of the art of EIA's reliability. Moreover, some policies and measures to move users away from private car are discussed.
V. **Conclusion and Future Research:** Throughout the final chapter of the thesis, we present a summary of this study's findings, accompanied by a discussion of the transportation sector's role in re-ducing CO_2 emissions.

2

LITERATURE REVIEW

2.1 Climate Change from global to local scale

2.1.1 Global Scale

Climate change has been one of the most important topics in both science and politics worldwide. Climate change can be defined as extended-term changes in weather conditions and temperatures. These changes can come from natural sources such as changes in the sun, emissions from volcanoes, variations in Earth's orbit and levels of carbon dioxide. However, since the 1800s, anthropogenic activity has been the main driving force for climate change, mainly due to fossil fuel burning such as coal, oil and gas, which emits greenhouse gases to the atmosphere (United Nations, 2024).

Greenhouse gases trap energy near the Earth's surface, generating a greenhouse effect. However, an excessive emission of GHG, mainly carbon dioxide and methane, results in an enhanced greenhouse effect, which leads to an abnormal increase in Earth's temperature (NASA, 2023).

According to the Intergovernmental Panel on Climate Change (IPCC, 2023), between 2011 and 2020, the global Earth's temperature was 1.1ºC higher when compared to 1850-1900 values, registering a higher increase over land (1.59ºC) than in the ocean (0.88ºC).

Furthermore, as data from the National Oceanic and Atmospheric Administration (NOAA) shows, despite all the efforts, CO_2 levels have been increasing worldwide, which underlines the urge to tackle this problem. Figures 1 illustrates carbon dioxide levels from 1980-2020 and 2021-2024.

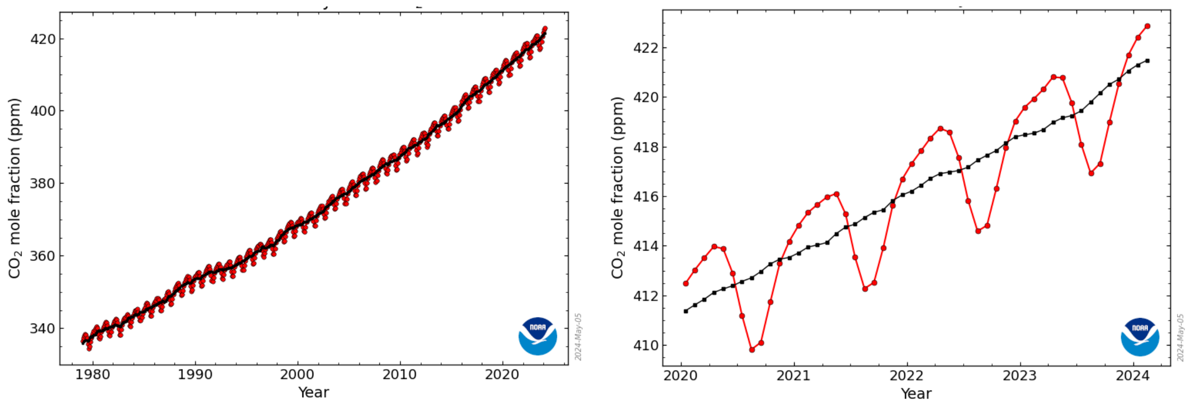

Figure 1- Global monthly mean carbon dioxide (1980-2024) (Source: NOAA, 2024)

Adopted in 1997, but only entering into force in 2005, the Kyoto Protocol serves as the operational framework for the United Nations Framework Convention on Climate Change (UNFCCC), and its main goal was the GHG emissions reduction by industrialized countries and economies in transition according to individual goals, recognising the need to bind developed countries to urgent efforts (UNFCCC, 2024). Kyoto Protocol's targets aimed for a 5% reduction in GHG emissions by developed countries between 2008 and 2012, compared to 1990 levels.

After this first commitment period, in December 2012, getting into force in 2013, the Doha Amendment comprised new commitments for Annex I Parties of the Kyoto Protocol for this second period (2013-2020), a revision of the report GHG by the Parties, and further amendments to some Kyoto Protocol's articles. The Doha Amendment had the main goal of Parties to reduce their GHG emissions by at least 18% compared to 1990 levels (UNFCCC, 2024).

Adopted during COP 21 in Paris, in December 2015 by 196 Parties, the Paris Agreement constitutes a global effort to tackle climate change, marking a milestone in its mitigation. Its main goal is to limit average global temperature below 2ºC compared to pre-industrial levels, while fully committing to avoid surpassing 1.5ºC (UNFCCC, 2015). The Paris Agreement's goals are intended to be achieved through Nationally Determined Contributions (NDC) which comprise national goals for each one of the parties that adopted the Agreement. Furthermore, the Paris Agreement also possesses technology, finance and capacity-building frameworks to support countries struggling to achieve their, so called, National Determined Contributions (NDCs).

However, according to the 2030 Emissions Gap Report (UNEP, 2023), we are still further away from meeting the Paris Agreement's goals. As Table 1 shows, if we keep our current policies, by 2050, we will be 46 $GtCO_2eq$ away from meeting the Agreement's primary goal: keep global warming below 1.5ºC, compared to pre-industrial levels.

Table 1- Average GHG emissions and estimated gap to least-cost pathways of UN policies (Source: UNEP, 2023)

Scenario	GHG emissions (GtCO2eq)	Estimated gap to least-cost pathways consistent with limiting global warming to specific levels (GtCO2eq)		
	Median and range	Below 2ºC	Below 1.8ºC	Below 1.5ºC
2030				
Current Policies	56 (52-60)	16 (11-19)	22 (17-25)	24 (19-27)
Unconditional NDCs	55 (54-57)	14 (13-16)	20 (19-22)	22 (21-24)
Conditional NDCs	52 (50-55)	11 (9-15)	17 (15-20)	19 (17-23)
2035				
Current Policies continued	56 (45-64)	20 (9-28)	29 (18-37)	31 (20-39)
Unconditional NDCs continued	54 (47-60)	18 (11-25)	27 (20-34)	29 (22-36)
Conditional NDCs continued	51 (43-58)	15 (8-22)	24 (17-31)	26 (19-33)
2050				
Current Policies continued	55 (24-72)	35 (4-52)	43 (12-60)	46 (16-63)
Unconditional NDCs and net-zero pledges using strict criteria	44 (26-58)	24 (6-38)	32 (14-46)	36 (18-49)
Conditional NDCs and all net-zero pledges	21 (6-33)	1 (-14-13)	9 (-6-21)	12 (-2-25)

It is crucial to underline that while unconditional NDCs are the ones that each country committed achieving by relying only on its resources and capabilities, conditional NDCs can only be achieved if the country in question receives external support, these being more ambitious. Nevertheless, as stated previously, the Paris Agreement contemplates external support to help countries achieve their NDCs.

2.1.2 European Scale

Greenhouse gas emissions are a crucial part of atmospheric degradation, hence the European Union (EU) urges to reduce GHG emissions recognising that transport, agriculture, building, and waste management sectors are the ones which contribute the most to GHG emissions. These goals were revised in March 2023, when the Parliament agreed to an even further reduction in GHG emissions. In Portugal's case, from a 17% to a 28.7% reduction in 2030 for non-ETS sector, when compared to 2005 levels (European Parliament, 2023).

This initiative is directly linked with the European Green Deal, which aims for carbon neutrality in the EU by 2050, comprising also milestones in 2030 (European Commission, 2024b). The Deal's financing comes from the EU's seven-year budget and one-third of the 1.8 trillion euros in investments from the NextGeneration EU Recovery Plan. To achieve its three main objectives which are being the first climate-neutral continent, reducing GHG emissions by 55% when compared to 1990 levels, and planting a total of 3 billion trees by 2030, Europe intends to rely on decoupling economic growth from resource use while assuring that all countries achieve their goals.

To enforce the European Green Deal's goals, the EU approved the European Climate Law (European Parliament, 2021), which represents a framework to meet climate neutrality by 2050, while aiming to reach negative carbon emissions thereafter. Moreover, the European Climate Law also presents binding targets for all parties to ensure that all the targets are met.

One of the main initiatives launched by the European Commission is the "100 climate-neutral cities by 2030 - by and for the citizens" (Krogh Andersen & Jordan, 2020). According to the European Commission (Krogh Andersen & Jordan, 2020), the main goal of this project is to create innovation hubs for all cities, thereby facilitating climate neutrality in 2050 by Europe as a unified entity. As for the main project's objectives, it is highlighted the fostering of a just transition by implementing Agenda 2030 and the Sustainable Development Goals (SDGs) associated, finding policy gaps and R&I (Research and Innovation) priorities to meet the European Green Deal's goals, and helping cities find financing to meet these same goals.

2.1.3 National Scale

Aiming to achieve carbon neutrality by 2050, the Portuguese Government published the "RoadMap for Carbon Neutrality 2050" (Portuguese Government, 2019) which presents Portugal's long-term strategy to reach this goal. According to the report, between 2007 and 2017, Portugal averaged an annual emission of 69 Mt of CO_2, where the transport sector contributed 25%, being also the sector where emissions most grew in recent decades.

According to a study conducted by AMT (2023), in order to be carbon neutral by 2050, Portugal must reduce their GHG emissions by 85 to 90% when compared to 2005 levels, as stated in Portuguese Climate Law, enforced on February 1st, 2022, which acknowledges the concept of climate emergency (Diário da República, 2021). The remaining 10 to 15% must be balanced with land use and forestry activities to minimize its impact. Moreover, Portugal also has reduction milestones in 2030 and 2040 of -55% and -65% of CO_2eq. The estimated investment, considering the goals the country must achieve, should be between 2.1 and 3.2 billion euros by 2034, considering the current scenario (AMT, 2023).

Later, in May 2020, the National Energy and Climate Plan (NECP) (República Portuguesa, 2020) presented Portugal's revised goals for GHG emission reduction for the interval 2021-2030, working alongside the RoadMap for Carbon Neutrality. The main goal of this plan is to promote a just energetic transition while decarbonising the economy. In the transportation sector, we highlight two main goals which are the 40% reduction in CO_2eq emissions while incorporating renewable energies to be used in 20% of the sector.

In June 2024, Portugal's NECP was revised (Diário da República, 2024), however it kept the goals previously updated in 2023. The country now aims for a more ambitious CO_2eq reduction, as illustrated in Table 2. Additionally, regarding the renewable energy incorporation sector, the initial scenario suffered a slight change, reducing incorporation from 13% to 10% by 2025, even though the final goal rises from 20% to 23% by 2030.

Table 2- Current and previous goals from Portugal's NECP (Source: Diário da República, 2023)

	2030	2040	2050
NECP 2030	45% to 55%	65% to 75%	85% to 90%
Updated NECP 2030	55%	65% a 75%	90%

The document also refers that new strategies should be adopted, aiming to reduce carbon intensity in the transportation sector by stating the importance of putting into force the Sustainable Urban Mobility Plans by municipalities and Metropolitan Areas between 2020 and 2030.

2.2 Road Transport as a Key Mitigation Factor

Transportation significantly contributes to worldwide CO_2 emissions, comprising a 20% share. Road transport alone accounts for 75% of the total transportation emissions, of which passenger vehicles account for 45.1%, which makes this particular segment responsible for most of the emissions (Ritchie, 2020).

When taking a deeper look into the EU, and according to the European Environment Agency (2023), we note a similar trend since road transport has a share of 76% in all EU's transport greenhouse gas emissions. Between 2013 and 2020, greenhouse gas emissions from the transport sector exhibited a steady increase. However, the global COVID-19 pandemic resulted in a worldwide reduction of CO_2 emissions. Nevertheless, as the economy recovered, so did emissions which rose 8.6% from 2020 to 2021, even though they suffered a decrease of 13.5% during the pandemic. Furthermore, it is crucial to state that "individual cars use up to four times more energy per passenger-kilometre than the majority means of public transport" (Miralles-Guasch et al., 2014).

In Portugal, road transport represents 96% of the sector's emissions, which can be justified by a clear overuse of individual road transport, an average occupation of 1.2 passengers per private vehicle and an occupancy rate of public transport oscillating between 17 and 24%, which is under the European average (Diário da República, 2019). Table 3 shows the evolution, past and forecasted, of the transport sector's emissions along with the incorporation of renewable fuels and/or electricity. Note that from 2030 onwards, the data oscillates between minimum and maximum values due to scenario considerations.

Table 3- Portuguese Transport sector's emissions and renewables incorporation (Source: Diário da República, 2019)

	2005	2015	2020	2030	2040	2050
Emissions ($Mt\ CO_2eq$)	19.59	16.19	16.27	10.61 | 16.27	3.19 | 2.91	0.47 | 0.42
Renewables	0%	7%	8%	36% | 34%	58% | 61%	96% | 94%

During the year 2022, in Portugal, the energy sector, which includes transportation, contributed to 67% of the total emissions of the country, which was 50.5 Mton of CO2eq. Carbon dioxide was the most emitted GHG gas emitted, accounting for 72% of the total emissions (APA, 2024).

The influencing factors that contribute to transport mean choice, according to (Burian, 2018) can be organized into five main groups: physical environmental factors, socio-demographic, economic, psychological, and environmental factors. Within these groups, more specific factors that affect a person's choice can be identified, such as individual characteristics, lifestyle of the population, journey type, and service performance (Beirão & Sarsfield Cabral, 2007). Moreover, another crucial factor affecting users' willingness to rely on public transport is the information given by service providers (Beirão & Sarsfield Cabral, 2007). Furthermore, according to AMT (2023), in Portugal, an average employee, on commuting to work, would take on average 18.8 minutes by car, while taking 43.5 minutes using public transport, which also impacts the chosen means of transport.

However, not only the public transport perception, but also the user's characteristics, impact the chosen means of transport, The Behavioural Insights Toolkit (Bacon et al., 2011) highlights six main factors that are particularly impactful regarding transportation behaviour which are: attitudes, emotions, social, cultural and moral norms, knowledge and awareness, and finally, capability and self-efficacy. Attitudes are defined as the rational perspective towards an object, person, or behaviour, while emotions are defined as the feelings towards a certain object, person, or behaviour. As for social, cultural and moral norms, these stand for the "prevailing attitudes, behaviours or moral standards in a given context" (Semenescu et al., 2020). Habits are defined as behaviours as a reaction to external factors. Finally, knowledge, awareness & capability, and self-efficacy translate into the person's belief that he/she can correctly perform a task in a given situation.

A city's layout (shape and size) is highly impactful in the means of transport used by its citizens since it was observed that in smaller cities the proportion of pedestrian transport rises

(Burian et al., 2018). Furthermore, in areas where urbanization is sparser, it was found that public transport cannot compete with private cars, since what users value the most is speed, reliability, and service quality, disregarding comfort and environmental factors. We have to keep in mind that, as stated by Steg, (2005) a car is more than a means of transport because it brings other emotions to its users, such as power, freedom, status and superiority.

Thus, to effectively promote a modal shift, we must target the policies to the fraction of users that are motivated to reduce their car use (Beirão & Sarsfield Cabral, 2007), while also taking into account that, although we should not expect that all users will shift from private cars to public transport, we must understand their opinion regarding public transport and the reputation the sector has (Jensen, 1999).

2.3 The role of Environmental Impact Assessment in urban transportation projects

Anthropogenic activities have been one of the main driving forces for environmental damage, hence the urge to find tools to assess how humankind's development is affecting the environment. Thus, in 1996 in the United States, along with the implementation of the National Environment Protect Act, the Environmental Impact Assessment (EIA) emerged (Morgan, 2012). In Europe, EIAs were introduced as part of the 1985 Council directive on the assessment of the effects of certain public and private projects on the Environment (European Union, 1985). This directive was then updated in 2011.

EIAs can be defined as "an assessment of the impact of planned activities on the environment, including impacts on biodiversity, vegetation and ecology, water, and air" (IISD, 2024), being conducted in numerous sectors such as tourism, manufacturing, agriculture, transportation projects, industry among others.

According to the International Institute for Sustainable Development (IISD) ((IISD, 2024a), EIAs comprise seven steps: Screening, Scoping, Impact Assessment & Mitigation, Impact Management, EIA Report, Review, and Licensing and Monitoring.

Screening is the first step in an Environmental Impact Assessment and consists of a crucial phase where the decision to conduct further assessment or not is taken. The European Union specifically designed a set of 17 questions to quickly address the necessity for further investigation in project proposals, where all of them must be answered with a "Yes"; otherwise, further analysis is not conducted (European Commission, 2001).

Scoping comprises the description of the main impacts associated with the project's implementation. It addresses four main categories, them being: identifying relevant factors such as cumulative effects, social and health impacts; present time and space boundaries of the EIA; present the main issues to draw a baseline for further analysis, while also presenting alternatives and finally facilitate public engagement.

The third step of an EIA Is also the most important. During the Impact Assessment and Mitigation phase, a meticulous analysis of the impacts is made. Qualitative and quantitative assessment takes place which results in the classification of the impacts as high, medium or low. The project's alternatives are also assessed to illustrate which one will result in lower impacts for the environment.

To mitigate the impacts described in the Impact Assessment and Mitigation part, we must elaborate plans to tackle those impacts, and it is when the Impact Management stage takes place. While some of these plans are compulsory in the majority of countries, others are context-specific or directly linked to local legislation.

In the fifth stage, the EIA report is issued, where many components are compiled, such as the project's description, the assessment of the impacts previously highlighted in the Impact Assessment and Mitigation step, as well as the elaborated mitigation plans. However, some adversities can be linked to this phase, like the insufficient data to describe the impacts and lack of comprehensive mitigation measures.

After the EIA report is submitted, it must be revised and approved for the project to move forward. This review will focus on the impacts that were identified in the EIA report as well as the proposed mitigation measures. If the review committee considers the impacts too harmful to the environment, the project won't be licensed, therefore not moving forward. Afterwards, the document follows public consultation for 30 business days, during which the EIS committee issues an Environmental Impact Declaration after public consultation.

Lastly, we reach the monitoring stage, where the plans previously descripted are put into action to monitor the impacts that come from the project's implementation. These monitorization results are important data on the environmental impacts derived from the project.

From a legislation point of view in Portugal, the jurisdiction which applies to EIAs is ruled by the Decree-law n. º 152-B/2017, from December 11th, which replaced Decree-law nº151-B/2013, from October 31st The applicable criteria for an EIA can be stricter depending on the area affected by the project since sensible areas such as Rede Natura 2000 and protected areas require different criteria. Table 4 presents the infrastructure projects where EIAs are mandatory according to Annex II of Decree-Law 152-B/2017 (Diário da República, 2017), depending on the type of areas being impacted.

Table 4- Decree-Law 152-B/2017 Annex II (Source: Diário da República, 2017)

	Default	Sensible areas
Tramlines, overhead and underground metro lines, suspended or similar lines of specific types, used exclusively or mainly for passenger transport	Mandatory EIA: ≥20ha or ≥5km	Mandatory EIA: ≥4ha or ≥1km

Furthermore, even though some projects might not tick all the requirements to demand an EIA, according to the Decree-Law previously described, depending on its location, size and nature, along with possible impacts that can come from the project, an EIA can be demanded (Diário da República, 2017).

However, EIAs are not perfect. Morgan (2012) conducted a SWOT (Strengths, Weaknesses, Threats and Opportunities) analysis at EIAs and the outcomes are convenient for future research.

EIAs are crucial in the decision-making process and the range of decision types where they are used have been growing. Moreover, EIAs have also been a target of extensive research which aims to make them even more reliable, accurate, and effective.

However, it also has its flaws, mainly due to impact assessment information's low quality. Moreover, problems related to institutional arrangements, and reduced commitment by proponents also impact the EIA's effectiveness. "The resulting practice inertia provides a real challenge to the EIA community as the consequences of poor practice (delays, poor decision, increased costs to proponents, etc.) tend to be blamed on the EIA process rather than on the practitioners themselves" Morgan (2012).

Regarding threats to EIA, political reasons are at its core. The urge for economic growth coupled with physical infrastructure can lead to decision-making speed up, which can result in the provision weakening of environmental assessment.

Finally, as for opportunities coming from EIAs it is stated that EIAs should be integral to the project and not just "left to the final legal step before the project's implementation" (Morgan, 2012). This would make EIA a much stronger tool and much for effective as well.

2.4 Policies and Measures towards a modal shift

After reviewing the main factors affecting users' transportation mode choice, it is crucial to design policies and interventions that encourage a modal shift. Intervention types to tackle car use, can be distinguished into two main categories: Push and Pull approaches (Kuss & Nicholas, 2022), where Push approaches rely on strategies to reduce car use by increasing the costs of car use, discouraging its users from relying only on the private car. Some examples of this approach are taxes and fees. On the other hand, Pull approaches tend to increase low-carbon or non-motorized means of transport through, for instance, monetary incentives and infrastructure improvement, leading to an incentive to use public transport or other more sustainable means of transport than private cars.

As for policy approaches, they can be split into four major groups: Regulatory, Economic Instruments, Information and Education Policies, and Public Goods and Services (Kuss & Nicholas, 2022). Regulatory approaches are mainly based on rules, standards, and prohibitions. Economic Instruments can either discourage the user from using private cars by relying on taxes and fees, or they can be incentives such as subsidies. As for Information and Education Policies, they are a more qualitative approach that relies mostly on information campaigns and persuasion. Finally, Public Goods and Services are correlated with the quality of the service provided, since they are based on physical infrastructure, planning, and provision of services. Furthermore, KhrEIAR et al. (2023) conducted an urban policy inventory where the outcome concluded that policies can also be divided into six categories, which are Pricing, Land-Use, Infrastructure, Behavioural, Technology and Management, and Standards and Services.

Kuss & Nicholas (2022) analysed numerous intervention studies to address their effectiveness in the city of Lund, Sweden. They concluded that twelve main interventions can effectively reduce car use based on previous literature reviews, which are presented in Table 5 below.

Table 5- European intervention studies assessment (Source: Kuss & Nicholas, 2022)

Intervention type	Intervention approach	Policy Instrument(s)	Main Measures	Cities where measures were successful
Congestion Charge	Push & Pull	Economic, Public Goods & Services	Daily/time-dependent charges for cars in defined charging zone, roughly city centre (cordon-based system); Revenues for public transport or infrastructures investments.	Gothenburg London Milan Stockholm
Worplace Parking Charge	Push & Pull	Economic, Public Goods & Services	Charges fpr car parking spaces at workplace; Cash-out scheme for employees to use public transport (Rotterdam); Revenues for public transport investment (Nottingham).	Nottingham Rotterdam
Limited Traffic Zone	Push & Pull	Regulatory, Public Goods & Services	Time and weekday dependent access restrictions in city centre; Access only with special entrance permit for residents or with annual fee; Revenues from entrance permit + violation fines for public transport investments.	Rome
Parking & Traffic Control	Push & Pull	Regulatory, Public Goods & Services	Removal of parking spaces in & around city centre; Introduction of car-free streets; Change of traffic routes; New bike lanes & pedestrian friendly infrastructure.	Oslo

Table 5 (cont.)- European intervention studies assessment (Source: Kuss & Nicholas, 2022)

Intervention type	Interven-tion ap-proach	Policy Instru-ment(s)	Main Measures	Cities where measures were successful
Mobility Services for commuters	Pull	Economic, Public Goods & Services, Information & Education	Free public transport pass for employees; Private Shuttle Bus from local companies to Park' n' Ride stations, train stations, etc; Marketing of measures & communication plan.	Utrecht
Mobility Services for Universities	Pull	Economic, Public Goods & Services	Fare-Free public transport for students (including Erasmus and PhD's); Bus Rapid Transit and a metro-shuttle bus to cam-pus site outside the city centre;	Catania
Integrated Car-Sharing Action Plan	Pull	Economic, Public Goods & Services, Information & Education	Increase of number of car sharing & stations; Intro-duction of car sharing into residential areas; Integration of car sharing into residential areas, pub-lic transport, bike infra-structures, parking spaces; Awareness-raising for car sharing services.	Bremen Genoa
Workplace Travel Plan-ning	Push & Pull	Information & Education, Regulatory, Economic, Public Goods & Services	Travel plans + advice for companies and employees; Parking management (Norwich & 20 cities in Great Britain); Company shuttle busses (Norwich & 20 cities in Great Britain); Discounts for public transport (Nantes & 20 cit-ies in Great Britain); Improved bike infrastruc-tures (Brighton & 20 cities in Great Britain).	Brighton Graz Nantes Norwich 20 cities in Great Britain study

Table 5 (cont.)- European intervention studies assessment (Source: Kuss & Nicholas, 2022)

Intervention type	Intervention approach	Policy Instrument(s)	Main Measures	Cities where measures were successful
School Travel Planning	Pull	Information & Education, Public Goods & Services	Travel plans + advice for pupils and their parents; Promotion of walking + biking + car-pooling; Improved bike infrastructure; Promotional events + awareness-raising.	Brighton Nowrich
University Travel Planning	Push & Pull	Information & Education, Regulatory, Economic, Public Goods & Services	Travel plans + advice for staff and students; Promotion of car sharing, walking, biking, public transport; Parking management on/around campus; Improved bike infrastructure (Bristol); Discounts for public transport (Bristol); Information + awareness-raising (San Sebastián).	Bristol San Sebastián
Personalized Travel Planning	Pull	Information & Education, Economic	Personal travel analysis and plans for individuals; Public transport discount offers (San Sebastián, Munich, Maastricht)	Marseille Munich Maastricht San Sebastián
App for Sustainable Mobility Competition	Pull	Information & Education, Economic	App for individual users + teams of local companies; Collection of points for sustainable mobility behaviour through mobility tracking of the app; Rewards from local businesses for the achievement of a certain point threshold.	Bologna

One of the most effective interventions in reducing the number of commuters travelling by car took place in Utrecht, Netherlands (Kuss & Nicholas, 2022) and was considered a Pull approach that relied upon Mobility Services for commuters. Some of the main measures were

Free Public transport passes for employees, private shuttle buses from local companies to Park' n' Ride stations, and public transport stations. All these measures were implemented along with a proper marketing and communication plan to increase effectiveness. This measure had a 37% success rate in reducing car use.

Other greatly impactful interventions happened in London (Kuss & Nicholas, 2022), which relied on congestion charges, considered a Push & Pull approach. The main intervention was based on charges for cars in pre-determined charging zones, mainly located in the city centre (cordon-based system), time-dependent. The goal of this intervention was not only to Push users from private car use while using generated revenue to reinvest in the public transport sector, pulling users towards public transport. It had a success rate of 33%, being considered, out of the twelve analysed measures, the one which resulted in the highest car use reduction.

The Clean Cities Campaign which aimed to reduce mobility-related emissions (Baierl, 2024). During this campaign, five major European cities (Brussels, Madrid, Milan, Greater Manchester & Warsaw) were modelled using four different scenarios, where a reduction ranging between 55% to 94% was observed.

Scenarios 1 and 2 rely on two different approaches. Scenario 1 "Active and Collective" has its focuses on shared and public transport, while Scenario 2 "All-electric" intends to increase the share of electric vehicles. As for Scenario 3 "Everything all at once", uses a combined approach of Scenarios 1 & 2. Finally, Scenario 4, although it uses the same policies as Scenario 3, the commitment levels are much higher, aiming to achieve close to zero emissions by 2030. In Table 6, a summary of the policies of each of the four scenarios is presented.

After analysing all Scenarios, we can conclude that amongst all of them, only Scenario 4 triggers a +90% reduction in mobility emissions, which leads us to believe that only an increased commitment by all parties results in outcomes that are aligned with our goals (Baierl, 2024).

Non-monetary approaches and soft interventions also compel the range of measures that can be implemented to trigger the modal shift to public transport, being usually wrongly disregarded. As found by De Witte et al. (2008), across Europe, monetary approaches have been implemented and the outcome is that they are not the only decisive factor in to shift to public transport. As stated previously, service quality is one of the main driving forces to use public transport. Hahn et al. (2023) conducted an assessment in Germany to examine how a non-monetary approach such as service expansion affects modal shifts finding that, along with an attractive price, a reliable and high-quality public transport sector is crucial to trigger a modal shift away from private car, while also stating that young individuals highly depend on public transport and endorse a traffic turnaround. Out of the 15% of users that shifted to public transport after the timetable changes, 80% were able to reduce car travel.

Table 6- Clean Cities Campaign Scenario description (Source: Baierl, 2024)

Group	Policy	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Vehicle Fleet and Charging Infrastructure	Electric vehicle (EV) uptake		✓	✓	✓
	EV charging infrastructure		✓	✓	✓
	Green public transport fleet	✓	✓	✓	✓
	Green logistics fleet		✓	✓	✓
	Cooperative ITS		✓	✓	✓
Innovative and Shared Mobility Services	Bike sharing	✓		✓	✓
	Car sharing	✓		✓	✓
	Moped sharing	✓		✓	✓
	E-scooter sharing	✓		✓	✓
	Mobility-as-a-service (MaaS)	✓		✓	✓
	Demand-responsive transport (DRT)	✓		✓	✓
Transport Infrastructure	Cycling network expansion	✓		✓	✓
	Bus network expansion	✓		✓	✓
	Tram network expansion	✓		✓	✓
	Metro network expansion	✓		✓	✓
	Park & Ride	✓		✓	✓
Traffic Management and Control	Prioritizing public transport	✓		✓	✓
	Limited traffic zones (LTZ)	✓		✓	✓
	Low-emission zones (LEZ)	✓		✓	✓
	Traffic calming	✓		✓	✓
	Pedestrian areas	✓		✓	✓
Transport Avoidance	Working from home	✓		✓	✓
	Car-free days	✓		✓	✓
Pricing Schemes	Parking pricing	✓		✓	✓
	Public transport fare reduction	✓		✓	✓
Urban Logistics	Urban delivery centres	✓		✓	✓
	Delivery and servicing plan	✓		✓	✓
	Cargo bikes	✓		✓	✓

Soft interventions can also be crucial to change users' perspective and behaviour towards public transport. Based on what was discussed previously concerning the individual's characteristics, Semenescu et al. (2020) found that the most efficacious soft interventions are the ones addressing social, cultural, and moral norms, followed by the ones tackling knowledge and awareness, while interventions tackling people's habits are the least effective. Globally soft interventions could reduce modal split share by 7%. Nevertheless, for an intervention to be worth it, its costs are an important parameter to consider. However, James & Ker (1999) concluded that over a 10-year timeframe benefits coming from soft intervention can offset costs by a factor between 11 and 13.

Urban Vehicle Access Regulations (UVAR) are an important set of policies that aim to reduce urban traffic (Ricci et al., 2017). There are three main motivations to introduce UVARs which are Environmental, Congestion Reduction and Revenue Raising. Environmental factors comprise mainly air quality, focusing on particulate matter and nitrogen dioxide, but indirectly reducing CO_2 emissions in urban environments, increasing air quality by tackling vehicle non-compliance with emission norms. Urban congestion negatively impacts accessibility, air quality and impedes the development of new means of transport in urban environments, which underlines the importance of tackling this parameter. Finally, revenue can be crucial for reinvestment in the transportation sector to improve it. For example, the Norwegian road toll system reverts to road construction.

To achieve the previously described goals, different measures can be implemented. The European Commission (Ricci et al., 2017) presents five core policies that can be introduced, as described in Table 7.

Table 7- Urban Vehicle Access Regulations policies (Source: Ricci et al., 2017)

Policy	Description
Cordon-based	Vehicles are not allowed to cross a cordon which can be dependant on time of the day, direction of travel, vehicle type and location.
Area license-based pricing	A fee is charged to vehicles circulating within an area during specific hours.
Toll Rings	Toll Rings work as a toll scheme in a similar way as a cordon-based, however for the whole city.
Point-based	Vehicles are not permitted to cross a bridge or enter a specific section of the city.
Distance or time-based	Price scheme based on the distance or time a vehicle travels along a congested route or in a specific area. It varies with time, vehicle type and location.

A study conducted by Ogunkunbi & Meszaros (2023) addressed the willingness and acceptance of Budapest's citizens to support UVAR policies. The study relied on a questionnaire and concluded that not only 42% of the enquired group stated that were willing to support such measures, but also, the respondents also underlined core categories for a successful implementation of UVARs: governance, trust and transparency, social justice and equity, transport infrastructure and service improvement and incentives and complementary measures. Thus, the study also concluded that for a set of policies to be effective, engagement and participation from all interested parties is crucial along with complementary policies that help with a just transition for a carless environment.

Moreover, a study by Fabre et al., (2023) that took place in the city of Brisbane, Australia assessed the best policy framework for transport decarbonisation. The research depended on the comparison between the best-practice framework (obtained through a literature review), and the current actions being taken in the city. A summary of the actions to be implemented to align Brisbane's policies with the best-practice framework and shown in Table 8.

Table 8- Policy framework for transport decarbonisation in Brisbane (Source: Fabre et al., 2023)

Type of intervention	Projects/Programs	Desired outcomes
Invest in rail public transport in the suburbs	Implement similar projects as the Cross River Rail project in the suburbs by extending rail lines and building new transport infrastructures.	Increase in public transport modal share and reduction of car use.
Develop transit-oriented development (TOD) in the suburbs	Install new pedestrian facilities and densify residential areas, shops, city services and private businesses around suburban rail stations.	Reduce urban sprawl and car dependency.
		Reduce travel distances.
Reduce investment in road infrastructure	Increase in the transport budget allocated to public transport, and active mobility.	Reduce urban sprawl, car dependency and emissions from road transport.
	Prioritise road investment to build additional green bridges and cycle paths.	
	Allocate more budget to public transport, active mobility and electric transport.	
Massively increase investment in electric transport	Renew the bus fleet towards electric buses through public-private partnerships.	Reduced emissions from road transport.
	Introduce subsidies/incentives in the automotive market for the production of electric vehicles.	
	Expand the scale of subsidies for purchasing EVs on a larger scale.	
	Expand the scale of subsidies for purchasing EVs on a larger scale.	Increase the energy efficiency of car use.
	Expand the development of communication campaigns to encourage the purchase of private EVs.	
	Create additional charging stations.	

The study determined that a strong set of policies might not be enough to trigger a modal shift away from private cars. It must be accompanied by supplementary practices such as polycentric governance, firm institutional commitments, urban renewal, and technology (Fabre et al., 2023).

Universities are considered crucial places to induce a modal shift from private cars to public transport, although they comprise a very characteristic travel behaviour among its users. Anwar & Yang (2017) carried out a study at the University of Wollongong, Australia, to test the effectiveness of two policies in modal shift by its students: An hour direct bus service from home to the university and a park-and-ride facility (PnR).

The enactment of both policies had a positive impact on the modal shift from private cars to public transport. It also concluded that travel time is considered the most important factor among students, acknowledging also that the direct bus is more effective than the PnR facility (Anwar & Yang, 2017).

However, universities are not only composed of students. We must also tackle the faculty and other staff's travel behaviour. Miralles-Guasch et al. (2014) found that, within a university environment, one of the main reasons to commute by car is the person's social status, reinforcing the correlation between car commuting and social status. It becomes evident that such correlation persists, particularly within the context of hierarchic positions within the university setting, with individuals opting for private car usage not solely for ostentatious display, but rather as a reflection of their status. Furthermore, factors such as time efficiency and convenience emerged as justifications for private car usage, although linked to the individual's social standing.

Teleworking emerged during the pandemic as one of the solutions to not only increase productivity, but also reduce car use. Telecommuting changed workers' lifestyles. However, its impacts on road traffic were unexpected (Lachapelle & Tanguay, 2021). Theoretically, people who telework need their private car less, which leads them to rely more on carpooling and carsharing platforms, as well as use other means of transport, such as bikes or even walking (European Environment Agency, 2023a).

Thier (2023) & Lachapelle & Tanguay (2021) underline that, as a consequence of flexible working hours, people tend to go to work and leave earlier, which generates a more extent peak hour since traffic builds later and comes back earlier in the day. Some reports stated that in some cities, there was observed late congestion at 11 am followed by rush hour starting at 4 pm. Not only did time spent in traffic in the cities of Atlanta, Chicago, and Miami grow between 2021 and 2022, but also the share of traffic at peak hours only decreased from 10.3 to 9.8% (Thier, 2023).

As Lachapelle & Tanguay (2021) stated, there are several factors that can lead to the data presented above. Firstly, a commuting reduction at a certain time can lead to its increase, since other commuters start using their cars because there is less traffic. Moreover, telecommuting can lead to increased distances between home and the workplace, leading to increased travel distances (telesprawl). Telepsprawl can consequently lead to increased traffic, which makes the reduction in GHG much less impactful than it was first thought (European Environment Agency, 2023a).

For teleworking to be effective in tackling all its threats, including transportation issues, social and economic policies must be applied to prevent rebound effects and trade-offs that can impact this tool's sustainability (European Environment Agency, 2023a).

In delving further into the current status of the Portuguese public transport sector, it becomes apparent that our current approach to this issue may not be sufficient to achieve the established goals set by the European Union.

In 2005, the Emissions Trading Scheme (ETS), works based on the polluter-pays principle and intends to make power-plants and fabrics to emit less CO_2 using a financial incentive (European Parliament, 2023b). The Emissions Trading System (ETS) operates on a market-based mechanism involving purchasing and selling emission allowances. This system is designed to be efficient, ensuring that entities can manage their emissions effectively. Initially, a specified quantity of allowances is acquired through an auction process, where entities participate to obtain the necessary allowances to offset their emissions. This system encourages entities to manage their emissions efficiently, as allowances must correspond to their emission levels. Further down, they can sell unused allowances to companies which are struggling to meet up with their emissions threshold. This initiative, by 2021, had already lowered power generation and energy energy-intensive industries by 42.8% (European Commission, 2021). However, the initial ETS did not cover all sectors, ETS II was created, within the scope of the 2023 revisions of the ETS Directive. The ETS II will get into force in 2027 at the earliest, depending on energy prices till then, and will act in the building industry and mobility sectors (European Commission, 2024a). Throughout the first three years of the ETS II, to prevent the lack of allowances, if allowances' prices reach 45€, new allowances will be released. Furthermore, the ETS II Is expected to lead to a 42% emission reduction by 2030.

To reduce air pollutant concentrations in the city centre, many municipalities implemented Low Emission Zones (LEZ) Even though their main goal is not to tackle carbon dioxide emissions, they are crucial tools to reduce GHG emissions by reducing car use, in combination with co-benefits on safety, noise, and mainly air pollution ((Holman et al., 2015)). Many European cities adopted LEZs such as Barcelona, Oslo, London, Stockholm, Madrid and Paris. LEZs have been a success all across Europe. A LEZ rely on specific areas within the city which comprise regulations for car use and circulation. Taking as an example Lisbon's LEZ is composed of two main areas, each one with different restrictions. Zone 1 comprises the section Avenida da Liberdade/Baixa, where only vehicles from 2000 onwards or/and built under the EURO 3 emission parameters, while Zone 2 encompasses Avenida de Ceuta, Eixo Norte-Sul, Av. das Forças Armadas, Av. EUA, Av. Marechal António Spínola e Av. Infante D. Henrique where only light vehicles built from January 1996 onwards and heavy vehicles from October 1996 onwards complying with EURO 2 emission regulations can circulate (ZERO, 2019; CML, 2020).

However, some cities such as London, go beyond Low Emission Zones, implementing Zero Emission Zones (ZEZ). ZEZs are described as small areas within the city (usually the city centre) going from 1.5 to 11 square miles, where only zero-emission vehicles - like fully electric vehicles, pedestrians, bikes, and public transport have unlimited access, while vehicles which are not zero-emission are either prohibited from entering the ZEZ or must pay a fee to be able to circulate (Chen & Xue, 2024). Nevertheless, for ZEZs to become effective, they must be introduced alongside supporting measures. Transport of London (2019) enumerates a few supporting measures that can be applied to increase users' willingness to shift their means of transport. For instance, increasing the number of charging points for EVs and assuring that public transport and taxis also meet no emission requirements imposed by ZEZs.

However, ZEZs can produce negative impacts in the cities where they are introduced. The major negative impacts rely on the socioeconomic dimension, since ZEZs can result in increased difficulties for the most vulnerable share of the population (Chen & Xue, 2024).

2.4.1 Portugal case study

Firstly, it is crucial to give a brief overview of the metropolitan areas assessed in the present dissertation along with some headliners of their transportation patterns. Starting with Lisbon's metropolitan area it comprises a total area of 3 015 square kilometres and a total of roughly 2.9 million habitants (INE, 2023). As for the transportation patterns in Lisbon's population, according to (INE, 2018) which might be a bit outdated, that on average a habitant travels 11 kilometres per day, spending around 72.5 minutes doing so which indicates a ratio of 6.6 minutes per kilometre. Moreover, around 56% of the population has expenses with public transportation. The study also indicates that among Lisbon habitants, the main justification for using a private car is speed and comfort while the main reasons why commuters rely on public transport is because they don't own a private car and lack of other alternatives to commute to their destination.

As we shift our focus to Porto's metropolitan area, we state total of 1.8 million habitants and an area of 2 000 square kilometres (INE, 2024).Regarding the transportation patterns observed in Port's metropolitan area we immediately notice a significant reduction in travel time compared to Lisbon (66.8 minutes) along with a slight decrease in travel distance which is 10.6 kilometres, resulting in an average of 6.3 minutes per kilometre. We also state a smaller percentage of habitants having expenses with public transportation, being 46% in Porto. Furthermore, looking into the reasons while user tend to rely on private car and public transport, we conclude that they follow the same pattern as we verify in Lisbon's metropolitan area (INE, 2018).

As found by the study done by AMT (2023) Portugal did not have the same path as the EU regarding the consumed energy by road transport. After the pandemic, road transport energy consumption raised in 2021 to 5.3 million ToE (Tons of Oil Equivalent), where diesel has the biggest share of 4.2 million ToE, while the EU's average energy consumption kept a decreasing trend. Additionally, the transport sector has been playing bigger shares every year in GHG emissions.

As for renewables in the transportation sector, Portugal broke the trend, where it used to be higher than the EU average. In 2021 Portugal was slightly under the EU (9.1%) which reveals that a lot of work needs to be done to achieve the 14%-mark goal (AMT, 2023). Furthermore, out of the current public transport fleet, only 2% run on either hydrogen or electricity.

Under the need to change the current fleet, AMT (2023) presented three scenarios for its upgrade and/or replacement. Scenarios 1 and 2 rely on a transition to more modern EURO norms, more precisely to EURO 5 and EURO 6, respectively, while scenario 3 is based on Decree Law 86/2021, which aims the transition to vehicles with zero emissions. Not only does the investment needed for each scenario vary, but also the number of vehicles that must be substituted. In scenario 1, a total of 5 355 vehicles must be substituted, comprising a total investment of 2 677 million euros. As for scenario 2, the total expenditure adds up to 3 212 million euros, while needing a total of 6 424 vehicles substituted. Finally, scenario 3, includes the lowest investment amount, 2 148 million euros, needing a total of 4 296 vehicles to be substituted, within two different phases. The first is until December 31st, 2025 when vehicles from EURO I, II, and part from EURO III are substituted, while the remaining EURO III are substituted until 2030.

As for CO_2eq savings, for the period between 2025 and 2034, the scenario which will reduce equivalent carbon dioxide emissions the most is scenario 2, aiming for a total reduction of 3.7 million tons of CO2eq, followed by scenario 1 with 3.1 million and finally scenario 3 with roughly 3 million tons of CO_2eq.

As stated in the Portuguese Carbon Neutrality RoadMap (Portuguese Government, 2019) for light passenger vehicles, it is expected that, by 2030, diesel cars will no longer be cost-effective for consumers, while petrol vehicles keep their cost-effectiveness until 2040 while electricity satisfies 30% of total mobility demands by 2030, raising to 100% of the demand by 2050. Another crucial intervention relies on shared and autonomous mobility which is anticipated to result in increased efficiency and higher utilisation rates. Figure 2 illustrates a simplification of Portugal's main milestones in its long-term strategy to achieve carbon neutrality by 2050.

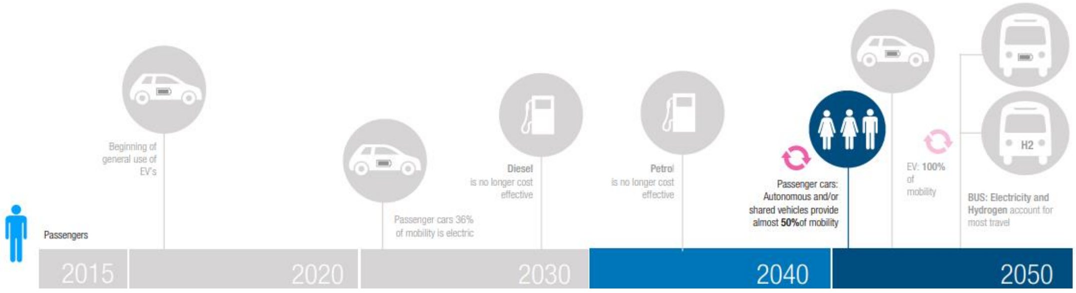

Figure 2- Portugal's long-term carbon neutrality strategy and milestones (Source: Portuguese Government, 2019)

Table 9 shows the expected GHG reduction (compared to 2005) and electrification percentage incorporation in the overall transport sector.

Table 9 - Portugal's expected GHG reduction and electrification in the transport sector (Source: Portuguese Government, 2019)

	2020	2030	2040	2050
Electrification (%)	1%	12%	52%	69%
GHG reduction	-17%	-43%	-85%	-98%

The data shows that a lot of effort must be put in to achieve these goals. Nevertheless, with the correct approach and policies, Portugal can become carbon neutral by 2050.

In 2023, Portugal presented a revised draft version of its NECP where a set of revised goals is presented. Portugal has committed to a more ambitious target for reducing its greenhouse gas (GHG) emissions. It aims for at least a 28.7% reduction by 2030 compared to its 2005 emission levels, a significant increase from the previous target of 17%. This new goal reflects a more substantial commitment at the European Union level, particularly in the non-ETS (Emissions Trading System) sectors (Portuguese Government, 2023). Numerous measures for the transportation sector are presented, where we will delve deeply into two main categories: Promoting a Modal Shift to Public Transport and Encourage the Energy Transition in the Transport Sector.

Regarding the measures to promote a modal shift, we highlight the "Support Programme for Tariff Reduction and Support Programme for Densification and Strengthening of Public Transport Provision (PROTransP)" (Portuguese Government, 2023) where the government tackles public transport ticket prices to increase their accessibility and the commitment to expand transport network and facilities, which does not constitute a monetary approach. However, as stated previously, past literature concluded that monetary and non-monetary approaches should work alongside each other to magnify their effectiveness.

As for promoting the energy transition in the transport sector, Portugal's NECP emphasizes the urge to renew the bus fleet, since Portugal's bus fleet has an average of 16 years of age which must be tackled and coupled with the promotion of renewable usage in the sector. Furthermore, another crucial measure that must be underlined is the prioritisation of environmental performance and low carbon criteria when awarding concessions for public transport services, which can be crucial further down, enhancing EIA's importance as well.

3

Methodological Approach

The methodological approach applied in the present study can be divided into three main sections. Firstly, we conducted a road transport assessment based on traffic data retrieved from Instituto da Mobilidade e Transportes (IMT), aligning our study with the real-world issue of traffic congestion. We delved deeper into traffic oscillations between 2014 and 2023, a period of significant change in transportation. Furthermore, we also assessed the projects' occupancy rate when applicable to assess how passenger numbers have fluctuated during their lifetime, providing insights into the practical use of these projects. The previous assessment's outcome was then compared with the predictions stated in the projects' Environmental Impact Assessment Report to assess projects' effectiveness throughout their lifetime. From the Environmental Impact Assessment Reports (EIAR), we also retrieved emission savings data, which were then measured against fuel selling data aiming to examine if the predictions regarding GHG emissions do match what we observe. Finally, based on the previous analysis, a set of practical interventions was designed to increase public transport attractiveness and reduce car use.

The methodological approach adopted throughout this dissertation is presented in Figure 3.

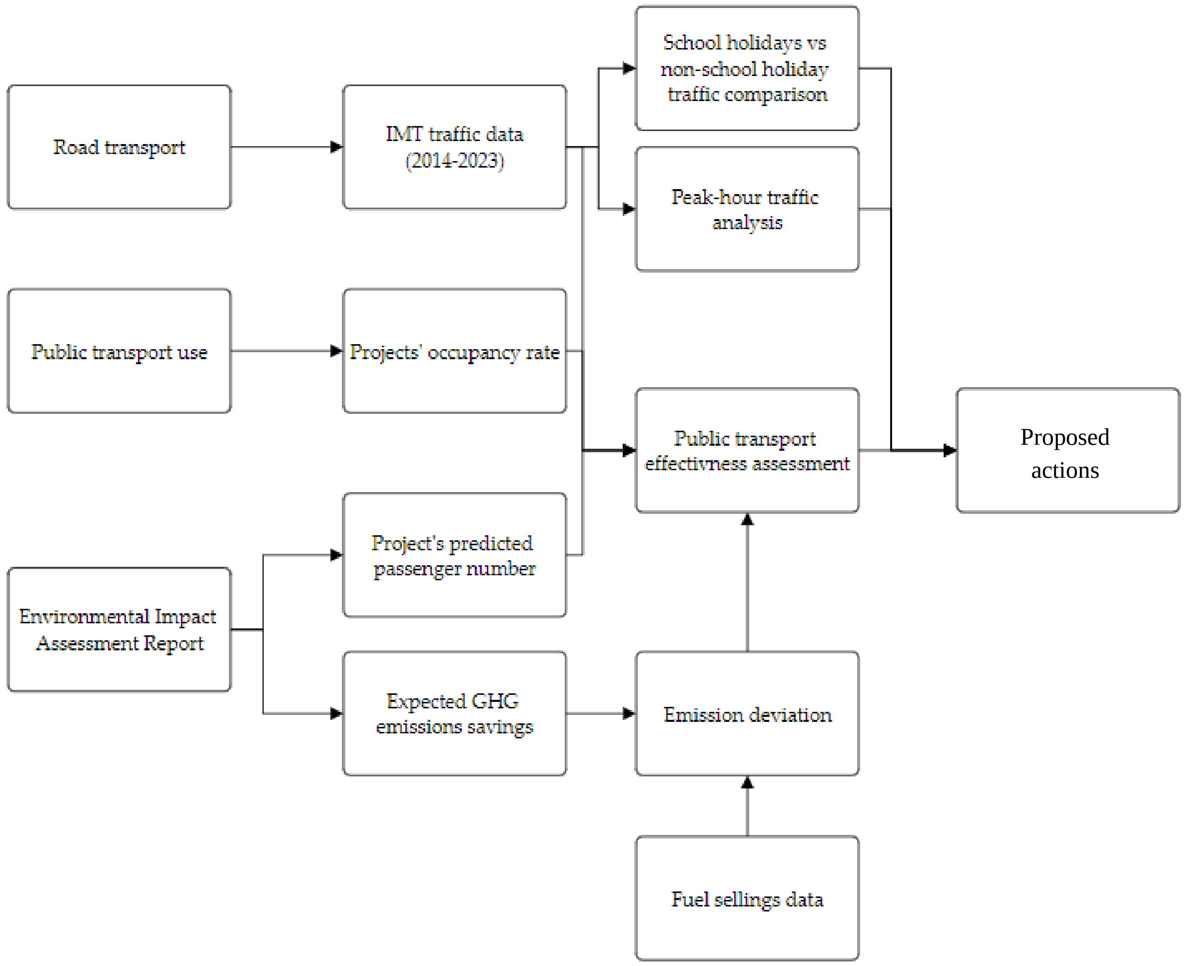

Figure 3- Methodological approach flowchart

3.1 Road transport

Our traffic analysis was based on data from IMT's database and included a thorough investigation into the fluctuations in number of vehicles between 2014 and 2023. We began by identifying the roads that were most representative of the metropolitan areas of Lisbon and Porto and used these as the starting point for our analysis. This involved a detailed examination of the traffic on these roads over the specified period, with additional, more detailed assessments carried out where necessary.

As an example, to design future policies, assessing how traffic fluctuates during and outside school holiday periods, we can find if it makes sense and how to design measures to tackle traffic driving for school transportation. For this the period between April 3rd and April 14th, 2023, traffic behaviour was analysed and then compared with the rest of the month to address how traffic fluctuates. Moreover, an hourly assessment was also made considering traffic variation during peak hours in the morning (7AM until 10AM) and afternoon (5PM until 8PM).

3.2 Public transport use

In this section, we analyse data from Lisbon and Porto's metros to examine public transport use patterns and how they have evolved over the project's lifetime. We intend to focus primarily on occupancy rates, allowing us to address projects' efficiency and capacity utilisation. We retrieved passenger numbers from the metro's database to obtain this data. With the data retrieved, we could compare it with similar data stated in the project's Environmental Impact Assessment Report and assess its reliability.

3.3 Environmental Impact Assessment Report

Environmental Impact Assessment Reports present projects' impacts in a nutshell. This document also contains crucial data regarding the expected passenger number the project will accommodate and what GHG emissions will be prevented. We proceeded to analyse EIARs of Lisbon and Porto's mobility projects between 2000 and 2023. To assess these predictions' accuracy, we started by comparing the predicted passenger number stated in the EIARs with the number of vehicles retrieved from the traffic analysis and the passenger number retrieved from the metro's database (occupancy rate). Furthermore, to address the accuracy of GHG emission reductions, we also relied on fuel-selling data to compare it with the data stated in the EIARs. Thus, in Table 10 we present the analysed projects and some of their main headlines. Moreover we must underline the fact that although Cascais' train line lacks an Environmental Impact Assessment Report it was considered in this study due to its importance as an interface to other public transport modes.

Table 10 - Public transport projects under analysis

Project	EIAR date	EIS date	Public consultation period	Starting date (if applicable)
“Transporte Coletivo em sítio próprio” (TCSP) in Loures e Odivelas Municipalities (Violet Line)	November 2022	April 2023	January 4th to February 14th 2023	-
Lisbon Metro Red line expansion between São Sebastião and Alcântara	April 2022	August 2022	April 21st to June 2nd 2022	-
Lisbon Metro Expansion between Rato station (Yellow line) and Cais do Sodré station (Green line) including new connections in Campo Grande's viaducts	February 2018	November 2019	July 11th to August 22nd 2018	-
Lisbon Metro Blue line expansion between Amadora-Este and Reboleira	October 2006	July 2007	March 24th to May 30th 2007	2016
Lisbon Metro Red line expansion between Oriente and Aeroporto	July 2005	December 2005	August 24th to September 27th 2005	2012
Lisbon Metro Red line expansion between Alameda and São Sebastião	October 2002	March 2003	November 18th to December 20th 2002	2009
Cascais' train line (modernisation project)	-	-	-	-
Porto Metro Casa da Música - Santo Ovídio line expansion	September 2022	March 2023	October 6th to November 17th 2022	-
Porto's metro expansion between Santo Ovídio a Vila d'Este	July 2018	March 2019	November 5th to December 14th 2018	-
Porto Metro Circular line Liberdade/S.Bento - Boavista /Casa da Música section	July 2018	February 2019	November 5th to December 14th 2019	-

3.4 Proposed actions

After all the data analysis described before, a set of measures was developed, aiming to reduce car use and improve the use of public transport in Lisbon and Porto’s metropolitan area. Building upon the interventions and parameters previously analysed, this study seeks to address key challenges identified within the transportation sector in the metropolitan areas of Lisbon and Porto.

A number of focused actions will be suggested after a thorough examination of the data gathered in order to successfully discourage the use of cars, lessen traffic in cities, and promote the use of public transportation in these areas. In addition to easing the current burden on urban mobility, these actions hope to encourage a change to sustainable modes of transportation that can help both metropolitan areas achieve their long-term social and environmental objectives.

4

Results and discussion

Throughout the present chapter, we will delve deeper into the main findings of this dissertation. Firstly, we present the outcomes of the EIAR analysis, showing the projects' main characteristics and predictions regarding GHG reductions and passenger numbers. We then proceed to our traffic analysis, where we delve deeper into the data collected from other sources such as IMT and Lisbon and Porto's metros. A more detailed analysis is then conducted. We then close this chapter with a section dedicated to needed interventions with proposed measures to be applied in both metropolitan areas, hopefully promoting a significant reduction in car use.

4.1 Environmental Impact Assessment Report Analysis

In this chapter, we will describe and analyse the public transport mobility projects previ-ously mentioned. The study will be divided into three main sections: Project Description, De-mand Analysis and CO_2 savings. The projects are presented by metropolitan area and chrono-logical order.

In the Project Description chapter, we will introduce the project, heading some topics such as total investment, public consultation period, and EIAR issued date. Moreover, we will also present a brief description of the project.

Regarding the Demand Analysis, we aim to delve deeper into the modal changes in the mobility sector made by the implementation of the respective project by relying on Demand Studies to provide the data for this matter.

In the final chapter, considering the insights gained from the Demand Analysis, we will examine the predictions regarding the reduction of pollutants, mainly CO_2, expected with the implementation of the project.

However, we must underline the fact that not all entities sent the data we were seeking for. The EIAR left-out from analysis due to lack of documentation belonging to the projects of

MTS "Metropolitano da Margem Sul do Tejo", Anteprojeto Metropolitano da Margem Sul do Tejo" and Porto's metro " Aeroporto Francisco Sá Carneiro-Estação Verdes".

4.1.1 "Transporte Coletivo em Sítio Próprio" (TCSP) in Loures and Odivelas Municipalities

Project Description

This project aims to better connect to municipalities, Loures and Odivelas over a tram line and added up a total expenditure of 250 million euros, funded by the Portuguese recovery and resilience plan. As part of the project, a total built length of 13 km is expected, along with nineteen stations, the majority of them at ground level. The project's Environmental Impact Assessment Report was first issued in August 2022 and received its last update in November 2022. Moreover, the project underwent public consultation between January 4th and February 14th, 2023, and received its Environmental Impact Statement in April 2023. The project's localisation is shown in Figure 4.

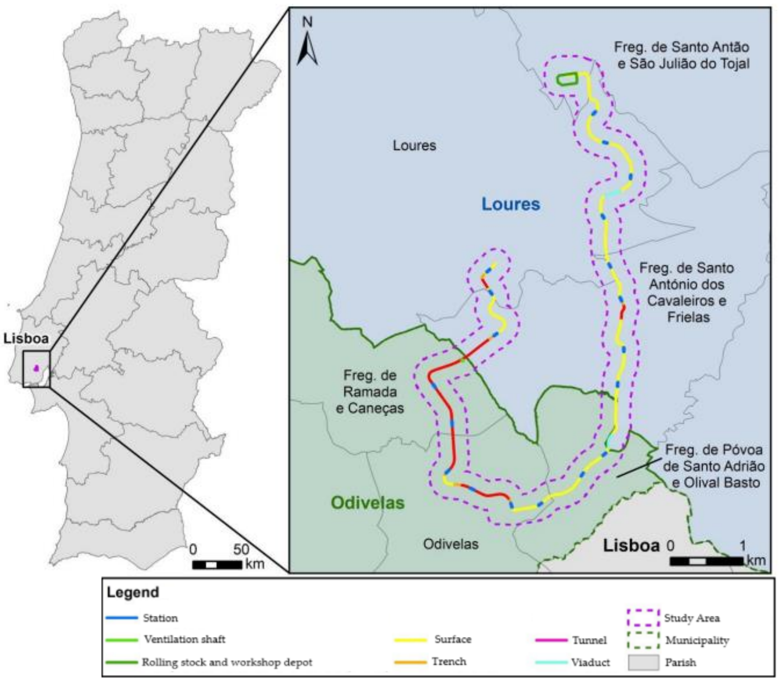

Figure 4- TCSP Loures-Odivelas map

Demand Analysis

As for the demand analysis, the implementation of this project will create a positive impact on car traffic and will slightly affect the public transport sector. Most of the demand will come from car users (65%), while only 4% are expected to be induced. Table 11 illustrates the balances among all transportation methods.

Table 11- TCSP Loures-Odivelas impacts on other transportation methods

Transportation Method	Passengers per business day	Passengers.km per business day
Individual Car	-20 554	-107 261
Metro	2 452	11 458
Bus	-4 187	2 455
Other	-10	-205

As stated before, the impact generated by the project are shallow even though a substantial increase in metro users is expected. This data matches the primary goal of this project since it captures new passengers while amplifying the current number of public transport users.

Carbon Dioxide Savings

Regarding carbon dioxide savings, the project's EIAR justifies the reduction based on modal changes that will occur with the project's implementation. Moreover, they also consider and increase GHG emissions associated with electricity production. Regarding road traffic, Table 12 shows the expected savings when comparing the "Do Nothing" scenario and the one where the project moves forward, considering that the project is scheduled to operate between 2026 and 2050.

Table 12- TCSP Loures-Odivelas emission savings compared to scenario "Do-Nothing"

Pollutant	Emissions (tons/year)		
	"Do Nothing" scenario	Project's implementation scenario	Total emission balance (implementation scenario - "Do Nothing" scenario
CO_2	144 173.4	138 683	5 490.6
CH_4	54.5	51	3.4
N_2O	4.7	5	0.2
CO_2eq	146 931.7	141 300	5 632.2

Thus, due to reduced road traffic, we expect a reduction of roughly 5 500 tons of CO_2 yearly, which rises to 5 600 tons per year if we consider CO_2eq.

4.1.2 Lisbon Metro red line expansion between São Sebastião and Alcântara + LIOS

Project Description

The expansion's total length will be 3.7 kilometres, of which 3.3 are tunnels, and the remaining 0.4 km corresponds to viaducts. Furthermore, this investment also includes the construction of four new stations: Amoreiras, Campo de Ourique, Infante Santo and Alcântara.

With a total investment of 304 million euros, financed by EU funds through Portugal's program entitled Recovery and Resilience Plan, this project aims to expand the current metro's red line from São Sebastião station to Alcântara, where a new vital public transport interface will be created. Additionally, note that the project's Environmental Impact Statement was issued on August 26th, 2022, and the project underwent public consultation between April 21st and June 2nd, 2022.

The Environmental Impact Assessment Report under analysis was issued in April 2022. in Figure 5, we can observe the project's mapping. This expansion is expected to be operational from 2025 or 2026 onwards and is not being planned for deactivation.

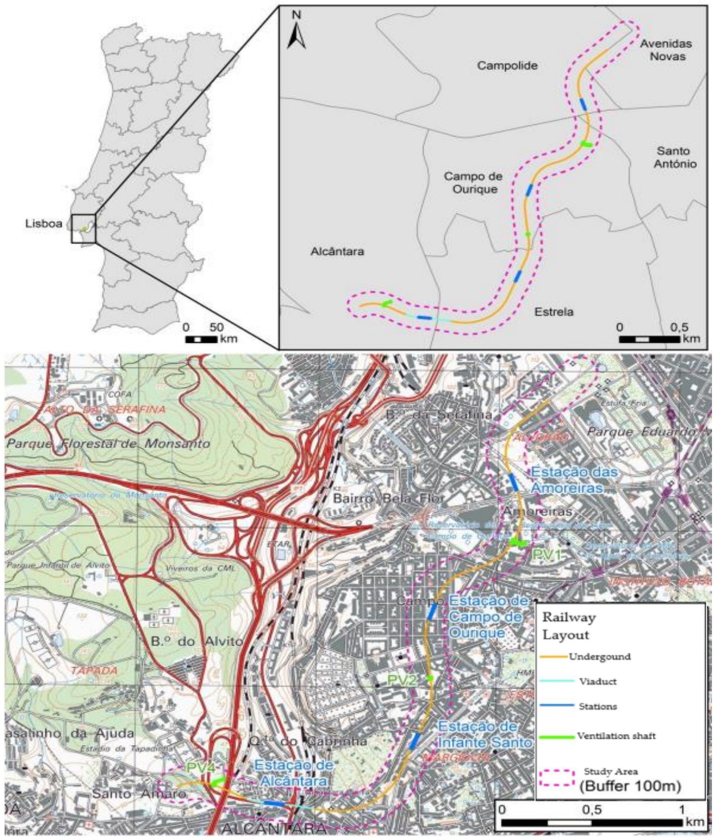

Figure 5- Red line expansion map

Demand Analysis

In this chapter, we assess how the modal changes affect both car use and public transport. Thus, we relied on the demand study, which provides all the data regarding this topic. The values shown are based on the project's lifetime, which means from 2025/2026 onwards, with no expected date for deactivation, as already mentioned.

The metro line is combined with another project namely LIOS. It stands for "Linha Intermodal Sustentável" (Sustainable Intermodal Line), and its primary goal is to expand the current tram line number 15 through two extensions, the Oriental and Occidental lines. The Occidental LIOS is of predominant importance for this specific project as it aims to connect Oeiras to Alcântara, thereby anticipated to attract even more users to the red line expansion project.

As for the mechanical connection, this project intends to connect the new Alcântara station and the one that already exists - Alcântara-Mar. Like the Occidental LIOS line, the mechanical connection is expected to affect the number of users positively.

In the upfront analysis, we will consider the worst and best-case scenarios, where the best-case scenario refers to the one where both LIOS and mechanical connection are implemented and the worst-case scenario where none move forward. The following tables (from Table 13 to Table 14) show the number of passengers the project predicts will accommodate and the expected passenger flux within the new stations to be built for both scenarios.

Table 13- Red line expansion projected users with LIOS and mechanical connection

C34 2026 Variant	Coming from public transport	Coming from car	Induction	Total Passengers	Cars removed from circulation	Vkms removed from circulation
Average business day	69 852	8 400	285	78 536	6 461	165 788
Annually	21 250 585	1 973 883	66 901	23 291 369	1 518 371	38 960 257

Table 14- Red line expansion projected users without LIOS and mechanical connection

C34 2026 Variant	Coming from public transport	Coming from car	Induction	Total Passengers	Cars removed from circulation	Vkms removed from circulation
Average business day	73 720	10 866	336	84 922	8 358	218 082
Annually	22 427 320	2 553 499	78 922	25 059 741	1 964 230	51 249 262

It is evident from the analysis of Tables 15 and 16 that LIOS and mechanical connection will increase the number of users accommodated by this expansion by roughly 131% when compared to the worst-case scenario.

Table 15- Metro's new stations passenger balance with LIOS and mechanical connection

Station	Total passenger number entering and leaving the station
Amoreiras	24 283
Campo de Ourique	8 948
Infante Santo	4 322
Alcântara	19 686

Table 16- Metro's new stations passenger balance without LIOS and mechanical connection

Station	Total passenger number entering and leaving the station
Amoreiras	24 992
Campo de Ourique	8 589
Infante Santo	5 671
Alcântara	32 609

Moreover, after a further look into the passenger flux throughout the stations, we state that "Amoreiras" and "Campo de Ourique" suffer minimal oscillations in their passenger flux, even predicting a reduction in the second one. Contrastingly, it is expected that a moderate increase in the "Infante Santo" station and a considerable passenger flux increase in the "Alcântara" will be justified by merging numerous public transport projects resulting from implementing LIOS and mechanical connection projects.

Moreover, the user fluctuations extend beyond car use, escalating to the public transport sector. The following tables (Table 17 and Table 18) show the public transport user balance for the scenarios previously described.

Table 17- Metro's expansion transport sector passenger and passenger.km balance with LIOS and mechanical connection

Transportation type	Passengers	Passengers.km
Bus	-49 764	-703 444
Ferry	-942	-11 746
Train	13 965	84 701
Tram	-4 626	-12 710
Metro	69 852	413 386

Table 18- Metro's expansion transport sector passenger and passenger.km balance without LIOS and mechanical connection

Transportation type	Passengers	Passengers.km
Bus	-58 394	-828 649
Ferry	-847	-11 063
Train	13 609	64 214
Tram	17 489	56 241
Metro	73 112	453 004

Evaluating the previous tables, we affirm that the significant passenger differences rely on the tram passenger's number, mainly due to LIOS, whose passenger input Is reflected here. This shift also impacted bus users, which decreased to roughly 9 000 passengers.

Carbon Dioxide Savings

Regarding CO2 savings, the EIAR splits the emissions into two significant groups: vehicles removed from circulation and passengers captured from other public transports.

Firstly, emissions of vehicles removed from circulation are calculated by combining the expected number of cars stopping circulation with the emission factor associated with GHG gases: CO_2, CH_4 and N_2O. Table 19 shows the emission conversion factors.

Table 19- Emission conversion factor

Emission factor light vehicles (g/km/vehicle)		
CO_2	CH_4	N_2O
158	0.0675	0.00532

Thus, the emissions expected to be saved from cars removed from circulation are presented in Table 20.

Table 20- Metro's expansion overall emission savings

Scenario	Emission Savings (t/year)	
	CO_2	CO_2eq
Without LIOS or mechanical connection	6 149	6 277
With LIOS and mechanical connection	8 089	8 257

Moreover, the amount of CO_2 emissions avoided depends on the balance between emissions and reductions related to the passenger number changes. Thus, it was considered that this balance depends on the amount of carbon dioxide reduced due to passenger decrease in buses, ferries, and trams, as well as the emissions added, a consequence of increased passenger flux in metro and train, as Table 21 shows.

Table 21- Project's overall emission savings per saving source

Scenario	Emissions CO_2 (t/ano)		
	Avoided (captured passengers from bus, ferry and tram)	Added (added passengers from metro and train)	Total emissions avoided
Without LIOS or mechanical connection	19 676	5 998	13 678
With LIOS and mechanical connection	23 039	6 800	16 239

Furthermore, examining the previous table, although we state a noticeable emission increase from the metro and train if LIOS and mechanical connection move forward, its corresponding emission decrease from other public transport is much higher, resulting in a higher CO_2 avoidance of 16 239 tons per year. The results presented can be justified by recurring to Tables 17 and 18, where we demonstrated that LIOS had a massive impact on the tram passenger number, which results in higher emissions from this specific transportation method while also increasing the metro's passenger number.

In summary, Table 22 shows the overall CO_2 savings from implementing the project.

Table 22- Metro's expansion emission balance

Scenario	Emissions CO_2 (t/ano)			
	Avoided (captured passengers from bus, ferry and tram)	Avoided (Cars removed from circulation)	Added (added passengers from metro and train)	Emission balance (Avoided - Added)
Without LIOS or mechanical connection	19 676	6 149	5 999	19 826
With LIOS and mechanical connection	23 039	8 089	6 801	24 327

4.1.3 Lisbon Metro Expansion between Rato station (Yellow line) and Cais do Sodré station (Green line), including new connections in Campo Grande's viaducts

Project Description

It will be split into two main zones and aims to extend the current Lisbon metro line in 2 km, entirely underground, connecting stations "Rato" and "Cais do Sodré" through two intermediate stations, "Santos" and "Estrela", yet to be built (Zone A). The project also includes the construction of two new viaducts in Campo Grande (Zone B), which makes a total built extension of 2.55 kilometres. This project's costs are expected to reach 331.4 million euros, partially funded by POSEUR.

The project's Environmental Impact Assessment Report was elaborated in February 2018, having its Environmental Impact Statement Issued in November 2018 and undergoing public consultation between July 11th 2018, and August 22nd 2018. The project Environmental Impact Statement was issued in November 2018. Figures 6 and 7 show the project’s localisation for both Zone A and B.

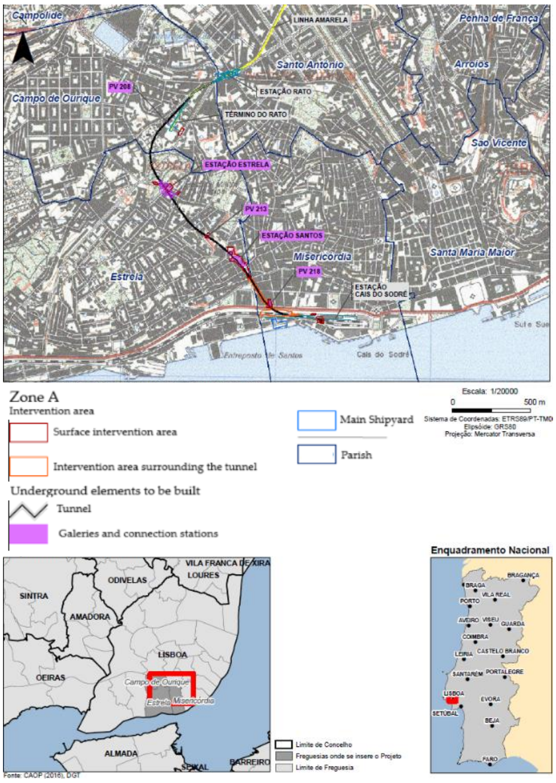

Figure 6- Lisbon Metro Yellow Line expansion project's map (Zone A)

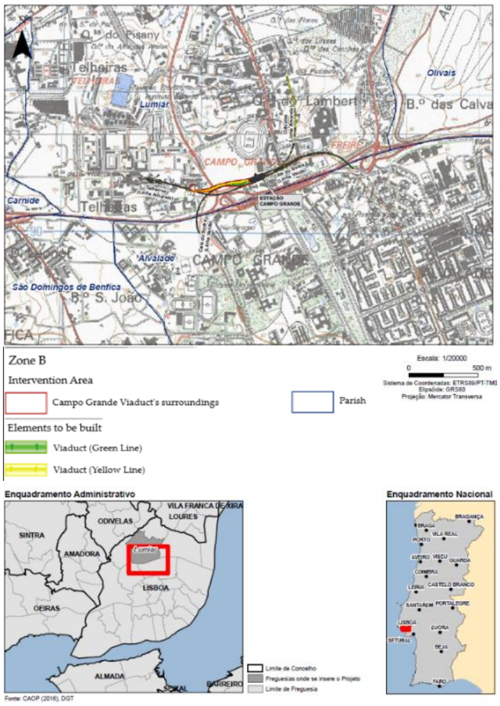

Figure 7- Lisbon Metro Yellow Line expansion project's map (Zone B)

Demand Analysis

The project's EIAR does not account for another viable option. Thus, only one case scenario regarding the demand analysis is presented. Some passenger fluctuations are expected at all levels, from individual transportation methods to the public transportation sector. The following table (Table 23) presents the expected oscillation for the first year the project was expected to start running, 2022 while Table 24 shows the balances across all transportation methods.

Table 23- Yellow Line overall passenger balance

Line Reconfiguration	Railroad traffic (Metro)	Railroad traffic (train)	Ferry	Individual car	Public road transportation
Impacts (passenger .km)	47 837 630	9 021 340	1 322 760	-17 050 245	-27 424 640

Table 24- Yellow Line passenger balance across all transportation methods

Line Reconfiguration	Metro	Car	Bus	Train	Ferry
Impacts (Passenger .km)	131 062	-46 713	-75 136	24 716	3 624

A further look at Table 23 confirms that one of the significant impacts will be in-car traffic. However, we state that public road transportation will also suffer a significant impact overall. The passenger fluctuations can justify this phenomenon verified in public transit, especially in bus traffic, as Table 24 illustrates, fomenting an increase in metro, train and ferry user numbers.

Moreover, table 25 shows the expected passenger flux (entering and leaving) for the stations which are planned to be built, "Santos" and "Estrela".

Table 25- Passenger balance across Yellow Line project's new stations

Metro line Reconfiguration		Passengers entering	Passengers exiting
Estrela	Business day	5 597	5 743
	Annually	1 623 155	1 665 495
Santos	Business day	3 749	4 123
	Annually	1 087 335	1 195 740

As for the two new stations, the table shows that Estrela station will be the one which is expected to have the highest passenger flux and is consequently predicted to be the busiest. The data regarding the passenger flux was obtained relying on soil occupation surrounding each station, accounting for population, job number and business and teaching areas.

The following table (Table 26) shows a synthesis of the modal changes across the mobility sector for the beginning of the activation phase in 2022.

Table 26- Yellow Line project's demand impact

Parameters per transportation method	Ferry	Metro	Train	Parameters per transportation method	Car	Public road transportation
pkm REF (thousands)	104 076	2 865 000	2 263 049	pkm REF (thousands)	14 264 507	440 400
increase in pkm in 2022 (thousands)	1 323	47 838	9 021	decrease in pkm in 2022 (thousands)	17 050	27 425
pkm 2022 (thousands)	105 398	2 912 838	2 632 070	pkm 2022 (thousands)	14 247 457	412 975
vkm REF (thousands)	861 975	23 919	21 106	vkm REF (thousands)	11 887 089	24 331
increase in vkm for 2022 (thousands)	11	399	73	decrease in vkm for 2022 (thousands)	14 209	1 515
vkm in 2022 (thousands)	873	24 318	21 179	vkm in 2022 (thousands)	11 872 881	22 816
Increase (%)	1.27	1.67	0.34	Reduction (%)	0.12	6.23

Taking a deeper look into the previous table, we can affirm that the project will positively impact the mobility sector. There is expected to be a higher increase in railroad transportation methods, while road traffic is predicted to decrease, with a significant 6.23% increase in public road transportation.

Carbon Dioxide Savings

Regarding carbon dioxide emission savings, the following table presents the expected emission increase and reduction due to the project's implementation for the year 2022. This information is then synthesised in Table 27 and Table 28, where the emission balance is calculated.

Table 27- Yellow Line project's impact on GHG emissions

Parameters per transportation method	Ferry	Metro	Train	Parameters per transportation method	Car	Public road transportation
Emission increase in 2022 (t)				Emissions reduction in 2022 (t)		
NO_x	7.156	0.780	0.214	NO_x	7.180	4.580
PM	0.213	0.013	0.004	PM	0.608	0.112
CO	0.694	0.221	0.061	CO	36.175	1.275
COVNM	0.142	0.064	0.018	COVNM	1.961	0.198
SO_2	0.094	0.118	0.032	SO_2	0.016	0.003
CO_2	292.905	571.290	157.159	CO_2	3 379.851	469.811
Reference scenario's emissions (t)				Reference scenario's emissions (t)		
NO_x	731	47	62	NO_x	4 060	69
PM	24	1	1	PM	437	2
CO	69	13	18	CO	9 338	19
COVNM	16	4	5	COVNM	1 145	3
SO_2	9	7	9	SO_2	9	0.04
CO_2	29 000	34 215	45 696	CO_2	828 714	7 075

Table 28- Project's GHG emission balance in 2022

Emission balance in 2022 (t)	
No_x	-3.6
PM	-0.5
CO	-36.5
COVNM	-1.9
SO_2	0.2
CO_2	-2828.3

Observing both tables, we can conclude that, balance-wise, almost all pollutants will decrease in concentration, focusing on CO2, where a reduction of 2 828 tons is expected. However, SO_2 is expected to undergo a slight increase. All this data is supported by the fact that electrified public transport will increase its pkm and vkm indicators, which, coupled with a parallel decrease in car and public road transportation results in lower emissions.

4.1.4 Lisbon Metro Blue line expansion between Amadora-Este and Reboleira

Project Description

The Blue Line expansion, which connects the station "Amadora-Este" with "Reboleira," an all-new station is expected to cost 55 million euros. It has a total built length of roughly 579 meters, most of which is straight. The project's location can be observed below in Figure 8.

The project’s EIAR was issued in October 2006 and underwent public consultation between March 24th and May 30th, 2007. Moreover, it received its Environmental Impact Statement in July 2007.

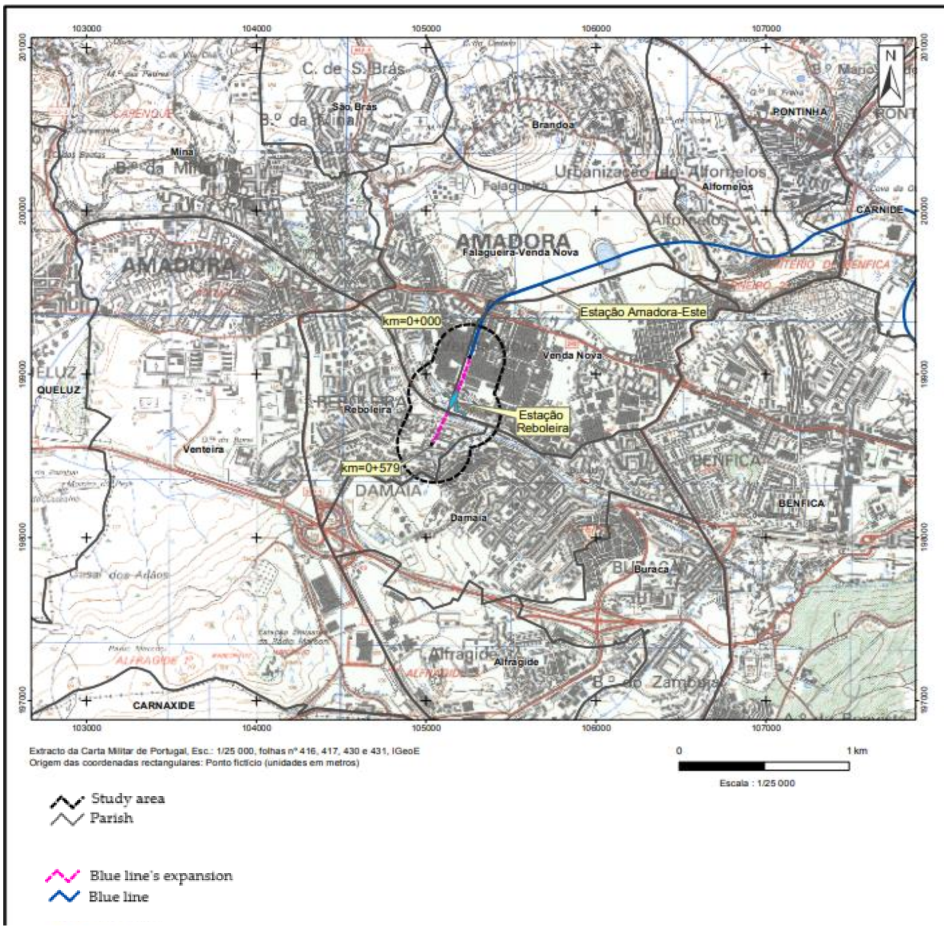

Figure 8- Lisbon Metro Blue Line project's map

Demand Analysis

For this specific project, the available data reveals that, according to the demand study Issued, there are 20,000 passengers per day at Reboleira station, which means a total of 28 724 000 passengers per km/year. Furthermore, the project also states that out of the total 20,000 passengers, 11% will come from Individual transport users, 53% from public transport, and 36% from Induced users.

Carbon Dioxide Savings

Following the modal shifts described, different amounts of pollutant savings are expected from Individual and public transport. Thus, Table 29 illustrates the expected pollutant savings (CO, HC, and NOx) from individual and public transport. Moreover, it also presents the total predicted pollutant savings in CO2eq units. It is crucial to underline that all the savings presented are for the first year of operation.

Table 29- Lisbon Metro Blue Line project's GHG emission balance

	CO (kg)	HC (kg)	No_x (kg)
Individual transport	5 933	1 647	948
Public transport	1 594	1 091	19 386
Total savings	7 527	2 738	20 354
Total savings (kg CO2eq)	1 311		

Analysing the Table, we can immediately state that individual transport will have the most significant impact on pollutant savings, which was predictable due to the modal shift noted in the project's EIAR.

4.1.5 Lisbon Metro Red line expansion between Oriente and Aeroporto

Project Description

This expansion comprises a total length of 3.186 or 4.642 kilometres, depending on the layout, which results in the construction of five new sections: Oriente-Moscavide, Moscavide-Encarnação, Encarnação-Aeroporto, final section in "Aeroporto" station and galleries. The project also includes the construction of three new stations: "Moscavide", "Encarnação" and "Aeroporto" for Layout 1, while Layout 2 required four new stations: "Moscavide", "Portela", "Prior Velho" and "Aeroporto". In Figure 9, the project's location is presented. Its location is presented in Figure 10. The project saw its EIAR being issued in July 2005, undergoing public consultation between August 24th, 2005, and September 27th, 2005. Furthermore, its Environmental Impact Statement was issued in December 2005.

Moreover, as stated before, the project considers two different layout hypotheses, presented in Figure 10. The primary distinction between both layouts is that Layout 1 comprises a more direct connection to the airport. At the same time, Layout 2 also supplies the office area around the airport, where significant services and entities are located.

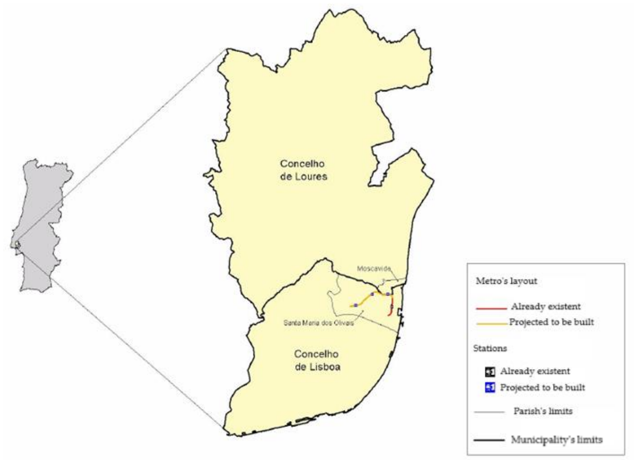

Figure 9- Lisbon Metro Red Line expansion project's map

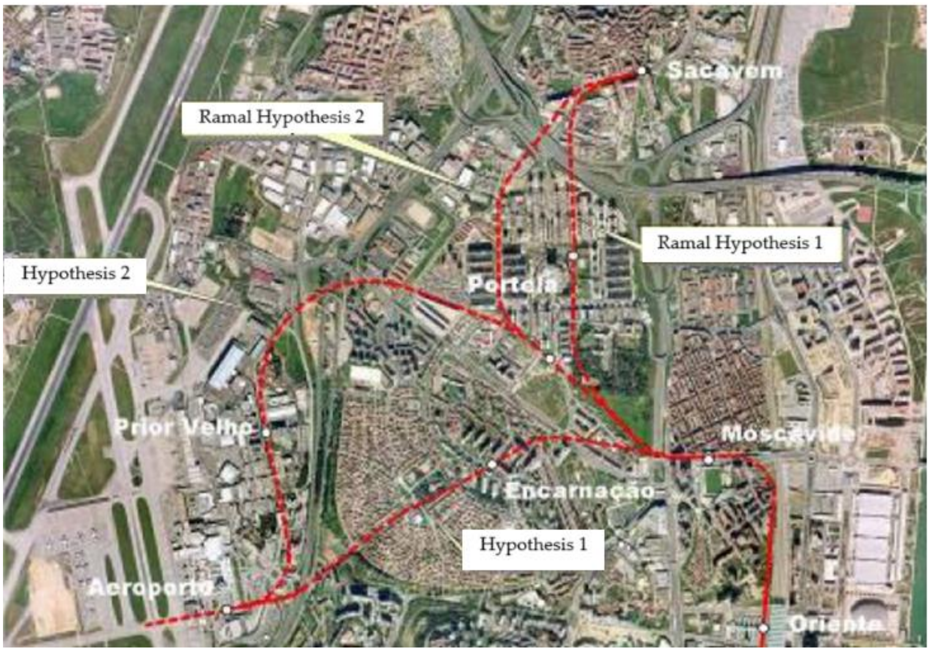

Figure 10- Lisbon Metro Red Line expansion project's hypothesis

Demand Analysis

Regarding the expected daily demand for this project, Table 30 presents the predicted daily entries and exits for each station in each hypothesis in 2006.

Table 30- Lisbon Metro Red Line project's expansion demand balance for each new station per hypothesis

Hypothesis 1		Hypothesis 2	
Moscavide	19 831	Moscavide	17 027
Encarnação	9 577	Portela	11 134
		Prior Velho	5 597
Aeroporto	8 424	Aeroporto	6 160
Total	37 832	Total	39 916

The Table shows that Layout 2 will generate higher demand than Layout 1. This can be justified due to the increased number of stations. Also, as stated previously, layout 2 comprises a less direct connection to the airport, covering the offices close to the airport, which contain many services and entities.

Moreover, the study also states the expected daily entries and exits from each station for 2012, 2020, and 2036, as Table 31 shows.

Table 31- Lisbon Metro Red Line expansion project's new stations passenger entries and exits

Station	2012	2020	2036
Moscavide	23 416	27 471	34 860
Encarnação	16 967	20 368	25 847
Aeroporto	13 028	17 312	26 930
Total	53 411	65 151	87 637

Carbon Dioxide Savings

This project does not mention carbon dioxide as a pollutant savings. However, it addresses carbon monoxide (CO) and NOx savings. Two scenarios are considered: Scenario 1, where a traffic decrease of 10% is considered in Rua João Pinto Ribeiro and Rua Vasco da Gama, and Scenario 2, where a reduction of 25% in traffic was considered for these same places. Thus, Table 32 presents the savings for both pollutants.

Table 32- Lisbon Metro Red Line expansion project's emission reduction per scenario

	Scenario 1	Scenario 2
NO_x emission reduction (ton/year)	0.6 (1.0%)	1.4 (2.0%)
CO emission reduction (ton/year)	4.2 (1.5%)	7.9 (3.0%)

We notice a major reduction in Scenario 2, which can be justified by the more impactful traffic reduction in Rua João Pinto Ribeiro and Rua Vasco da Gama.

4.1.6 Cascais' train line (Modernisation project)

Project Description

Firstly, it is crucial to underline that this project did not have an EIA since it does not involve any extension of change of the current line. Thus, the data analysed for this specific project comes from its cost-benefit analysis and market research. Diverging from other projects already analysed, this one does not intend to expand the current Cascais train line but to modernise it. In Figure 11, we can observe Cascais' train line from a geographical point of view.

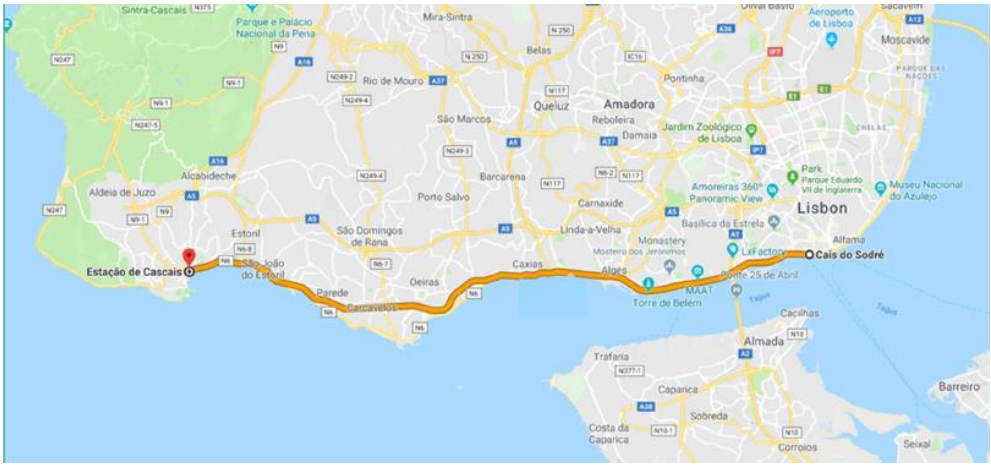

Figure 11- Cascais train line project's map

This modernisation comprises three main goals: changing the current electrification system to 25kV, which is predicted to result in a 45% decrease in electric energy consumption; modernising the signalling system, which will result in more reliable timetables; and station rehabilitation, which is aimed at increasing attractiveness and security.

Moreover, according to the cost-benefit analysis, the total investment for this project is 118 million euros.

Demand Analysis

For the demand analysis, nine scenarios are presented, which are further divided into two different approaches. The major difference between the two approaches is that in the first one, the expansion in Lisbon's metro does not move forward, which keeps the metro's transport offer steady across time, while in approach II, this expansion does take place and the metro's transport offer increases. Regarding the scenarios considered, Table 33 comprises a summary of each scenario's offer.

Table 33- Cascais train line project's scenario characteristics

		Peak Hour			Business Day			
Scenario	Rolling Stock	Number of trains	Number of Seats	Seats-km (in thousands)	Number of trains	Number of seats	Number of seats/km	Production
		[train/h/way]	[seats/h/way]	[seats-km/way]	[train/way]	[seats/way]	[seats-km/way]	[train-km/way]
I	CC. 1000	10	10 000	208 285	102	102 000	2 290 881	2 291
II	CC. 1000	10	10 000	208 285	102	102 000	2 290 881	2 291
III	CC. 1000	8	8 000	166 628	90	90 000	2 040 939	2 041
IV	CC. 1000	10	10 000	208 285	102	102 000	2 290 881	2 291
V	CC. 1000	12	12 000	250 868	135	135 000	2 862 924	2 863
VI	CC. 1000	13	13 000	315 754	122	122 000	3 131 721	3 132
VII	CC. 1000	10	10 000	287 482	102	102 000	3 158 614	3 159
VIII	TT. 750	13	9 750	199 612	130	97 500	2 148 627	2 865
IX	TT. 750 & CC. 1000	16	12 750	314 004	143	115 250	2 973 798	3 583

Legend:

CC. 1000 – Conventional train with 1000 seats

TT. 750 – Tram-Train with 750 seats

As a result of the data shown in Table 33, which presents each scenario's offer regarding the number of passengers each one of them can accommodate, Table 33 illustrates the characteristics of approach I of each scenario when compared to scenario I, which comprises the current state of the art of Cascais' train line. Moreover, Table 34 shows the expected demand for the project's lifetime while Table 35 illustrates the expected passenger demand. On the other hand, the same data is shown in Tables 36 and 37, although for approach II.

Table 34- Cascais train line approach I demand

		I	III	IV	V	VI	VII	VIII	IX
Cascais' train line demand [2015]									
Annually	[thousand pax]	31 696	30 993	31 696	32 771	35 808	31 911	30 948	35 708
Average day	[thousand pax]	86.84	84.91	86.94	98.10	98.10	87.43	84.79	97.83
Dif vs Scenario I	[thousand pax]	-	-1,93	0	11.27	11.27	0.59	-2.05	10.99
	%	-	-2.2	0.0	3.4	13	0.7	-2.4	12.7
Cascais' train line Passengers-km (pkm) [2015]									
Annually	[million pkm]	471	462	471	483	529	494	447	517
Average day	[thousand pkm]	1 289	1 265	1 289	1 322	1 449	1 354	1 225	1 418
Dif vs Scenario I	[thousand pkm]	-	-24	0	33	160	65	-64	128
	%	-	-1.9	0.0	2.5	12.4	5.1	-5.0	9.9
Average distance	km	14.85	14.90	14.85	14.73	14.77	15.49	14.45	14.49
Cascais' train line offer [2015]									
Annually	[Number of trains]	62 680	55 306	62 680	82 959	75 970	62 680	79 886	87 875
Average day	[Number trains/way]	86	76	86	114	103	86	109	120
Business day	[Number trains/way]	102	90	102	135	122	102	130	143
Dif vs Scenario I	[Number of trains	-	-12	0	33	20	0	28	41
	[%]	-	-12	0	32	20	0	27	40
Av. occup. rate	[%]	32	36	32	27	27	25	33	28
Occupation	[Seats/ train]	1 000	1 000	1 000	1 000	1 000	1 000	750	750 | 1000

Table 35- Cascais train line project's approach I passenger demand

	2025	2033	2043	2053
Scenario I	31 696	36 268	42 310	49 751
Scenario III	30 993	35 477	41 403	48 700
Scenario IV	31 696	36 268	42 310	49 751
Scenario V	32 771	37 485	43 713	51 385
Scenario VI	35 808	40 912	47 650	55 960
Scenario VII	31 911	36 488	42 533	49 985
Scenario VIII	30 948	35 455	41 415	48 748
Scenario IX	35 708	40 815	47 559	55 874

As the previous tables illustrate, for approach I, the scenario that results in a higher number of passengers across the project's lifetime is scenario IX. The significant difference between scenario IX and the others is the rolling stock it is crucial to state that scenario IX provides the best numbers from a long-term point of view.

Table 36- Cascais train line approach II demand

		II	III	IV	V	VI	VII	VIII	IX
Cascais' train line demand [2015]									
Annually	[thousand pax]	33 327	32 697	33 327	34 298	37 159	33 437	32 463	36 909
Average day	[thousand pax]	91.31	89.58	91.31	93.97	101.81	91.61	88.94	101.12
Dif vs Scenario I	[thousand pax]	-	-1,73	0	2.66	10.50	0.30	-2,37	9.81
	%	-	-1,9%	0%	2.9%	11.5%	0.3%	-2,6%	10.7%
Cascais' train line Passengers-km (pkm) [2015]									
Annually	[million pkm]	496	488	496	507	551	512	469	536
Average day	[thousand pkm]	1 359	1 336	1 359	1 388	1 511	1 404	1 285	1 469
Dif vs Scenario I	[thousand pkm]	-	-23	0	29	151	44	-75	109
	%	-	-1,7%	0%	2.1%	11.1%	3.3%	-5,5%	8%
Average distance	km	14.89	14.91	14.89	14.77	14.84	15.32	14.45	14.52
Cascais' train line offer [2015]									
Annually	[Number of trains]	62 680	55 306	62 680	82 959	74 970	62 680	79 886	87 875
Average day	[Number of trains/way]	86	76	86	114	103	86	109	120
Business day	[Number of trains/way]	102	90	102	135	122	102	130	143
Dif vs Scenario I	[Number of trains	0	-12	0	33	20	0	28	41
	[%]	0%	-12%	0%	32%	20%	0%	27%	40%
Average occupation rate	[%]	34%	38%	34%	28%	28%	26%	35%	29%
Occupation	[Seats/train]	1 000	1 000	1 000	1 000	1 000	1 000	750	750 | 1000

Table 37- Cascais train line project's approach 2 passenger demand

	2025	2033	2043	2053
Scenario II	33 327	38 188	44 616	52 522
Scenario III	32 697	37 481	43 808	51 588
Scenario IV	33 327	38 188	44 616	52 522
Scenario V	34 298	39 286	45 879	53 993
Scenario VI	37 159	42 508	49 574	58 278
Scenario VII	33 437	38 296	44 720	52 625
Scenario VIII	32 463	37 245	43 574	51 350
Scenario IX	36 909	42 204	49 198	57 817

On the other hand, when considering approach II, scenario VI is the scenario with the highest number of users in 2053.

Carbon Dioxide Savings

Tables 38 and 39, respectively, present the total CO_2 savings for the project's lifetime (2025-2053) regarding approaches I and II.

Table 38- Approach I emission balance

	Scenario	III	IV	V	VI	VII	VIII	IX
Co2 emissions (difference to scenario I)	tCO2	42 370	0	-61 516	-148 664	-15 337	74 440	-128 764

Table 39- Approach II emission balance

	Scenario	III	IV	V	VI	VII	VIII	IX
Co2 emissions (difference to scenario II)	tCO2	4 010	0	-51 867	-134 223	-14 002	96 250	-76 660

By analysing tables, we can immediately conclude that CO_2 emission savings. However, they differ between approaches; the one that saves the most significant amount of pollutants is the same as scenario VI. Nonetheless, it is crucial to note that scenarios III & VIII result in negative impacts on CO_2 emissions in both approaches.

4.1.7 Red line expansion between Alameda and São Sebastião

Project Description

The extension of the Red line between stations "Alameda" and "São Sebastião comprises a total expanded length of 2 187 meters and the construction of two new stations: Saldanha II Station and São Sebastião II. The amount invested in this project is not included in the project's EIAR.

Figure 12- Red line expansion project's map

The analysed EIAR was issued in October 2002, and public consultation was conducted between November 18th and December 20th 2002, while it got its Environmental Impact Statement in March 2003.

Demand Analysis

The project EIAR does not detail the expected passenger increase with the implementation of the project; thus, no demand analysis is to be conducted.

Carbon Dioxide Savings

Similarly to the previous subchapter, the project's EIAR does not detail the variations in atmospheric pollutants, stating only that there will be no negative impacts coming from the implementation of the project since there is expected a modal shift from private car to metro without clarifying the truly expected fluctuations in passengers.

4.1.8 Porto Metro Casa da Música-Santo Ovídio line expansion

4.1.8.1 Project Description

The analysed project's expenditures are expected to total 299 million euros. It is predicted to be under construction between 2023 and 2026 and entirely funded by PRR.

The expansion will consist of 6.27 km of underground, viaduct, and surface-level sections and will also include the construction of eight new stations: "Casa da Música," "Campo Alegre," "Arrábida," "Candal," "Rotunda," "Devesas," "Soares dos REIAR," and "Santo Ovídio." The intervention will occur in two different locations: Porto and Vila Nova de Gaia. Figures 13 and 14 show the localisation in both areas, respectively.

The project's EIAR was issued in September 2022 and underwent public consultation from October 6th to November 17th 2022. Furthermore, it received its Environmental Impact Statement on March 11th 2023.

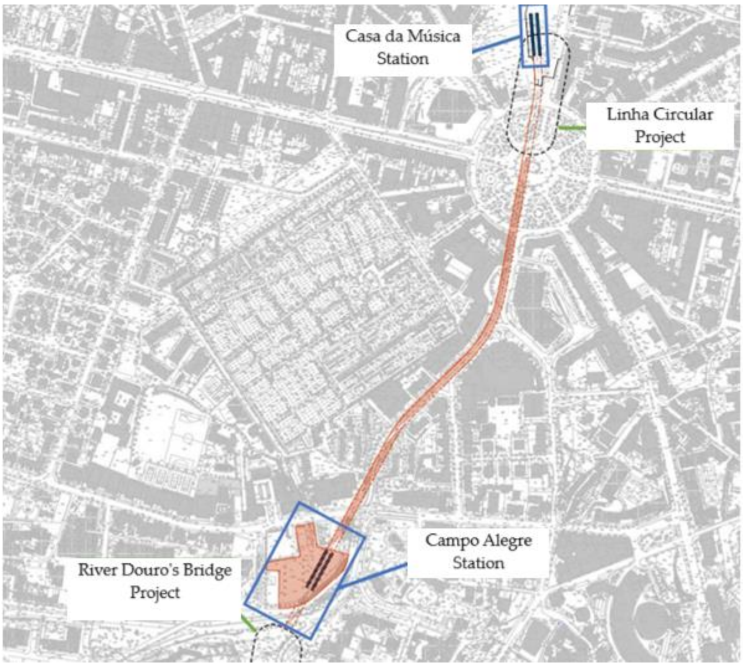

Figure 13- Porto Metro Casa da Música-Santo Ovídio project's map

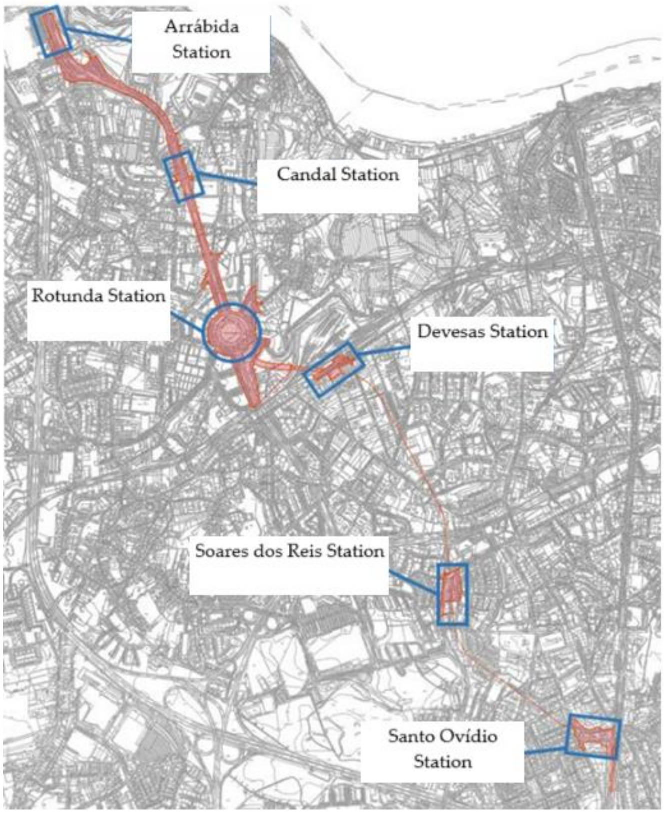

Figure 14- Porto Metro Casa da Música-Santo Ovídio project's layout

Demand Analysis

The following demand analysis is based on the interval between 2023 and 2051, with a ramp-up effect expected until 2009. Furthermore, Table 40 illustrates the modal changes between the "do nothing" scenario and the scenario where this expansion moves forward.

Table 40- Porto Metro Casa da Música-Santo Ovídio project's demand balance compared to scenario "Do Nothing"

"Do Nothing" Scenario	2026	2029	2041	2051
Metro Passengers [thousand passengers]	93 776	97 041	110 421	127 381
Metro Passengers.km [thousand km]	509 667	527 413	600 135	692 308
Metro Vehicles.km [thousand km]	10 402	10 754	12 198	14 027
The project's implementation scenario balance				
Metro's total Passengers [thousand passengers]	11 487	12 662	14 408	16 621
Public transport passengers	2 025 092	2 232 278	2 540 072	2 930 197
Individual car passengers [thousand passengers]	-5 255	-5 793	-6 592	-7 604
Metro's induction passengers	404 925	446 353	507 897	585 904
Metro's total Passengers.km [thousand km]	83 613	92 167	104 876	120 983
Public transport passengers.km [thousand km]	9 902	10 915	12 420	14 328
Individual car passengers.km [thousand km]	-75 544	-83 273	-94 754	-109 307
Metro's inductioned passengers.km	1 541 039	1 698 702	1 932 924	2 229 798
Metro's total Vehicles.km	1 208 452	1 280 110	1 566 744	1 805 605

The previous results are justified by the presuppositions considered in this Demand Study. Apart from the ramp-up effect expected to last until 2009, as stated before, which can be defined as the period when there is a demand for adaptation to the new public transport offer, there are other phenomena that will influence the demand during the project horizon's date, 2051.

Induced demand corresponds to new passengers who are predicted to start using public transportation that they previously did not, which means a shift from other mobility methods to the metro.

Moreover, another important effect to be considered regarding the demand is the time gained by metro users. With the implementation of the project, users will experience a time reduction in their daily trips, which will increase the number of users.

Additionally, the Demand Study assessed the number of users entering and exiting each station planned to be built in 2029, which means a post-ramp-up effect, as shown in Table 41.

Table 41- Porto Metro Casa da Música-Santo Ovídio new station's passenger balance

Station	Entering	Exiting	Overall transfer number
Casa da Música III	9 885	9 232	19 117
Campo Alegre	0	8 640	8 640
Arrábida	0	4 125	4 125
Candal	0	3 116	3 116
Rotunda	0	887	887
Devesas	41	8 978	9 019
Soares dos REIAR	0	3 919	3 919
Santo Ovídio II	1 153	6 606	7 759

The provided data allows us to state that among the studied stations, "Casa da Música" has the highest number of transfers, which also exist in two other stations: "Santo Ovídio" and "Devesas." Furthermore, "Rotunda" and "Arrábida" will be crucial in capturing new users, and they are expected to attract 91% and 75% more people compared to current values, respectively.

Carbon Dioxide Savings

As for CO_2 savings, they were calculated based on three main dimensions: added emissions due to increased metro and Public Road Transportation users and emissions reduced as a consequence of fewer car users. Table 42 shows the parameters for each dimension as well as the overall annual balance up until 2051.

Table 42- Porto Metro Casa da Música-Santo Ovídio project's emission balance

Scenario (year)	Emissões CO_2 (tons/year)			
	Avoided (Captured passengers from car users)	Added (Added passengers from Public Road Transportation)	Added (Added passengers from metro)	Total emission balance (Avoided-Added)
2051	9229.2	1734.7	89.2	7475.4

Analysing the data, we state that an annual saving of 7.5 kton of CO2 is expected. Nonetheless, it is crucial to underline that the data available only refers to 2051 and does not present values for the years between the project's operation date and 2051. The values given are mainly justified by the modal changes observed in Table 40.

4.1.9 Porto Metro expansion between Santo Ovídio and Vila D'Este

Project Description

Partially funded by POSEUR, this project's expenditures are projected to total 407 million euros, with a predicted starting date of 2022. Its implementation is justified by the increased demand verified in Porto's metropolitan area.

The project comprises a total expansion length of 3.2 km and will also build three new stations: Manuel Leão, Hospital Santos Silva, and Vila D'Este. The project's localisation is presented in Figure 15, along with the layout alternatives considered.

The analysed EIAR was issued on July 9th 2018, and its Environmental Impact Statement was issued On March 9th 2019. Furthermore, the project went under public consultation from November 5th to December 14th, 2018.

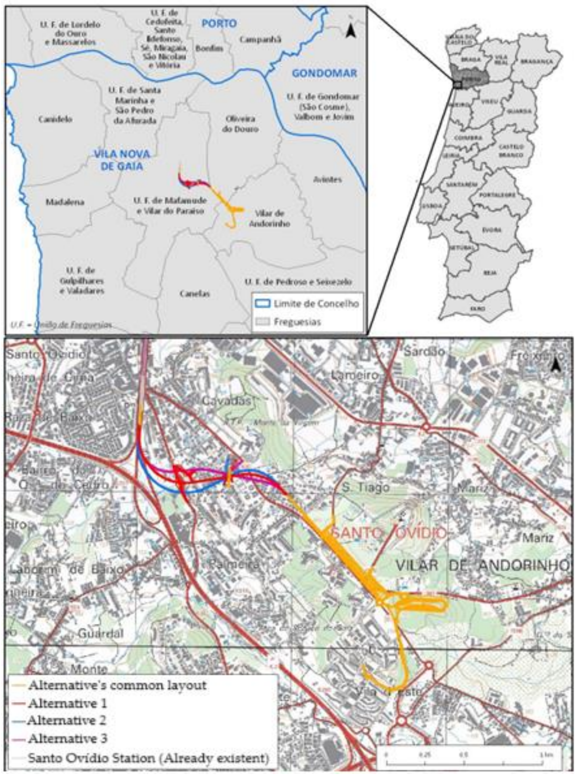

Figure 15- Porto Metro expansion Santo Ovídio-Vila d'Este project's map

Demand Analysis

Firstly, note that the following analysis is based on some presuppositions, such as the fact that this project's starting date is 2022, considering also a 30-year operation period.

Thus, Table 43 illustrates the modal changes, comparing the "do nothing" scenario to the scenario where the project moves forward. Like the previous project, this one is expected to suffer from a ramp-up effect between 2023 and 2026.

Table 43- Porto Metro expansion Santo Ovídio-Vila d'Este project's demand balance compared to scenario "Do Nothing"

"Do Nothing" Scenario	2022	2026	2031	2041	2051
Metro Passengers [thousand passengers]	61 300	64 500	68 900	76 500	84 300
Metro Passengers.km [thousand km]	313 000	329 200	351 500	390 300	430 200
The project's implementation scenario balance					
Metro's total Passengers [thousand passengers]	64 200	68 000	72 600	80 600	88 800
Public transport passengers	2 000 000	2 400 000	2 500 000	2 800 000	3 100 000
Individual car passengers	800 000	1 000 000	1 100 000	1 200 000	1 300 000
Metro's induction passengers	100 000	100 000	100 000	100 000	200 000
Metro's total Passengers.km [thousand km]	327 000	345 900	369 300	410 100	452 000
Public transport passengers.km [thousand km]	9 300	11 100	11 800	13 100	14 400
Individual car passengers.km	4 400 000	5 200 000	5 500 000	6 200 000	6 800 000
Metro's inductioned passengers.km	400 000	400 000	500 000	500 000	600 000

The previous data can be justified by the presuppositions considered in the Demand Study. In this specific one, there are only two presuppositions: the previously described ramp-up effect and the natural demand increase, which is also observable over time.

Moreover, in addition to the modal changes already discussed, we will also delve deeper into the total daily transfers each new station is expected to have. These transfers are shown in Table 44, which is next.

Table 44- Porto Metro expansion Santo Ovídio-Vila d'Este new station's entrances and exits

Station	Entering	Exiting	Overall transfer number
Vila D'Este	0	4 459	4 459
Hospital Santos Silva	0	3 078	3 078

Among the stations predicted to be built with the project's Implementation, "Santo Ovídio" will have the fewest transfers, while "Vila D'Este" will have the most.

Regarding the capture of new passengers, "Manuel Leão" station will contribute the most, with 96%, while "Vila D'Este" and "Hospital Santos Silva" will have a new passenger capture share of 81% and 88%, respectively.

Carbon Dioxide Savings

As for CO_2 savings, the project's EIAR considers that the increased number of passengers will not generate emissions by the metro since the metro travels based on electric power only.

The values for CO2 emissions by the metro are associated with the production of electricity itself. Thus, carbon dioxide emissions are directly related to the expected reduction in road traffic, as Table 45 shows. The data presented is based on the average road traffic reduction from 2022 until 2051, the timeframe for the project's operation.

Table 45- Porto Metro expansion Santo Ovídio-Vila d'Este project's emission balance by 2051

Scenario (year)	Emissions (tons/year)					
	Avoided CO2 (light vehicles removed from circulation)	Avoided CO2 (heavy vehicles removed from circulation)	Avoided CO2eq (light vehicles removed from circulation)	Avoided CO2eq (heavy vehicles removed from circulation)	CO2 emission savings	CO2eq emission savings
2051	1 264	765	1 264	769	2 029	2 033

Analysing the previous data, we can conclude that the implementation of this project will generate an average CO_2 saving of 2029 tons per year, which rises to 2033 tons per year if we consider CO_2eq mass.

The results obtained were based on three-time intervals that have different presuppositions associated with them:

- From 2022 until 2030, there are no relevant impacts from electric vehicles, and the cars circulating are equally distributed among EURO 4, EURO 5 and EURO 6 emission standards;
- From 2031 until 2040, it is considered that 4% of the vehicles are electric while the rest are equally distributed among EURO 5 and EURO 6 emission standards;
- From 2041 until 2051, it is considered that 6% of vehicles are electric, while the rest meet EURO 6 emission standards.

4.1.10 Porto Metro Circular line Liberdade/S. Bento - S. Bento/Casa da Música section

Project Description

The increased demand justifies this project noticed in Porto's metro; thus, it was necessary to expand the current line to satisfy this demand. The project's expenditures are predicted to add up to 332 million euros, partially funded by POSEUR, which is expected to start operating by 2022.

This expansion comprises a total expansion length of roughly 3km, including the construction of 4 new stations: "Liberdade/S. Bento," "Hospital de St. António," “Galiza," and "Boavista/Casa da Música." The project's location and the alternatives considered are shown in Figures 16 and 17, respectively.

Moreover, the EIAR analysed was issued in July 2018, getting its Environmental Impact Statement by February 2019. The project underwent public consultation from November 5th 2018, until December 14th 2018.

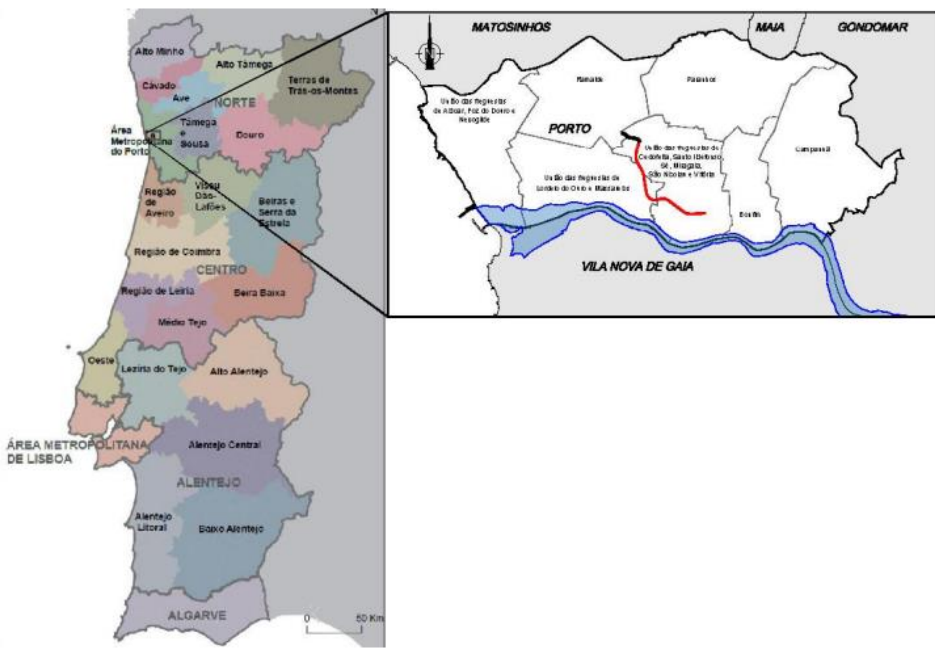

Figure 16- Porto Metro Circular Line project's map

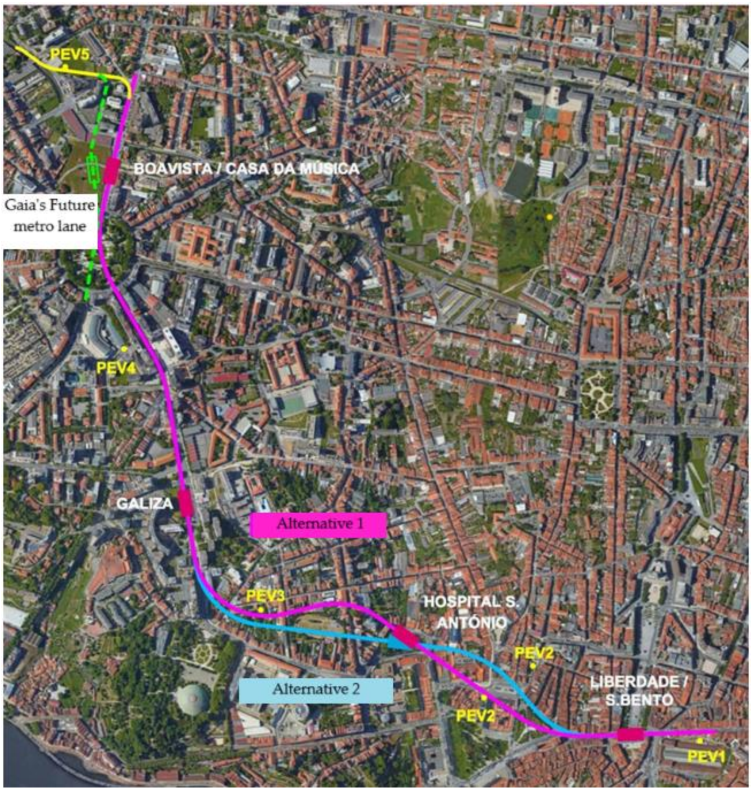

Figure 17- Porto Metro Circular Line project's layout

Demand Analysis

For the demand analysis, we considered the balance between the "do-nothing" scenario and the scenario where the project moves forward. Thus, in Table 46, we present the data related to the project's demand, where a 5-year ramp-up effect and a 30-year operation period are expected.

Table 46- Porto Metro Circular Line project's demand balance compared to scenario "Do Nothing"

"Do Nothing" Scenario	2022	2026	2031	2041	2051
Metro Passengers [thousand passengers]	61 300	64 500	68 900	76 500	84 300
Metro Passengers.km [thousand km]	313 000	329 200	351 500	390 300	430 200
The project's implementation scenario balance					
Metro's total Passengers [thousand passengers]	69 300	74 000	79 000	87 700	96 700
Public transport passengers	4 800 000	5 700 000	6 100 000	6 800 000	7 400 000
Individual car passengers	500 000	600 000	700 000	800 000	800 000
Metro's induction passengers	100 000	100 000	100 000	100 000	200 000
Metro's total Passengers.km [thousand km]	335 500	356 100	380 100	422 100	465 200
Public transport passengers.km	8 100	9 700	10 400	11 500	12 700
Individual car passengers.km	3 400 000	4 100 000	4 400 000	4 900 000	5 300 000
Metro's inductioned passengers.km	600 000	700 000	700 000	800 000	900 000

Like the previous project, the only two presuppositions considered for the demand increase are the ramp-up effect and the natural demand increase.

Additionally, we can examine the expected transfer number in each of the new stations, as Table 47 shows.

Table 47- Porto Metro Circular Line new station's entrances and exits

Station	Entering	Exiting	Overall transfer number
Liberdade/S.Bento	10 423	6 512	16 935
Hospital Santo António	0	108	108
Galiza	0	920	920
Boavista/Casa da Música	15 152	10 923	26 075

We can conclude that "Liberdade/S.Bento" and "Boavista/Casa da Música" will be the stations with the highest number of transfers, while "Hospital Santo António" will have the lowest.

However, regarding new passenger capture, "Hospital de Santo António" is expected to be the station which will contribute the most, 80%, while "Boavista/Casa da Música" will contribute the least, with 59%. We can conclude that most new passengers will be captured in areas not covered by Porto's Metro yet.

Carbon Dioxide Savings

Like the previous project, this expansion won't contribute to increased emissions since the metro will move on electric power only, the only emissions considered the ones due to electricity production.

Thus, the total emissions saved directly correlate with the heavy and light traffic that will stop circulating.

The ramp-up effect will also impact the emissions avoided since an adaptation period is expected during the first five years, which will increase the demand and, therefore, the number of heavy and light vehicles removed from circulation.

Moreover, the values from year five onwards will be the same since we have surpassed the ramp-up period. Note that the data presented in the EIAR is in grams per second; thus, we considered a conversion factor from grams per second to tons per year of 31.56. Light and heavy vehicle oscillations are presented in Table 48 and Table 49 respectively.

Table 48- Porto Metro Circular Line light vehicle traffic emissions avoided

Year	Light vehicles removed from circulation (vehicles/year)	Emissions avoided light vehicle traffic (tons/year)	
		CO_2	CO_2eq
2022	1 917 450	2 768	2 787
2023	2 019 859	2 916	2 936
2024	2 098 300	3 029	3 050
2025	2 152 773	3 108	3 129
2026	2 178 920	3 146	3 168
Average (2022-2051)	2 161 343	3 121	3 142

Table 49- Porto Metro Circular Line heavy vehicle traffic emissions avoided

Year	Heavy vehicles removed from circulation (vehicles/year)	Emissions avoided heavy vehicle traffic (tons/year)	
		CO_2	CO_2eq
2022	31 998	82	82
2023	33 708	86	86
2024	35 017	89	90
2025	35 926	92	92
2026	35 998	92	92
Average (2022-2051)	35 753	91	92

We notice a significant reduction in car traffic emissions. As stated before, the increased demand in the Metro won't generate direct emissions, which allows us to conclude that the accounted avoided emissions add up to 3212 tons of CO_2 per year, which rises to 3234 tons per year if we consider CO_2eq mass.

4.1.11 Overall analysis of projects' data

In this chapter, we now present a summary of the project's main emission highlights which are displayed in Table 50. We evaluated a total of ten mobility projects out of which only two were new projects and the other eight were extension of already existing ones. The total emission savings accounted by the projects are roughly 49 164 tons of CO_2 per year with a total investment of 2 096 million euros, although we must be aware that the Red line expansion between "Oriente" and "Aeroporto" stations and the Red line expansion between "Alameda" and "S. Sebastião" stations do not possess in their EIARs neither investment nor CO_2 emission savings data. In accordance with the Portuguese emissions inventory, the total CO_2eq emissions add up to 56.4 Mt, from which 30.3% come from transport activities. Thus, the total savings coming from the analysed project only represent 0.29% of the total emissions deriving from the transportation sector which corresponds to, which makes us conclude that these projects are far from impacting emissions as we would aim for hence our urge to create policies and measures that can help bring this number up.

Table 50- Public transportation projects' emission savings

Project	Carbon dioxide emissions savings (tCO2/year)
"Transporte Coletivo em sítio próprio" (TCSP) in Loures e Odivelas Municipalities (Violet Line)	5 490.6
Lisbon Metro Red line expansion between São Sebastião and Alcântara	19 826 to 24 327
Lisbon Metro Expansion between Rato station (Yellow line) and Cais do Sodré station (Green line) including new connections in Campo Grande's viaducts	2 828.3
Lisbon Metro Blue line expansion between Amadora-Este and Reboleira	1.3 (CO2eq)
Lisbon Metro Red line expansion between Oriente and Aeroporto	No CO_2 data
Lisbon Metro Red line expansion between Alameda and São Sebastião	No CO_2 data
Cascais' train line (modernisation project)	3 802 in approach I and 3 583 in approach II
Porto Metro Casa da Música - Santo Ovídio line expansion	7 475.4
Porto's metro expansion between Santo Ovídio a Vila d'Este	2 029
Porto Metro Circular line Liberdade/S.Bento - Boavista /Casa da Música section	3 212

4.2 Project performance assessment

A crucial analysis is how the implemented projects have performed so far. Thus, using passenger occupancy data provided by Porto and Lisbon metros, we compared the obtained data with the predicted data in the project EIAR.

Starting by analysing the projects belonging to Lisbon's metropolitan area, opening in 2016, the extension of the Blue line between stations "Amadora-Este" and "Reboleira" predicted, according to its demand study, a total number of passengers at Reboleira station of 20 000 passengers a day (either leaving or entering the station). However, as Table 51 illustrates, that expectation has never been achieved yet. Although in 2024, the average occupancy rate is roughly 87% of the claimed value even though we must underline that we only have data until July 2024. The occupancy rates observed in 2020, and the COVID-19 pandemic can justify 2021.

Table 51- Blue line Amadora-Este Reboleira demand comparison

Project	Number of passengers per year [thousand passengers]								
	2016	2017	2018	2019	2020	2021	2022	2023	2024 *
Lisbon Metro Blue line expansion between Amadora-Este and Reboleira	1 706	3 052	3 790	5 149	3 341	3 141	4 759	6 175	6 394
Percentage of claimed passenger numbers at Reboleira Station	23%	42%	52%	71%	46%	43%	65%	85%	87%

Starting in 2012, the expansion of the Red line between stations "Oriente" and "Aeroporto" predicted the daily number of passengers as follows in Table 52 for the years 2012 and 2020 even though our comparison was made with 2019 due to the COVID-19 pandemic. It is crucial to state that Hypothesis 1 was moving forward, constructing three new sta-tions, as illustrated in Table 53 below. Further analysis was conducted, and the percentage of the annual claimed number of passengers per station was calculated.

Table 52- Red line Oriente-Aeroporto predicted daily passengers' demand

Station	2012	2020
Moscavide	23 416	27 471
Encarnação	16 967	20 368
Aeroporto	13 028	17 312
Total	53 411	65 151

Table 53- Red line Oriente-Aeroporto annual passengers' demand comparison

	2012		2019	
Station	Real occu-pancy	Percentage of predicted occupancy	Occupancy	Percentage of predicted occupancy
Moscavide	1 308 026	15%	4 864 863	48%
Encarnação	439 623	7%	1 690 943	23%
Aeroporto	1 190 746	25%	6 180 580	98%

As the previous table illustrates, the claimed values were exaggerated since occupancy rates are much lower than predicted at two of the stations while station "Aeroporto" reaches a 98% of the annual predicted occupancy. Still, data suggests that the number of passengers does not rise to expectations, having achieved its maximum value in 2024 with an average daily occupancy of roughly 13 000 passengers in “Moscavide”, 4 424 passengers in “Encarnação” and 18 107 passengers in “Aeroporto” being the only station where the predicted values are achieved. However, we must state that occupancy rates were not achieved within the predicted timeframe which was 2020.

Although the Environmental Impact Statement of the Red line expansion between "São Sebastião" and "Alameda" does not present any data regarding its demand, we will assess how its passenger number fluctuated between 2009 (when it started operating) and nowadays. Figure 18 below shows the project stations' total transfers (entries and exits).

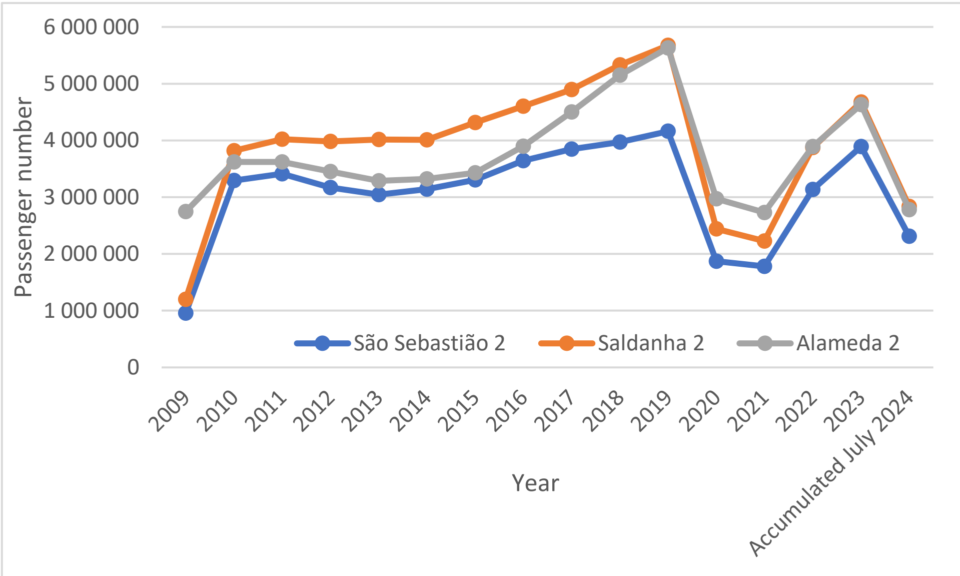

Figure 18- Red line São Sebastião-Alameda demand (2009-2024)

As Figure 18 shows, the number of passengers behaved similarly across all stations. As expected, during 2020 and 2021, we saw an impactful decrease in passenger number due to the COVID 19 pandemic, which recovered quickly from 2022 onwards. Thus, we can conclude that, currently the passenger number is expected to keep increasing, rising over the highest values previously registered (2019).

4.3 Road traffic Analysis

For this analysis, we considered the main road sections accesses to Lisbon and Porto's metropolitan area since they are the ones mirroring traffic variations the best. Thus, in Table 54 below, the main road accesses to each of the metropolitan areas are presented.

Table 54- Lisbon and Porto's main roads

Metropolitan area	
Lisbon	**Porto**
A1 | Sacavém	A1 | Ponte da Arrábida
A12 | Ponte Vasco da Gama	A3 | Porto VCI
A2 | Ponte 25 de Abril	A3 | Águas Santas
A5 | Viaduto Duarte Pacheco	A20 | Antas
A8 | CRIL	A28 | Matosinhos
A9 | Jamor	A44 | Gaia
IC17 | Odivelas	-
IP7 | Av Ceuta	-
IP7 | Av Padre Cruz	-

Taking a further look into the traffic data collected presented in Figure 19, we observe the average daily traffic (ADT) and number of cars, annually for the interval between 2014 and 2023 acknowledging that we only had data from January until September for 2023.

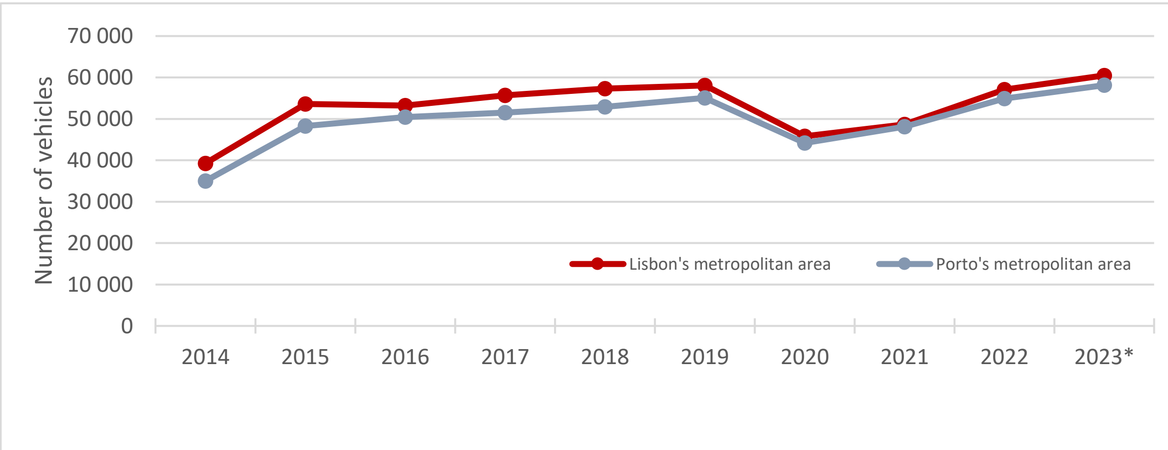

Figure 19- Annual average daily traffic

Firstly we notice a significant increase in traffic from 2014 to 2015, which kept increasing steadily until 2020. The years 2020 and 2021 represent the COVID-19 pandemic and its respective recovery. From 2022 onwards, we can observe an increase in car traffic, which by 2023 had already surpassed pre-pandemic values. The post-pandemic data can be justified by external factors, such as behaviour, like the fear of sharing the public transport space with other citizens, increasing the chances of getting infected.

Addressing the significant roads to both Lisbon and Porto, as Figure 20 and 21 show, respectively, we can highlight, in Lisbon, "Ponte 25 de abril" and "Viaduto Duarte Pacheco". In contrast, in Porto, the major roads are "Antas" and "Águas Santas". Moreover, as stated before, COVID-19 played a vital share in traffic fluctuation since we observed a decrease in 2020 for both metropolitan areas. However, it is essential to underline that, among these four main roads, only Ponte 25 de Abril saw its traffic levels rise above pre-pandemic values in 2023.

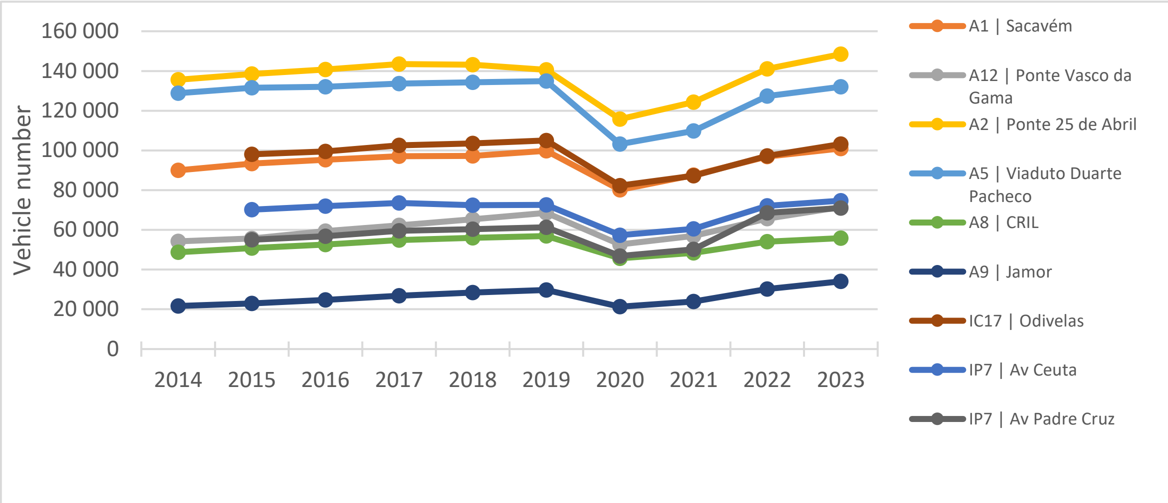

Figure 20- Average daily traffic on Lisbon's main roads

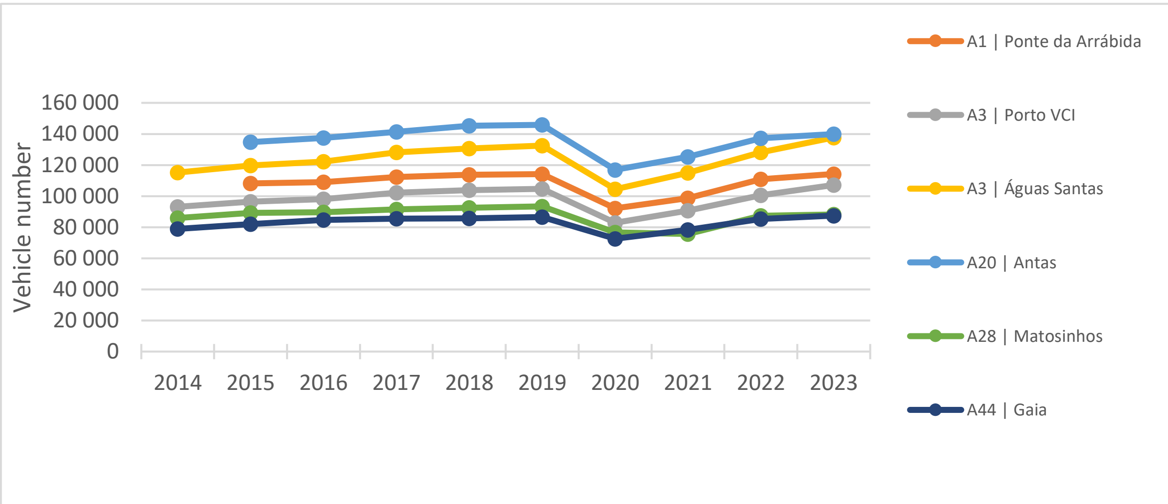

Figure 21- Average daily traffic on Porto's main roads

Assessing how traffic oscillates across each weekday. Figures 23 and 24 present the traffic variation by weekday plays a crucial role in developing measures to tackle car traffic for April and May, respectively, for the city of Lisbon.

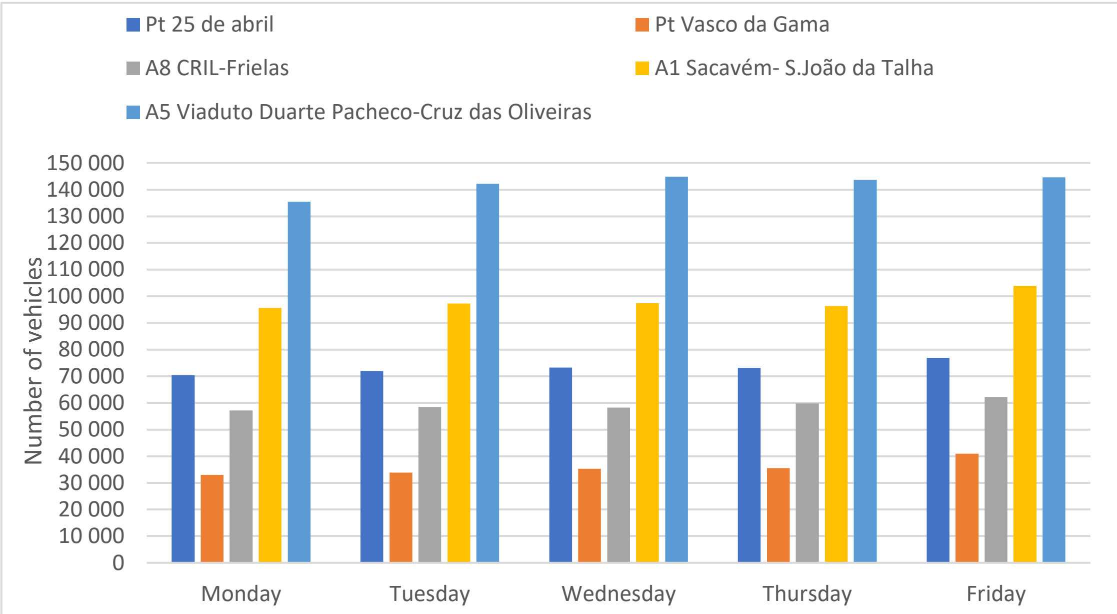

Figure 22- Lisbon main roads' average daily traffic per weekday during April

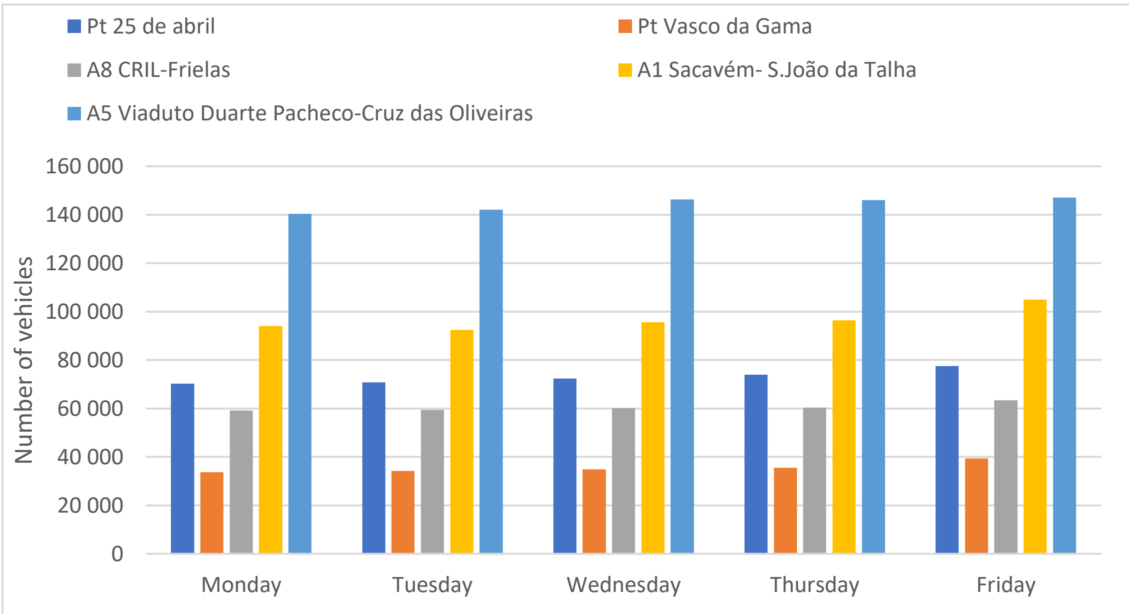

Figure 23- Lisbon main roads' average daily traffic per weekday during May

When we delve into Lisbon's traffic patterns during April, a consistent trend emerges. Across almost all roads, Friday emerges as the day of the week with the highest traffic, with the exception of A5 Viaduto Duarte Pacheco-Cruz das Oliveiras, where Wednesday takes the lead. This pattern holds true for May as well, with all roads experiencing peak traffic on Fridays. This regularity in the data allows us to confidently conclude that, despite a slight shift from April to May, primarily due to school holidays, the majority of traffic on all roads is concentrated on Fridays.

Down in Figures 24 and 25 we present the average daily traffic in Lisbon and Porto's main accesses.

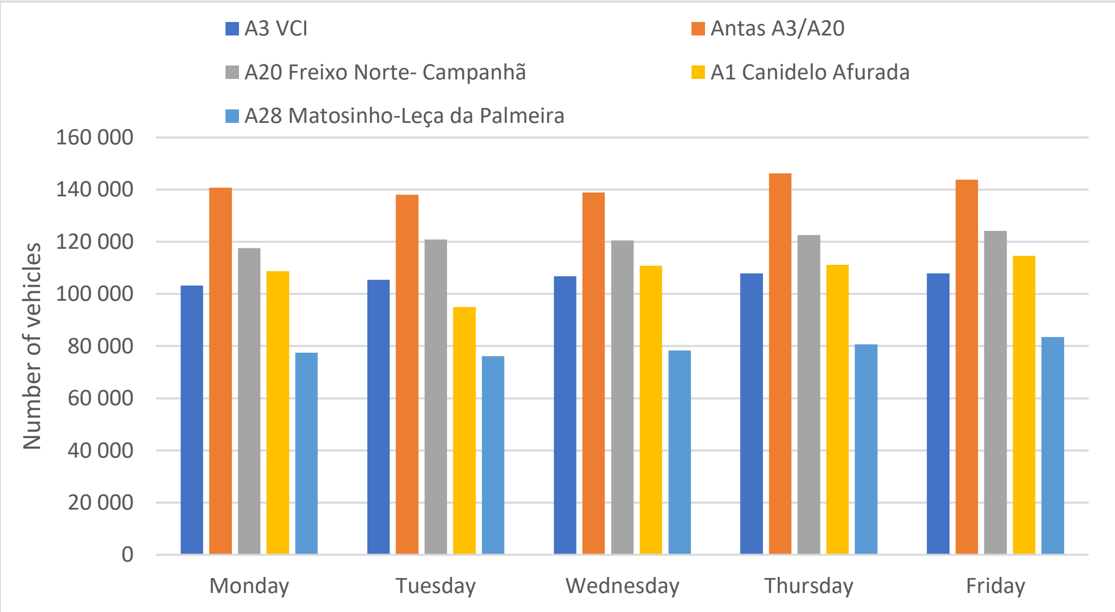

Figure 24- Porto main accesses' average daily traffic per weekday during April

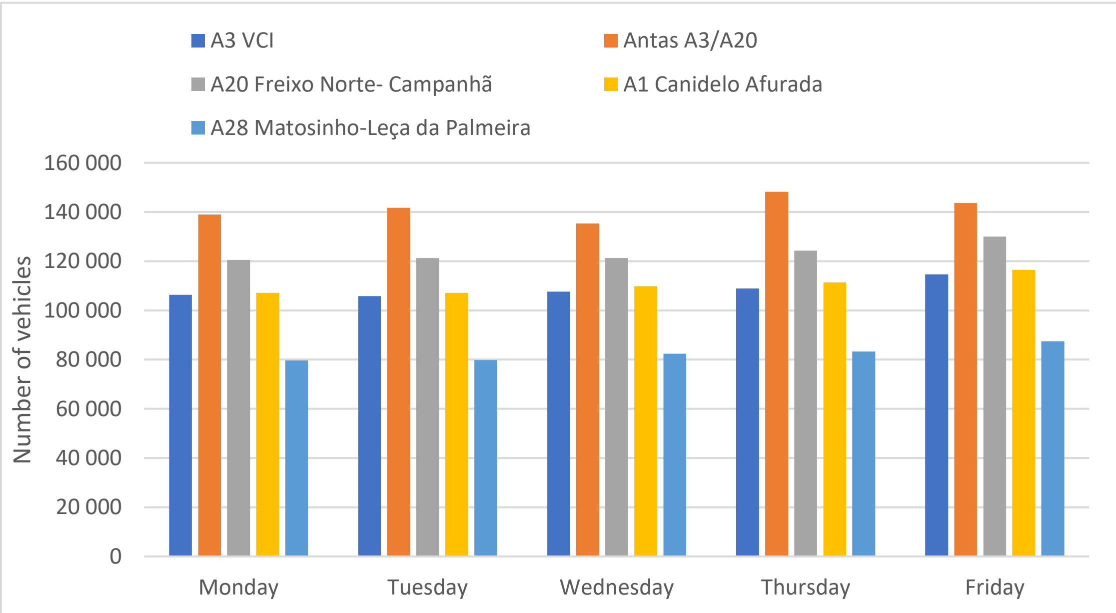

Figure 25- Porto main accesses' average daily traffic per weekday during May

As we look into the traffic patterns of Porto in April, we notice a trend that is distinct from Lisbon. Most of the roads we analysed experience their peak traffic on Fridays, with the exception of A3 VCI and Antas A3/A20, which see their highest vehicle count on Thursdays. This pattern continues into May, with Antas A3/A20 maintaining its Thursday peak.

Furthermore, we conducted a comprehensive assessment of peak and off-peak hours. This allowed us to present the traffic variations during peak hours, specifically the morning peak hours from 7 a.m. to 10 a.m. and the afternoon peak hours from 5 p.m. to 8 p.m. Figures 27 and 28 illustrate these parameters in Porto's metropolitan area for the months of April and May respectively. It's important to note that we are presenting hourly data only for Porto, as Lisbon did not have such data for the roads we analysed, making it impossible to create a peak-hour graph.

As we delve deeper into both Figures, we notice a similar behaviour across the whole 24-hour time period. Firstly, a sudden increase is noticeable from 6 AM until 7 AM, when traffic peaks on almost all roads, apart from Antas A3/A20, where at 8 AM, we state an even higher vehicle count. After this sudden increase, the number of vehicles starts to come down and stabilize until peak hour strikes again, around 5 PM, apart from Antas A3/A20, where a sudden decrease is registered, peaking at 6 PM and then slowly coming down again. However, we have outlined a sudden increase in traffic in Antas A3/A20, verified at around 2 PM in April and around 3 PM in May.

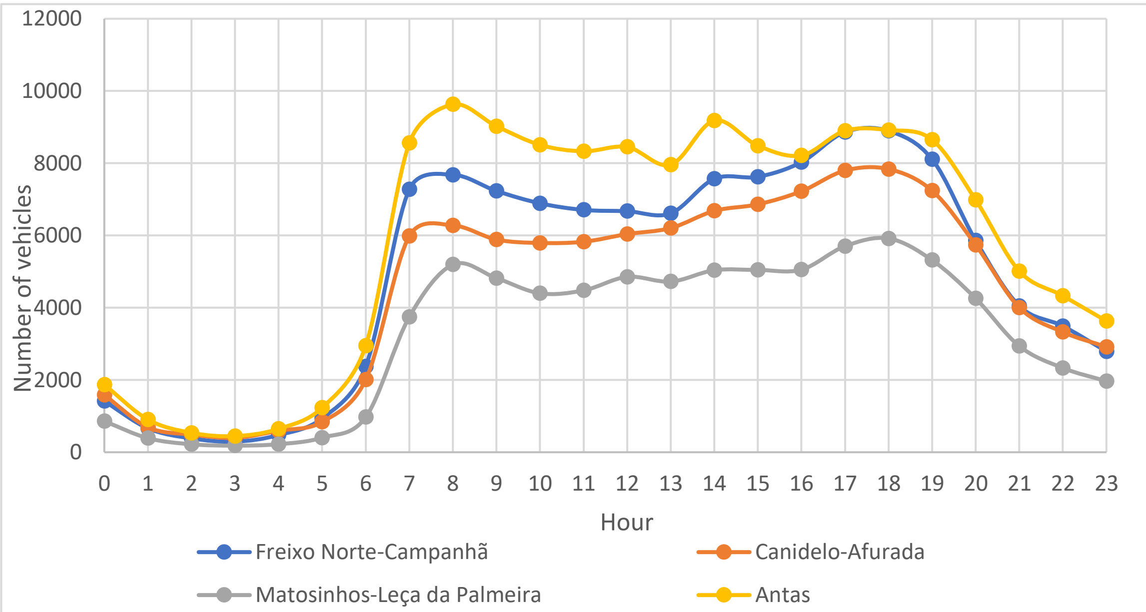

Figure 26- Porto's average hourly traffic in April

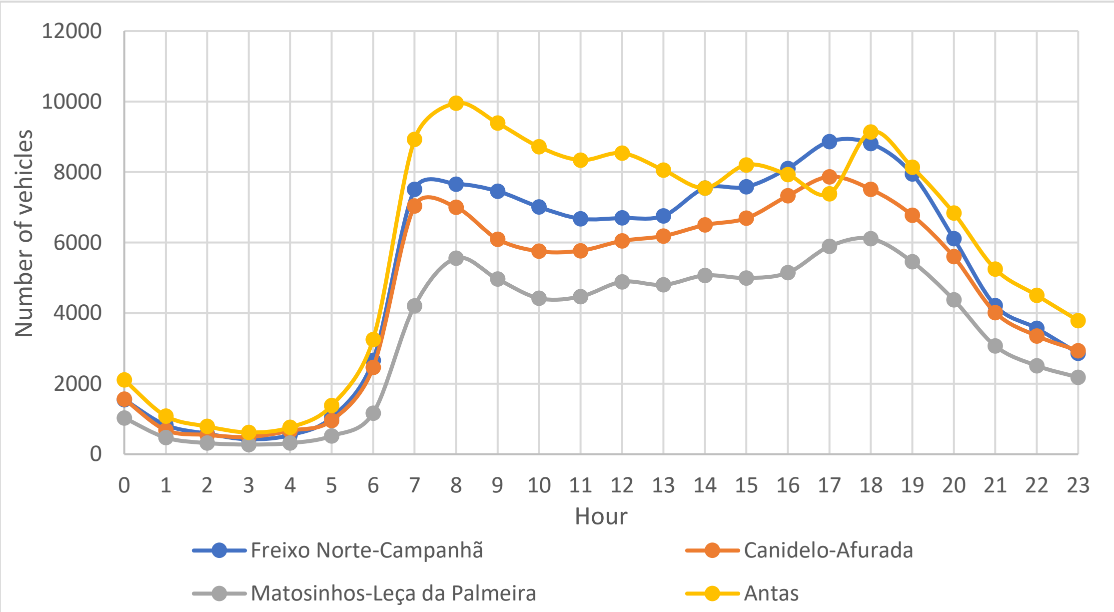

Figure 27- Porto's average hourly traffic in May

4.4 Energy and Emissions analysis

From a sectorial perspective, the graphs presented below (Figure 28 and 29) show that road transportation was the main contributor to energy consumption in both metropolitan areas in 2022. However, its share is quite different since it comprises 60% of Lisbon's energy consumption while only representing 46% in Porto's case. Vapour and electricity production compensate for this fluctuation, which only plays a 10% share in Lisbon while contributing 36% of Porto's energy consumption.

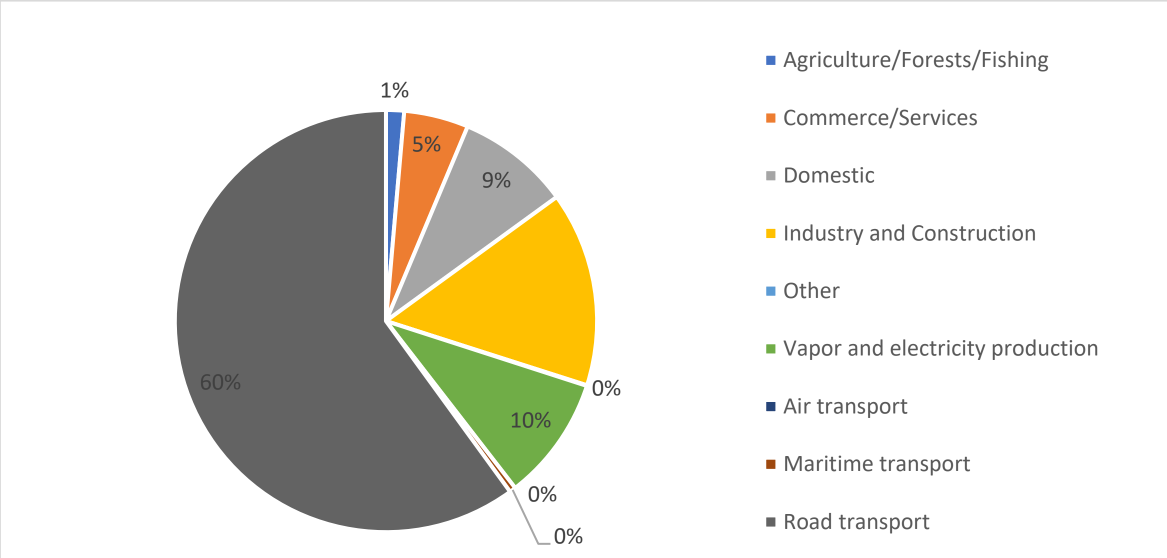

Figure 28- Energy consumption by source in Lisbon's metropolitan area in 2022 (Source: Based on sales of oil and derivatives by municipality and activity sector)

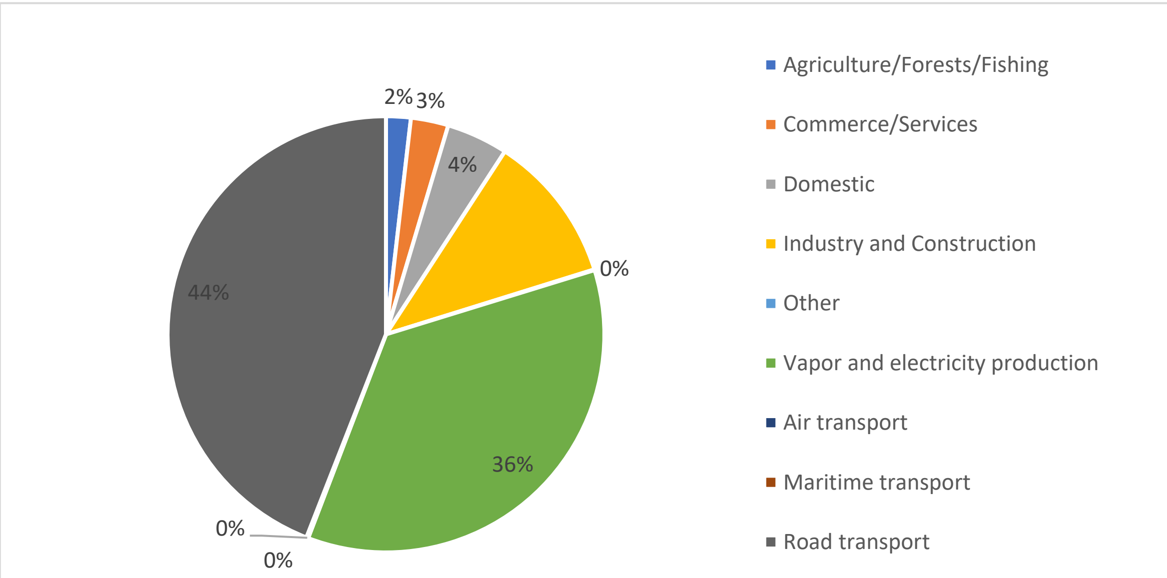

Figure 29- Energy consumption by source in Porto's metropolitan area in 2022 (Source: Based on sales of oil and derivatives by municipality and activity sector)

Going into further detail on energy consumption from road transport, as Figures 30 and 31 illustrate, this data is directly linked to traffic data oscillations, which were analysed previously. Thus, we can conclude that both Lisbon and Porto saw their road transport emissions go down significantly by 2020 due to the COVID-19 pandemic. However, they rose back close to the pre-pandemic values, making this recovery more significant in Lisbon.

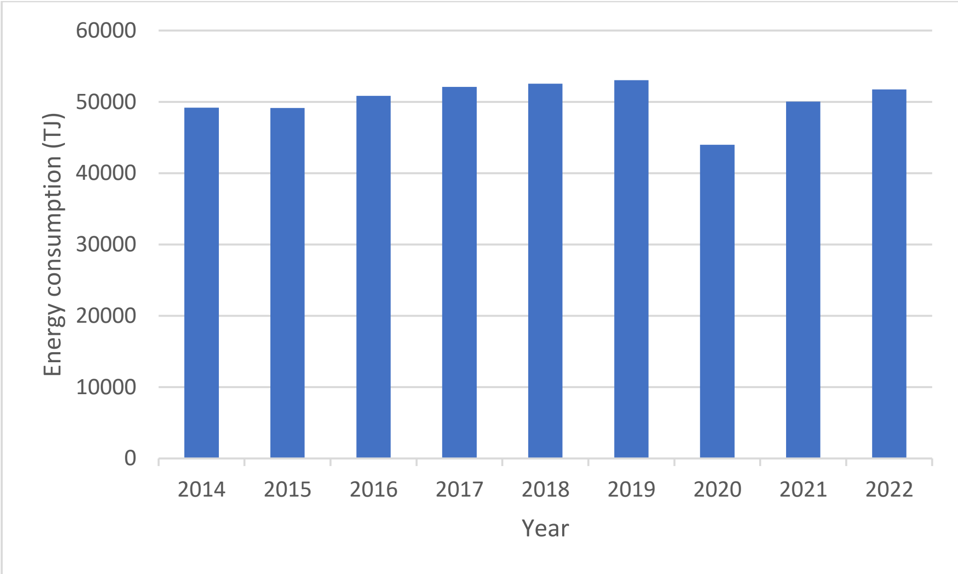

Figure 30- Energy consumed by Road Transport in Lisbon's metropolitan area (Source: Based on sales of oil and derivatives by municipality and activity sector)

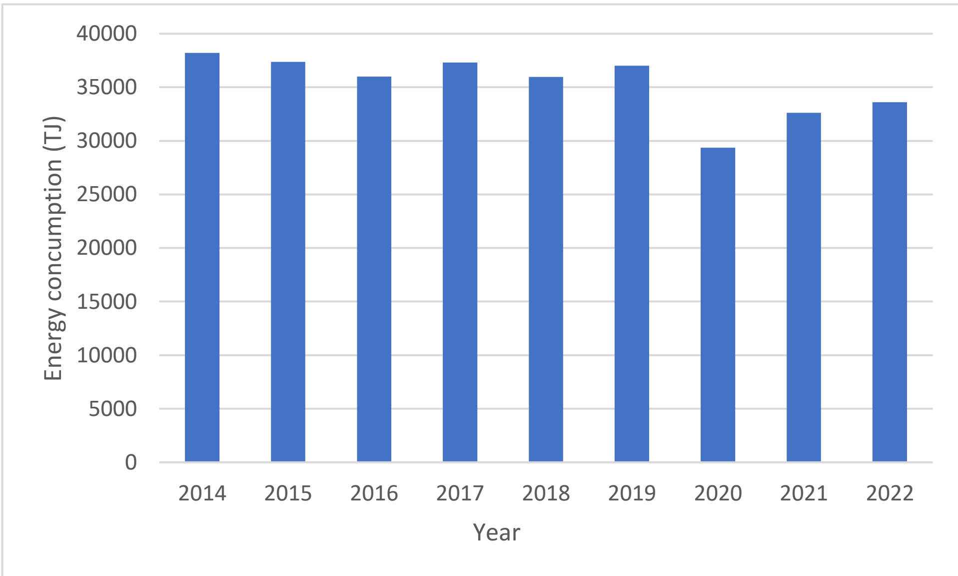

Figure 31- Energy consumed by Road Transport in Porto's metropolitan area (Source: Based on sales of oil and derivatives by municipality and activity sector)

From an emission point of view, as stated before, the most recent data belongs to 2019. As both Figures (32 and 33) illustrate, both metropolitan areas have road transport as their central carbon dioxide emission source, having, in both cases, similar shares accounting for 5 201 and 3 353 kton of CO_2eq for Lisbon and Porto respectively. It is, though, crucial to underline that we do not possess results during and post-pandemic, which would be helpful to analyse how this evolved. However, other data can allow us to infer how emission data could behave during COVID-19 and post-pandemic scenarios. Since we can link energy consumption and CO_2 emissions, the values fluctuated similarly to the ones observed in the energy consumption analysis. Thus, we can infer that CO_2 levels from road transport suffered a decrease in 2020, rising back in 2021 and the following years without reaching pre-pandemic levels.

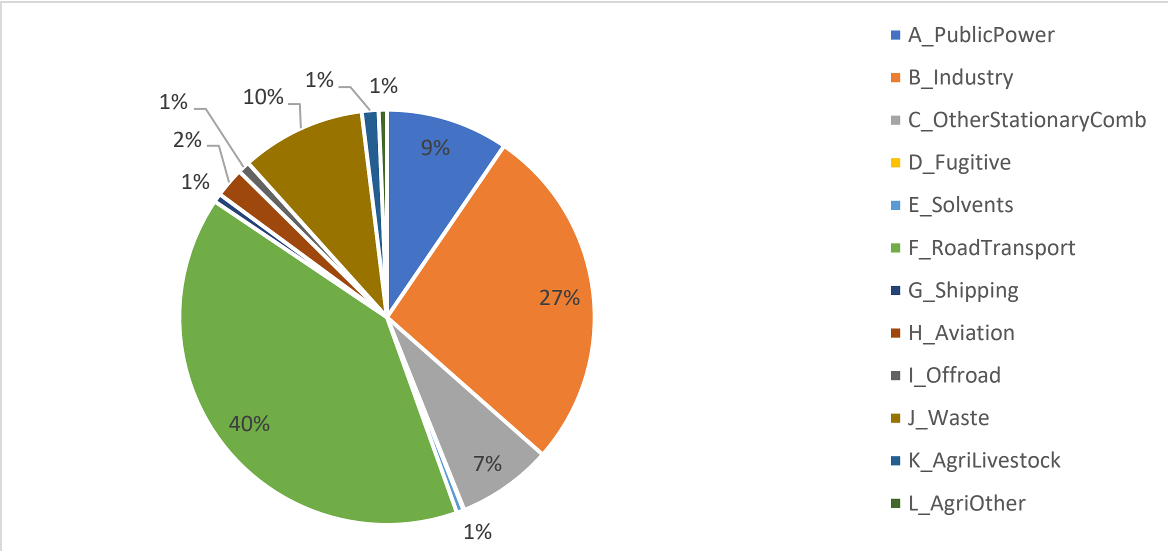

Figure 32- Carbon dioxide emissions by source in Lisbon's metropolitan area in 2019 (Source: APA, 2024)

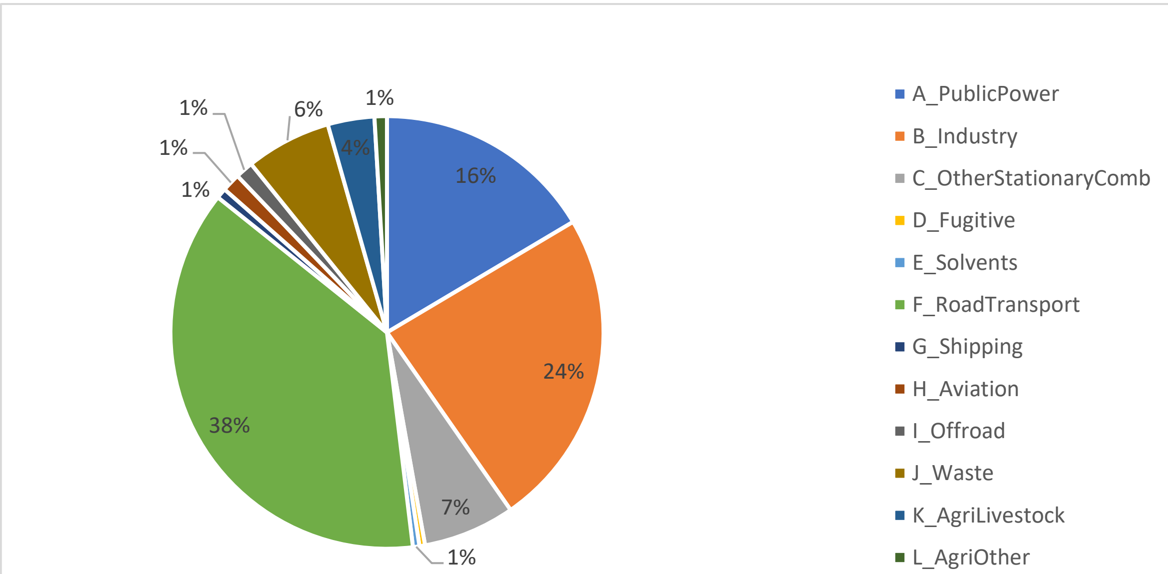

Figure 33- Carbon dioxide emissions by source in Porto's metropolitan area in 2019 (Source: APA, 2024)

4.5 Suggestion of Policies and Measures

Building on our data analysis, we will present a series of measures designed to avoid excessive car use in the metropolitan areas of Lisbon and Porto. We will initially propose a broad set of measures, then progressively refine our interventions to more specific goals based on our analysis, such as traffic patterns during school holidays and peak hours.

Our intervention design must strike a balance between thoroughness and social acceptance. Therefore, the following measures are not only effective but also designed to encourage user adoption. In Table 55, we provide an overview of the proposed measures.

Table 55 - Policies and measures suggested

Municipalities	Companies	Private users
Parking and Traffic Control	Company Travel Plans	Integrate suburban transit with mixed-use development
Development of shared mobility options such as bikes and scooters	Free Public Transport Pass for Employees	Establish Direct Public Transit Links from Suburbs to City Centre
Electrify the public transit fleet	Teleworking	-
Urban Vehicle Access Regulations	Workplace Parking Charges	-
Reduce investment in private car Road Infrastructure expansion	Shuttle from and to the Workplace from Park-n-Ride facilites	-

4.5.1 Municipalities

4.5.1.1 Parking and Traffic Control

Increased traffic in the city centre has become one of the most emergent problematics regarding excessive car use. One solution found and implemented in Oslo comprises a set of adopted interventions that minimise the impact of cars in the city centres.

Removing parking spaces in and around the city centre would be the first measure to be implemented, though we are aware of this measure's lack of social acceptability. In addition, it would be crucial to create car-free streets along with an improvement of the pedestrian and bike/scooter infrastructure. A not so urgent measure to be adopt is the rearrangement of the traffic routes. The enforcement of the previously described interventions would reduce the urge from users to travel by car when commuting to the city centres, making them used to commuting by public transport, which is a vital part of our urban mobility system. Moreover, the inexistence of parking spaces would require more monitorisation from the municipality avoiding illegal parking.

4.5.1.2 Development of shared mobility options such as bikes and scooters

Following Parking and Traffic Control regulations, we must provide users with optional transportation methods within the city centre, hence this measure. Shared mobility options can mitigate the consequences of Parking and Traffic Control in the way that they provide sustainable transportation methods for users. Moreover, the construction of cycle paths would create a safe infrastructure for users to rely on, and the seamless integration of these mobility services with the existing public transport network would ensure convenient access to different transport methods.

4.5.1.3 Electrify the public transit fleet

Electrifying the public transit fleet would result in a massive reduction in GHG levels, especially CO_2. As we are aware, and as was stated previously, the transportation sector is highly responsible for GHG emissions worldwide. Thus, we must tackle this issue as effectively as possible. Aligning with the previous intervention would also complement the parking and traffic control measures by reducing the municipality's fossil fuel dependency while providing a greener option to users who do not intend to use their private cars. Furthermore, this intervention will also impact the air quality in the city centre by reducing the emitted pollutants.

For an effective implementation of this intervention, it's not just about substituting the public transport fleet. We must also invest in the infrastructure these vehicles require, such as charging stations. This is a crucial step that cannot be overlooked, as it will create a seamless operation and pave the way for a greener future.

4.5.1.4 Urban Vehicle Access Regulations

As discussed in the literature review chapter, UVAR is a powerful tool for reducing car traffic by tackling environmental and congestion adversities and increasing revenue for further investment in the public transport sector.

As Ricci et al. (2017) discuss, some of the policies comprised by UVAR are cordon-based, area-licensed pricing, toll rings, point-based and distance or time-based pricing. A cordon-based intervention prevents vehicles from crossing a cordon, which depends on time of the day, direction of travel, vehicle type and location. As for an area license-based pricing demands a fee on vehicles circulating in a specific area for a specific period. Toll rings work similarly to a cordon-based intervention; however, they resemble a taxation scheme for vehicles that want to cross a certain cordon, usually towards the city centre. A point-based intervention intends to prevent a vehicle from accessing a particular city section or crossing a certain bridge, for instance. Finally, distance- or time-based pricing establishes a pricing scheme based on the distance or time a vehicle travels a specific route or area, depending on time, vehicle type, and location.

It's imperative to underscore the significance of the proposed interventions. They represent a crucial step towards reducing traffic in the city centre, thereby facilitating the development of pedestrian and clean mobility infrastructures. This underscores the urgency of the issue and the need for immediate action.

4.5.1.5 Reduce investment in private car Road Infrastructure Expansion

Municipalities still invest large amounts of budget in road infrastructure, aiming to make private car use more comfortable and less stressful for its users. However, this is the wrong premise since we should strive to reduce its use, not try to magnify it. Thus, municipalities should be directing their funds to increase and make better public transport road infrastructure, such as bus lanes. The urgency of this shift is underscored by *Jornal Expresso's* report on the lowest bus speed levels ever recorded in Lisbon and Porto, which makes public transport not attractive to users.

This intervention relies on shifting the funds used for private car road infrastructure expansion to public transport infrastructure improvement and expansion. By doing so, we aim to make public transport, mainly buses, more attractive to users. This change has the potential to transform our cities, making them more liveable and sustainable.

4.5.2 Companies

4.5.2.1 Company Travel Plans

Companies have been increasing their businesses based on travelling; thus, they can trust an organized travel plan to reduce their costs and reduce their emissions based on how their employees commute to work. A structured company travel plan relies on strategies that aim to shift their employee's commuting behaviour by offering alternative means of transport, such as company shuttles or free public transport passes for their employees (these strategies will be presented and discussed throughout this chapter). A proper company travel plans helps reduce traffic congestion and the environmental impact of daily commuting, consequently impacting carbon dioxide emissions.

For an effective company travel plan, there must be a collaboration between all stakeholders, such as employees and even the municipalities, to create these alternative transport methods in an attractive way for the users.

4.5.2.2 Free Public Transport Pass for employees

The proposal of a Free Public Transport Pass for employees is a part of the larger Company Travel Plans. As companies aim to shift their employees' travel behaviour, public transport emerges as a viable solution. However, users often show reluctance towards it. By offering the Public Transport Pass for free, the company is demonstrating its commitment to changing their perception, making public transport a more appealing alternative to their usual commuting method.

4.5.2.3 Teleworking

As addressed in the daily traffic analysis, we concluded that Thursdays and Fridays see the highest vehicle count. Thus, those are the days we must tackle more urgently. Despite the downsides of teleworking highlighted by Thier (2023) and Lachapelle & Tanguay (2021), we could prevent these excessive traffic numbers if workers telework during the busiest business days, especially Fridays. However, other interventions can be applied alongside teleworking to make it more effective. These could include flexible work hours to stagger the rush hour, encouraging the use of public transportation, and promoting walking or cycling to work. For instance, creating resilient and organised teleworking guidelines, where workers have assigned weekdays to work from home, would prevent disorganised trips to the office. Furthermore, the companies' creation of carpooling and carsharing facilities would also tackle an excessive number of vehicles commuting to the office.

4.5.2.4 Workplace Parking Charges

As outlined in the literature review chapter, one of the main issues verified in Portugal is the low occupancy rate in private cars (1.2 people per car). One of the main reasons for this is that the primary method of commuting to work is the private car.

To tackle this problem many interventions can take place, being one of them Workplace Parking Charges. Many companies possess parking spots for their employees thus this intervention relies on making those parking spots paid so that employees start opting for other alternatives to get to their workplace.

4.5.2.5 Shuttle from and to the workplace from Park-n-Ride facilities

As previously mentioned, the issue of car reliance among our workforce is a significant concern. To address this, we propose the implementation of a shuttle service. This service would require employees to commute to a designated Park-n-Ride facility, from where they would take a company shuttle for the final leg of their journey to work. The key benefits of this initiative are a reduction in parking demand and traffic congestion around our headquarters, and a more relaxed and stress-free commute for our employees.

However, a shuttle is not the solution for all company employees. We understand that this measure is only effective when big groups of employees share a similar work schedule, so the shuttle reduces the number of vehicles commuting to the workplace. Furthermore, the effectiveness of this solution depends on the location of Park-n-Ride facilities, which must be accessible to workers who commute there, especially by public transport.

4.5.3 Private Commuters

4.5.3.1 Integrate suburban transit with mixed-use development

Urban sprawl, a significant adversity of our times, is an uncontrolled expansion towards the suburbs of a city. This issue is not only a direct consequence of abnormal population growth but also a potential outcome of telework, as workers can commute to their offices less often. As the population spreads further away from the city centre, the growth of public transport often lags, leading to a poor supply in these more rural areas and a subsequent increase in private car usage. It is clear that a comprehensive approach is urgently needed to address this complex issue.

One effective way to tackle urban sprawl and car dependency is by shortening the last commuting leg for users. Thus, integrating suburban transit with mixed-use development rose as one of the solutions. By densifying residential areas, shops, city services and private businesses around suburban rail stations and other public transport infrastructure we are reducing the last commuting leg for users, making public transport much more attractive to users, consequently reducing car dependency.

4.5.3.2 Establish Direct Public Transit Links from Suburbs to the city centre

Even though we can integrate suburban transit with mixed-use development, we must be aware that the majority of employees are concentrated in the city centre, hence the urge to reduce car use in these specific situations.

Therefore, aiming to reduce urban sprawl's impact on traffic, extending the current public transport infrastructure to the suburbs is essential, creating a fast and direct commuting route towards the urban centres and improving the budget allocated to active mobility, such as electric scooters.

4.5.4 School holidays

Further analysing traffic, we will examine the traffic variation between an average week-day and a weekday that belongs to a school holiday timeframe. Thus, based on the main road roads to Porto and Lisbon, Figure 34 shows the traffic fluctuation between a school holiday and a non-school holiday period. The data existent comprises the month of April, hence the focus on the easter holidays, which took place between the 3rd and the 14th of April. We shall also underline that, for both traffic assessments, weekends and holidays were left out.

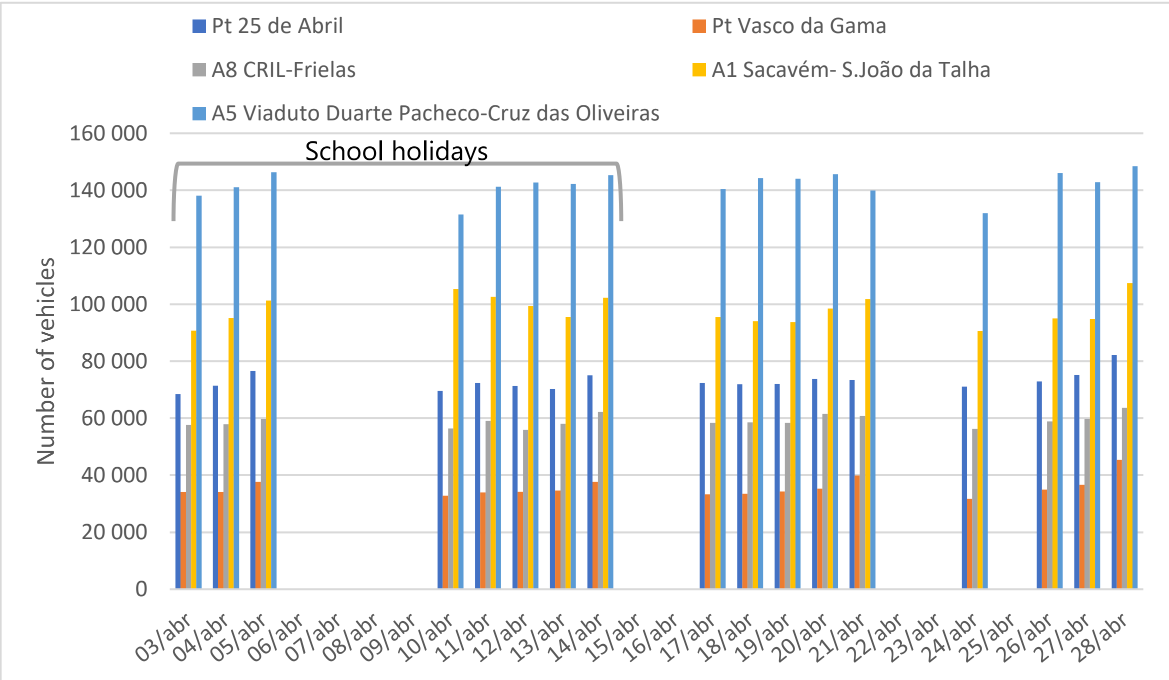

Figure 34- Lisbon main road's daily traffic during April

Analysing the graph, we notice immediately that A5 Viaduto Duarte Pacheco – Cruz das Oliveiras is the road with the most traffic, followed by A1 Sacavém – S. João da Talha. When comparing both periods, the average traffic registered is higher during non-school holidays in Ponte 25 de Arbil and A8 CRIL-Frielas, the other way around was registered for the other three roads. We also underline the fact that April 6th although it's not a holiday, it represents Holy Thursday and a 24-hour strike from infraestruturas de Portugal, having been left out as well from the analysis.

Taking a deeper look at Porto's scenario (Figure 35), the roads chosen for this analysis were A3 VCI, Antas A3/A20 (which happens to be the road with the most traffic), A20 Freixo Norte-Campanhã, A1 Canidelo-Afurada and A28 Matosinhos-Leça da Palmeira. Furthermore, the roads where a higher vehicle count was observed during school holidays compared to non-school holidays were Antas A3/A20 and A20 Freixo Norte-Campanhã.

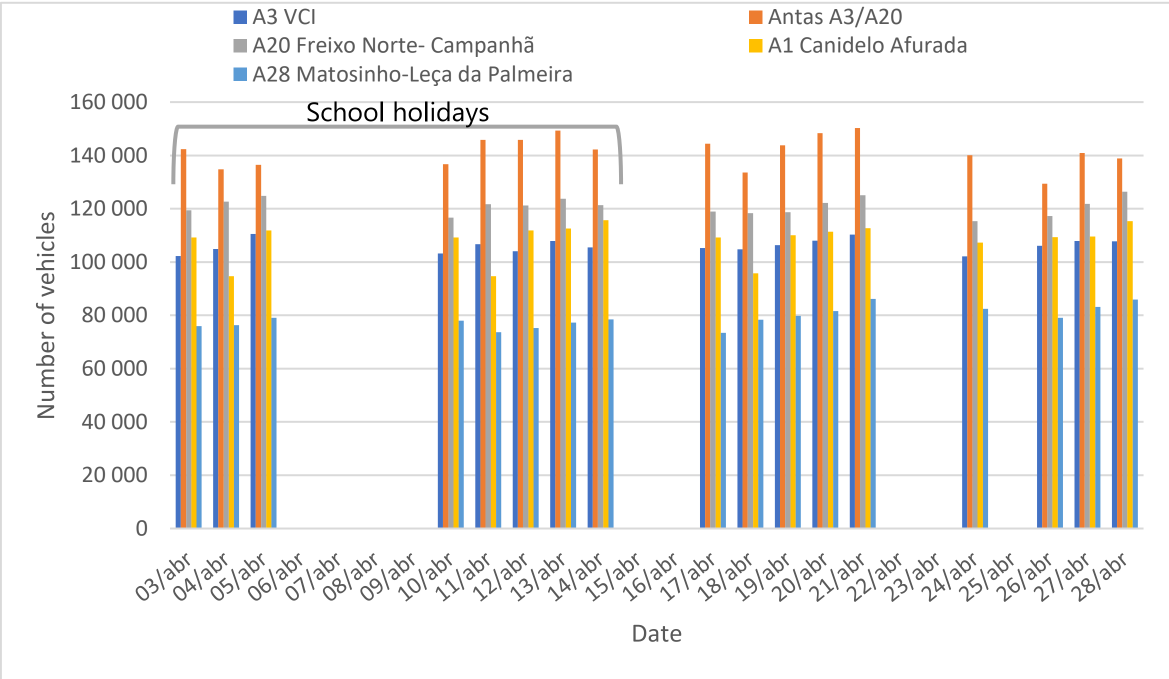

Figure 35- Porto's main roads daily traffic during April

Considering that the use of car by several families could be stimulated by the need to transport kids to school, the opportunity of measures targeting that circumstance was evaluated based on data already presented. The traffic levels between school holidays and non-school holidays could give a better insight into actions along this pathway. Our study concluded that the majority of the assessed roads had their higher vehicle count outside the school holiday timeframe. However, A1 Sacavém-S. João da Talha, A20 Freixo Norte-Campanhã and A1 Canidelo-Afurada showed otherwise. Overall, the difference observed is not significative and therefore, at least at a metropolitan level there seems to be no influence of school holidays in road traffic patterns and possible measures to avoid school transport should be assessed at a municipal/local level

5

CONCLUSION AND FUTURE RESEARCH

Mitigation actions towards a reduction of greenhouse gases emissions, particularly carbon dioxide, in the road transport sector, are fully necessary to comply with 2030 medium-term and 2045 long-term carbon neutrality goals under climate change policies set by Portugal. This dissertation was dedicated to evaluating the emissions reductions, since the year 2000, obtained by the construction of large public transport infrastructure projects in the metropolitan areas of Lisbon and Porto. This work also evaluated the accuracy of the Environmental Impact Assessments of those projects, specifically by the Environmental Impact Assessment Reports (EIAR), proposing actions to curb car use, thereby contributing to the crucial mitigation global effort.

A total of ten public transport projects were evaluated, where two were new projects and the other eight were extensions of already existing ones. Firstly, according to the calculations performed under the EIARs, we can state that these mobility projects do not deliver the necessary greenhouse gases emission reductions since we concluded that the total annual reduction only comprises 0.29% of the total emissions coming from the transportation sector at the national level, corresponding approximately to fifty thousand tons of CO_2, which is quite insignificant, especially when considering a total investment cost of more than two billion euros. Additionally as we move down to the metropolitan area scale, the projects taking place in Lisbon's metropolitan area aim to reduce 0.70% of the total road transport CO_2eq emissions (5 201kton) while in Porto's scenario this percentage goes up/comes down to 0.37% of the road transport total emissions, which was 3 353kton of CO_2eq. Moreover, as we assess the projects' performance, an identifiable lack of demand forecasting in the EIARs is common, since only three projects had data regarding their future occupancy rates. For these cases, a considerable discrepancy can be found since only the Lisbon's metro Blue line extension between "Reboleira" and "Amadora-Este" is close to comply with the predicted demand in its EIAR being at 87% of the claimed occupancy in 2024, while the others felt far from their goals, with the best scenario at only 34% of claimed occupancy at "Aeroporto" station under the extension of the Red line which allows us to consider either the projects performance as unsatisfactory, or an inaccurately prediction of demand data.

All the data previously analysed, evaluated, and summed up, allows us to draw the main conclusion out of the present research: public infrastructure mobility projects are not being effective enough the meet GHG emission values, mainly due to the fact that we have not been implementing strong policies avoiding private cars enough for them to become unattractive to users. Individual road transport still offers a viable solution to a massive share of commuters, which makes any improvement in the public transport sector quite irrelevant, besides the financing of passes and the harmonization of ticketing.

Thus, aiming to tackle increased car traffic, a set of policies and measures were suggested. These measures acted in three distinct dimensions: municipalities, companies, and private users, each playing a crucial role in reducing car use in each one of these areas. Starting with municipalities, we underlined their crucial role in reducing car dependency, improving public transport infrastructure, and promoting shared mobility options. This is a collaborative effort that involves not only the government, but also companies and private users. Companies play a significant role in reducing their employees' car use through interventions such as implementing travel plans, offering free public transport passes, promoting teleworking, and introducing shuttle services from park-and-ride facilities. Private users also have a role to play in reducing car emissions. By integrating suburban transit with mixed-use developments and establishing direct public transit links between suburbs and city centres, we can address the growing issue of urban sprawl and help shift commuters away from private cars.

Furthermore, from an emission point of view, we notice that road transport still plays the most significant share in greenhouse gases emissions, enhancing our urge to tackle them. At the same time, as for energy consumption, we see road transport suffer a decrease due to the pandemic, rising right after it, which underscores the need for significant improvements in public transport. Our research did not include traffic data from within the city, but only from the roads that lead to it. Therefore, further exploration in this area is urgent and essential to gain a deeper understanding of how public transport influences inner-city traffic. Additionally, expanding our analysis to include seasonal variations, such as the impact of summer and winter on traffic, could provide valuable insights for future planning, even though suburban traffic seems not to vary considerable under school and non-school days under the evaluation performed.

Summing up, the present thesis underscores the potential and the need of a well-planned and organised public transport investment and promotion strategy. Its role in reducing car use, and consequently lowering of GHG emissions, particularly carbon dioxide, should be significant, if the overall mobility system and the users get the right incentives and penalties. While the gap between projected and actual values in the EIAR may be disappointing, it is important to remember that a more comprehensive approach can give both more accurate results and reduce the allure of private cars, offering hope for the future.

Additionally, several limitations were found in the quality and accuracy of EIARs. For instance, Porto's metro has been using the same emission factor since 2008, leading to undated information, which results in unrealistic overestimated emission reductions. In Lisbon, the Red line expansion between "Oriente" and "Aeroporto" stations and the Red line expansion between "Alameda" and "S. Sebastião" stations EIARs do not provide carbon dioxide emission data, with the latter not presenting either passenger demand data or emission data at all, which is a considerable deficiency of relevant area within the EIAR. Fortunately, recent studies incorporated more and better information, reflecting an improvement of the EIAR details, which makes us conclude that the quality of the studies have been improving.

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