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Lisbon’s Electric Vehicle (EV) Fleet: A Cost-Benefit Analysis of a Mass Adoption of EVs in Lisbon by 2050

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SIT Study Abroad

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Abstract

As the impacts of climate change increase, the EU and its member countries are attempting to achieve carbon neutrality by 2050. The adoption of electric vehicles is proving to be a promising solution to achieve this goal, and specifically, reductions in the transport sector emissions. This study analyzes the potential costs and benefits resulting from a mass adoption of electric vehicles in Lisbon by 2050. Through a cost-benefit analysis, this study aims to quantify the major costs and benefits associated with electric vehicles. The results display the potential monetary benefits of a city-wide shift to electric vehicles in addition to environmental benefits. This report recommends government incentives to subsidize the diffusion of electric vehicles and emphasizes the importance of a simultaneous shift to renewable energy. These actions will promote sustainable mobility in Lisbon and set the city on a path to carbon neutrality.

Abbreviations

AVC - Average Fuel Consumption
AC - Average Consumption
AD - Average Annual Distance Traveled
AEC - Average Annual Energy Consumption
BEV - Battery Electric Vehicle
CBA - Cost-Benefit Analysis
CE - Charging Efficiency
CTEMC - Cumulative Total Emissions Cost
DC - Damage Costs
EC - European Commission
EMC - Emissions Costs
EM - Emission Mass
EGD - European Green Deal
EEA - European Environmental Agency
ELP - Price of Electricity
EU - European Union
EV - Electric Vehicle
FNC - Fuel Not Consumed
GHG - Greenhouse Gas
ICEV - Internal Combustion Engine Vehicle
LC - Life Cycle
LDV - Light-Duty Vehicle
LMA - Lisbon Metropolitan Area
NPV - Net Present Value
NV - Number of Electric Vehicles
PT - Portugal
SB - Savings per BEV
TAC - Total Annual Cost
TCO - Total Cost of Ownership
TELC - Total Electricity Consumption
TELP - Total Electricity Consumption Price
TEMC - Total Emissions Costs

1. Introduction & Background

1.1 The European Green Deal & Reducing Greenhouse Gas Emissions

In December of 2019, the European Commission (EC) launched the European Green Deal (EGD), a set of policies aimed at achieving climate neutrality in the European Union by 2050 (European Council, n.d.). One initiative included in the European Green Deal is the European Climate Law which establishes a legal obligation for member countries to commit to cutting net greenhouse gas (GHG) emissions by 55% compared to 1990 levels (European Council, n.d.). Dissecting the EU's GHG emissions, "the transport sector alone accounts for almost one-third of… CO^2 emissions," and 60.6% of the transport sector's emissions are produced by passenger cars (Ela et al., 2021; European Environmental Agency (EEA), 2022). Although trends in GHG emissions display an overall decrease, Figure 1.1 reveals that GHG emissions from the transport sector are increasing; "this sector increased by 50 million tonnes of CO2-equivalents (CO2-eq) (+7%) in 2020 compared with 1990" (EEA, 2022). In Portugal, the transport sector accounted for 34.7% of final energy consumption in 2021, and passenger cars were responsible for 57% of this consumption (ODYSSEE-MURE, 2024). This immense amount of energy consumption combined with the rising population (in 2024, the population of Lisbon reached three million inhabitants) and rising demands for transportation, vehicle ownership and fossil fuel demands are bound to face sizeable increases, creating adverse implications for "energy supply security and climate and urban air quality" (University of Birmingham, 2015; Bastos et al., 2019).

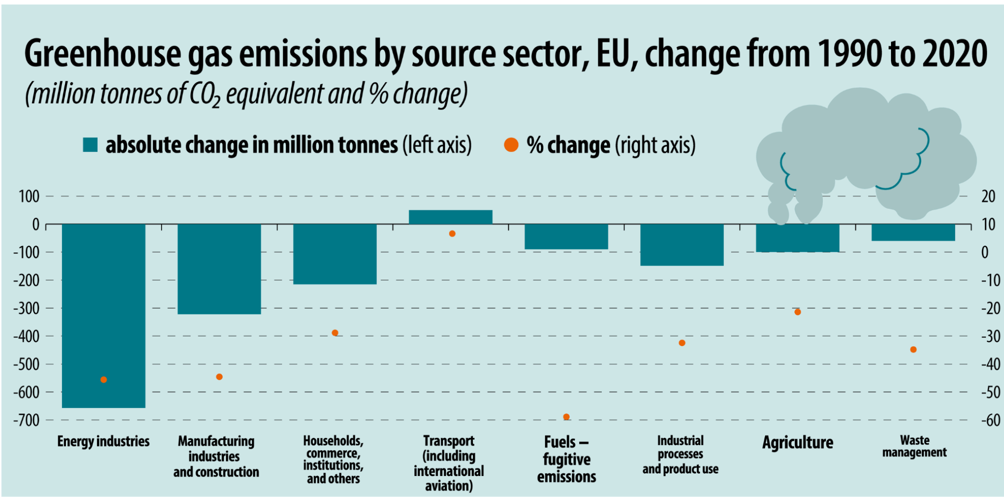

Figure 1.1: GHG emissions by source sector (European Environment Agency , 2022)

These implications have both a global and a local effect. Globally, transportation and tail-pipe emissions contribute to human fossil fuel consumption, which, in turn, intensifies climate change and the deterioration of the environment. Since 1990, CO_2 emissions from vehicles have been increasing. Achieving the European Commission's EGD is only feasible with major reductions in the transport sector. In addition to the country's global obligation to an emissions reduction, transportation's effects on urban air quality present a public health burden as exposure to air pollutants can induce health issues.

1.2 The local effects of air pollution in the Lisbon Metropolitan Area

Inhabitants of metropolitan areas like Lisbon are at a higher risk of urban air quality degradation because proximity to major roads increases exposure to pollutants (Ghafouri-Azar et al., 2023). Carbon monoxide (CO), Nitrogen oxides (NO_x), hydrocarbons (HC), sulfur dioxide (SO_2), and particulate matter (PM_{10} and $PM_{2.5}$) are all key air pollutants that are produced from car emissions. Respirable particulate matter (PM_{10}) and fine particulate matter ($PM_{2.5}$), which are classified by a diameter of ≤10 microns and ≤ 2.5 microns, respectively, are considered the most hazardous pollutants as they are inhalable into the lungs, and $PM_{2.5}$ is capable of passing through the lung barrier and entering the bloodstream. Inhalation of these pollutants can result in cancer, cardiovascular diseases, and respiratory diseases (Correia et al., 2020; Sarroeira et al., 2023). In 2016, it was estimated that air pollution and exposure to $PM_{2.5}$ caused 4.2 million premature deaths (Ghafouri-Azar et al., 2023). Most vulnerable to air pollution-related illnesses include the elderly, those with preexisting heart and lung conditions, and children because they inhale more air per kilogram of body weight (Ghafouri-Azar et al., 2023). In addition to air pollution, it is important to consider noise pollution created by vehicles which can also create health hazards like high blood pressure and risk of heart disease (Ghafouri-Azar., 2023).

Since 2005, Lisbon has surpassed the European and national legal concentration limits for $PM_{2.5}$ and PM_{10} (Lajas et al., 2014). According to the World Health Organization's (WHO) yearly air quality guidelines, the limit values for CO, NO_2, $PM_{2.5}$, and PM_{10} are listed as 4000 $\mu g/m^3$, 10 $\mu g/m^3$, 5$\mu g/m^3$, and 15 $\mu g/m^3$ respectively (Sarroeira et al., 2023). As displayed in Figure 1.2 (a,b,c,d), multiple areas in the Lisbon Metropolitan Area (LMA) exceed the yearly air quality guidelines for these four pollutants. These maps display the unequal distribution of pollutants in higher-density urban areas. Because of these health risks and alarming statistics, air pollution and air quality have gained attention from the EU and Portugal. For example, Portugal's Decree-Law nr. 276/99 of 23_{rd} July, which was last amended in 2017, defines the Coordination and Regional Development Commission (CCDR) as "responsible for air quality management" and gives it the right to "any necessary measures to ensure the respect of air quality legal limits" (Silva et al., 2014). Recently, to address these issues, Lisbon has also enacted policies including car bans and low emission zones (LEZ) which are defined as specific areas that can only "be accessed by vehicles that respect certain pollutant emission standards" (Silva et al., 2014). Additional sustainable transportation initiatives instated by the city promote the adoption of EVs through "purchase subsidies" and "the development of [charging] infrastructures" (Ela et al., 2021).

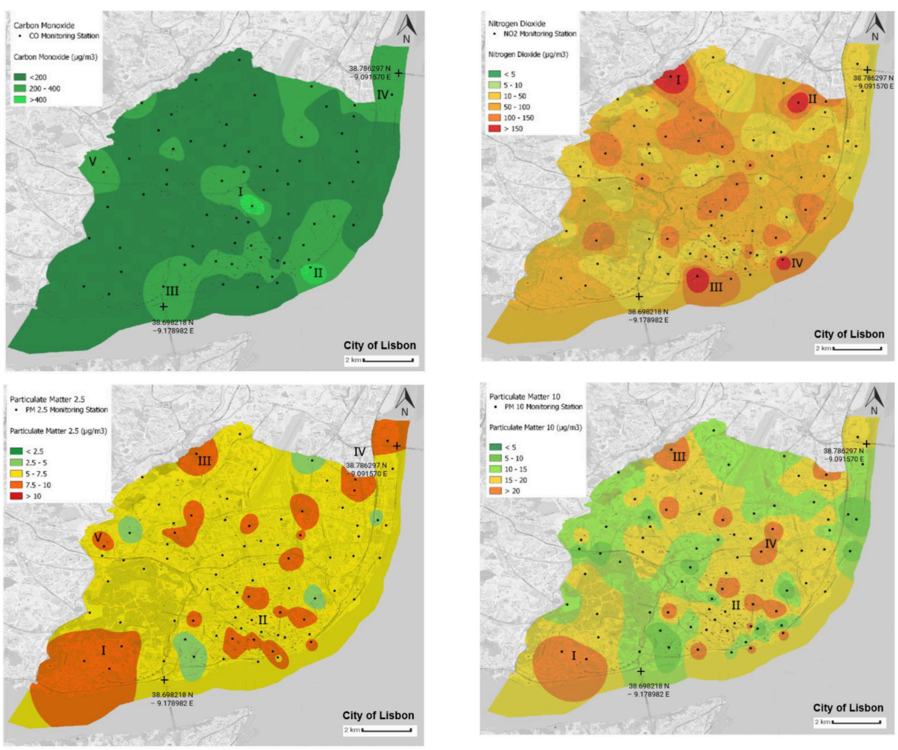

Figure 1.2: Average annual distribution of (a) CO, (b) NO, (c) PM 2.5, and (d) PM 10 in the LMA (Sarroeira et al., 2023)

1.3 Sustainable transportation solutions & Electric Vehicles

Solutions to improving the efficiency and sustainability of transportation can be divided into four categories: "structural changes, reduction of the number of trips, shift to more efficient transport modes, and technological innovations" (Lopes et al., 2014). While most of these solutions are difficult to implement because they require immense financial support or behavioral changes, this project focuses on technological innovations like electric vehicles (EVs) which have already witnessed an introduction into society. Analyzing the advantages of car ownership, having a private car allows for flexibility and accessibility to a degree that car-sharing or public transportation does not. Because of this, it is nearly impossible to remove cars from the transportation system; thus, vehicles with alternative energy sources—hybrid vehicles (HEV), plug-in hybrid vehicles (PHEV), and EVs—present possible sustainable transportation alternatives. Compared to an internal combustion engine vehicle (ICEV), EVs require less energy consumption and are not dependent on fossil fuels, therefore, reducing GHG emissions and pollutants. It is important to note, however, that a replacement of ICEVs with EVs will not entirely solve the sustainable transportation problem because "the energy for driving means of transport still comes from the combustion of fossil fuels" (Nęcka & Knaga, 2021). To achieve the EGD goals of carbon neutrality, the diffusion of EVs must be accompanied by the development of renewable energy sources. This combination will achieve a reduction of energy consumption and GHG emissions, providing benefits for individual consumers and society through energy efficiency and emission.

While EVs present a promising solution to making the transport sector more sustainable, it is essential for its environmental footprint to be assessed on two levels: "(1) the manufacture of vehicles, and (2) their useful life" (Guzmán et al., 2022). The manufacturing of EVs presents potential environmental harm because of human toxicity, ecosystem effects, and resource depletion (Guzmán et al., 2022). BEVs require precious metals such as lithium and copper for battery production. Recently, the sustainability of BEVs has been questioned due to the overconsumption of water required for lithium mining, the large generation of tailings and sulfur dioxide from copper acquisition, and the poor working conditions in the cobalt industry (Guzmán et al., 2022). When in circulation, BEVs exhibit a clear reduction in CO_2 emissions, but water consumption remains roughly equivalent to ICEVs (Guzmán et al., 2022). Strictly analyzing the environmental footprints of the ICEVs and BEVs at the stage of production, ICEVs display better performance for water consumption, energy consumption, and CO_2 emissions. Through renewable energy production, EVs have the potential to offset manufacturing impacts once in circulation.

If a 70% penetration of EVs is achievable by 2050, estimations suggest a reduction of "energy consumption by 34% and CO_2 emissions by 39%" (Baptista et al., 2014). This presents a promising solution to both the environmental and social injustices that arise from transportation issues. Despite the immense potential that electric and hybrid vehicles display, there exists "substantial technical, social, and economic barriers to widespread adoption of electric vehicles" (Transportation Research Board & National Research Council, 2013). "The limited driving distance…, duration of the battery charging…, safety and reliability…, [and] the high battery replacement cost" are all existing barriers that prevent consumer adoption (Pamidimukkala, 2023). Most prominently, EVs are more expensive than ICEVs, meaning it "could take the entire vehicle life to compensate for the initial investment" (Faria et al., 2012). Currently, these factors exist as barriers to a mass adoption of EVs. The primary objective of this project is to compare these common EV costs with the benefits to examine the feasibility of reaching penetration levels high enough to produce reductions in energy consumption and GHG emissions.

1.4 Research Objectives & Motivation

The objective of this report is to conduct a cost-benefit analysis of EVs in Lisbon to answer the question: Is a mass adoption of EVs sustainable in Lisbon? By analyzing the costs and benefits of EVs, this report explores the role EVs play in a more sustainable road transportation sector in Lisbon. Additionally, an investigation of the potential environmental and social benefits of EVs in Lisbon presents further motivation to make EVs more accessible. As innovations in EV technology increase, research pertaining to their effectiveness in regard to the EU's climate neutrality goals is imperative. With rising demands for transportation and rising pressures on the environment, developing sustainable and accessible transportation alternatives is crucial. A cost-benefit analysis of the diffusion of EVs in Lisbon presents a systematic approach to determining the impacts of this ongoing evolution of sustainable transportation technology.

2. Literature Review

2.1 The EGD and its sustainable transportation goal

Prevailing threats of climate change and anthropogenic impacts on greenhouse gas emissions (GHG) have prompted the enactment of environmental policies. The European Union (EU) is a "conglomerate of industrialized countries with relatively high carbon emissions;" to combat these emissions the European Commission ratified the EGD in 2019 (Sporkmann et al., 2023). The primary goal of the EGD is to make Europe "the first climate-neutral continent in the world" by 2050 (European Commission, 2019). This is achievable by reducing emissions by at least 55% by 2030, compared to 1990 levels. One key aspect of the EGD's climate neutrality goal is to make transport sustainable for all; the EGD declares that "all new cars and vans registered in Europe will be zero-emission by 2035" (European Commission, 2019).

Almeida et al. (2023) further explores the EGD's origins, design, and core elements as a "continuum of colonial and neo-colonial relations" to transform the EU. They list the key areas of the EGD Strategic Framework as:

1) Climate ambition for 2030 and 2050, which focuses on carbon pricing
2) Clean, affordable and secure energy
3) Industrial strategy for a clean and circular economy
4) Sustainable and smart mobility
5) Greening the Common Agricultural Policy/"Farm to Fork Strategy"
6) Preserving and protecting biodiversity
7) Zero pollution ambition for a toxic free environment
8) mainstreaming sustainability in all EU policies
9) positioning the EU as a global leader
10) European Climate Pact (EC, 2019) (Almeida et al., 2023)

This paper focuses on the fourth aspect listed by Almeida et al.—sustainable and smart mobility—as a priority of achieving the EGD.

2.2 The impact of the transport sector in the EU

The European Commission has published an extensive amount of reports on EGD progress. The latest EU Climate Action Progress Report from 2023, details that the EU has witnessed a 32.5% decrease in GHG emissions in 2022. As displayed in Figure 2.1, despite this

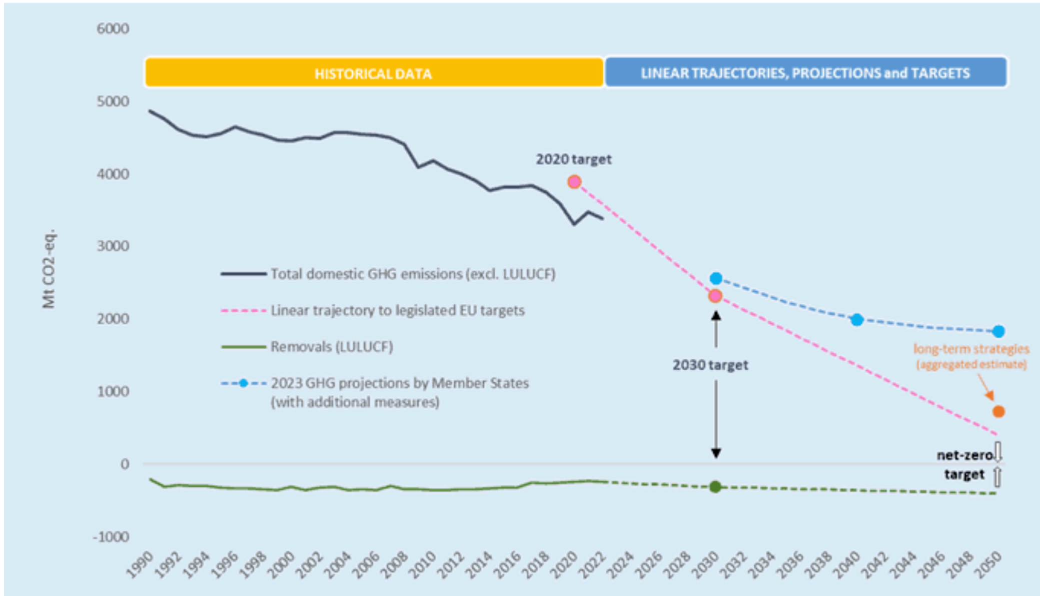

Figure 2.1: Assessment of progress towards the EU 2050 climate-neutrality objective (European Commission, 2023)

decrease, the EU is not on track to reach the 2030 target of a 45% reduction of the 1990 levels (EC, 2023).

Achieving the EGD requires an analysis of greenhouse gas emission sources, and a large body of literature analyzing each sector that contributes to the EU's GHG emissions has emerged with evidence that the transport sector is playing a large role in emissions sources. Sporkmann et al. (2023) conducts a comprehensive analysis of carbon emissions from European land transportation. Their data shows that 1990 CO_2 emission levels measured around 3.8 billion tons. Actual levels in 2019 measured around 2.9 billion tons. This data displays an overall decrease in carbon emissions; however, in relation to the 2030 target set by the EGD, carbon emission levels in 2019 were 1.17 billion tons above the 2030 target of a 45% decrease of the 1990 actual (Sporkmann et al., 2023). To reach this target, a more in-depth analysis of carbon emission sources must be conducted.

Dividing up the EU's total GHG emissions into transport, agriculture, industry, manufacturing and construction, and electricity and heat, Figure 2.2 displays changes in carbon emissions by each sector since 1990. Agriculture, industry, manufacturing and construction, and electricity and heat have all faced reductions in carbon emissions; however, the transport sector has witnessed a 26.51% increase as compared to 1990 levels (Sporkmann et al., 2023). The transport sector is the "only sector in the EU where emissions increased from 1990 to 2019" (Sporkmann et al., 2023). Data from the European Commission (2023) reveals a 4.7% or 361 MtCO2-eq increase in GHG emissions due to transport.

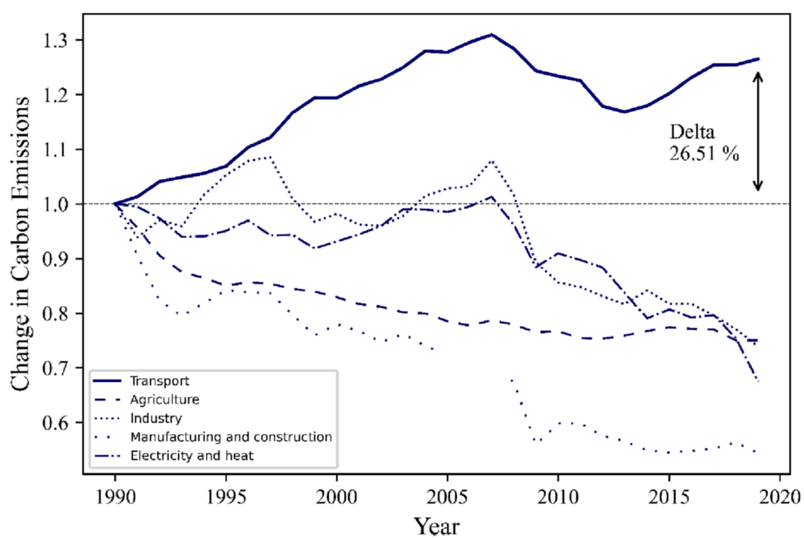

Figure 2.2: Changes in carbon emissions by sector (Sporkmann et al., 2023)

Building off of this data, Bhat & Garcia (2021) employ a sustainability assessment of road transport carbon emissions. Focusing on road transport GHG emissions—carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O) gas emissions—they analyze the role of fuel combustion in road transport, revealing that road transport accounted for 24% (=7.75GtCO2) of the world's CO2 emissions in 2015 and 24% of Europe's CO_2 emissions (Bhat & Garcia, 2021). Utilizing the International Panel for Climate Change's (IPCC) mobile source methodology, Bhat & Garcia calculate that from 2000 to 2018 the EU's road transport sector added 0.23 -- 0.24 Gt of carbon to the atmosphere each year. Continuing at this consumption rate, the EU will have depleted its carbon transport budget by the early 2060s (Bhat & Garcia, 2021). Bhat & Garcia recommend an electrification of the transport sector to help achieve carbon targets.

An information paper created by the Environmental Coalition on Standards (ECOS), the European Environmental Bureau (EEB), and Deutsche Umwelthilfe (DUH), builds on these findings and further explores Bhat & Garcia's recommendations for an electrification of the transport sector and specifically road transport. With passenger cars accounting for 60.6% of transport emissions in the EU, this report discusses the importance of adhering to the EGD targets (ECOS et al., 2023). The report details that current projections estimate that the EU is on track to reach a 22% decrease in transport emissions by 2050, far behind the 40% reduction goal set forth by the EGD (ECOS et al., 2023). The information paper proposes two ways to reduce passenger car CO_2 emissions and meet the EGD goals, making vehicles more efficient and changing the fuel used.

2.3 The potential of electric vehicles

With the proposal of an electrification of the transport industry, research and literature regarding the sustainability of this strategy have increased. In addition to an analysis of the transport sector's GHG emissions, the ECOS, EEB, and DUH (2023) information paper provides information comparing the environmental impacts of ICEVs and EVs through an analysis of their production and consumption. In 2020, the global warming potential of combustion drive gasoline vehicles is listed at 100%; whereas, the global warming potential of battery drive vehicles is 50% (ECOS et al., 2023). Battery drive vehicles possess a much lower global warming potential than combustion engine vehicles; however, its environmental impact exists as abiotic resource depletion because of the production of the lithium-ion battery, which can additionally create water, soil, and air pollution as a result of mining and manufacturing processes (ECOS et al., 2023).

Faria et al. (2012) expand on the comparison of the sustainability of ICEVs and EVs by applying a Well-to-Wheel (WTW) methodology, a specific type of life cycle assessment to different energy supply and vehicle technology scenarios. Using a custom built data acquisition system, the authors find that for the average EU electricity mix, "BEVs have less than a half of the emissions than an ICEV" (Faria et al., 2012). The authors emphasize the importance of sources of electricity; coal produces 916 gkWh of CO_2; whereas, photovoltaics (PV) produce 90 g/kWh of CO_2, and hydro and wind both produce less than 20 g/kWh (Faria et al., 2012). They address the total ownership costs of EVs and ICEVs being roughly equivalent despite the lower operational costs of EVs; however, they argue that future battery price reductions will reduce investment costs and ultimately, encourage the adoption of EVs (Faria et al., 2012).

Exploring the importance of sustainable energy production, Nęcka & Knaga (2021) conduct an environmental analysis of three EVs—e-crafter 35, e-NV200 and Nissan Leaf—in comparison to ICEVs. The analysis begins with estimations of the energy demand of these EVs.

Considering the three vehicles' battery capacity [kWh], loads per 24 hours, daily energy demand [kWh], number of working days per week, total daily demand [kWh], and annual energy demand [kWh], Nęcka and Knaga (2021) calculate the total annual demand of the three vehicles as 67,558 kWh. With this information, they calculate the annual CO_2 emissions of the three vehicles to be 52,560 kg (Nęcka & Knaga, 2021). Comparing this value to the calculated value of the annual CO_2 emissions of three combustion vehicles (Crafter 35, Dobo Cargo Standard, Micra)—44,015kg—, Nęcka and Knaga (2021) find that replacing the entire fleet with EVs would result in an increase in CO_2 emissions of around 16%. With these results, they discuss the importance of using renewable sources to charge EVs which would reduce CO_2 emissions by 44Mg per year (Nęcka & Knaga, 2021).

Expanding on the potential environmental damages of EVs Guzmán et al. (2022) present a study on the sourcing of metals for EVs, while also arguing that accurate sustainability assessments can only be conducted after taking into consideration vehicle use. Their findings support Nęcka and Knaga's (2021) claims that EVs have higher emissions when analyzed on a cradle-to-gate scale. The cradle-to-gate model is a life cycle assessment model that analyzes a product's environmental footprint from raw extraction (cradle) to the factory's 'gate'. The authors find that EVs begin to offset manufacturing impacts and surpass ICEVs environmentally after vehicle use. Additionally, if vehicle use is fueled using renewable energy sources, the margin between EV and ICEV environmental footprints widens (Guzmán et al. 2022). Ultimately, the authors argue that the environmental performance of BEVs is reliant on efficient management of: "(1) the energy grid; (2) the useful life of the vehicles (amount of expected driven kilometers); and (3) the source of the commodities used to manufacture those cars" Guzmán et al. (2022).

Although EVs present extensive potential to reach the EGD sustainability goals, existing literature researches the barriers preventing the diffusion of these technologies. Pamidimukkala et al. (2023) expand on EV research with a state-of-art review of the adoption of EVs. This paper investigates the factors affecting mass adoption and the reasoning behind the market penetration of EVs still being at the nascent stage. This report categorizes influential factors into four types—contextual, situational, demographic, and psychological. Through a review of 312 relevant articles, the authors discovered the most cited factors preventing EV adoption to be a lack of infrastructure and the limited driving range; however, their reduction in air pollution and the availability of policy incentives encouraged EV adoption (Pamidimukkala et al., 2023).

2.4 An application of EVs to Portugal and Lisbon

Concentrating on Lisbon, Portugal, extensive literature has engaged with the possible electrification of road transportation in this urban area. The EU's GHG emissions are exemplified by the European Commission's (2020) energy balance sheets detailing Portugal's energy consumption and production. The total final energy consumption for 2018 is listed as 16,200.8 ktoe, and the final energy consumption for the transport sector is 5,859.3 ktoe, meaning that the transport sector accounts for 36.2% of Portugal's total energy consumption (European Commission's, 2020). Assessing electrification to mitigate this issue, Freire & Marques (2012) conduct a comprehensive "integrated energy, GHG and cost-life-cycle analysis of EVs for Portugal. Through a sensitivity analysis, the authors discover that subcompact EVs have an "overall GHG performance superior to conventional vehicles for an electricity generation GHG intensity below 800gCO_2eq/kWh (Freire & Marques, 2012). They discuss that electricity does not emit GHG emissions at the point of use; "however, the [life cycle (LC)] GHG intensity of electricity (gCO2eq/kWh) used to charge EVs is a key parameter in estimating the LC GHG emissions of vehicles" (Freire & Marques, 2012).

Baptista et al. (2014) further quantifies the potential environmental footprint reductions from the adoption of EVs in the Lisbon region. Through the road monitoring of 9 drivers in Lisbon, the authors quantified the impacts of using alternative vehicles, "concluding that the alternative technologies would reduce the Well-to-Wheel (WTW) energy consumption per kilometer between 37% and 68%" (Baptista et al., 2014). Supporting this data, Rolim et al. (2013) gathered data from 25 EV users to assess their motivations, daily patterns, and vehicle operation and management. From this data, the authors revealed that EVs reduce energy consumption by 35-43% and CO_2 emissions by 58-63% when compared with ICEVs (Rolim et al. (2013). Similar statistics were found in the Ribau & Ferreira (2014) study. They calculated that "around 43% of the energy consumption, 47% of CO2 emissions, and 17%-40% of air pollutants could be reduced with the expected electric vehicle evolution" (Ribau & Ferreira, 2014). Figure 2.3 from Ribau & Ferreira (2014), displays the percentage of energy consumption and CO_2 emissions decrease of an electrified light duty vehicle (LDV) fleet. They calculate that a reduction of "around 44% and 47% of energy consumption and CO_2 emissions respectively can be achieved by 2050" (Ribau & Ferreira, 2014). The authors note that a 100% BEV scenario would require a large amount of electricity, thus, rapidly increasing energy consumption and emissions. They conclude that the efficiency of EVs and overall energy consumption and emissions would maintain their advantages over ICEVs. In resume, all of these studies estimate a potential reduction of around 40% of the energy consumption and at least 47% of the CO_2 emissions, and thus, EVs contain immense potential for the reduction of GHG emissions.

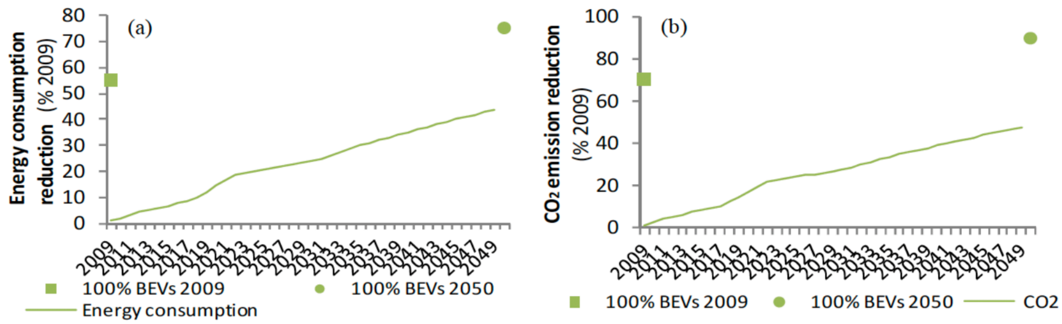

Figure 2.3. Percent reduction of (a) energy consumption and (b) CO2 emissions for LDV fleet (Ribau & Ferreira, 2014)

Lopes et al. (2013) expands on these estimations of the sustainability of EVs and explores consumer advantages and disadvantages of vehicle purchase. Utilizing a well-to-wheel analysis, the authors generated data comparing ICEVs and EVs. Similar to the previous studies, this study calculates a 45.9% and 58.1% reduction in energy consumption and CO_2 emissions for EVs (Lopes et al., 2013). They list these statistics, lower lifecycle energy consumption, operating costs, and air and noise emissions as advantages of EV purchases; the high purchase price, reduced driving range, and insufficient charging system are identified as disadvantages (Lopes et al., 2013). Utilizing these factors, the authors evaluated the market potential of EVs based on car and consumer attributes. Utilizing a rule-based screening methodology, results suggest that the diffusion of EVs in the LMA is only suitable for 10.4% of households (Lopes et al., 2013). Upholding these findings, Braz da Silva & Moura (2016) find that the "uptake of the electric vehicles is expected to be rather low (less than 10% of new cars until 2030)" through a scenario analysis. This data corresponds to roughly 25% of the Portuguese population; thus, the impact of EVs on the national environmental footprint is minimal (Braz da Silva & Moura, 2016). Nevertheless, the adoption of EVs would reduce local emissions and improve the air quality of concentrated urban areas.

3. Methodology

3.1 Definition of Cost-Benefit Analysis

A cost-benefit analysis (CBA) is defined as the "process of comparing the projected or estimated costs and benefits (or opportunities) associated with a project decision" (Stobierski, 2019). Comparing the total costs to the total benefits produces a quantifiable value or ratio that provides a "benchmark for project evaluation" (Goel & Sharma, 2022). The CBA in this report consists of four main steps: (1) establishing a framework for the analysis, (2) identifying the costs and benefits, (3) assigning a numerical value to each cost and benefit, and (4) comparing the total costs and total benefits (Stobierski, 2019).

(1) Establishing a framework: In order to accurately compare the costs and benefits, a framework and common currency of the two elements needs to be established.
(2) Identifying the costs and benefits: This element of the analysis can be broken down into direct, indirect, intangible, and opportunity costs. Similarly, benefits can be classified as direct, indirect, intangible, and competitive.
(3) Quantifying the identified costs and benefits: Utilizing the previously established framework, values can be assigned to all of the costs and benefits.
(4) Accumulating and comparing total costs and benefits: A CBA accumulates all of the costs and benefits and compares the total costs to the total benefits. This comparison formulates an evaluation of the value of a product or business.

(Stobierski, 2019)

3.2 Research Design

This report evaluates the costs and benefits of battery electric vehicle (BEV) penetration in Lisbon by 2050 based on existing CBA structures conducted by M.J. Bradley & Associates (2021) in Nevada and Manuel Branco Nery Nina (2010) in Portugal. This report contains a discussion of both the user and societal benefits of EV adoption. From the user perspective, the CBA analyzes the total cost of ownership (TCO) of an EV compared to an ICEV. The societal perspective utilizes two different penetration scenarios, one moderate and one high, to examine the potential reductions in fuel consumption and carbon emissions.

This paper conducts a modified CBA of EVs to evaluate the potential impacts of a theoretical mass adoption of the technology in Lisbon. To conduct this research, this report relies on an extensive quantitative analysis of data from a variety of sources—existing CBAs, government reports, graduate dissertations, and academic journals. Energy and electricity generation and consumption data is sourced primarily from the European Commission and the International Energy Agency (IEA); data on EVs is sourced from the IEA, the European Environment Agency (EEA), and European Automobile Manufacturers' Association (ACEA).

To calculate user savings of purchasing a BEV, the TCO of the electric Peugeot 208 5 Portas was compared to the TCO of the gasoline engine Peugeot 208 5 Portas. The TCO consisted of a summation of the purchasing price of the vehicle and home charger, annual costs of electricity consumption, and annual maintenance costs. Comparing the TCO of the electric and gasoline versions of the vehicle, this data is used to estimate the average annual financial user benefits. The formula from Nina's (2010) CBA was adapted to fit the accessible data for this project.

Final cost = (acquisition cost) - (sale revenue) + (legal cost) + (operational costs) - (operational revenue)

As identified by M.J. Bradley & Associates (2021), the costs related to the BEV adoption include "the cost of electricity generation, the cost of transmission, incremental peak generation capacity costs for the additional peak load resulting from [BEV] charging, and annual infrastructure upgrade costs for increasing the capacity of the transmission and secondary distribution systems" (M.J. Bradley & Associates, 2021). This study utilizes current data and future estimates of BEV characteristics and driver usage to predict electricity consumption in 2050. Electricity consumption is then used to estimate Lisbon's electric distribution revenue. It is important to note that future adoption of BEVs may coincide with government incentives to manage user charging sessions. As EV charging increases, unsustainable levels of power demand can overwhelm the grid; thus coordination of EV charging and peak periods must be managed (Meintjes et al., 2021). This report does not account for these charging scenarios. The electricity consumption is then compared to the amount of fuel not consumed (FNC). To calculate the increase in electricity demand and the fuel not consumed, modified versions of the following formulas from Nina's (2010) CBA were used. Then, using the average electricity/fuel consumption and electricity/fuel prices (0.24€/kWh; 1.76€/L), the cost of electricity was calculated and compared to fuel consumption costs (Eurostat, 2024; GlobalPetrolPrices.com, 2024).

Total electricity consumption, TELC, (GWh):

$$TELC = NV * \left(\frac{AC}{CE}\right) * AD$$

Where: NV - number of EVs circulating; AC - average consumption per kilometer; CE - charging efficiency; AD - average annual distance traveled (13,000 km) (Nina, 2010)

Fuel not consumed, FNC, (L):

$$FNC = NV \times AD \times AVC$$

Where: AVC - Average Fuel Consumption

Analyzing the potential environmental costs and benefits of BEV penetration, this report calculates the annual greenhouse gas emissions from electricity generation in comparison to ICEV GHG emissions. Electricity generation for BEV charging is analyzed under a zero-carbon electricity scenario in which the city is on track to meet 2050 carbon neutrality goals. ICEV GHG emissions account for direct tailpipe emissions and fuel production and transportation emissions. The following formulas were adapted from Nina's (2010) CBA to calculate the emissions cost with the accessible data.

Total emission costs, $TEMC$ (in €/km):

$$TEMC = \sum_j EC_j$$

Where: EMC_j - emission costs for pollutant j (in €/km)

$$EMC_j = DC_j \times EM_j$$

Where: DC_j - damage costs of pollutant j (in €/kg) and EM_j- emission mass of pollutant j (in kg/km)

To quantify all elements using the same unit, the net present value (NPV) of future cash flows is calculated using a 3 percent discount rate (M.J. Bradley & Associates, 2021). The discount rate accounts for the fluctuating value of money in the future, and the NPV of a system is “ the present value of all the investment costs that it incurs during its lifetime minus the present value of all the revenue that it earns over its lifetime (GOEL). To calculate the NPV of this system the following formula from Harvard Business (Gallo, 2014) is used:

$$NPV = \sum Cash\ Flow \div (1 + Discount\ Rate)^{n}$$

3.3 Research Boundaries

Due to the unpredictability of future prices, this analysis assumes a constant of data over time; thus, the results are not accurate projections of future costs and benefits. This report acknowledges that prices of electricity and EVs are likely to decrease by 2050 because of innovations in battery technology; however, these reductions were not fully accounted for in the resulting estimates (M.J. Bradley & Associates, 2021).

Additionally, in this system, there exist both positive and negative externalities, “an impact on a party that is not directly involved in the transaction” (Nina, 2010). Consequently, the prices estimated in this report do not reflect the full costs and benefits of the production and consumption of EVs. Although a CBA presents an efficient method/strategy to evaluate the impact of the diffusion of EVs, difficulty in predicting future scenarios and difficulty in establishing a functional unit in which to quantify all of the variables prove to be limitations of this study. Further limitations are discussed in section 5.3.

3.4 Statement of Ethics

The ISP Statement of Ethics highlights these fundamental principles: the responsibility towards the people and cultures under study; the importance of transparency and honesty; the recognition of personal and cultural biases that may impact the research; the proper citation of sources; the acknowledgment of contributions; the anticipation and mitigation of potential study-related consequences; and the readiness to seek advice and address ethical concerns promptly (SIT, 2022). This study adheres completely to the ISP Statement of Ethics.

4. Results

4.1 Penetration Scenarios

The CBA will be conducted under two different estimates of EVs in circulation under the 2050 timeline. These amounts will be referred to as the penetration scenarios—a moderate scenario and a high scenario. This CBA only accounts for 100% electric passenger light-duty vehicles. These scenarios were calculated utilizing this data: “Portugal will register an annual increment of 113,008 light-duty vehicles from 2018 to 2030” (which was calculated using a linear regression model created by Meintjes et al. (2021); as of 2018 there were 19,689 electric LDVs in Portugal (Meintjes et al., 2021); and “Lisbon is the national territory with the highest concentration of EVs, as it concentrates 23% of registrations of light EVs until June 2018” (Ala et al., 2021). Utilizing this data, estimates for the increase in electric LDVs in Portugal were calculated and then distributed to the city of Lisbon.

The moderate and high scenarios are based on penetration estimates provided by Braz da Silva & Moura (2016) and goals set in the RoadMap Portugal 2050 (República Portugal et al., 2019). Committed to the 2050 goal of carbon neutrality by 2050, Roadmap Portugal 2050, sets objectives to reach neutrality through adaptations made in the transport sector. As detailed in the Roadmap, the objective of the country is to reach 80% penetration of the entire vehicle fleet by 2050 (República Portugal et al., 2019). This data is used to calculate the high penetration scenario. For the moderate scenario, Braz da Silva & Moura (2016) estimate that there will be a 39% EV share in the passenger vehicle market in 2050. Both the moderate and high scenarios assume that high emissions constraints will promote the sale of EVs; however, it is important to note that if EV travel demand and growth remain at the pace that it exists, EVs will only have a 16% market share by 2050 (Braz da Silva & Moura, 2016).

The moderate scenario has been calculated using the 39% diffusion estimation in addition to the aforementioned vehicle registration information and growth estimates. In 2050, a 39% penetration of the Portuguese vehicle fleet equates to approximately 1,430,029 EVs in Portugal and 328,907 in Lisbon.

Moderate scenario (NV_m) using a 39% penetration:

Estimated increase in LDVs in PT:

$$113008\,LDVs \cdot (2050 - 2018) = 3616256$$

Estimated increase in electric LDVs in PT:

$$3616256 \cdot 0.39 \approx 1410340$$

Estimated total of electric LDVs in PT:

$$1410340 + 19689 = 1430029$$

Estimated total of electric LDVs in Lisbon:

$$1430029 \cdot 0.23 \approx 328907$$

Calculated in a similar manner, the high estimate envisions a scenario in which actions have been taken to meet the objectives in the Roadmap Portugal 2050 and in the EGD. This scenario is based on the Roadmap's objective of reaching an 80% market share of electric passenger vehicles by 2050 (Seixas et al., 2010). Applying this data to the calculations utilized for the moderate scenario, the estimated number of EVs in 2050 in Portugal is 2,912,694 and 669,920 in Lisbon.

High scenario (NV_h) using an 80% penetration:

Estimated increase in LDVs in PT:

$$113008LDVs \cdot (2050 - 2018) = 3616256$$

Estimated increase in electric LDVs in PT:

$$3616256 \cdot 0.80 \approx 2893005$$

Estimated total of electric LDVs in PT:

$$2893005 + 19689 = 2912694$$

Estimated total of electric LDVs in Lisbon:

$$2912694 \cdot 0.23 \approx 669920$$

Using these two scenarios, NV_m and NV_h, the following sections calculate the cumulative costs and benefits of a mass adoption of EVs in Lisbon in 2050.

4.2 User benefits

A CBA from the user point of view contains the following variables (as adapted from Nina's CBA (2010)):

- Circulation tax for ICEVs and BEVs
- Fuel and electricity costs in 2050;
- Battery costs in 2050;
- Technological advances of LDV options in 2050

As mentioned above, data regarding the fuel, electricity, and battery costs in 2050 was inaccessible, so the prices calculated in this analysis utilize 2024 prices.

Utilizing the 2050 vehicle purchase and maintenance projections provided by M.J. Bradley & Associates (2021) CBA and Peugeot 208 5 Portas consumption data, the table below displays total annual cost comparisons between a BEV and an ICEV for vehicle owners. The primary benefits of consumer BEV purchase are the exemption from the vehicle tax (ISV), the circulation/road tax (IUC), and the independence from gasoline (MOBI.E, n.d.). Additionally, as electricity prices decrease over time, BEV users will further benefit from these lowered costs.

Table 4.1: Total annual cost of an ICEV (M.J. Bradley & Associates, 2021; Peugeot, n.d.)

ICEV (*Peugeot 208 5 Portas* 1.2 PureTech 100 cv CVM6)	
Vehicle Purchase (€)	9 225.48
Vehicle Tax (ISV) (€)	891.49
Circulation Tax (IUC) (€/yr)	143.68
Maintenance (€/yr)	362
Consumption (l/100km)	5.2
Distance (km/yr)	13 000
Annual Consumption (l/yr)	676
Gasoline (€/yr)	1 187.92
Total Annual Cost (TAC_G) (€/yr)	11 448.57

Table 4.2: Total annual cost of a BEV (M.J. Bradley & Associates, 2021; Peugeot, n.d.)

BEV (Elétrico 136 cv (100 kW) - Bateria 50 kWh Automático)	
Vehicle Purchase (€)	8 681.10
Home Charger Purchase (€)	119.11

Maintenance (€/yr)	201
Consumption (kWh/100km)	16
Distance (km/yr)	13 000
Annual Consumption (kWh/yr)	2080
Energy (€/yr)	484.66
Total Annual Cost (TAC_E) (€/yr)	9485.87

Savings per BEV, SB, (€):

$$SB = TAC_E - TAC_G \quad \rightarrow \quad 11\,448.57 - 9485.87 = 1962.70€$$

Where: TAC_E - total EV annual cost (€); TAC_G - total ICEV annual cost (€)

$$SB_m \qquad SB \times NV_m \approx 646\,€\,million$$

$$SB_h \qquad SB \times NV_h \approx 1.3\,€\,billion$$

The savings per BEV (SB) equates to €1962.70. Applying this to the projected penetration scenarios, the net savings for the moderate scenario would amount to around €646 million and €1.3 billion for the high scenario. These calculations were made without the application of a government incentive. Current government incentives in Portugal provide a €4000 reduction in the purchasing price of electric, light passenger vehicles (Mobie, n.d.).

4.3 Societal benefits

Analyzing a CBA of EVs from a societal point of view, this report focuses on a comparison of fuel and electricity consumption prices and the potential reduction in CO_2 emissions.

4.3.1 Electricity consumption

Table 4.3 displays the daily average energy consumption and charging times of the three most popular EVs in Portugal—Nissan Leaf, Tesla Model 3, and the Renault Zoe (Nogueira et al., 2022).

Table 4.3 Daily average energy consumption of the Nissan Leaf, Tesla Model 3, and Renault Zoe (Nogueira et al., 2022).

Energy [Wh]				
	Nissan Leaf	Tesla Model 3	Renault Zoe	Total
Long route	14 974	16 088	13 908	44 970
Short route	2 376	2 595	2 261	7 232
Average trip	8 675	9 342	8 085	26 101
Weighting factor	42,2%	35,2%	22,3%	100%
Weighted energy	3 663	3 289	1 825	**8 776**

Using this data, the total electricity consumption in Lisbon for both penetration scenarios in 2050 were calculated as 1052 GWh for the moderate scenario and 2143 GWh for the high scenario.

Total electricity consumption, TELC, (Wh):

$$TELC \qquad 8\,776 \cdot 365 = 3199.59\ kWh$$

$$TELC_m \qquad \frac{(TELC \cdot NV_m)}{10^6} \approx 1052\ gWh$$

$$TELC_h \qquad \frac{(TELC \cdot NV_h)}{10^6} \approx 2143\ gWh$$

Assuming a price of €0.23 in Europe (per kWh), total electricity consumption prices are estimated to be €242 million for the moderate scenario and €493 million for the high scenario (Eurostat, 2024).

Total electricity consumption prices, *TELP, (€):*

$$TELP = AEC \cdot ELP$$

Where: ELP - price of electricity (0.23 €/kWh)

$$TELP_m \qquad AEC_m \cdot ELP = 242\ €\ million$$

$$TELP_h \qquad AEC_h \cdot ELP = 493\ €\ million$$

These values exist as the projected annual revenue of electricity consumption from BEV charging in 2050. This report does not account for the utility revenue, production costs, or potential net revenue.

4.3.2 Fuel Consumption Reduction

Comparing revenue of electricity consumption from EV charging in 2050, the adoption of BEVs consequently results in a loss of fuel consumed. For the moderate penetration scenario, the amount of fuel not consumed is estimated to be 222 million liters a year, or 6.7 billion liters by 2050. The high scenario projects a loss of 453 million liters of fuel consumed, totaling 13.6 billion liters by 2050. Assuming a price of 1.76€/L, this reduction in fuel consumption coincides with a loss in revenue of approximately €391 million and €796 million for the moderate and high scenarios, respectively (GlobalPetrolPrices.com, 2024).

Fuel not consumed, FNC, (L):

$$FNC = NV \times AVC$$

Where: AVC - average fuel consumption for ICEVs (676 L)

$$FNC_m \qquad NV_m \times AVC \approx 222\ million\ liters$$

$$FNC_h \qquad NV_h \times AVC \approx 453\ million\ liters$$

Cumulative fuel reductions, CFNC, (L):

$$CFNC = FNC \times T$$

Where: T - cumulative years

$CFNC_m$ $\quad FNC_m \times (2050 - 2020) \approx 6.7\ billion\ liters$

$CFNC_m$ $\quad FNC_h \times (2050 - 2020) \approx 13.6\ billion\ liters$

Cost of fuel not consumed, CF, (€):

$$CF = FNC \cdot 1.76\ €$$

CF_m $\quad FNC_m \cdot 1.76€ \approx 391\ €\ million$

CF_h $\quad FNC_h \cdot 1.76€ \approx 796\ €\ million$

4.3.3 CO_2 Emissions Reduction

While the shift to EVs suggests a loss in revenue, as fuel prices are estimated to be higher than electricity prices, BEVs present immense potential in reducing environmental damage. The following results attempt to quantify these benefits, specifically, a reduction in carbon emissions, in monetary value.

Using this data provided by the EPA (n.d.), "every gallon of gasoline burned creates about 8,887 grams of CO2" or every liter of gasoline burned creates about 2348 grams of CO_2, the total emission costs reduced through EV penetration was calculated below. Additionally, to calculate the damage cost of carbon in Portugal, the Tax Foundation (n.d.) was consulted to obtain this data: €23.20 per ton of $CO2_e$ or 0.0232 €/kg. The cumulative potential benefits of a reduction in damage costs of carbon amounts to €23.9 million for the moderate scenario and €48.7 million for the high scenario.

Total emission costs, TEMC (€):

$$TEMC = DC \times EM \times NV$$

Where: DC - damage costs of CO_2 (€/kg) and EM - emission mass of CO_2 (kg/km)

$DC = 23.2\ €/ton\ of\ CO2_e$ (Tax Foundation, 2023)

$EM = 116\ g/km$ (Peugeot, n.d.)

$TEMC_m$ $\quad DC \times EM \times NV_m \approx 885\ 154\ €$

$TEMC_h$ $\quad DC \times EM \times NV_h \approx 1.8\ €\ million$

Cumulative TEMC, CTEMC (€):

$$CTEMC = TEC \times T$$

Where: T - cumulative years

$CTEMC_m$ $\quad TEMC_m \times (2050 - 2023) \approx 23.9\ €\ million$

$CTEMC_h$ $\quad TEMC_h \times (2050 - 2023) \approx 48.7\ €\ million$

These projections display the potential amount of savings that a mass adoption of EVs in Lisbon would exhibit. An accurate prediction is difficult to calculate because the positive externalities of a reduction in carbon emissions are immeasurable and the damage cost of carbon does not account for all benefits related to the mitigation of climate change. These projections also do not account for all tailpipe emissions and only represent the potential savings presented by a reduction in CO_2 emissions; thus, by 2050, a quantification of the reduction in GHG emissions would be much higher.

5. Discussion

The results of the modified CBA conducted in this report reveal positive net benefits of a mass adoption of EVs in Lisbon by 2050. As a modified CBA, this report attempts to compare the total costs and benefits of EVs; however, not all costs and benefits were able to be calculated. Overall, the CBA produced results that prove EVs to be monetarily beneficial in terms of the total cost of ownership and emissions reduction. Electricity and fuel consumption revenue prices revealed savings for consumers but a loss in revenue for utility producers, as electricity prices are lower than fuel prices.

5.1 User Benefits

The adoption of EVs presents immense potential for consumers. Because EVs exhibit increased efficiency, require less maintenance, and do not rely on fuel, the TCO of a BEV is less than that of an ICEV. As EV technology becomes more accessible in the future and as electricity prices decrease, this margin will continue to grow, and accessibility to EVs will increase, further reducing the TCO. For the moderate scenario, there is a potential for a cumulative reduction of €646 million in TCO. In the high scenario, the cumulative reduction of TCO equates to around €1.3 billion. These estimates do not account for existing or future consumer tax benefits and government incentives enacted to encourage the purchase of EVs. The inclusion of these elements would generate additional savings for the vehicle user.

Electricity in these scenarios assumes a renewable energy grid. Based on Portugal's goals of carbon neutrality by 2050, the costs related to fossil fuel energy generation have been omitted in the EV CBA, as this study assumes 100% clean energy production by 2050. If this is not achievable by 2050, these calculations do not account for the cost of emissions that the electricity production used for EV charging would generate. Electricity production proves an instrumental aspect of EV sustainability. Only through clean electricity generation are zero emissions achievable.

5.2 Society Benefits

Analyzing the costs and benefits of a societal shift to EVs, Lisbon will acquire €242 million (moderate scenario) or €493 million (high scenario) in electricity consumption revenue due to charging. This increase in electricity consumption would also signify a reduction in fuel consumption. This equates to a loss in fuel consumption revenue of €391 million (moderate scenario) or €796 million (high scenario). These projections do not account for fuel tax or value-added taxes. Although these projections denote a loss in revenue for producers, they are also considered benefits for consumers, as the cost of consumption will be reduced with the transition from gasoline to electricity. Additionally, as the price of electricity is projected to decrease over time and the price of gasoline is projected to increase, the margin between these estimates will grow.

Environmentally, in 2050, Lisbon would experience €23.9 million or €48.7 million saved in terms of the social cost of carbon emissions. These calculations do not account for the damage costs of other emissions and pollutants such as particulate matter or nitrous oxide; however, the diffusion of BEVs would reduce these emissions as well. A quantification of the benefits of a reduction in GHG emissions is difficult to accurately predict. The primary positive externality of a reduction in carbon emissions—the mitigation of climate change—arguably, cannot be measured by a monetary value. Nonetheless, the damage cost of carbon attempts to provide a numerical value to visualize the environmental harms of emitting carbon dioxide into the atmosphere. The adoption of EVs reveals mass savings in these costs.

Currently, the popularity of EVs is low due to a lack of infrastructure, limited driving range, and high purchase price in comparison to ICEVs (Pamidimukkala et al., 2023). These findings demonstrate a need for government incentives and investments in EV technology to initiate the EV shift. Innovations in EV technology are already being made; thus, adaptations to meet clean energy production must also begin. With an uptake in electricity consumption through EV charging, a zero emissions future requires renewable energy production and a clean energy grid. Overall, the results of this study reveal net positive benefits for a mass adoption of EVs in the city of Lisbon by 2050, signifying a not only (environmentally) necessary action, but an (economically) advantageous opportunity for the future.

5.3 Limitations

This study has limitations, and as a result, this report focuses on three aspects of EV implementation: total cost of ownership, electricity consumption and fuel consumption, and CO_2 emissions. The most prominent limitations are limited access to data, a flawed methodology, and a research deadline.

This research utilizes the methodologies utilized in M.J. Bradley & Associates (2021) CBA and Manuel Branco Nery Nina's (2010) CBA which conduct cost-benefit analyses in Nevada and Portugal, respectively. The application of these methodologies to Lisbon presents potential limitations as the data utilized in these reports is not directly applicable to the targeted region. A lack of availability to current data resulted in difficulty in making predictions for future data; thus, estimates presented in this paper may not accurately reflect future prices. Additionally, estimates were calculated using current data on Portuguese electricity prices, fuel prices, and the social cost of carbon; however, it is projected that "beyond 2020, average electricity prices remain broadly stable up to 2035 and then are projected to moderately decrease up to 2050" (European Commission, 2014). Assuming these prices remain constant between the most recent data collected and 2050, the estimates in this report do not account for these projected changes, and thus, do not accurately predict future savings. Similarly, the inability to predict future price reductions in lithium-ion batteries and BEV purchase prices results in inaccurate estimates. Lastly, cumulative calculations in this report use projected data for 2050 and apply this to previous years. The calculations do not incorporate or correspond with a natural growth of EV penetration; rather, the data represents final projections in the year 2050, not a timeline of projections from now until then. Because of an unpredictability in future prices, the estimates made in this report are flawed.

Calculations utilized in this report are modified versions of calculations provided by the methodology in Nina's (2010) CBA. The methodology provided centers on Portugal as a country; however, this report focuses on the city of Lisbon, meaning modifications to the formulas needed to be made. Basing projections on these existing formulas was difficult as the proportions between the city of Lisbon and the country of Portugal had to be accounted for. These modifications may not be accurate to the existing proportions between Lisbon and Portugal. Other modifications made include an attempt to calculate cumulative values. These calculations do not account for the progression of values from current costs to future costs. Utilizing the methodologies established in the CBAs conducted by M. J. Bradley & Associates

(2021) and Manuel Branco Nery Nina (2010) was helpful in creating a framework; however, the modifications made to adapt these methods to the target city prove to have errors.

Lastly, due to time constraints, it was difficult to quantify all of the aforementioned costs and benefits. To present the most thorough analysis possible, this report focuses on the main benefits and costs of EVs—reduced total cost of ownership, reduced fuel consumption and emissions, and increased energy consumption. Despite the limitations, this report provides a broad overview of the potential savings that two different EV penetration scenarios could generate in Lisbon in 2050.

5.4 Recommendations for Future Work

As this report presents a modified and succinct CBA of EV penetration in Lisbon, future studies can conduct a more in-depth CBA. A more in-depth CBA could consist of a quantification of these variables: "the cost of electricity generation, the cost of transmission, incremental peak generation capacity costs for the additional peak load resulting from [BEV] charging, and annual infrastructure upgrade costs for increasing the capacity of the transmission and secondary distribution systems" and the "cost savings to Lisbon drivers, utility customer savings from reduced electric bills and the monetized benefit of reduced GHG and NOx emissions" (M.J. Bradley & Associates, 2021). With more time and an access to more data, an analysis of all of these elements would be beneficial in providing a concrete comparison of the total costs and total benefits of EV diffusion. It is recommended that this study focuses on the timeline of 2030-2050. Utilizing different price change scenarios for BEV purchase prices, electricity and fuel consumption prices, and carbon costs, future CBAs can provide insightful data for future decisions.

As this study was conducted assuming a clean energy grid, a future study consisting of a CBA conducted on two different electricity supplies—fossil fuel and renewable—would provide an alternate analysis of the impact of electricity sources on EV circulation. This would provide data analyzing the effect energy production has on EV circulation.

6. Conclusion

As demands for transportation rise, sustainable mobility proves necessary to achieve the European Commission's goals of carbon neutrality by 2050. EVs present a promising future for sustainable transportation, and this report aims to quantify the costs and benefits incurred by a mass adoption of this technology. Projections of EV-related costs and benefits calculated in this study reveal immense savings in total cost of ownership, energy consumption prices for users, and emissions costs. As innovations in technology arise, such as more efficient batteries, purchase prices of EVs will decrease, further decreasing the total cost of ownership for users. Similarly, as the city begins to transition to cleaner energy production and depart from fossil fuels, EV charging will become more affordable and cleaner. If EV charging is not sourced from clean electricity, the environmental impact of EV circulation could potentially be as damaging as ICEV circulation. It is instrumental that the penetration of EVs is accompanied by a shift to renewable energy production. As transportation accounts for 40% of final energy consumption in Lisbon, the adoption of EVs is not only necessary but beneficial.

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