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SUSTAINABLE MOBILITY EVALUATION AT CASCAIS: THE IMPACT OF BIKE SHARING ON THE ENVIRONMENT, USING CARBON FOOTPRINT

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Dissertation submitted for the degree of

MASTER ON ENVIRONMENTAL ENGINEERING

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June 2017

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“You don't have
to be great to start
but you have to start
to be great”

Zig Ziglar

THESIS ENVIRONMENT

This dissertation was made in an academic-enterprise environment, at CEiiA.

The Centre of Engineering and Product Development has four main areas of intervention, designated by automotive industry, aeronautics, naval/offshore and mobility. CEiiA offers solutions based in engineering skills and project methodologies, covering all product development phases from concept to production, and the operation of intelligent systems.

The Unit of Mobility and Intelligent Systems is the department where this dissertation took place and this study was integrated in mobi.me, a smart management system for urban mobility, created and conducted by CEiiA's intelligent platform. The company's vision, regarding mobility as a utility, is based on a user-centered approach and a provision of information to help users in real-time decisions. The aims are the reduction of costs, commuting times and the impact of carbon footprint of mobility.

This investigation is focused on the MobiCascais project that was created based on mobi.me, in a partnership between CEiiA and the municipality of Cascais.

MobiCascais was conceived for an integration of all the mobility services and operators of Cascais. This allows the creation of a unique mobility interface for the users of this system, connecting transportation solutions such as parking and public transportation access, and payment though a single card.

This project also contains an innovative bike sharing and parking service, built through the development of several elements, for instance a universal bike docking stations, which are also capable of charging electric bike batteries. The management entity of this services is Cascais Próxima, E.M., S.A., a municipal company whose shared capital is wholly owned by the Municipality of Cascais.

This investigation is focused on the bike sharing system, which is part of a growing process due to its recent implementation.

ACKNOWLEDGMENTS

First I would like to thank my University supervisor Profª Cecília Silvia, not only for guiding and supporting me along this year, but also giving me all motivation and the opportunity of working in this field.

I also have to make a profound thanks to CEiiA, especially to all the individuals that form the Academia and the Engineering Systems teams, in which R&I and BI are particularly included. I thank you all for the opportunity that you have given to me, and I will always remember it with great care. The chance of completing this study with so privileged working conditions will never be forgotten.

I would like to make a very special thanks to my company supervisors, Carolina, André and Vladimiro, for transmitting the knowledge and enthusiasm that allowed me to do this dissertation, in a truly enviable working environment.

I would like to express my gratitude to the Municipality of Cascais, and especially to Cascais Próxima for giving me all the necessary help and cooperation, in order to have the opportunity to achieve the results of this dissertation.

It would also be highly irresponsible of me, not to thank all my friends who accompanied me during all my academic journey. For I am pretty sure that without them, none of this would be possible. They were my company, they were my strength and my great source of inspiration. A special heartfelt thanks to all my friends of BEST Porto, for teaching me the great value of true and honest friendship.

Last but not least, I express my warmest gratitude to my mother and sister, Lucia and Isabel, for never giving up on their ghost son and brother, principally during this phase of his life. To my father Domingos, my uncles Miguel and Fátima, and my other relatives, for always believing in me. I thank you all with all my heart.

ABSTRACT

Although there are factors immutable and intrinsic to each city reality, others can be shaped based on governmental decisions, such as, the promotion of sustainable mobility. The demand for mobility solutions that supports sustainable policies and the use of modes of transportation with low emission factors, allow a greater reduction of GHG emitted by cities.

The numerous commitments, made over the years, seek to support the reduction of environmental impacts caused by anthropogenic activities. The measures created at the local level can have a fundamental effect on the fulfilment of this responsibilities. Some parameters, as modal shift, can help to comprehend the local prerequisites, in order to achieve the current reductions goals of the road transport sector in GHG emissions. A higher share of bike use would unquestionably help a minimization of harmful impacts on the environment.

This dissertation has as its main goals the evaluation of the environmental impact of bike sharing and bike share on an urban area, using the global and the individual carbon footprint. The case study of the Cascais is presented on this investigation, as the direct and indirect GHG emissions of road transportation, in the municipality, are taken into account by using a WTW analysis.

The bike sharing system, in Cascais, is still on the initial phase of implementation and therefore, it is going through a process of growth on use and on infrastructure matters. This means that modifications can still be done, in order to answer to users' necessities, as it still does not have a representative impact in the municipality decarbonisation. A strategy to support soft transportation as bike sharing, mainly in the commuting trips, should be define as a priority. Action measures must be adapted frequently and the planning of the new integrated mobility project should be carefully analysed throughout its development.

The scenarios created for yearly increases, on cycle trips and cycle trip length in the municipality, support the possibility of reducing the environmental impact of local mobility, thought a greater modal transition to cycling. Transitions trips from different transportation modes to bike provide the opportunity to complete, not only all current targets and even exceed the established reduction goals in GHG emissions.

KEYWORDS: Sustainable Mobility, Carbon Footprint, GHG emissions, Emission Factor, WTW analysis, Bike Share, Bike Sharing Systems, Cascais

RESUMO

Apesar de haver fatores intrínsecos a cada cidade, outros podem ser adaptados com base decisões governamentais, assim como a promoção da mobilidade sustentável. A procura de soluções de mobilidade que suportem políticas sustentáveis e o uso de meios de transportes com fatores de carbono reduzidos, permite uma maior redução a nível de emissão de GEE, por parte de cidade.

Os vários compromissos, feitos ao longo dos anos, procuram apoiar a redução dos impactes ambientais causados pelas atividades antropogénicas. As medidas criadas a nível local podem ter um grande efeito no cumprimento de responsabilidades humanísticas.

Alguns parâmetros, como a escolha modal, podem ajudar a perceber os pré-requisitos locais, de forma a alcançar as reduções necessárias em GEE, no sector dos transportes rodoviários. Um maior uso de bicicleta ajudaria certamente, a minimizar impactos prejudiciais para o ambiente.

Esta dissertação tem como principais objetivos a avaliação dos impactes ambientais do sistema de partilha de bicicletas e da transferência modal para a bicicleta, ao usar a pegada de carbono global e individual da área de estudo. O caso de estudo é o município de Cascais, no qual as suas emissões diretas e indiretas, no sector dos transportes rodoviários, são tidas em conta ao usar o método WTW.

O sistema de partilha de bicicletas, recentemente implementado em Cascais, continua a sofrer um processo de crescimento, a nível de uso e de infraestrutura existente. Isto significa que alterações poderão ainda ser feitas, de forma a responder às necessidades dos utilizadores, tendo em conta que a percentagem de uso de bicicleta atual ainda não representa grandes reduções a nível de descarbonificação do município. Uma estratégia que poderá provocar essa redução é o apoio a este tipo de transportes suaves com iniciativas inovadoras como este sistema, principalmente no tipo de viagens que apresentam uma maior rotina como os movimentos pendulares. Esses movimentos devem ser definidos com uma prioridade a nível de incentivo e as medidas tomadas devem ser adaptadas e planeadas, de forma a responder a uma melhor integração da mobilidade como apresenta o novo projeto existente na área de estudo.

Os cenários criados para aumentos anuais, em termos de viagem e da extensão das viagens efetuadas, apoiam a possibilidade de uma redução a nível de impactes ambientais dos transportes locais, através de uma maior transição modal para o uso de bicicletas. As viagens de substituição, em diferentes modos de transporte, oferecem uma oportunidade de completar e superar todos os objetivos traçados a nível de redução na emissão de GEE.

PALAVRAS-CHAVE: Mobilidade Sustentável, Pegada de Carbono, Emissões de GEE, Factor de Emissão, Análise WTW, Bike Share, Sistema de Partilha de Bicicletas, Cascais

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SYMBOLS, ACRONYMS AND ABBREVIATIONS

AFOLU – Agriculture, Forestry and Other Land Use

AML – Área Metropolitana de Lisboa

APA – Agência Portuguesa do Ambiente

BS – Bike share

BSS – Bike sharing system

CF – Carbon Footprint

CI – Carbon Intensity

CM – Câmara Municipal

CNG – Compressed Natural Gas

CO_2 – Carbon dioxide

CO_2e – Carbon dioxide equivalent

CONCAWE – Environmental Science for the European Refining Industry

CP – Comboios de Portugal

EC – European Commission

EEA – European Environmental Agency

EF – Emission Factor

EMEP – European Monitoring and Evaluation Programme

ETAC – Estudo de Trânsito de Âmbito Concelhio

EU – European Union

EU ETS – European Emissions Trading System

EUCAR – European Council for Automotive Research & Development

FEUP – Faculty of Engineering of University of Porto

GEF – Global Environment Facility

GHG – Greenhouse Gas

GWP – Global Warming Potential

HSC – High Shift Cycling

ICE – Internal Combustion Engine

IEA – International Energy Agency

INE – Instituto Nacional de Estatística

IPCC – Intergovernmental Panel on Climate Change

ITDP – Institute for Transportation and Development Policy

JRC – European Commission's Joint Research Centre

LCA – Life Cycle Assessment

NGO – Non-governmental Organization

PAMUS – Plano de Ação para a Mobilidade Urbana Sustentável

TDM – Transportation Demand Management

TTW – Tank-to-Wheels

UN – United Nations

WBCSD – World Business Council For Sustainable Development

WRI – World Resources Institute

WTT – Well-to-Tank

WTW – Well-to-Wheels

t or tonnes – 10^3 kg or one metric tonne

kt or ktonnes – kilo-tonnes or 10^3 metric tonnes

1.

INTRODUCTION

Evolution is an uncontainable growing process and a positive change of paradigms can only be achieved with the right tools. As dominant specie and part of an entire ecosystem, we have the responsibility and duty to empower ourselves with the knowledge to build a well-developed society. A resilient and active society can only be achieved by the harmony between all the essential factors to the citizen's life and inspired by sustainable development.

The growth of world's population has, in general, an important contribution to greenhouse gas (GHG) emissions, principally in urban centres and over populated cities. The anthropogenic releases of several pollutants have a large contribution towards a global climate change and cities have been developing strategies to reduce their local GHG emissions. The decrease of harmful gases, in transportation sector, has a great impact in the global picture of emissions and although its reduction still represent a major challenge, cities all over the world are trying to put some efforts in creating innovative mitigation measures (IPCC, 2014b).

Technological evolution doesn't always mean a crossed mile on the road of sustainability and an explicit example is the industrialization that occurred in the 19th century. This revolution was the first step in the process that allowed car to become a relatively low cost and easy type of transportation. Even though this modal choice has solved connectivity issues associated with long distances, it has generated several environmental problems. EEA (2016) states that a possible solution is the reduction of commuting distance travelled, accomplished by measures supported with social and financial incentives. Pourbaix et al. (2015) claim that urban mobility choices are strongly linked with density and denser areas normally contain greater concentration of activities. There is also an opportunity in this type of areas for the public transport to respond efficiently to the demand and connect the locations where the origins or destinations of trips are concentrated.

Sustainable mobility is a clear sign of evolution, and rightly leaves its mark on international index associated with the development of cities and communities. The attraction for cities with the best accessibility indicators is a reality that affects migratory flows, and its impact can already be observed in worldwide mobility patterns. Nowadays, cities want to be an example in terms of mobility and to offer their citizens means to safe and fast trip options. Due to a growing desire of the population to increase their productivity and to ensure maximum efficiency in their time use, the demand for agile and integrated transport systems are now on top of the high density cities agenda (WBCSD, 2016).

To hold a system that interconnects and integrates different options for modal choice, is synonymous of offering a greater connectivity. Connectivity that will generate productivity and savings not only monetary level but also in terms of time.

An effective mobility relies on a good connectivity and in the integrity of available means of transport in a city. This perception may have effects on the way that leaders and rule makers think about mobility options for their cities and the results are quite satisfactory in some cases (Fernández, 2011). New commitments are encouraging the best use of accessible transports and the creation of new options for the movement of concerned groups. Normally, the interest arises from the knowledge acquired and an informed population opens the possibility of a population that is aware of new paths of sustainability.

Equipping a city with efficient solutions and services that also represent intelligent options, such as controlling the emission of pollutants into the atmosphere, serves as a positive promotion and a projection of a city futuristic mentality. The increasing concern about environmental issues and global warming has lead several governments, institutions and companies to the purchase of innovative measuring instruments and more trustful solutions.

As need for individual trips with vehicles imply fuel consumption and production of carbon emissions, there is an opportunity in replacing it with alternative transportation type, such as bicycling, especially in short distances within a city. The benefits associated with modal change towards this sustainable transport option are commonly known and can be analysed not only on environmental level, but also in social, economic related aspects.

A short-term electronic and automated service that provides the opportunity to access bicycles without the need of private ownership is the extensively used term in this dissertation designated as bike sharing or bike sharing systems (BSS). BSS provide opportunities for cities to promote themselves as part of a consciousness society and to show their commitment in investing on sustainable initiatives. The quality of implementations, initiatives and communication based on awareness can have a vital influence on urban performance and strategies must be defined in each city context.

Bike sharing has been experiencing an exponential growth, since its introduction with the 1st generation program. It started with the "Witte Fietsen" or White Bikes in 1965, as illustrated in **Figure 1.1**, with the initiative of Luud Schimmelpennink, one of the local activists who had as goal to reduce traffic congestion in Amsterdam. The action didn't have the expected result at first but it served as inspiration for the next years (DeMaio, 2009).

Figure 1.1 - The "Witte Fietsen" action plan as pioneer for the 1st generation of bike sharing ("Terug naar de toekomst - Vrij Nederland" 2015)

The popularity of this type of system is increasing in communities all over the world, as demonstrated in **Figure 1.2**, quite a few governments see it as a resourceful sustainable solution with great potential of being integrated in multi-modal systems (WBCSD, 2016). Bike sharing has been, undoubtedly, gaining a new dimension in cities as lessons learned and prevision models can increase effectiveness and usability.

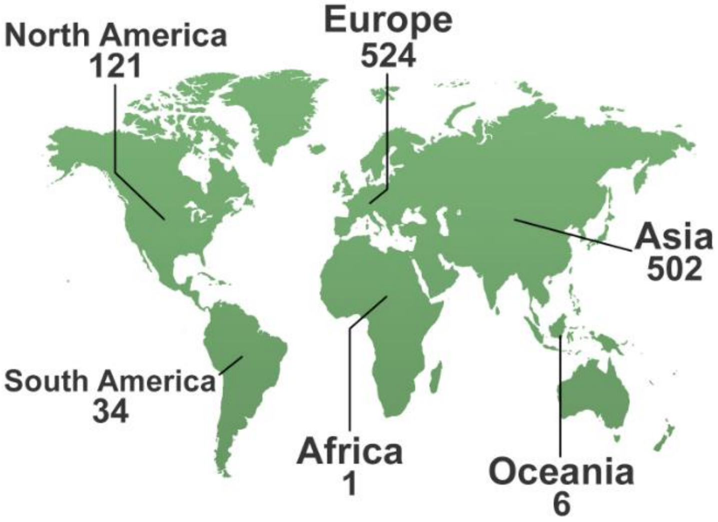


Figure 1.2 - Public Use Bicycle Programs by Continent at the end of 2016 (Russell Meddin, 2017)

At the moment, we are witnessing the results of 4th generation programs as it's getting quite widespread (Léchaud, 2016). This generation of bike scheme can be distinguished from the others with the improvements made on docking stations and connected information systems. It also contains a new type of connectivity, that allows an effective bike redistribution by using a constructive "Demand-Responsive" analysis (Shaheen et al., 2010).

Practical results about bike sharing impacts are explicit in DeMaio (2009) paper, which shows the effects of this schemes on creating a larger cycling population. Having more people willing to use this type of transport can result in a large reduction of corresponding greenhouse gas emissions and in the improvement of public health. The raise of bike mode share in cities is becoming a common thing and there are examples, such as, Barcelona and Paris that had once a low cycling use. The first one saw a rising from 0,75% to 1,76%, in a 2 years period, while the "city of love" increased a poor percentage of 1% in 2001 to 2,5% in 2007 (DeMaio, 2009). Both mentioned periods finished in the same year, which was also marked by the launch of their own BSS, Bicing in Barcelona (Romero, 2008) and Vélib' in Paris (DeMaio, 2009).

Researches on the potential reduction of greenhouse gas emissions (GHG) emissions from mode-share changes, specifically when a bike sharing system is implemented, are in several situations, still not enough to understand global effects and total dimension of this modal choice (Rudolph, 2014).

1.1. OBJECTIVES

The main goal of this dissertation is to assess environmental impacts of bike share and bike sharing systems in an urban area, using the total GHG emissions of transportation and the individual carbon footprint of citizens. In the same line of work, the secondary goals are:

- Estimate and analyse the impact of emissions factors on road transportation options, in the study area, with a more complete approach as Well-to-Wheels.
- Analyse the reductions already accomplished with BSS and the potential reduction offered by the bike share and the bike sharing system.

1.2. STRUCTURE

This dissertation follows a structure divided in six chapters.

This initial chapter explores and refers the problematic of the field of study, exposing the relevance and the purpose of the topic of this investigation. It also includes the objectives and structure of the dissertation.

The second chapter corresponds to the literature review, where the main themes of this investigation are referred and discussed. The review made on the field of study allowed a better understanding about several topics and the establishment of the necessary methodologies required to achieve the results.

The next chapter refers to the case study and is a key section to operate a model developed according the study area specifications, general aspects and features that have defined all the basis of estimations. It was important not only to comprehend the overall picture of the municipality, but also to include and assess relevant aspects, as those directly connected to demography, mobility options, modal share and available services in the transportation sector.

The fourth chapter is the methodology of the investigation. The parameters defined in this chapter permitted the calculation by comparing existing and available transportation options with the recent availability of a bike sharing scheme, in the study area. The empirical analysis of the main theoretical concepts addressed in the third chapter are exposed in this fourth chapter, which includes all the phases of the workflow used in this investigation and offer the means to reach all stalished goals and intended results.

The fifth chapter presents the results of several analysis and estimations made during the investigation. The calculation's outcomes about the current impacts of Cascais mobility patterns are based on the environmental dimension of sustainability, using GHG emissions as indicator, and exposed according to different analysis approaches and scenarios.

The sixth chapter exposes the conclusion about the results obtained in this dissertation. Further recommendations and suggestions for an improvement are also included

2.

SUSTAINABLE MOBILITY

Sustainability is a type of development, which fulfils the current needs, without compromising the possibility of future generations to meet their own needs (Brundtland, 1991; 129). The three interconnected pillars of sustainable development, known as economic, environmental, and social aspects, represent the heterogeneity and multidisciplinary dimension of sustainability. A single change in one of them would create a rupture in the process and each system must consider the concept of resilience to improve its adaptive capacity (Folke et al., 2002).

Some authors as Gillis et al. (2016) and van de Riet & Egeter (1998) agree that development of specific methods to asses and analyse interactions between all the aforementioned sustainable development pillars, and adding it to the mobility parameter would serve as a good basis to identify cities most relevant indicators. Indicators provide a help in building a better sustainable development strategy and "solid bases for decision-making at all levels by contributing for a self-regulating sustainability of integrated environment and development systems" (UN, 1992). Indicators can become a powerful tool in identifying gaps on systems or even in recognizing the best practices for a performance improvement (Hidas & Black, 2002).

Numerous studies have been listing examples and sets of sustainable mobility indicators (Barcellos et al., 2005; EEA, 2016c; Gilbert et al., 2003; Gillis et al., 2016; Haghshenas & Vaziri, 2012; Hidas & Black, 2002; Litman, 2008, 2009; Nicolas et al., 2003; Wang, 2014; Zhou et al., 2015), but although there is an extensive literature relating to the search of sustainable development indicators that best characterize a community, the opinions differ and some approaches don't consider all the aspects of cities options and urban reality. A wide-ranging set of indicators found in literature are illustrated in **Figure 2.1**.

Considerations at national level are easier to make and allow an orientated overview for companies and institutions, but local context requires a deeper analysis in cultural and social aspects to comprehend citizens needs and possibilities (Gillis et al., 2016). An holistic and systematic overview may not still be defined, but once the study area is defined, a set of indicators can be select and use in evaluation frameworks for each predefined sustainable goals and purpose (Gillis et al., 2016; WBCSD, 2015).

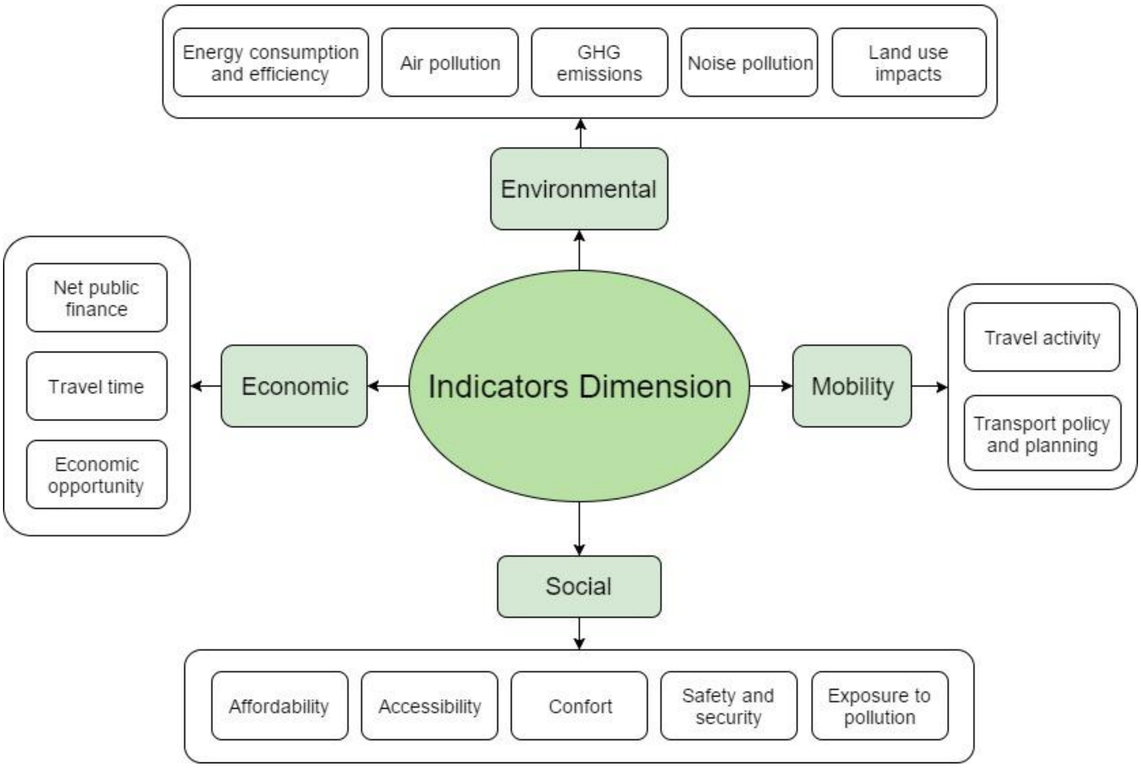


Figure 2.1 - Sustainable mobility indicators overview. Source: The Author

2.1. ENVIRONMENTAL IMPACT

Environmental indicators, such as, air and noise pollution are important, and have a direct implications in citizens' life quality. Another indicators that have great environmental impacts, mainly in the transportation sector are the energy consumption and the energy efficiency (Gillis et al., 2016; Haghshenas & Vaziri, 2012; Litman, 2009; Nicolas et al., 2003; Wang, 2014), although the impact of these indicators are not going to be study in this dissertation.

GHG emissions is the only indicator studied in this document, as different methods and considerations can be made to estimate this type of pollutant in different circumstances. Most of studies only use direct emissions, due to the fact that embodied emissions are more difficult to evaluate, and have many levels of specification (Brinkman & Wang, 2005).

Many economic sectors have not only direct, but also indirect GHG emissions associated with their activities, as shown in **Figure 2.2**, adapted from IPCC (2014b). According to IPCC (2014b), the total amount of global GHG emissions from different sectors, at international level, is around 49 Gt CO_2e, per year, where the transport sector represents about 14% of total share, referring to the direct emissions and involving fossil fuels burned for road, rail, air, and marine transportation. Considering that most of world's transportation energy comes from non-renewable sources, this singular sector produced 7,0 Gt CO_2e of direct GHG emissions and about 0,3 Gt CO_2e of embodied emissions associated with the grid-supplied energy consumption and others activities, in 2010.

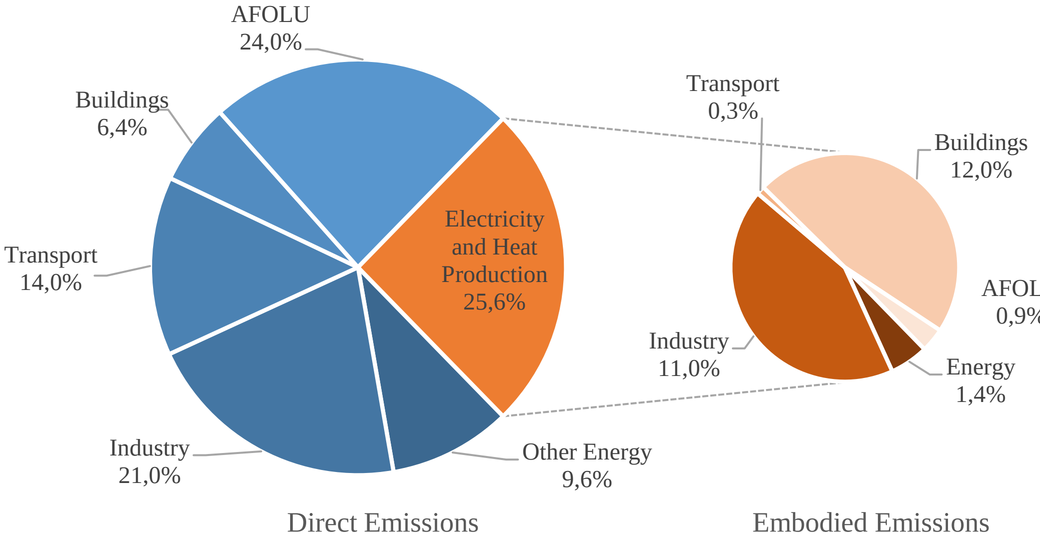


Figure 2.2 - Global direct and indirect Greenhouse Gas Emissions by economic sector in 2010, adapted from IPCC (2014a)

Although current international efforts and reduction targets have allowed a stabilization or a decrease of GHG emissions in some areas, the transport sector still has a large margin of progression in terms of reducing environmental impact, especially on road transport (EC, 2016b).

APA (2016) presents estimations for national GHG emissions, including in the transport sector which represent approximately 24% in the current Portuguese total GHG emissions. The highest values were attained in 2005, after a continuous growth since the 90's. Even though new peaks were reached in a recent past, the values have been decreasing and consolidating a national decarbonisation trajectory (**Figure 2.3**).

In fact, the verified increase of 13% on emissions in a period between 1990 and 2012, is much lower than the rise of 44%, reported between 1990 and 2005, reflecting the referred decarbonisation process (APA, 2015).

The evolution illustrated in **Figure 2.3**, articulates the weight of road transportation emissions in the overall mass emitted by Portuguese sectors and demonstrates a connection concerning the national target, stablished in Kyoto Protocol. The share of each economic sector in national overall GHG emissions, in which energy plays a dominant role representing the highest source of pollution. The on-road, railway, aviation and waterborne transportation were responsible for 25% of GHG emissions and about 32% of embodied emissions from grid-supplied energy consumption, in 2012. In overall, the emissions of national transportation were 65% above the values reached in 1990 (APA, 2015).

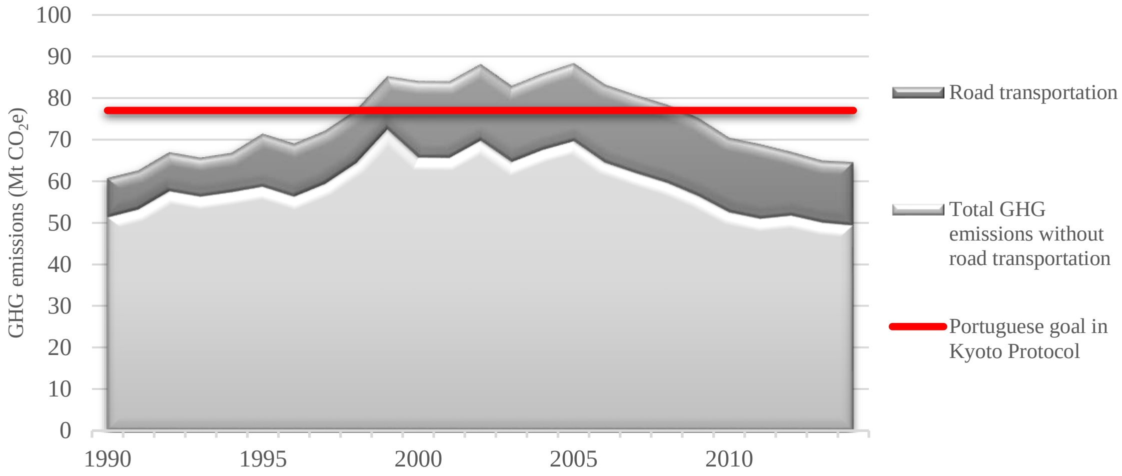
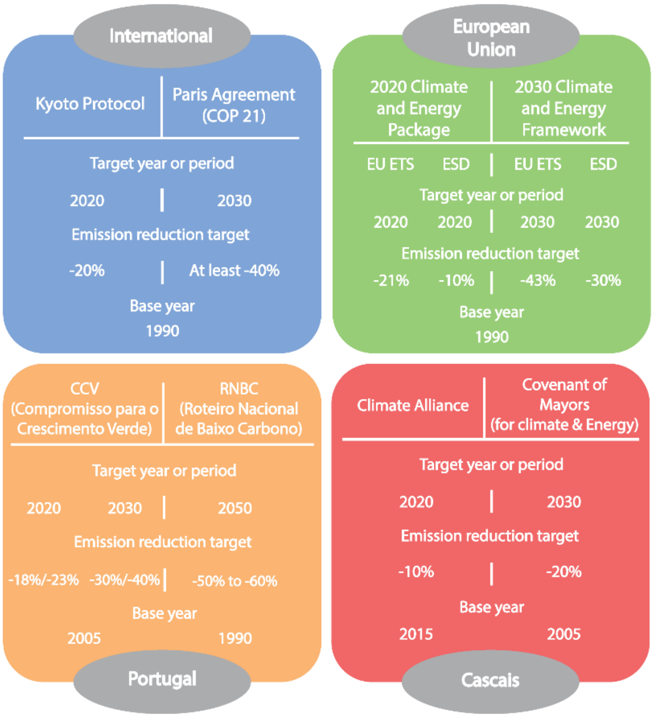


Figure 2.3 - Portuguese GHG emissions evolution, between 1990 and 2014. Data source: APA (2015)

Current targets are the moving force behind each strategy and global planning. As governments make commitments for improvement and direct their efforts to complete the defined goals, a chain of gains may start to be visible in the community (EC, 2016a).

The current international, European, national and local targets are presented in **Figure 2.4** according information available in different types of source. (APA, 2012, 2015; Climate Alliance, 2017; CM Cascais, 2012; Covenant of Mayors for Climate and Energy, 2015; EC, 2014a, 2016a, 2016b).



International

Kyoto Protocol	Paris Agreement (COP 21)
Target year or period	
2020	2030
Emission reduction target	
-20%	At least -40%
Base year	
1990	

European Union

2020 Climate and Energy Package		2030 Climate and Energy Framework	
EU ETS	ESD	EU ETS	ESD
Target year or period			
2020	2020	2030	2030
Emission reduction target			
-21%	-10%	-43%	-30%
Base year			
1990			

Portugal

CCV (Compromisso para o Crescimento Verde)		RNBC (Roteiro Nacional de Baixo Carbono)
Target year or period		
2020	2030	2050
Emission reduction target		
-18%/-23%	-30%/-40%	-50% to -60%
Base year		
2005		1990

Cascais

Climate Alliance	Covenant of Mayors (for climate & Energy)
Target year or period	
2020	2030
Emission reduction target	
-10%	-20%
Base year	
2015	2005

Figure 2.4 - Current international, national and local commitments towards GHG emissions reductions. Source: The Author

The United Nations Climate Change Conference 2015 (COP 21) is the most recent step in international agreement and commitment towards a more sustainable future. The outcomes of the conference, which took place in Paris, covers a post 2020 period with the purpose of replacing compromises of Kyoto Protocol. It settled not only, the goal of reducing at least 40% of global harmful emissions, compared to 1990, but also of setting more ambitious targets at every 5 years, depending on further technological advances allowed by science (EC, 2016b).

In Horizon 2020, the European Union (EU) Research and Innovation Programme has stablish as civic achievement, a reduction of at least 20% of GHG emissions goal in communities, in comparison with 1990 (EC, 2014a). At European level, sectors covered by the European Emissions Trading System (ETS) should reduce emissions by 21%, and the remaining sectors, such as the transports sector, by 10%, compared to 2005. (APA, 2012).

Regarding national goals, more specifically for 2020, Portugal has already completed their covenant of maintaining 2008-2012 emission levels, keeping the country in the right path to exceed expectations of reductions require by the second Kyoto Protocol compliance period. The local reduction goals are presented in action plans of the study area (CM Cascais, 2012) and other sources as Climate Alliance (2017).

2.2. CARBON FOOTPRINT

As environmental efficiencies and cost reductions are at the top of the environmental policy agenda today, the opportunity to accomplish better results can be provided by quantifying and identifying the main sources of emissions (Carbon Trust, 2012). Terms as Life Cycle Assessment (LCA) or Carbon Footprint (CF) are often used as indicators to measure the environmental impact of a common citizen, and to link consumption to global GHG emissions (West et al., 2016).

Life Cycle Assessment is extensively used method for assessing the overall environmental impact of a product from raw materials acquisition, through production and use stages, to the waste processing at the end of the product’s life. This tool can assess the environmental impacts and resources used throughout each product phases and it has been broadly applied in practice (Finnveden et al., 2009).

The term CF, has not been driven by an oriented research but mainly promoted by Nongovernmental Organizations (NGOs), companies, and different initiatives, therefore it has led to a great divergence in definition and to many proposals about how carbon footprint should be calculated (Weidema et al., 2008). Nevertheless, CF is widely known as the measure of the exclusive total amount of greenhouse gas (GHG) emissions caused directly and indirectly by an individual, organisation, event or product and is expressed as a CO_2e (Carbon Trust, 2012; Wiedmann & Minx, 2007). According with West et al. (2016), carbon footprint is a Life Cycle Assessment (LCA) with the analysis totally focused in emissions that have an effect on climate change.

Weidema et al. (2008) see some advantages in using this term, such as the ability of put it in context and stablish a comparison between city and citizens’ behaviour that might easily improve consciousness. CF has been naturally promoted and used as a tool for awareness, as the concept is more easily comprehended and widely accepted. West et al. (2016) believe that a comparison between citizens’ behaviour or environmental impact would provide them a more understandable information (West et al., 2016). For instance, a roundtrip flight between Porto (Francisco Sá Carneiro airport) and Luanda (4 de Fevereiro airport) would have an impact of approximately 2,15 tonnes of CO_2e for each passenger (Carbon Footprint, 2017) that according to Olivier et al. (2012) and considering this trip an average (unknown class) direct return flight, it would mean nearly 33% of an average CF from an European's inhabitant. The access to this type of logical information can serve as a door opener or a starting point to greater individual concern about individual impact.

Carbon footprint is seen as capable tool for the quantification of GHG emissions, estimating our own contributions to global climate change and mitigating problems that are caused by unsustainable consumption or production, mostly in environmental and social dimensions (Leonardo Energy & European Copper Institute, 2008). A restricted analysis based on specification in assessment gives us a better comprehension about how our choices directly or indirectly affects greenhouse gas emissions and consequently about the impact of transport and the use of integrated system. Davies et al. (2000) support the idea that stands behind this discussion, as an integration of transportation network usually serves a transition for a more sustainable behaviour in a perspective of reducing environmental impact of travel.

The results of mitigation measures and action plans depend on the precision of the estimation of correspondent emissions, in the accuracy of emission factors estimation for each activity, or in this case, the option of transport (Franco et al., 2013). This tool offers a convenient shortcut over the use of LCA by avoiding exhaustive calculations, as in most cases, default emission factors can be used, based on the different categories and generic fuel type (Wood & Cowie, 2004; WRI & WBCSD, 2005).

2.2.1. GHG ACCOUNTING

Pandey et al. (2011) affirm that there are two basic methods used to gathered information about this type of environmental impact. Data can be collected through direct onsite real-time measurements or estimations based on emission factors and models.

The same author refers the after choosing the fitted method, there are several regulations, guidelines or standards provided by widely known institutions and certified organizations that must be followed due to the support provided to the necessary accountings. Some relevant documents, which can provide data are:

- Carbon Trust Guide on Carbon Footprinting (Carbon Trust, 2012)
- TERM 2016: Transport indicators tracking progress towards environmental targets in Europe (EEA, 2016c)
- Manual for Calculating GHG Benefits (GEF, 2010)
- Fifth Assessment Report (AR5) (IPCC, 2014a, 2014b)
- The Sustainable Development Goals Report (UN, 2016)
- Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (WRI, 2014)
- The selection of characteristic properties of carbon footprint has an absence of consistencies and Wiedmann & Minx (2007) showed that even though the term should be use for analyses that include carbon emissions, it can also include non-carbon emissions as the Global Warming Potential (GWP) of each gas allows us to get a broadly indicator, designated by carbon dioxide equivalent (CO_2e). This unit mass based on 100 years global warming potential has been accepted as reporting unit of CF due to convenient calculations (Lynas, 2007; Pandey et al., 2011). The three gases - CO_2, CH_4 and N_2O - are exposed in **Table 1**, adapted from IPCC (2014b), are included in this dissertation. This GHG are part of an extensive list reviewed in IPCC Fifth Assessment Report and considered as some of the most harmful gases to the atmosphere.

Table 1 - Current international, national and local commitments towards GHG emissions reductions. Data source: (IPCC, 2014a)

Industrial designation or common name	Chemical formula	GWP values for 100-year time horizon		
		Second Assessment Report (SAR)	Fourth Assessment Report (AR4)	Fifth Assessment Report (AR5)
Carbon dioxide	CO_2	1	1	1
Methane	CH_4	21	25	28
Nitrous oxide	N_2O	310	298	265

The above-mentioned characteristic properties of carbon footprint depend on the considerations and methodologies followed in each accounting. After identifying the emission source and setting all the parameters, direct measurements of GHG emissions can be used for some activities, as GHG emissions can be estimated by multiplying activity data by an emission factor associated, exemplified by **Equation 1.** Activity data (A) is a quantitative measure of a level of activity and emissions factors (EF) is a measure of the mass of GHG emissions relative to a unit of activity (WRI, 2014).

$$\mathbf{GHG\ emissions} = \mathbf{Activity\ data} \times \mathbf{Emission\ factor}\ (1)$$

All the required coefficients to operate the model, such as fuel consumptions, densities and other inputs leading to emissions are available for a wide range of sectors, mainly in transportation where selected on the basis of Fuel Consumption Guide (2014), EEA (2016b) and Galp (2015).

In terms of GHGs selection, the level of difficulty in calculating the transport emissions depends on which gases are involved in the analysis and the pertinence of gases depends on the type of transport used and all factors associated with each vehicle, such as manufacture characteristics and fuel consumption (WRI & WBCSD, 2005).

The unfair effort of uniform gases selection in a comparative analysis is increased due to distinction between transportation modes and divergence in fuel types. Once that stablishing a clear pattern and uniformed analysis between the GHG effect in each transport considered is still not possible, a reliable method is with a relative measure – GWP – used according IPCC (2014b).

Classifying types of emissions, and setting boundaries is vital to understand the deepness of the analysis and it can only be done by setting limits in the universe of processes, associated with direct and indirect emissions. Confining and defining the most relevant activities used for GHG accounting supports a greater understanding of results.

The three usual scopes or tiers for a carbon footprint calculation are illustrated in **Figure 2.1**, as each scope includes different types of emissions and complement each other purposes. The difference between scopes is that the first one refers only to direct or onsite emissions, while the others incorporate and indicate all embodied emissions (Pandey et al., 2011).

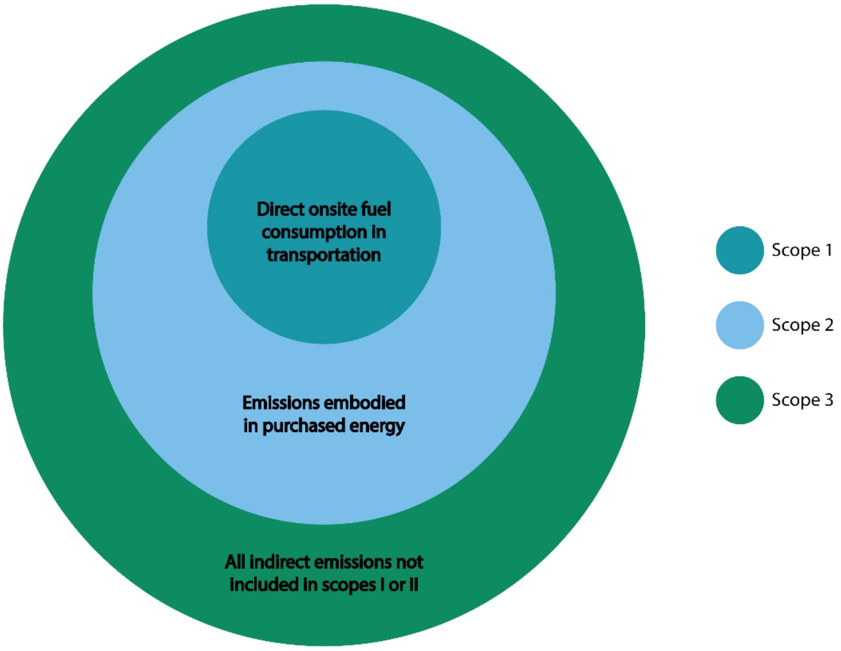


Figure 2.1 - Boundaries for calculation of carbon footprint. Adapted from Pandey et al. (2011)

An analysis based on the three mentioned tiers is frequently used in carbon footprint measurements of different types of activities, life cycle of products, events and cities (EEA, 2016a; Pandey et al., 2011; WRI, 2014). For the analysis undertaken in this dissertation, the intended boundary is only related to the cycle of fuel or energy used in transport sector, more exactly the modes included on the study area.

2.2.2. WTW ANALYSIS

As previously stated, the transport sector generates a considerable share of global GHG emissions, wherein part of these emissions is due to the use of on-road transportation. At the moment, this type of transportation is still mainly based on internal combustion engine (ICE) vehicles whose energy needs are supplied largely by oil based fuels and measure by the effects of direct emissions (IPCC, 2014b). As the current European regulatory framework for CO_2 emissions of cars is based on Tank-to-Wheels (TTW) contribution (EC, 2009), it is only considering the gases produced in the fuel combustion used in vehicles, designated tailpipe emissions, forgetting the contribution associated with process that goes from fuel extraction to the refuelling station, exemplified in **Figure 2.2**, a Well-to-Tank (WTT) analysis. By combining both TTW and WTT approaches, it's possible to estimate more faithfully the impact of the life cycle of the fuel production and the impact on fuel utilization resulting in a Well-to-Wheels (WTW) analysis. An approach that serve as an instrument to understand the overall GHG emission of each type of vehicle, although it shouldn't be confused with an usual LCA, as its going to be mentioned below (Silva et al., 2006; Thiel et al., 2014).

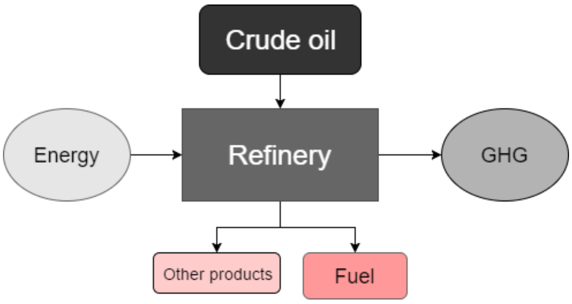


Figure 2.2 - Conventional fuel chain process. Source: The Author

Methodologies for the calculation of WTW emissions are getting established though the efforts of numerous studies to describe the different sources and fuels pathways allows the calculation of WTT emissions in a transparent and widely consented way. Authors such as Dimopoulos et al. (2008), Ramachandran & Stimming (2015) and Torchio & Santarelli (2010) studied WTW approaches taking in account both energy and environmental aspects.

There are still some divergent opinions about if a WTW analysis should be part of life cycle assessment. According to a research with a collaboration between the European Commission's Joint Research Centre (JRC), the European Council for Automotive Research & Development (EUCAR) and the Environmental Science for the European Refining Industry (CONCAWE), called JEC, this approach is different from a LCA, as it doesn’t consider energy and emissions involved in building or end of life aspects of facilities and vehicles. In other perspective, it can be an application of LCA, which is used to compare vehicles from a global perspective. Despite discordance about definition and methodology classification, there is a consensus about the use of this analysis which allows to see the overall picture of the energy resource utilization and its emissions involved (Edwards et al., 2014; Ramachandran & Stimming, 2015).

As markets are still dominated by gasoline or diesel fuelled vehicles, differences in WTT emissions are extremely important to analyse, when considering alternatively fuelled vehicles. The benefits of understanding the WTW implications of other fuelled vehicles are the opening possibilities for a greater understanding of scenarios with a larger shift towards more sustainable options (Thiel et al., 2014).

The existence of data allows the introduction of vehicle and energy type specifications, a useful but complex in a wide methodology as WTW. Trivial details may change the obtained results in each simulation, but makes the integration constrained by the existence of hard purchasing data. Vehicles propelled by electric motors differ in a large scale from vehicle with internal combustion engines and this analysis is no exception to the rule. Simplifying the integration of complex factors in EVs GHG emissions can be done in their WTT analysis, as shown in **Figure 2.3**, direct on-site emissions are commonly despised in electric vehicles, such as, Battery Electric Vehicles (BEVs) (Ke et al., 2017).

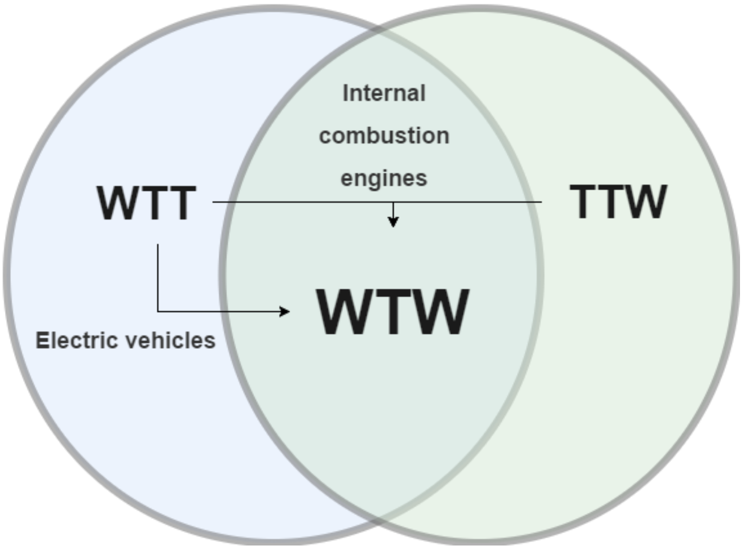


Figure 2.3 - Vehicles types in a WTW approach. Source: The Author

WTW methodologies shared common aspects, as integrations must consider, on the one hand, main aspects as source, type and level of energy consumed by the vehicle per unit of distance covered. And on the other hand, other important aspects as fuel density, type of injection per fuel, WTT expended energy, main pollutants per energy type, among others that are implicit in assumptions (Brinkman & Wang, 2005; Edwards et al., 2014).

Edwards et al. (2014) describes emission factors with WTW approach (gasoline & diesel vehicles) with a combination of the WTT expended energy per unit energy content of the fuel, the TTW energy consumed by the vehicle per unit of distance covered and finally but not least, the widely used GHG emissions in direct emissions per unit of distance. The refer combination are expressed in **Equation** (2.

$$\textbf{Emission Factor (EF)} =$$

$$= \textbf{WTW GHG}\left(\frac{\text{g CO}_2\text{e}}{\text{km}}\right) = \text{TTW GHG}\left(\frac{\text{g CO}_2\text{e}}{\text{km}}\right) + \frac{\frac{\text{MJ TTW energy}}{\text{100 km}}}{100} \times \text{WTT GHG}\left(\frac{\text{g CO}_2\text{e}}{\text{MJ fuel}}\right) \qquad \textbf{(2)}$$

The importance of alternative fuels is consequential of the succeed attempt for non-renewable sources independence, which leads to an appreciated GHG mitigation. Although this less emissive alternatives have great potential for a lower carbon footprint for their renewable nature, the scientific community is still seeking for increasing efficiency levels to create a greater shift in demand.

In summary, Well-to-Wheels approach provides a strong substitute to an ordinary procedure, such as, a boundary creation and division by the three scopes (Brinkman & Wang, 2005; Thiel et al., 2014). The GHG accounting in this investigation is generally based on a Well-to-Wheels analysis, as it integrates only the essential sections of each scope and raises attention to fuel production (WTT) and vehicle use (TTW), considered as main contributors of a lifetime energy use and GHG emission (IPCC, 2014a; Ke et al., 2017).

2.3. BIKE SHARING

The goals of each BSS depend on the type or responsible of the service but can be seen, in general, as increasing cycling ridership, providing people with a healthy, affordable and integrated alternative of transport option (Peter Midgley, 2011).

According to Buehler et al. (2010), cycling is hard to beat when it comes to an analysis based on sustainability. Its benefits are not only linked with economic savings or parking advantages, depending on the city, but since the only energy that conventional cycling requires is provided directly by the user and this energy means valuable cardiovascular exercise.

Soft modes of transportation are supported with policies of public organisms and cycling is the type of transport that covers the main aspects of sustainability. In scale with other vehicles, it causes no noise or air pollution and its contribution to make cities more liveable is widely known (Fernández, 2011). Replacing individual car trips for bicycling, especially in short distances, would result in reducing fuel consumption, reducing greenhouse gas emissions, improving air quality, boosting overall health and creating a better sense of community (Kisner, 2011).

Cases with low bicycle share, such as Portugal as proven in **Figure 2.4**, offer opportunities to promote a friendlier community environment and sustainable investments that ensure a greater socialization. A large number of local public authorities comprehend the opportunity adjacent in innovative schemes like bike sharing (Mota & Moura e Sá, 2013).

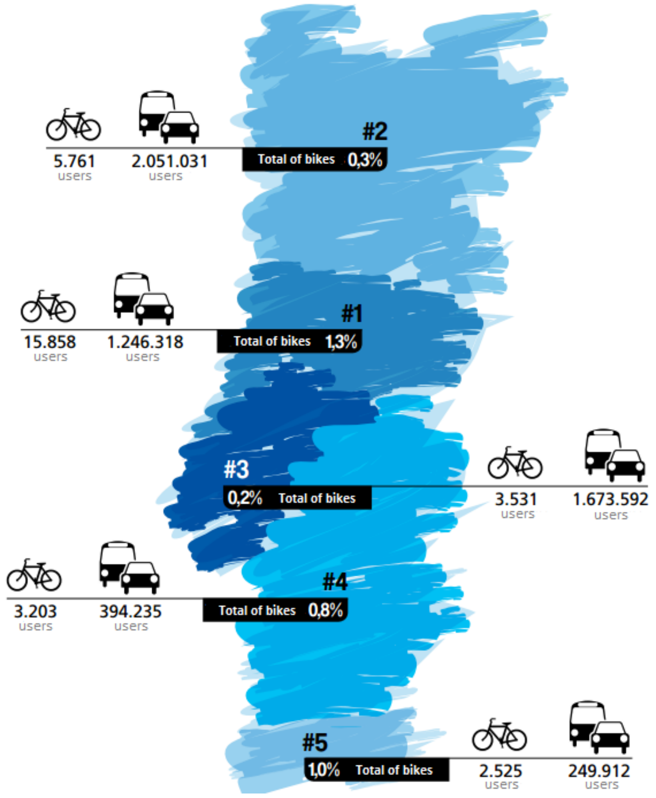


Figure 2.4 - Weight of bicycle in Portugal modal distribution by sub-region. Adapted from Mota & Moura e Sá (2013)

An illustration of bike sharing impact can be found in **Figure 2.5**, in which it shows different levels of performances in cities all over the world, after their implementation. European cities show some changes in modal choices from private vehicles to bicycles due to BSS. European schemes such as Santander Cycles (previously Barclays Cycle Hire/BCH) in London, Vélo'v in Lyon and Bicing in Barcelona, suffered some interesting variations in about 2% (Fishman et al., 2014), 7% (Fishman et al., 2013) and 9.6% (Rojas-Rueda et al., 2011), respectively.

Other highly developed countries as the United States of America and Australia have also great rate in this modal shift scenario with 7% in Washington DC (US), 19,3% in the twin cities of Minneapolis-Saint Paul (US), 19% in Melbourne and 21% in Brisbane (Australia) (Fishman et al., 2013, 2014).

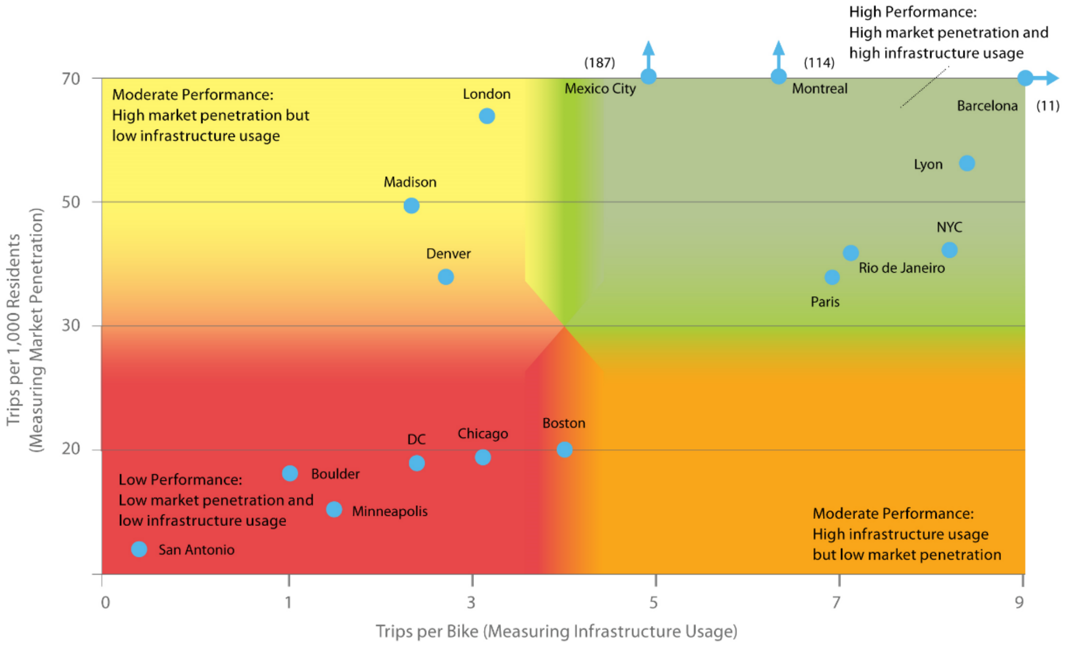


Figure 2.5 - Bike Share System Performance (Gauthier et al., 2014).

Although this results represent a modification in citizen's lifestyle and choices, the impacts on traffic congestion, public health, travel experience, generation of investment in local industry, among others, are evident but can't be analysed by a direct proportion as other implications must be considered. A lot of data would be needed to comprehend the change in cities dynamics (Ricci, 2015a).

Some evidence on the BSS impacts have been discover in cities that adopt sustainable transportation policies. Murphy & Usher (2015) studied and conclude that Dublinbikes users showed a large modal shift from other sustainable modes to bicycles, more specifically from walking (45,6%), bus (25,8%) and rail (8.8%), in total a substantial behaviour change in the order of 80,2%, in total. This Dublin scheme is still active in a limit area and this fact was given as one of the reasons for a lower rate in modal shift from the private car (19.8%).

While the lowest income earners in modal shift are more likely to occur from bus or walking to bicycle, statistical analysis results exposed that higher incomes would be connected to transfer from car trips to bikes (Murphy & Usher, 2015). As a matter of fact, some authors, such McDonald et al. (2015) are still discussing scenarios which can bring a hefty positive impact on the future and in several areas of concerned such as environmental and economic level. The authors present an analysis where a High Shift Cycling (HSC) scenario is considered, defend that a revolution in modal choices for the use of bikes in cities, over the next thirty-five years, would not only dramatically improve quality of life and low emissions from urban passenger transport by nearly 11% percent between 2015 and 2050, but also saving approximately 23 trillion euros over the thirty-five years' analysis, compared to a high shift scenario without a strong cycling emphasis.

As aforementioned, the HSC foresees that an increase in cycling and the corresponding reductions in other less sustainable vehicles would expressively reduce both energy use and CO_2e emissions. However, there are factors that shouldn't be dismissed as e-bikes use electricity and a large use of this type of bicycles would change the scenario. Other factors are the number of people per vehicle and per vehicle kilometer of movement, because it may take more bikes to replace a fully occupied cars and so the occupancy rates should also be taken into account (McDonald et al., 2015).

The transition of motorised trips to bike trips depends on a large range of factors. It doesn't depend only in factors as travel distance, trip purpose, safety concerns or docking station location, but also in others more difficult to evaluate, such as, individual predisposition to make a modal shift and behaviour change (Fishman et al., 2013, 2014).

Other factor connected to cycling infrastructure that may affect a modal transition is the implementation of a specific and effective signalling pathways, such as, bike maximum speed permissions and an increase in security and surveillance (Léchaud, 2016). Bike speed is one of the most important parameters used in this investigation, as the stipulation of an average velocity is a requirement in calculations. Various authors propose different values for average speed in shared bikes, in their studies (Campbell et al., 2016; Cherry, 2007; Cherry & He, 2009; Fishman et al., 2014; Jensen et al., 2010; Tran et al., 2015).

Cycling modal share would increase if latent trips were actually transferred to soft modes, and Fishman et al. (2013) claims that in areas with a large discrepancy between modal shares of cycling and car, it seems pertinent to access the upper bound of the cycling potential. Several methodologies were built and based in studies that aimed a combined estimation of active transportation latent trips available, in the corresponding study areas (Chillón et al., 2015; Godefroy & Morency, 2012; Monzon & Alfredo Vega, 2006; Morency et al., 2014, 2017). **Figure 2.6** adapted from Monzon & Alfredo Vega (2006), outlines a possible methodology used to predict a modal transition in a community, identifying which decisions would affect a potential transfer.

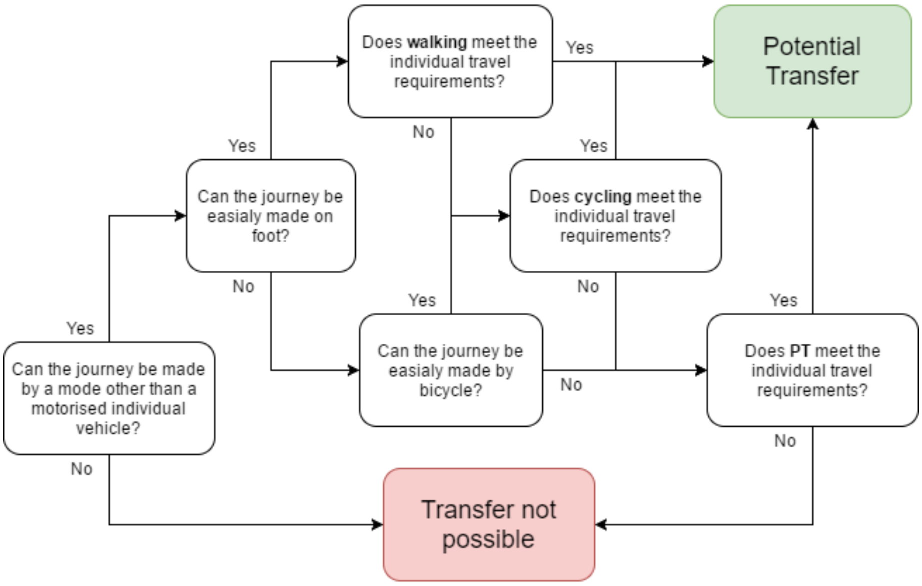


Figure 2.6 - Methodology with decisions to quantify the modal transfer potential. Adapted from Monzon & Alfredo Vega (2006)

Therefore, a question that numerous authors have, successfully or not, tried to answer is - how to access the upper bound of the potential of cycling and identify the latent trips? - Various studies provide methodologies to estimate the potential of cycling and bike sharing usage based on surveys, assumptions, system usage and availability and internal criteria based on each city context. Nevertheless, authors recognise that one of the most relevant criteria for estimating potential and latent cycling trips is the maximum distance that people are comfortable to cycle (Krizek et al., 2009). Different proposals for minimum and maximal distances have been appearing over the year, but an approximation of latent trips are frequently based on the concept of short trips. This can be seen as a cycle, as definitions of short trips also depends on the area of study, age, gender and other above-named factors as trip purposes (Morency et al., 2017).

CM Cascais (2010) performed a local study focused in mobility, where it states that trips between 0-4 km can be transferred to soft modes and the ones with more potential to be seen as latent bike trips. Several studies and reports refer potential threshold distance for cycling trips, as illustrated in **Figure 2.7**, and some of them propose their outcomes according their customized methodologies (Aoun et al., 2015; Krizek et al., 2009; Mayor of London, 2010; Monzon & Alfredo Vega, 2006; Nelson et al., 2008; Pooley, 2011; Pospischil & Mailer, 2014). As outcomes and estimation methods diverge, the difficulty to compare investigations and obtain a linear review in studies is seen as an obstacle for the use of similar criteria.

A wide-extending opinion supports that the best path is to estimate the cycling potential independently, adapting methodologies and parameters to each area background and reality (Godefroy & Morency, 2012; Iacono et al., 2008; Krizek et al., 2009).

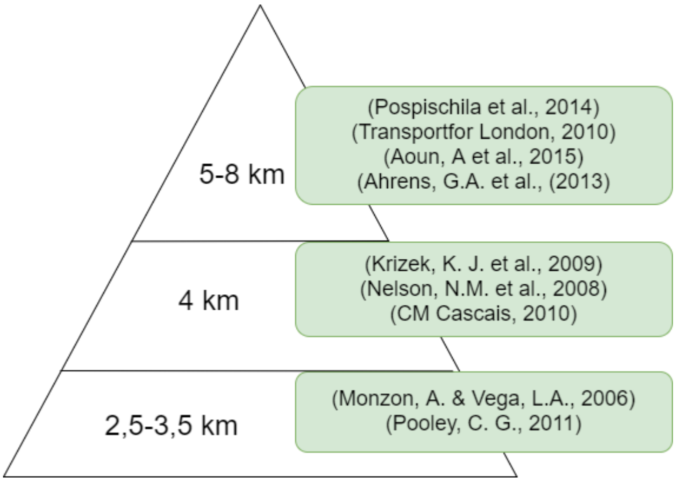


Figure 2.7 - Threshold distance for cycling trips in literature

Bikes recent improved connectivity with other modes, and more specific as first and/or last mile solution, is helping the decrease of private vehicle trips. As new public use programs are still appearing, new records on use percentage and trips made are being stablished every day. Although common belief thinks this system only serves the interest of citizens who don't own a bicycle, a matter fact bike share can be also convenient and interesting in practical terms for usual riders, as observed in the results of Institute for Transportation and Development Policy (ITDP) China survey, where previous private bike users mean 16% of total users (Gauthier et al., 2014).

As several studies using bike sharing systems data have been made over the past decade, the attraction for cycling benefits as a transportation mode in urban areas is been felt over the whole world as programs are evolving in the direction to maximize their effectiveness (Fishman et al., 2013).

Identifying the effect of bike sharing in GHG emissions reduction is a respectfully approach to intervene in terms of awareness, and for that it is necessary to identify and integrate the parameters, such as average length equivalent, distances covered and the emissions factors associated to each vehicle, that allow us an improved and closer approximation of how the modal shift evolves. Rudolph (2014) presents a study, explaining the importance of modal transition for soft modes, more specifically for bicycles, and shows a simple estimation of what would be the reduction of GHG emissions in different scenarios of BSS and cycling evolution.

3.

CASE STUDY

3.1. STUDY AREA CHARACTERIZATION

Cascais is a coastal town part of Lisbon Region and one of the nine municipalities of Greater Lisbon. Cascais is divided into 4 civil parishes, designated by Alcabideche, Carcavelos e Parede, Cascais e Estoril, and finally São Domingos de Rana. This cosmopolitan suburb of the Portuguese capital had 206479 inhabitants, last measured in 2011 (INE, 2011), and an estimation of 209869 inhabitants in 2015 according Pordata (2017). The area covered by the municipality, of about 97,40 km2 (DGT, 2017), is delimited in the north by the municipality of Sintra, south and west by the Atlantic Ocean, and east by the municipality of Oeiras, as illustrated in **Figure 3.1**.

Figure 3.1 - Map of Cascais ("Google Maps," 2017)

Greater Lisbon is the main economical sub-region of the capital and the country, covering an area of 1376 km² and it is the most populous and densely populated Portuguese sub-region, with almost 3 million inhabitants and 2043 inhabitants/km², respectively (INE, 2011).

The study area's goals were also considered in this investigation, as they outlined a viable and ambitious path at a local level. CM Cascais (2012) entrenched goals that are lined with the reduction potential inferred in the modelling work developed by APA (2015). A decrease in 20%, between the period of 2005-2020 can only be completed with resourceful initiatives. Adopting sustainable energy policies to benefit sectors with the greatest weight in emissions, such as transport, is the correct procedure to achieve the aspire reductions (CM Cascais, 2012).

3.1.1. MOBILITY PATTERNS AND INFRASTRUCTURE

A verification and scrutiny of an urban decarbonisation, through a BSS implementation and a change in mobility patterns, would better be achieved by a procedure that gives a complete perception of the impacts that have been made in the community. Although it is difficult to understand all the implications that an introduction like this might have, it is conceivable to get an overview of the impact in terms of GHG emissions reductions and the possible accomplishment of several climate change targets.

The level of success in a bike sharing system implementation can be estimated by different factors, as demand and necessity play a crucial role in adhesion and to support a change in the transportation system. As there are factors that represent an opportunity and a motivation to a paradigm change, others may be an obstacle that need to be treated with effective and valid solutions.

The modal split of the municipality is showed in

Figure 3.2, where the transport mode used in all trips made is taken into consideration. The predominance of the use of the car is quite evident, representing almost 58% of the trips.

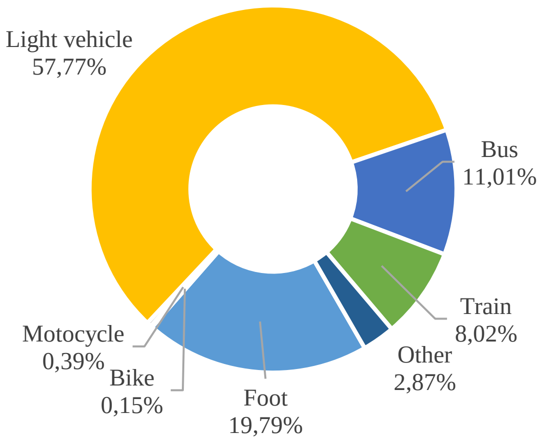


Figure 3.2 - Modal split in the municipality of Cascais, adapted from CM Cascais (2015a)

The modal share per each resident or non-resident travel motive, for the year of 2009, is represented in Figure 3.3, in which is evident the differences between the impact of activities on transportation choice. Commuting is widely known for having a great influence in both modal split and daily travel demand, affecting directly not only energy use and traffic congestion but also the general pollution in result of the travelled distance between residences and workplaces (Naess & Sandberg, 1996; Santos et al., 2013). The highest obtained share for individual and motorized transports is for travel motives related to “work” which can be explained by the need to reach areas farther away from residences. For pedestrians, the most expected destinations would be activities associated to “shopping”, “leisure” and “school”, as these activities can be more easily provided and found in residential areas. Concerning public transports, the greatest shareholder is the “school”, which represent the community with the lowest environmental impact in overall (CM Cascais, 2015a).

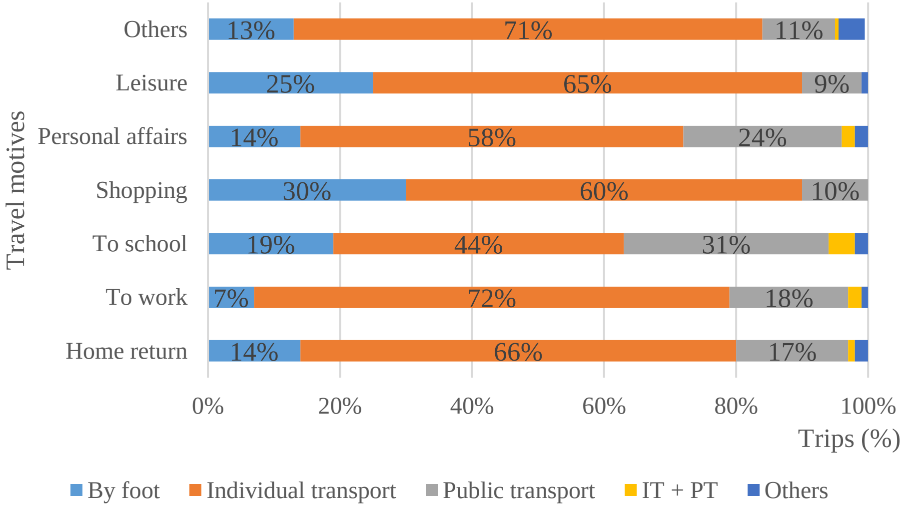


Figure 3.3 - Modal split in the main travel motives. Adapted from CM Cascais (2015)

According CM Cascais (2015), the social status of households, related to different income scales, is one of the most influential factors for the current modal split. Residents with higher salaries are more prone to choose individual transport (IT) due to financial and travel comfort, although it doesn’t automatically mean a faster and distressing trip, once traffic congestion is a common and usual urban problem. As incomes decline, according to social classes, the trend towards the use of public transport (PT) and the number of pedestrians increases (CM Cascais, 2015a).

A high dependence of motorized vehicles for the daily municipality displacements are verified and support by local statistics, with 60% of the trips made by residents (and 89% of the trips made by non-residents) are carried out by IT (CM Cascais, 2015a). Trips that combine IT and PT also have little significance, which can be a cause of parking limitations (CM Cascais, 2015b).

The current bike paths and lanes available in Cascais have a length of 19.1 km, covering a more seaside and populated zone. The infrastructure that is projected to be built, in the future, foresees an additional 25.3 km in bike paths and 25.6 km in bike lanes, which was thought to insure a larger covered area, and a greater use, in the coming years (Cascais Próxima, 2017). The **Figure 3.4** and **Figure 3.5**, express the evolution of the setup prepared for bikes in the municipality, in terms of bike paths or lanes length and location.

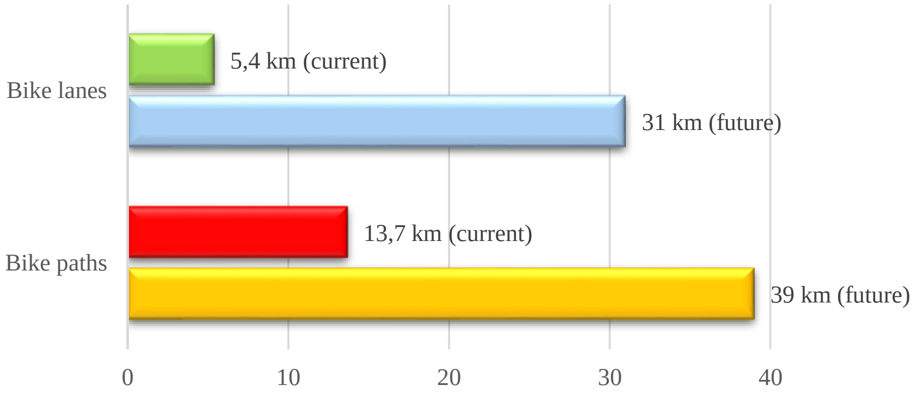


Figure 3.4 - Length increase of bike paths and lanes, in Cascais. Adapted from Cascais Próxima (2017)

The future length of bike paths and lanes in the different parishes, as exemplified in **Figure 3.5**, represent the pretended increment on Cascais cycling infrastructure. A development followed by the placing of new stations and bicycles in all county (Cascais Próxima, 2017).

Figure 3.5 - Current and future bike paths or lanes, in the study area (Cascais Próxima, 2017)

A solution found by the municipality to pursue their targets was an implement of an integrated mobility system which connects all the transport infrastructure and mobility devices all mobility devices and the transport infrastructure. This system operated and supported by CEiiA's intelligent platform, enables users to access all services from different mobility operators with a single authentication mechanism.

3.2. BIKE SHARING SYSTEM

The scheme used in the study area is on its first stages of implementation, started in October 2016, as the current structure have not still reached out its full potential, as a single or a complementary solution of an all integrated system. Until the end of this investigation, the physical structure did not had a change that could affected parameters used in the estimations. Components, such as, docking stations, illustrated in **Figure 3.6**, maintained the same during the analysis period, which helped avoid the addition of more external factors.

Figure 3.6 - Bike sharing system in the municipality of Cascais

Regarding the infrastructure connected to the system, the current available items are distributed by 12 selected zones, on which only 11 are currently working, and located on the coast line. The components of the scheme can be accounted as:

- 12 stations - infrastructures for the collection, parking and electric charging of batteries of shared and private bicycles.
- 12 totems - information structure and digital panel present in each dock
- 51 docking stations/102 bike racks - technological infrastructure used to put or remove any bike of the system, using a smart lock
- 54 conventional bikes available.

This stopping spots are commonly known by “docas” and each one has a reference to the location where it was placed. The next projections regarding the system are thought to make the scheme grow and evolve, as the new stations will be implemented during the present year. The current fleet of bikes available is only composed by non-electric bicycles, which are friendly called by “bicas”.

The management of the system is based on the authentication and control of the bicycle via smartphone application. There are open possibilities for the future, such as, the use metrics to business intelligence, operational management and traffic monitoring of bike lanes using computerized devices, such as, the mobility device control (MDC).

MobiCascais bike sharing system had a pilot phase, that last until the 28th of March 2017. During this time, the user had to register in the platform and then the riding would be free of charge. Since March, various subscription packages were made available to the users, in which it was created the possibility of integrate different transportation options with a unique card and billing system. The prices and the availability of services in each package changes according to the pretended subscription, however BSS is accessible in almost all of them, as illustrated in **Figure 3.7**.

Figure 3.7 - MobiCascais available packages (Cascais Próxima, 2017)

The introduction of this subscription service, not considered as part of the physical structure, was probably the only change made to the bike sharing system that may have influenced membership. This implementation has served as inhibiting factor to this scheme usage. Although, the prices for the use of bike sharing services vary per each user profile and available packages, it is considered by local citizens that it is an affordable alternative (Cascais Próxima, 2017).

BSS is not the only public bike service provided by MobiCascais to encourage cycling, as bike parking, another available system that allows a low cost option for private bike parking is also provided to its users, but not included in this investigation due to the current the investigation goals and impracticality of tracking the starting time of each trip.

In terms of system operation, this service is available between 8:00 a.m. and 8:00 p.m., and users can only use each “bica” for a maximum period of 2 hours. However, if they wish to continue benefiting from the system, they can unlock and use another bike for the same period. The use of helmet in conventional bikes is not mandatory but advised, which does not affect the affluence to the system.

Bicycle transportation in public transports, depends on the mean of transportation chosen. Bicycles are allowed in railway, but difficultly permitted in passenger buses unless they are foldable and can be accommodated in a way that does not disturb or jeopardize other passengers’ safety (CP, 2017; Scotturb, 2017).

3.3. CITY AND MUNICIPALITY FACTORS

The potential of bike sharing can suffer in hilly topography areas, as users can be dissuaded to use the system due to the necessary additional effort to travel a certain distance. Considerable height differences are generally seen as natural barriers which may discourage cycling, especially in cities where most of bike sharing customers are not fit daily cyclists (Jäppinen et al., 2013; Midgley, 2009). Nevertheless, cities, such as Barcelona, Lyon and Stuttgart, are considered sloping areas and still have a high number of rents and daily customers, particularly Stuttgart that have been gaining some popularity over their electric bike scheme called “Pedelec” (Fernández, 2011).

As current bike sharing docking station of Cascais are in the coastal area and in areas with lower level of inclination, as it can be seen by comparing with Porto’s downtown slope in

Figure 3.8, is fair to assume that topography may not have negative influence on the number of rents.

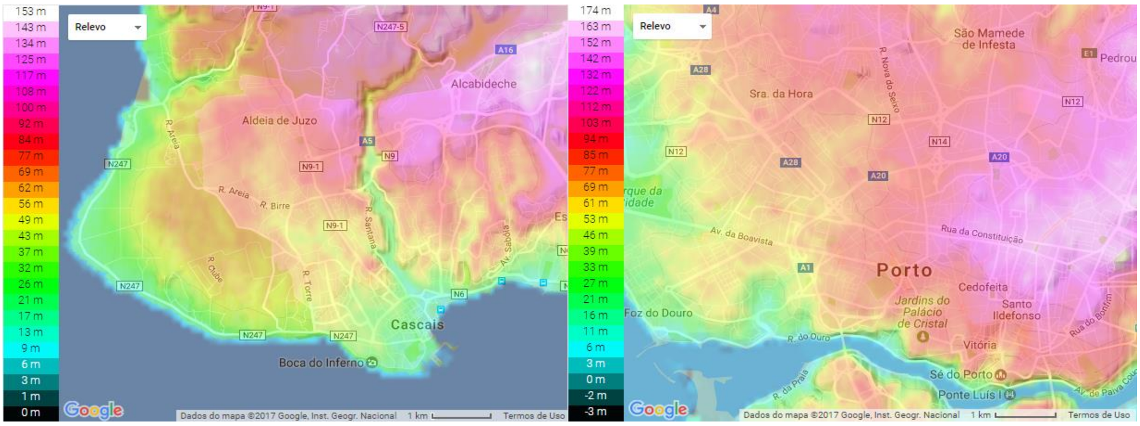


Figure 3.8 - Comparison between topographies of Cascais, at right, and Porto, at left (“Topographic map,” 2017).

Weather conditions are considered as another potential factor that can affect cycling and consequently the use of sharing schemes, especially during extreme weather conditions. Studies show that both weather conditions and seasonal variation affect recreational cycling and commuting patterns of cities, which results in great attraction for riding bikes during summer, rather than winter (Fernández, 2011; Nankervis, 1999). The evidence concerning a negative association between cycling and weather is still not robust enough to stablish definitive considerations about each parameter, as Sabir (2011) finds a negative association between cycling and the increase of precipitation, other authors like Pucher et al. (2011) do not report a link between.

BSS availability throughout the year is higher in warm cities, for instance, until the year of 2011, more than a half of BSS placed in cities with average yearly temperature below 11ºC had the necessity of a winter pause and more than 90% of the systems set in warm cities were active during all year (Castro & Emberger, 2010; Fernández, 2011).

As data about Cascais climate is not available, a summary related to Lisbon conditions is presented in A.2. Appendix – Case Study, in Table 10, as the two municipalities have almost identical weather conditions. This information considers averages for a time range of 30 years in parameters, as shown in **Figure 3.9**. The left axis of the referred figure is the reference used for observed local condition parameters like temperature, relative humidity and wind speed. On the other hand, the right scale is used to analyse precipitation, in millimetres (mm), in which this parameter reached it maximum value of 121.8 mm during the month of December and 725.8 mm as an accumulation of all monthly averages.

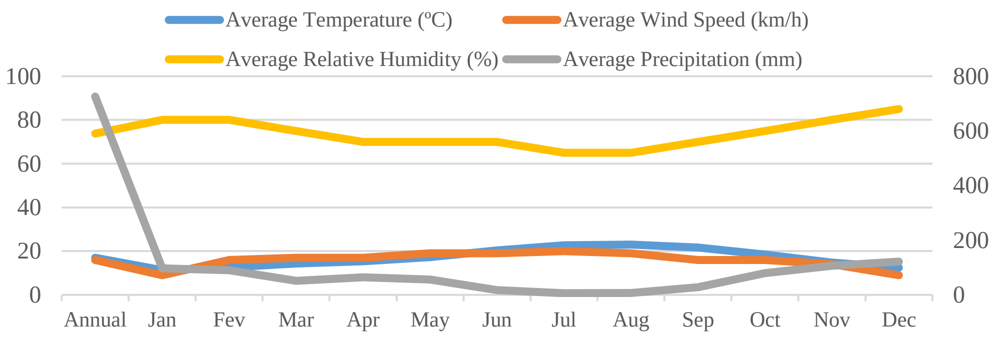


Figure 3.9 - Summary of Lisbon climate parameters, in the last years

The annual average for temperature is 17°C, with January as the coldest (11.3°C) and August as warmest month (23°C). Precipitation and relative humidity, present annual averages values of 725.8 mm and 73.8%, respectively. The yearly average wind speed in the Portuguese capital is 16 km/h, which is lower than reference European bike cities like Copenhagen and Amsterdam (Sabir, 2011).

In short, local weather conditions are classified by "Mediterranean" or "dry-summer subtropical", according the Köppen–Geiger climate classification system (Chen & Chen, 2013), and can be assumed as favourable to a BSS implementation and do not interfere as external factors that may hinder demand.

Looking at the mobility system, apart from individual transport options, the network for public transportation is composed by two main providers, CP – Comboios de Portugal E.P.E. and *Scotturb*, as illustrated according the both logotypes in **Figure 3.10**, a corporate public entity and a private company, respectively. CP offers railway connection between Cascais and Lisbon, serving more seaside and riverside locations. On the other hand *Scotturb* ensures that all municipality is relatively linked by public transport, as shown in **Figure 3.11**, as so other municipalities like Sintra. A third party, called *LT Transportes*, occasionally serves the municipality by providing connection from Carcavelos and Talaíde to Oeiras or Amadora municipalities.

Figure 3.10 - Main public transportation providers in the municipality of Cascais ("CP," 2017a, "Scotturb," 2017a)

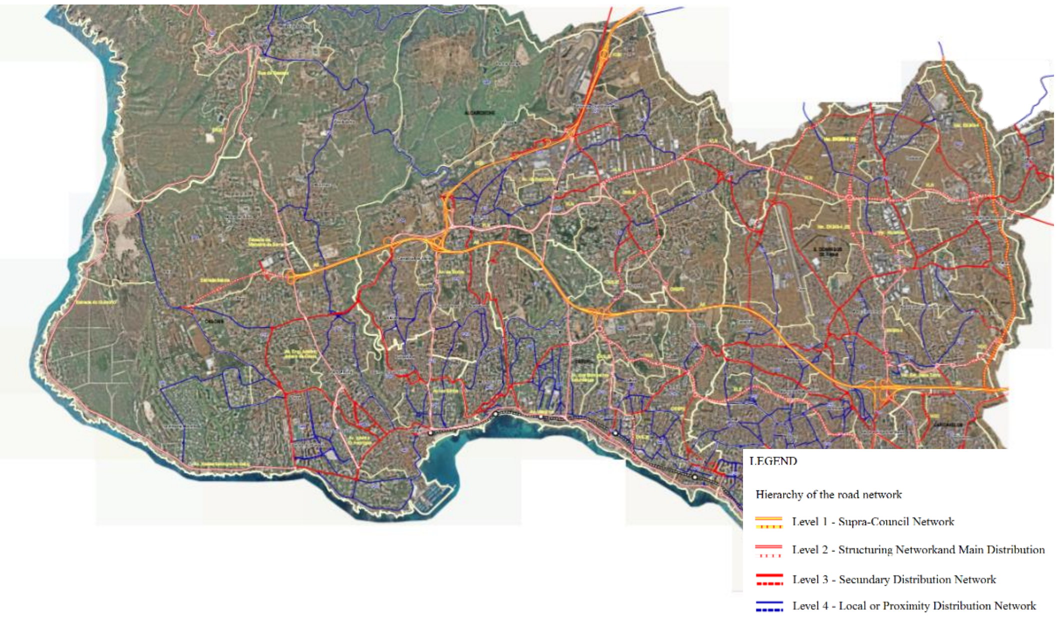


Figure 3.11 - Cascais road transportation network (CM Cascais, 2015b)

4.

METHODOLOGY

The different phases of this chapter are presented in **Figure 4.1**. As the preparation phase was thought to provide the necessary data for GHG estimation, the next phase had the purpose of operating the require bases to build all the analysis made during evaluation phase.

The processes with a lighter shadow in the follow **Figure 4.1**, illustrate the previous steps taken, and the several analyses, exposed with a darker colour, are the central core of this investigation.

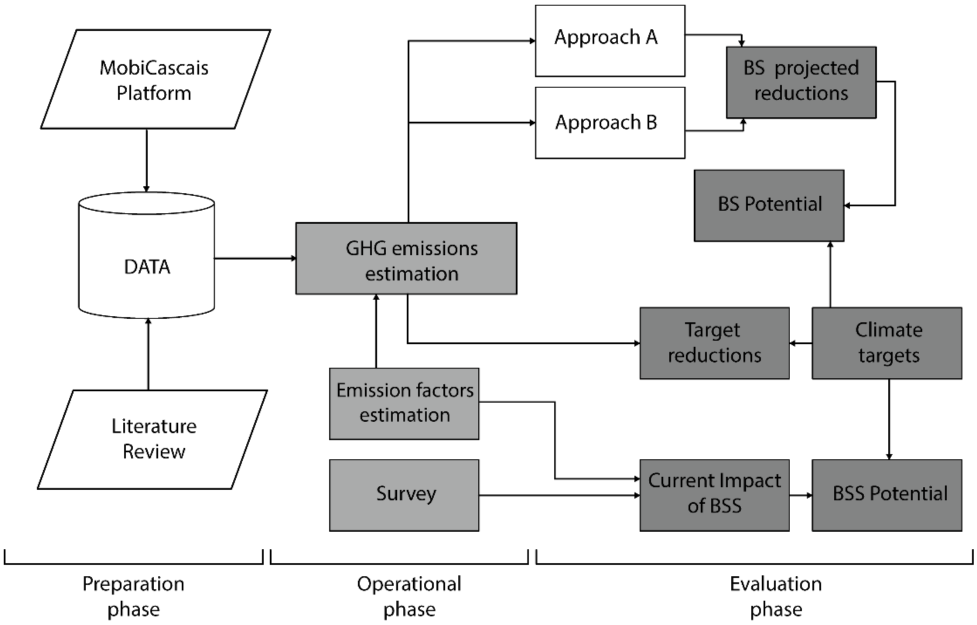


Figure 4.1 - Methodology overview

4.1. PREPARATION PHASE

4.1.1. DATA COLLECTION

Concerning the possibilities for analysis and the assumptions that have to be made, it is indispensable to know what sort of data is available. This dissertation contains information on each trip taken from 1 of December 2016 to 30 of April 2017, a five months' period, symbolizing the first contact of citizens with this automated system. As tracking devices, in current available bikes, are still not available in the study area, this analysis was made due to the availability of information about the starting and ending time of journeys, as well as their locations. Data for GHG accounting was obtained from the total trips already made using BSS.

Even though, some recorded trips are longer than 120 minute and shorter than 1 minute, as illustrated in **Figure 4.2**, these journeys were not considered in the analysis. The compliance with the terms and conditions, aforementioned in section 3.2, or the possibility of technical or operate errors were not the main reason. Longer or shorter trips may represent an undesired type of bike trip, as it is going to be explained in the next chapters.

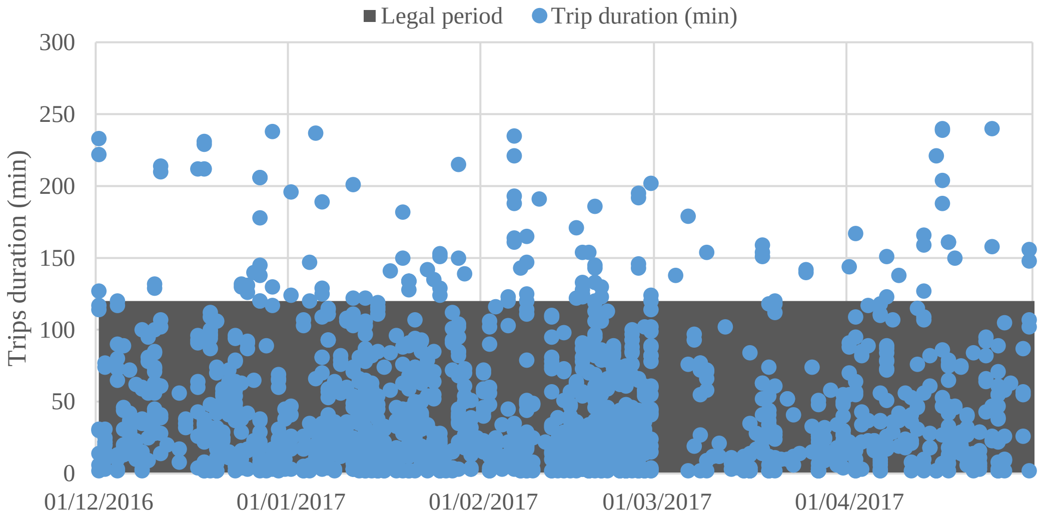


Figure 4.2 - Total quantity of trips made in the system. Data source: MobiCascais platform

Local specifications and aspects, mentioned in the previous chapter, as those directly connect to demography, mobility options and modal share, were gathered from Estudo de Trânsito de Âmbito Concelhio (ETAC) and Plano de Ação para a Mobilidade Urbana Sustentável (PAMUS) (CM Cascais, 2015a, 2015b, 2015c). These parameters are essential inputs to increase the accuracy of estimations

As previously refer, there are two basic methods to estimate GHG emissions. As the purpose and viability must be consider in selection of the method, the fitting choice was to create personalized models. In this dissertation, all emissions are calculated using models of estimation, based on:

- Information and assumptions
- Data exported from MobiCascais platform
- Survey

The estimation of GHG emissions savings are done through a process that demands the introduction of parameters directly related to citizens' behaviour and modal choices.

4.1.2. GHG ASSESSMENT

Defining the intervention sector and sourcing activities is essential in each GHG accounting. Transports is the only sector present in the analysis of this investigation, as on-road and railway transportation are the only options available for local displacement. To calculate the CO_2e emissions of different vehicles, an estimation of respective carbon intensities is required and can be accomplish by a model customized and adapt to each study area. Environmental assessments in transports should follow the development of the transport sector, such as the improvement of efficiency in fuel consumption, extraction or energy generation in different production types.

The GHG assessment methods used in this dissertation are based on Transport indicators tracking progress towards environmental targets in Europe (EEA, 2016c) and the Fifth Assessment Report (AR5) (IPCC, 2014b). The sources used to collect inputs about fuel consumptions and densities to estimate emissions were all the ones previously mentioned in subsection 2.2.1. The TTW analysis is based on APA (2016), EEA (2016) and IPCC (2014). The gases chosen for the estimation and included in the TTW approach are CO_2, CH_4 and N_2O.

In terms of Well-to-Wheels analysis for internal combustion vehicles, WTT assessment in ICE vehicles follows suggested procedures found in Edwards et al. (2014), as it provides a basis to comprehend the real influence for both fuel production pathways and powertrain efficiency. Although, a WTW approach is not applicable to all type of vehicles, such as BEVs, an EV referred in subsection 2.2.2.

4.2. OPERATIONAL PHASE

4.2.1. CALCULATION OVERVIEW

This section describes the method used to calculate the activity and emissions factors from available the data sources. Although **Equation 1** represents the general formula for calculation, both parameters have specified requirements, which are described in the following sections.

$$\text{GHG emissions} = \text{Activity data} \times \text{Emission factor} \quad (\mathbf{1})$$

4.2.1.1. ACTIVITY

The activity or total travel distance was estimated by two parameters, as presented in **Equation 2**, which were calculated for each type of vehicle.

The first parameter, average length equivalent was mainly given by ETAC (CM Cascais, 2015a) and the values obtained for each type of vehicle considered are illustrated in **Figure 4.3**. A different method was used for bikes. The access to distances covered by current BSS users in their trips by exporting data from MobiCascais allowed the estimation of this parameter based on real information. It was determined by multiplying trip duration and average bike speed.

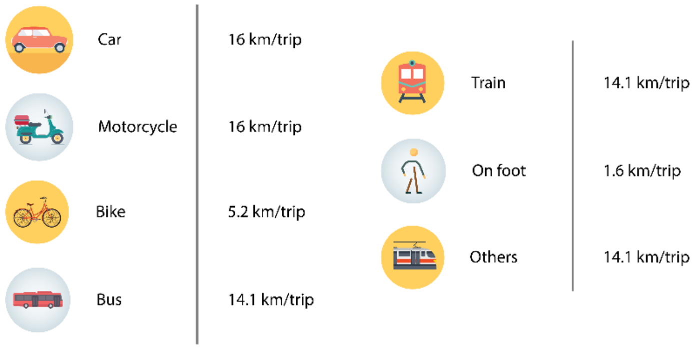


Figure 4.3 - Average length equivalent in each type of vehicle. Data source: MobiCascais Platform and CM Cascais (2015a)

The trip duration of bike trip was estimated by subtracting each trip end time with the starting time, exported from MobiCascais platform and the final result took into account the average of all trips made per month, once each month had a different value, depending on external factors.

The travel speed was estimated using a literature review in average speeds of shared bikes (Campbell et al., 2016; Cherry, 2007; Cherry & He, 2009; Fishman et al., 2014; Tran et al., 2015). Although there is a lack of consensus in literature, in part due the use of different estimation methods, authors as Campbell et al. (2016), Cherry (2007) and Jensen et al, (2010) fundamentally support an approximation of 11 km/h, the value used for this dissertation.

$$\text{Total travelled distance (km)} = \text{Average length equivalent} \left(\frac{\text{km}}{\text{trip}}\right) \times \text{Estimation of total trips made } (\mathbf{2})$$

The second parameter, an estimation of total trips made, was calculated by combining several metrics as shown in **Equation 3**

$$\begin{aligned}&\text{Estimation of total trips made}\\&\qquad = \text{Total population} \times \text{Average trips per inhabitant per day}\\&\qquad \times \text{modal share per type of vehicle } (\mathbf{3})\end{aligned}$$

4.2.1.2. EMISSION FACTOR

The formula used to measure the emission factor of the mean of transport chosen for this analysis differs in each type vehicle, as the assumptions and methods required an adaptation to each engine type and available data.

The first methodology used to estimate emission factors in vehicles, with a WTW approach, was in internal combustion engines, using as basis the **Equation 4**.

$$\text{Emission Factor (EF)} = \text{WTW GHG} \left(\frac{\text{g CO}_2\text{e}}{\text{km}}\right) \quad (\mathbf{4})$$

To reach TTW total GHG emissions of conventional fuels for internal combustion engine vehicles (ICE), more exactly on-site emissions of car, motorcycle and bus, a specified bulk emission factors values were used, regarding Portugal, as revealed in **A**.3. Appendix.

Each gas is a crucial part in the GHG accounting. The values of bulk emissions and GWP were provided by IPCC Fifth Assessment Report and the EMEP/EEA air pollutant emission inventory guidebook from 2016 (EEA, 2016a; IPCC, 2014b).

An indispensable parameter, used in the analysis, was the occupancy rate of each vehicle, due to EF factual distribution. This value varies by city, year and type of service provided to citizens.

Using the relative amount of car per segment provided by ETAC as shown in **Table 2**, it was feasible to qualify the burden of each fuel type per vehicle category, as demonstrated in **Table 3**, based on ETAC (CM Cascais, 2015b). As the results of the WTW integration are the emission factors for categories of vehicles that can have more than one possibility of fuel type, the final emission factor should consider the relative quantity of current usage in the study area.

Other type of vehicle with more fuel types, as bus, also had into account this percentage of use. Athough it was not possible to obtain information about the local service, the data available in Lisboa' bus company report provided the necessary information to estimate this parameter (Carris, 2014). The source used to define this parameter for train was the sustainable reports of CP (2014).

Table 2 - Relative quantity of vehicles by segment. Data source: CM Cascais (2015b)

Fuel	Engine displacement (ED)	Total share of car per fuel per ED	Total share of car per fuel
Gasoline	<1.4	47.0%	99%
	1.4-2.0	10.8%	
	>2.0	2.0%	
Diesel	<2.0	39.7%	
GPL	<2.0	0.4%	1%
Gasoline-electric Hybrid	<1.4	0.2%	
	1.4-2.0	0.2%	
	>2.0	0.2%	

Table 3 - Fuel category per type of vehicle, based on CM Cascais (2015a)

	Fuel category		
	Gasoline	Diesel	CNG
Car	x	x	
Motorcycles	x		
Bus		x	x

The emission factors related only to the TTW approach was estimated using **Equation 5**. The results obtained for one of the two metrics in this Tank-to-Wheels approach, considering the occupancy rate of each transport and the average fuel consumption, are presented in **Table 4.** The **Table 5** present another metric of TTW and a variable used in final integration of WTW analysis based on equations from Edwards et al. (2014). The values indicate the TTW total expended energy, in conventional fuels for internal combustion engines.

$$\text{TTW approach} = \text{TTW GHG}\left(\frac{\text{g CO}_2\text{e}}{\text{km}}\right) + \frac{\left(\frac{\text{MJ TTW energy}}{100\ \text{km}}\right)}{100} \quad \mathbf{(5)}$$

Table 4 - TTW GHG estimation for each fuel type

Type of vehicle	Category	Average fuel consumption (l/100 km)	TTW GHG (g CO₂e/km)
Car	Gasoline	7.9	136.6
	Diesel	7.9	151.5
Motorcycles	Gasoline	3.5	78.1
Bus	Diesel	55.4	94.6
	CNG	75.2	98.5

Table 5 - TTW expended energy consumed per unit of distance

Type of vehicle	Type of engine	TTW $\left(\frac{\text{MJ energy}}{100\ \text{km}}\right)$
Car	Gasoline - Direct Injection Spark Ignited engine	200
	Diesel - Direct Injection Compression Ignited engine	153
Motorcycle	Gasoline - Port Injection	212
Bus	Compressed Natural Gas - Direct Injection Spark Ignited engine	212
	Diesel - Direct Injection Compression Ignited engine	153

The values presented in the **Table 6**, already include the weighting of the occupancy rate in each ICE vehicle, using **Equation 6** based on Edwards et al. (2014).

$$\text{Emission Factor}\left(\frac{\text{g CO}_2\text{e}}{\text{passenger.km}}\right) = \frac{\text{Emission Factor}\left(\frac{\text{g CO}_2\text{e}}{\text{km}}\right)}{\text{Occupancy Rate}} \quad \mathbf{(6)}$$

Table 6 - WTT expended energy per unit energy content of the fuel

Type of engine per vehicle		WTT GHG $\left(\frac{\text{g CO}_2\text{e}}{\text{MJ fuel}}\right)$
Car	Gasoline	52.6
	Diesel	52.5
Motorcycle	Gasoline	65.5
Bus	Diesel	4.7
	CNG	3.6

The final conversion illustrated in the **Table 7** and shown in **Equation 7**, integrates a gasoline and diesel type of fuel, once they represent nearly the entire existing vehicles, as demonstrated in **Table 2**, and according data from CM Cascais (2015b). This type of vhicles are the only ones that are going to be reflected on the study, with the assumption that they represent the total share of cars used in the study area.

$$\text{WTW GHG}\left(\frac{\text{g CO}_2\text{e}}{\text{km}}\right) = \text{TTW GHG}\left(\frac{\text{g CO}_2\text{e}}{\text{km}}\right) + \left(\frac{\text{MJ TTW energy}}{100\text{ km}}\right)/100\times\text{WTT GHG}\left(\frac{\text{g CO}_2\text{e}}{\text{MJ fuel}}\right)\ (\mathbf{7})$$

Table 7 - The final emission factors with WTW analysis and based in estimations

	WTW GHG $\left(\frac{\text{g CO}_2\text{e}}{\text{km}}\right)$
Car	237.8
Motorcycle	217.01
Bus	102.2

The second methodology used to estimate emission factors in vehicles, with a WTW approach, was in electric engines by combining the carbon intensity (CI) of electricity in Portugal and the energy intensity per distance driven (EI), as expressed in **Equation 8** (Pandey et al., 2011).

$$\text{EF}\left(\frac{\text{g CO}_2\text{e}}{\text{kWh}}\right) = \text{CI}\left(\frac{\text{gCO}_2\text{e}}{\text{kWh}}\right)\times\text{EI}\left(\frac{\text{kWh}}{\text{km}}\right)\ (\mathbf{8})$$

The data for the CI metric was obtained using a specific font designated by European Network of Transmission System Operators for Electricity (ENTSO-E, 2017). The first procedure was extracting the aggregated generation per production type in 2016, where the sources are:

- Biomass
- Fossil gas
- Fossil hard coal
- Hydro run-of-river and poundage
- Hydro water reservoir
- Solar
- Wind on-shore

After collecting the necessary information, the treatment of data was made by converting data and measurement units. In other perspective, stablishing relationships between emission factors and the quantity of energy produced from each source. Although ENTSO-E provides the CI of each source, as shown in **Figure 4.4**, in real-time and daily period, it does not indicates the average carbon intensity of each source in a larger period, these parameters were acquired in analysis from the Portuguese National Inventory and AR5 (APA, 2016; IPCC, 2014b).

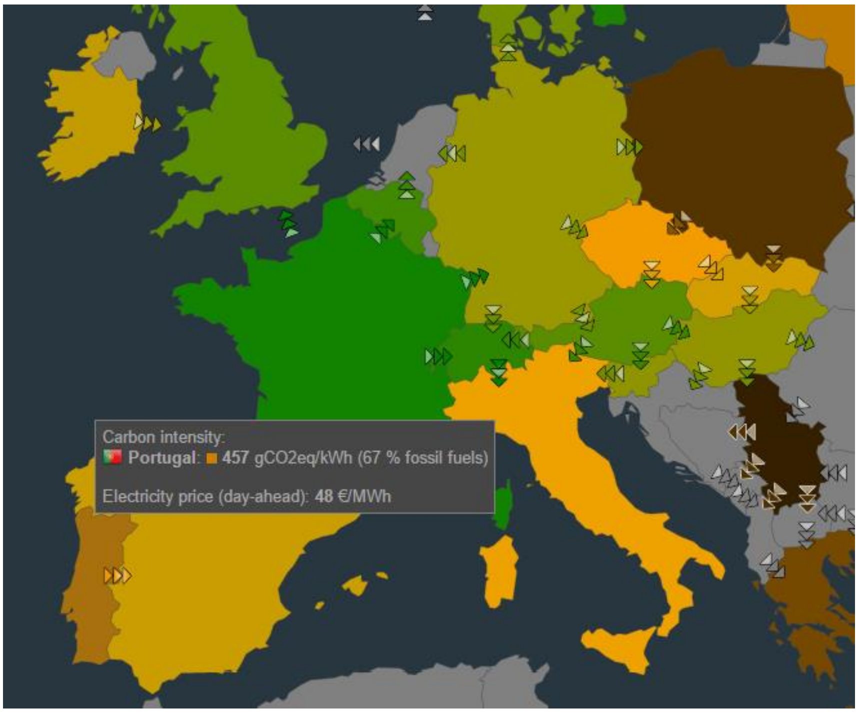


Figure 4.4 - Example of a real-time analysis. Source: "Electricity Map" (2017)

The CI of electricity, in each country, is measured from the perspective of a consumer. It represents the greenhouse gas footprint of 1 kWh consumed in a given country. Each type of power plant considers emissions arising from the whole lifecycle of the plant (construction, fuel production, operational emissions, and decommissioning) (ENTSO-E, 2017). The average carbon intensity estimated for Portugal for the year 2016 is 296.11 g CO_2e/kWh.

The second indispensable metric to calculate emission factors in vehicles with electric engines is the energy intensity or consumption, as proven in **Table 8**. This parameter is highly dependent of the electric vehicle used during the activity and the assumptions made in terms of battery wear, autonomy, etc.

Table 8 - Energy consumption per type of electric vehicle, based on estimations

Type of electric vehicle	Energy consumption (kWh/100 km)
Bicycle	1.24
Car	16.00
Motocycle	5.76

4.2.2. SURVEY

In order to obtain a better perception of the mobility patterns of BSS users and reach the intended results, a survey was created. It was made available on a Thursday, 1st of June 2017, after being authorized and sent by *Cascais Próxima, E.M., S.A*, to the users' mailing list. This mailing list have all users that subscribed the packages that include the BSS. The email had a link for an online questionnaire created by using SurveyMonkey®.

This questionnaire was developed to obtain answers from citizens that have already tried the system. The answers that eventually did not presuppose a previous use of this system, were not considered in this analysis. The surveys questions are illustrated in **Figure A.1** and **Figure A.2**, in A.1. Appendix – Survey.

The answers of this survey were exported five days after being sent, which coincides with the end of period that had a greater adhesion to the filling request. During this period, one hundred answers were obtained, in total, although fourteen of them were not considered valid(1). The final sample used for the analyses was 86 users.

The MobiCascais packages that includes the bike sharing system had, until the time that the survey was send, about 107 different subscribers. Considering that all these subscribers have already made at least one trip using the BSS, the adherence rate to the survey was around 80%.

Not all questions sent in the survey, shown in **Figure A.1** and **Figure A.2** were used, as just some of them serve the goals of this investigation. The **Figure 4.5** and **Figure 4.6** present the answers that it is going to be use in the next sections.

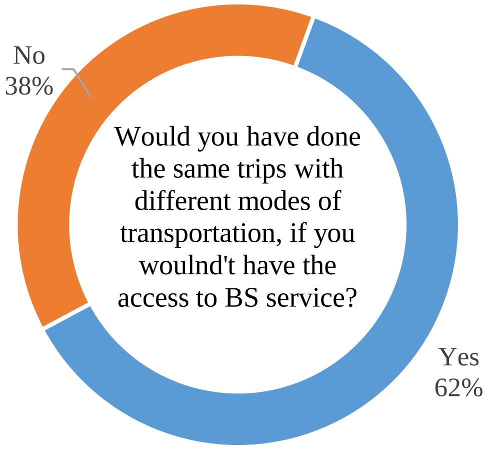


Figure 4.5 - Answers to question 7 of the survey

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(1)It was explicit in two of these responses that users had never used the system before, and the other twelve answers, due to the assumption that they never did any trip. This last assumption was made because all the twelve users that skipped the survey on the same question, and it can have something to do with the fact that it is the first question that presupposed that they had already made a trip with this public program.

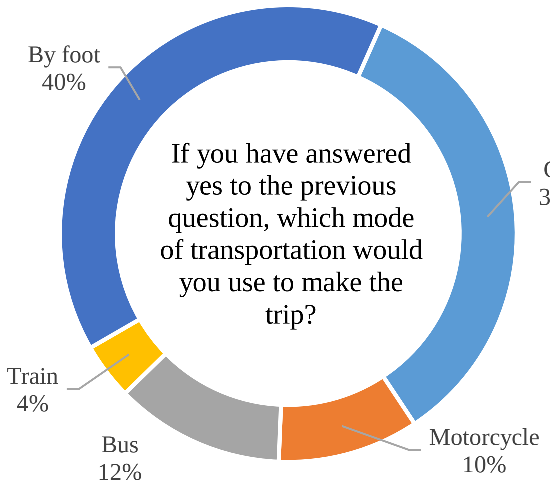

Figure 4.6 - Answers to question 8 of the surveys

4.3. EVALUATION PHASE

4.3.1. ANALYSIS OVERVIEW

All the assessments and estimations of GHG emissions mentioned throughout this study, are only referred to the transport sector, as the accountings made are essential to estimate the project reductions associated with mobility. The several integrations, made using the chosen methodology, have served as input to achieve the intended results in different sorts of analysis throughout this investigation.

The methodology followed during this investigation was not the same in all analysis made. Methods of estimation depends on inputs, such as, local mobility patterns and characteristics to reach more accurate approximations and the pretended results. The data and inputs used for each estimation or evaluation are presented in **Figure 4.7**.

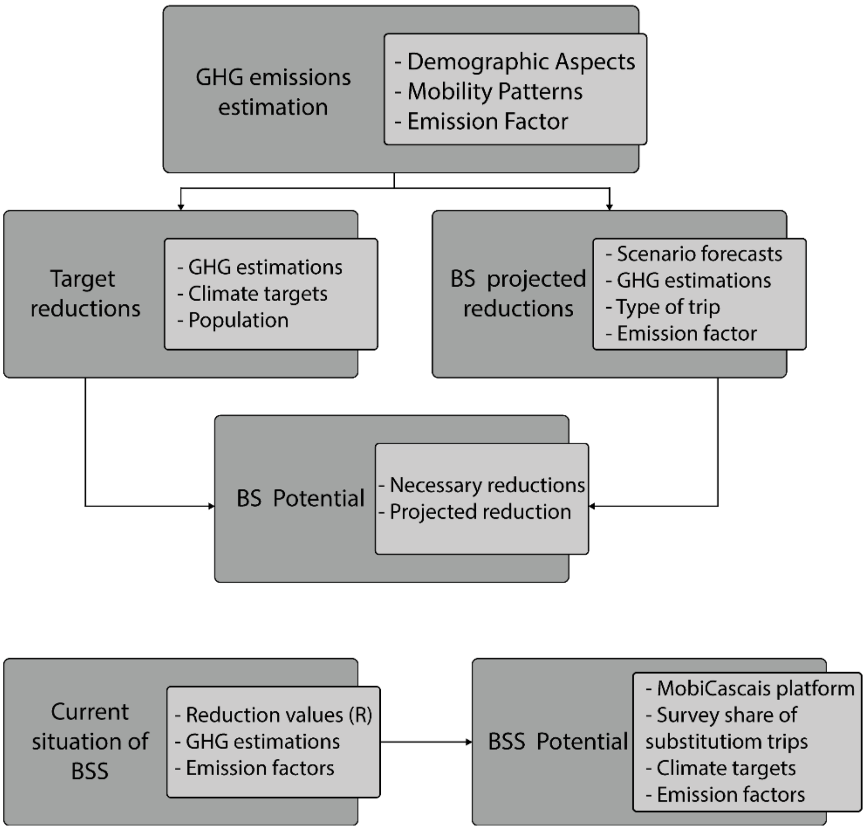

Figure 4.7 - Parameters used for each analysis

The validation of GHG emissions estimation was accomplished by using different methods in each analysis.

As aforementioned in WTW analysis, a TTW approach is only based on direct emissions. An approximation of the current EF, using TTW analysis is made to support the assumptions made in the development of this method for GHG estimation. The values obtained in the TTW approach are similar with the municipality estimation and presented in the Action Plan for the Energy and Sustainability of Cascais (CM Cascais, 2012). This assumption that several of this municipalities do not account all direct and indirect estimation is due to the fact that embodied emissions have high level difficulty in estimation, as previously cited in subsection 2.2.2.

4.3.2. TARGET REDUCTIONS

The goal of this analysis is to find the necessary reduction values for GHG emissions, to reach the different climate targets. The estimation is based on the global and individual carbon footprint values of the study area, and in the local, national and European commitments for 2020 and 2030.

The outcomes for inhabitant CF in road transport emissions are result of an integration of municipality GHG emissions and the population. The second parameter used, the most recent approximation of inhabitants given by Pordata (2017).

The different dimensions of commitments that meet road transportation targets are clarified in **Figure 4.8**, and abbreviations were created to support the analysis subsequently described in several phases of this thesis. Another municipality responsibility is due to a recent updated commitment made in the Climate Alliance of European cities that want to take local action towards global climate change. Although this goal drives cities to reduce CO_2e emissions by 10% every 5 years, it is not going to be included in this analysis. The non-inclusion can be explained by the simple fact that the year that would be needed to stablish a comparison, the base year, has the same amount of current GHG emissions, according the assumptions used in the investigation.

LT-2020 Local target for transportation subsector in 2020
- Reduction of 20%

NT-2020 National target for transportation subsector for 2020
- Reduction of 14%

NT2-2020 National target for non-ETS sectors for 2020
- Reduction of 15%

NT-2030 National target for transportation subsector for 2030
- Reduction of 26%

NT2-2030 National target for non-ETS sectors for 2030
- Reduction of 31%

ET-2020 EU target for non-ETS sectors for 2020
- Reduction of 10%

ET-2030 EU target for non-ETS sectors for 2030
- Reduction of 30%

Figure 4.8 - Levels of commitments for road transportation, based on APA (2015, CM Cascais (2012), EC (2016a) and EC (2016b).

Once the transport sector is classified as non-ETS (EC, 2014b), the targets designated/classified by NT2 in **Figure 4.8**, will not be included in the results due to the existence of national targets, specifically, focused in transportation.

Although the local commitment is the one with more relevance for the study area, the other commitments and reduction targets are also included in this dissertation. All targets take the year of 2005, as bases for comparisons in reductions. These different layers of responsibility are essential to provide comparable information. This analysis allows an overview of the current situation of Cascais, in terms of the impact of road transport emissions.

4.3.3. CURRENT IMPACT OF BSS

This analysis combines the reduction already made by the system, according data gathered from the survey and the GHG emissions that may be saved by the BSS, in Cascais. To reach the decrease on road transport emissions, it was necessary to determine the total distance substituted, using **Equation 9**, which includes the share of substitution trips obtained with the surveys' answer, presented in **Figure 4.5.**

$$\text{Total Distance Substituted (km)} = \sum (\text{Total travelled distance in BSS (km)} \times \text{Substitution trips (\%)} \qquad \textbf{(9)}$$

Combining the total distance substituted and the modal share obtained by the answers of question 8, as proven in **Figure 4.6**, it was possible to achieve the last parameter required, the distance travelled per transportation mode, using **Equation 10**.

$$\text{Distance travelled per transportation mode (D) (km)} = \sum \text{Modal Share (\%)} \times \text{Total Distance Substituted (km)} \quad \textbf{(10)}$$

Considering that all trips were made with a conventional bicycle and that his bicycle does not have an EF associated with its use, the total GHG emissions saved were assessed by using **Equation 11**.

$$\text{GHG emissions saved (t CO2e)} = \sum \text{D (km)} \times \text{EF (t CO2e/km)} \quad \textbf{(11)}$$

For the assessment made on GHG emissions of the municipality road transportation, it is only considered the environmental impact of BSS, although other bike services are also available, such as bike parking referred in section 3.2.

4.3.4. BSS POTENTIAL

The outcomes in this section were based on the potential of a specific type BSS trip. Commuting, as aforementioned in section 3.1.1, provides a greater potential in GHG savings than other travel motives due to a possibility of more regular use. The assumptions used in this analysis are based on the possibility of turning current users in commuters.

Assuming a monthly average of 22 working days and that commuters would need to use the system, at least, twice-a-day, the monthly trips made would be 44 per user. The total number of users in the last month of the analysis period (April) was 45 and the average distance travelled by bike was 5,2 km. The total trips and the travelled distance that was substituted per month are in **Equations 12** and **13**.

$$\text{Total trips per month} = \text{Commuting trips per month per user} \times \text{Monthly number of users} \quad \textbf{(12)}$$

$$\begin{aligned} &Total\ travelled\ distance\ per\ month \\ &\qquad = Average\ distance\ travelled \times Total\ trips\ per\ month \times Substitution\ trips\ (\%) \end{aligned} \quad \textbf{(13)}$$

Distance substituted per modal share was calculated using the **Equation 14**, as the modal share was obtained from the answers of survey, as illustrated in **Figure 4.6**. Multiplying the substituted trip made per each vehicle and the responding EF, in tonnes of CO_2e/km, is possible to estimate GHG emissions saved per vehicle per month. Gathering all the savings and multiplying it for the twelve months, have allowed a yearly result.

$$\text{Distance per modal share} = \text{Modal share (\%)} \times \text{Total travelled distance per month} \quad \textbf{(14)}$$

As this result was achieved with the current users, which according with MobiCascais platform, the BSS in Cascais had in the last month of the analysis period, about 45 users.

It is possible to estimate how many commuters would be needed to reach the several commitments. This last analysis was made by dividing the necessary reductions per year and the estimated GHG emissions that would be saved by current commuters. The outcomes are explicit in the next chapter.

4.3.5. BS PROJECTED REDUCTIONS

The methodology used in this section has the purpose of a more effective reporting about the impact that a change of bike share, in general, may have in local GHG emissions and mobility patterns. This method takes as basis mobility patterns parameters used in a methodology developed by Rudolph (2014) on mobile 2020 project ("mobile 2020," 2014). A projection of possible reductions depends also in other factors, such as, the growth of the system and the evolution that EF may have in the coming years.

The two approaches made during this analysis take into account the possibility, or not, of EF evolution, being designated by A and B. On the one hand, if the approach A do not consider a decrease in each emission factor, in the other hand B considers this evolution in a yearly basis.

The method used to achieve a multiplying factor for EF of each vehicle that could be used to project its yearly reduction was, at first, by doing an estimation of EFs for 2020. The parameters used in this estimation were the same previously used on current EFs. Some sources already used, as Joint Research Centre of the European Commission (JRC), provide projections for the impact of different type of fuels in 2020, based in a WTW analysis (Edwards et al., 2014). This projection was only possible for car, motorcycle and bus, as the assumptions that would be needed for the other transport had higher degrees of uncertainty, due to the lack of information. The reductions predicted for car, motorcycle and bus, using the **Equation 15**, were 6.4%, 7.2% and 0.4%, respectively.

$$\mathbf{EF\ reduction}\ (\%) = \frac{\frac{\mathbf{EF\ 2020} - \mathbf{EF\ 2017}}{\mathbf{EF\ 2017}}}{\mathbf{3\ (years)}} \quad (\mathbf{15})$$

Different scenarios created in this section and shown in 4.3.5, opens possibilities in the analysis that are connected to different increases in modal split and cycle trip length. Scenario 0 does not consider the referred increases but a constant bike share. The **Figure 4.9** illustrates the modal share used in this section. The share of different covered distances in trips and the modal split in trips between 0 and 4 kilometers are quite pertinent for the results, due to the assumptions made in this study.

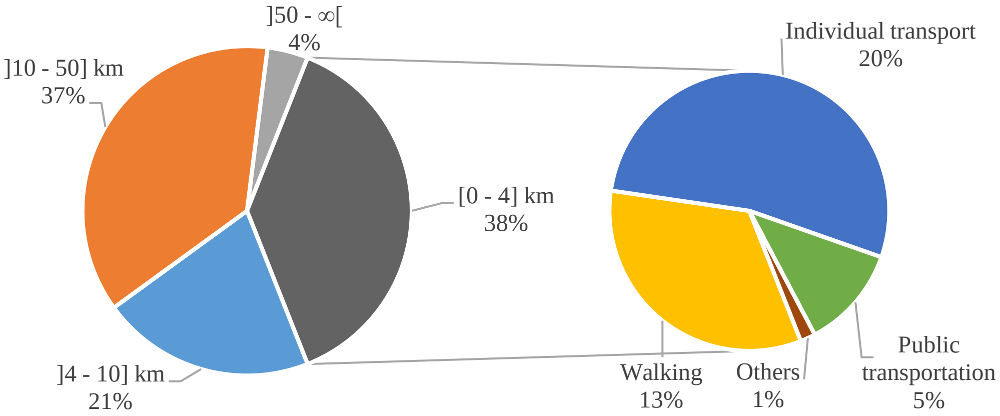

Figure 4.9 - Share of different types of trips in Cascais and the modal split in trips between 0 and 4 km, based in ETAC (CM Cascais, 2015a)

Table 9 - Scenarios for bike share evolution

	Forecast for the yearly increase of cycle trips	Forecast for the yearly increase of cycle trip length
Scenario 0	0%	0%
Scenario 1	2%	5%
Scenario 2	5%	10%
Scenario 3	10%	15%

4.3.6. BS POTENTIAL

The results of subsection 4.3.2 and 4.3.5 were used to analyse the potential to achieve the challenges faced by the municipal road transport, concerning the local, national and European commitments.

The potential offered by BS to reach and overtake the reductions is studied in this section by linking the subsections 4.3.2 and 4.3.5. A simple aggregation of the results obtained in the previous sections helped to understand the impact and potential of this system in comparison with the current commitments.

5.

RESULTS AND DISCUSSION

5.1. GHG EMISSIONS ESTIMATION

The emissions factors were obtained according to different settings and considerations already explained in subsection 4.2.1.2. The results are now presented in **Figure 5.1**, using carbon dioxide equivalent per kilometer per passenger (gCO$_2$e/km.passenger) as unit.

The integrations completed, using a WTW analysis, show some expected outcomes in most of vehicles. According to calculations made, the decrease of EFs verified from 2005 to 2020, in five types of ICE vehicles, is noteworthy, mainly in car and motorcycle. A forecast that considers an increase on energy efficiency and following the considerations taken by Edwards et al. (2014). These results assume an evolution of efficiency on different fuel phases that may reduce the environmental impact of ICE vehicles and the road transport sector.

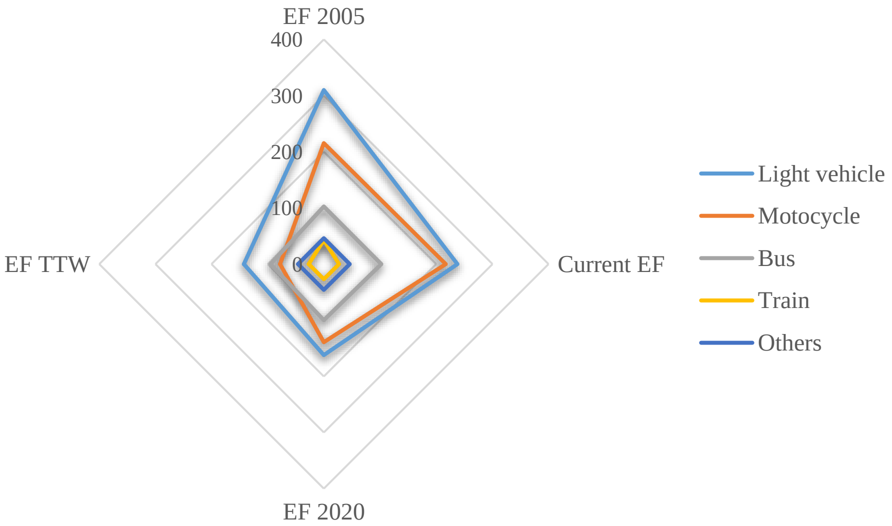

Figure 5.1 – Current emission factors evolution in each type of vehicle, based on estimations

The higher reductions in EFs of individual transportation can be explained by the chosen type of analysis taken in this dissertation. The impact of WTT is quite relevant in this EFs decrease due the proficiency of powertrain and energy sources. In this study, the TTW approach is more affected by parameters, such as, fuel consumption, occupancy rate and possible changes in GWP of each gas.

The occupancy rate of each vehicle category has a great influence in the total share of GHG emissions. For instance, analysing the different values obtained for individual and public transportation, it is notable that a transport with a higher capacity can theoretically have a lower impact in each carbon footprint.

The projected yearly reduction in EF, foresees a lower impact on regular motorcycles relating to bus. Although the outcomes of current estimations show this type of impact, this can be refuted in the future by a different gain in total efficiency, or a change in the type of fuels used in each one of them.

The EFs of electric vehicles were also estimated in this investigation, although they were not used due to the current low share of this type of vehicles, in the study area. It is difficult to project the increase that the number of EVs may have in the future. The EF estimated for common electric cars and electric motorcycles is 33.8 and 15.2 g CO_2e/km.passenger, respectively.

The main goal of this section was to achieve the result presented in **Figure 5.2** and **Figure 5.3**, considering latent trips of ETAC (CM Cascais, 2015a). This **Figure 5.2** shows the different values of Cascais on road GHG emissions, using a WTW analysis in different years. The values of 2017 allows to understand the current situation of the municipality, and the previous value for 2005 serves a base to obtain the necessary reductions in the next sections of this document. A total reduction on the transport sector was estimated in about 51 kt CO_2e, during a 12 years period.

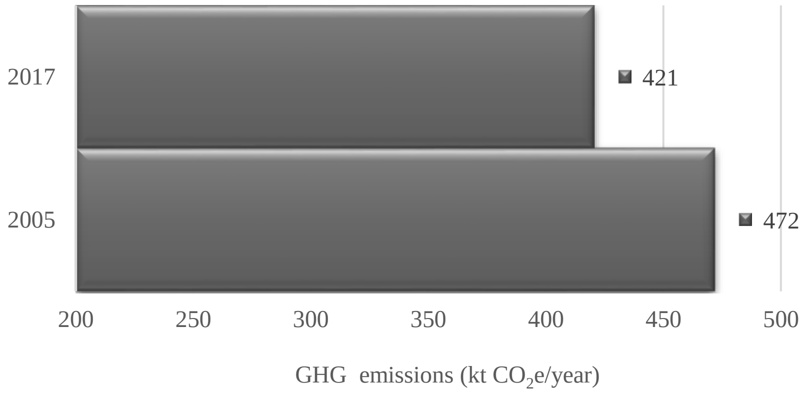

Figure 5.2 - Estimation evolution of GHG emissions from 2005 to 2017, based on estimations

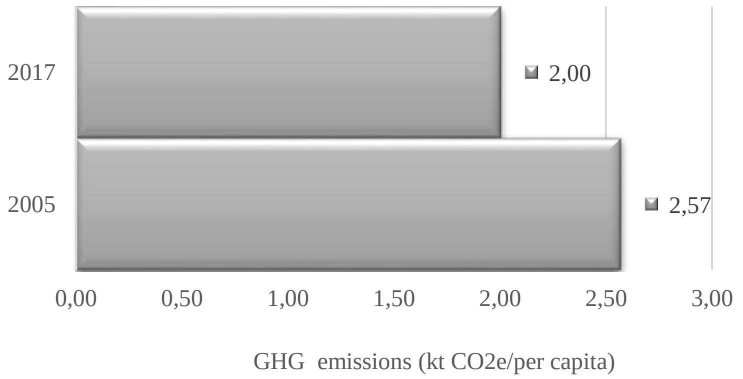

Figure 5.3 - Estimation evolution of GHG emissions per inhabitant from 2005 to 2017, based on estimations

5.2. TARGET REDUCTIONS

The evolution of road transport emissions varies in both approaches referred in section 4.3.1, meaning that different percentages for the current necessary reduction are expressed in this analysis.

The results, shown in **Figure 5.4**, reveal that the current reduction of emissions, in comparison with 2005, is 11%, according to approximations made during this section. This means that the targets for 2020 may have already been reached, although a decrease in emissions is still necessary to achieve the reduction goals for 2030, as seen in **Figure 5.5** or **Figure A.3** in A.4. Appendix – Results and Discussion.

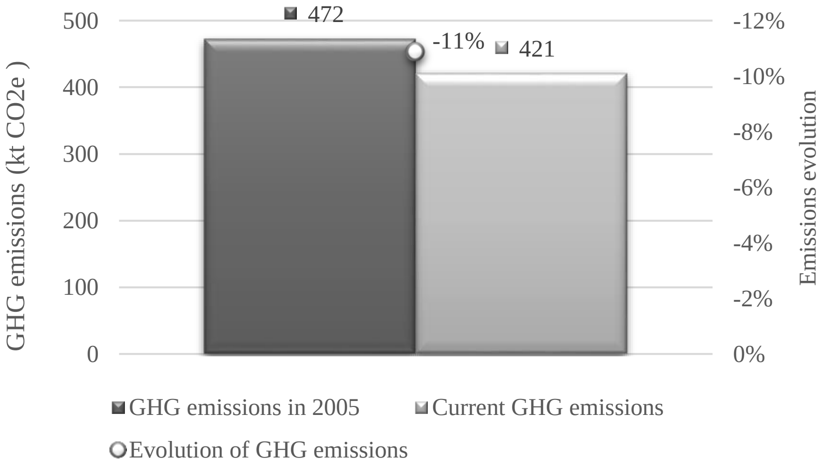

Figure 5.4 - Evolution of road transport emissions in Cascais

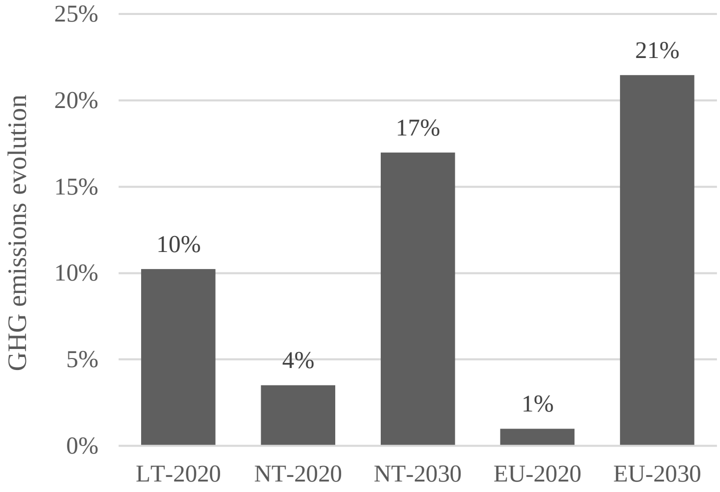

Figure 5.5 - Total necessary reduction to reach the targets (%) according current levels

The current target that the study area should reach, in terms of municipality and individual carbon footprint, until the end of the local and other levels of commitment is presented in **Figure 5.6** and **Figure 5.7**.

The values for GHG emissions per inhabitant, presented in **Figure 5.7**, show that targets for 2020 have already been reached, although there is a slight doubt in the local target. Both values are similar, with a slightly different, which points that the goal value has been reach by a margin of 0.06 tonnes of CO_2e/per capita. To accomplish stablished goals for 2030, is still necessary to reinforce some local measures that could assist the necessary reductions.

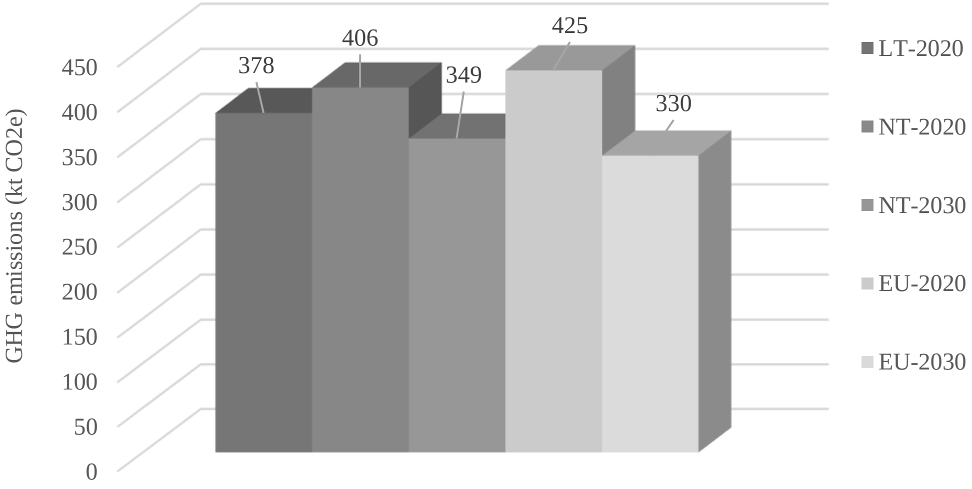

Figure 5.6 – Targets values for GHG emissions in different commitments

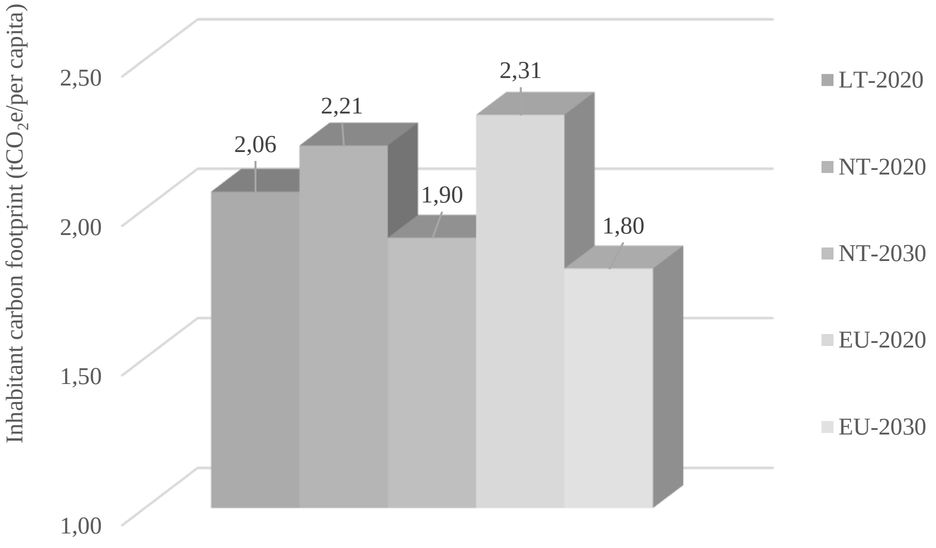

Figure 5.7 - Target values of inhabitant carbon footprint of GHG emissions

In terms of citizen carbon footprint, the reduction was 22% since 2005, as shown in **Figure A.4**, A.4. Appendix – Results and Discussion, mainly due to growth of population, in the study area. A rise of 14.3% in Cascais population was verified until 2015, according INE (2011), and this fact can be seen as one of the triggers that motivated and challenged the county to develop new mobility strategies and solutions that can meet the population needs.

The results of this section are important to support the next analysis and insert new components in the investigation.

5.3. BSS ANALYSIS

The decreasing number of monthly users in March, demonstrated in **Figure 5.8**, can be explained by the introduction of a payment system in the BSS. The mandatory subscription of packages, which includes this service have generated a sudden decline in the total amount of trips made, proven in **Figure 5.9**. This decrease in the total travelled trips induced a rise in the total number of trips per user, as indicated in the left vertical axis of **Figure 5.8**. The growth in the average number of trips per user can be seen as a transition in type of use of the system, towards daily routine trips as commuting. If this system is seen and used as a habitual choice to travel, the trend will be to reduce the impact of other transportation modes in the municipality carbon footprint.

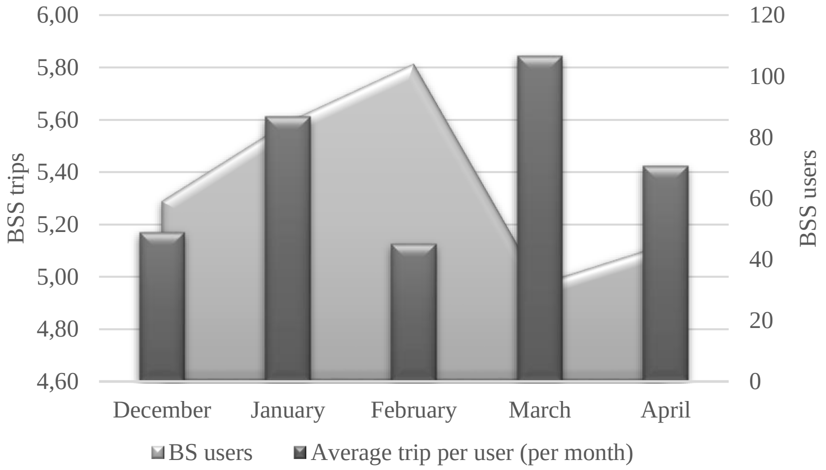

Figure 5.8 - Evolution of users and average trips per user

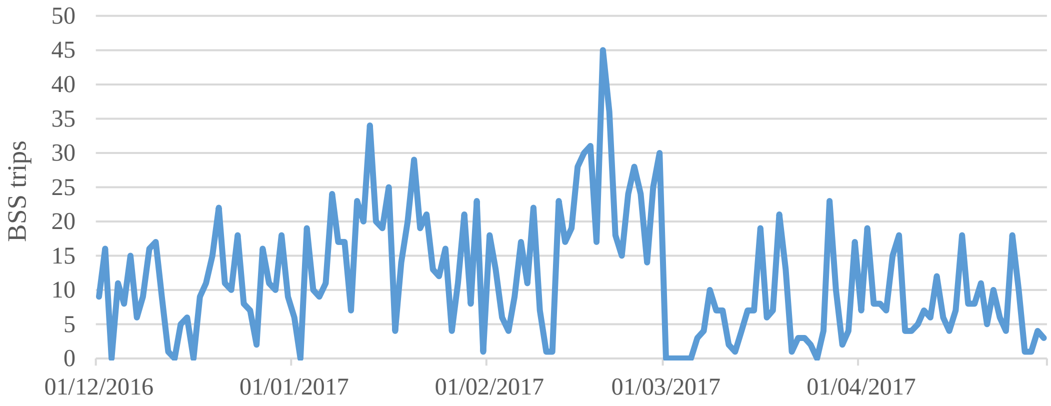

Figure 5.9 - Evolution of BS usage in Cascais

The curiosity towards this system has grown since its implementation, and since December, the total gain of users is 225 citizens, current subscribers and non-subscribers of the BSS, as presented in **Table 12**, in A.4. Appendix – Results and Discussion. New users have been joining this system, which can result, in a short or medium term, on a growth pattern. The peak recorded in February can have several explanations. This intensification of BSS usage could be explained, not only by the fact that these trips were made during the end of a free of charge period, but also for the possibility of an occasional events or activities that may have encouraged its use.

Some journeys were considered not representative, in terms of pollution reduction, mostly because they are additional and not replacement trips. The assumptions made to measure the quantity of pollutants, already consider the type of trips that may generate a substitution, known as latent trips. According CM Cascais (2015), the type of trips that potentially have more characteristics of a bike latent trip is the one that has a maximum length of 4 km. This analysis was restricted to trips made during the allowed period, which also coincides with the great concentration of trips verified in the system.

The **Figure 5.10** shows that a large share of total trips had a lower duration then 15 minutes. Using the average bike speed of 11 km/h, referred in section 2.3, a bike trip of 20 minute would mean a travelled distance of 4 km, and a pattern of maximum distances travelled demonstrated in **Figure 5.11**. According ETAC (CM Cascais, 2015a), this journeys can be consider as potential latent trips, and despite the possibility of using this assumption as it was made in 4.2.1.1, a question was asked in the survey to gather this input based in BSS, as shown in **Figure A.2**.

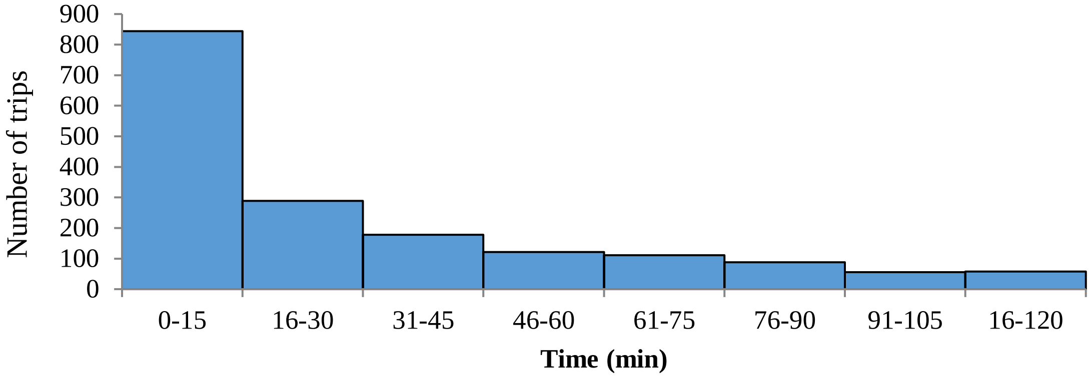

Figure 5.10 - Duration of BS trips

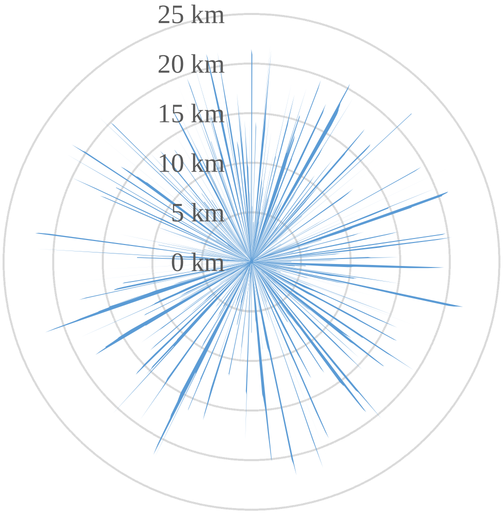

Figure 5.11 - Maximum distances covered by bike sharing trips in Cascais, until 2 hours of usage

The data provided by MobiCascais platform, for this investigation, is only regarded to the BSS and is related to each transaction made by its current users. This scheme was implemented and tested during October and November 2016, but its use is being more regular since just the beginning of December.

5.4. CURRENT IMPACT OF BSS

The strategical locations thought for each dock, as illustrated in **Figure 5.13**, might have a profound impact in bike sharing attractiveness. The potential use of this scheme depends upon the combination of other factors, such as, the hour of the day and the day of week. The comparison between the weight of a week day and a weekend day in terms of BSS use allows a possible scrutiny of motives for trips.

Although this is just a theoretical hypothesis, the purposes of trips during the weekend are usually associated with tourism, physical or recreational activities. The current weight is 14.5% in a week day and 13.6% in a weekend day. This shows that the probability of bike sharing being used on a regular week day is slightly higher than a regular weekend day, which may refute statements that say that the current system only serves for recreational purposes. This was proved by the answers of the survey, as illustrated in **Figure 5.12**, in which commuting and utilities combined have a quarter of the total share of BSS trips.

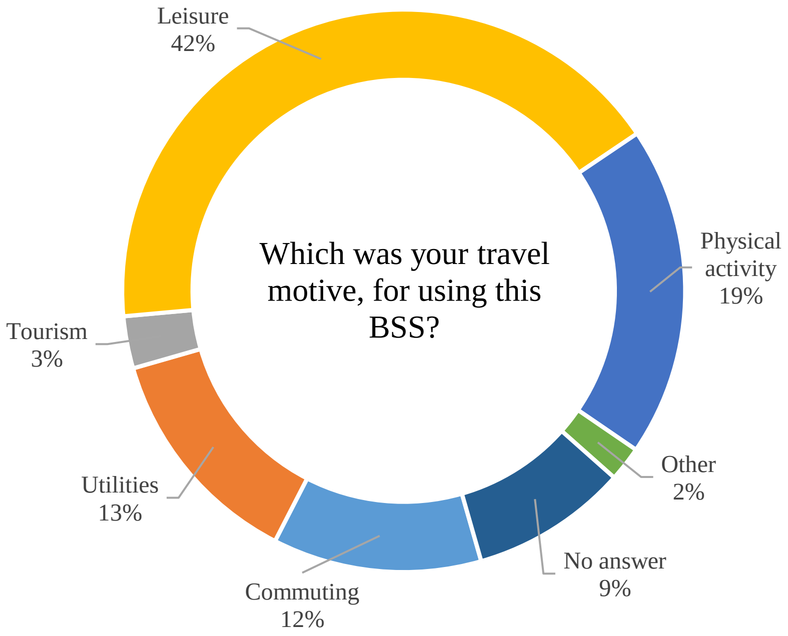

Figure 5.12 - Answers to question 5 from the surveys

The **Figure 5.13** shows a heatmap of the BSS use, related with the trip origin. The starting location of each trip are not evenly distributed. Two docking stations that have a similar percentage of use, are clearly above the average of use, with a share of 22% each. Doca CP Cascais, located nearby a train station and Doca Guia, placed in an attractive location for leisure activities, are currently the ones with the highest demand. Both stations are also placed near the current lengthier bike path and lane, in Cascais.

Figure 5.13 - Heat map of BSS, with each current docking station in Cascais. Retrieved from MobiCascais Platform.

The data used, as input, to estimate the reductions already made with the system was retrieved from MobiCascais platform and the survey, as above-mentioned in subsection 4.2.2. Considering only trips made during the defined time range of analysis (five months), the result was a total travelled distance of about 9000 km.

Although commuting and utilities bike trips are commonly seen as the ones that cause the substitution trips, other travel motives can still represent this type of trips (EEA, 2016c; IPCC, 2014a; Ricci, 2015b). According to the survey's answer and as presented in **Figure 4.5**, the percentage of substitution trips is 62%, which differs from the 25% that was result from aggregating the share of commuting and utilities trips. Using the methodology in the previous chapter, it was possible to achieve the travelled distance of substituted trips, which is an approximation of 5600 km.

The answer of the question made about the modes of transportation that they would use instead of cycling, as illustrated in **Figure 4.6**, have allowed a better perspective about the modal share. The percentage of use, in each type of vehicle, is directly connected with the concept of latent trips, which improves the confidence of the measurement. The current reduction of GHG emissions, in the road transportation sector, is around 0.65 tonnes of CO_2e, considering the five month period of analysis. An average of 0.13 tonnes of CO_2e per month.

The integration of this scheme with other transport options, as public transportation services, can also benefit and increase BSS potential. Projects in the study area, such as, the increment of cycling infrastructures, can help the growth of the system, mainly for attractiveness around this new and fashionable possibility (Gonzalo-Orden et al., 2014).

5.5. BSS POTENTIAL

The argument that BSS trips can support a greater reduction of GHG emissions, only depends on if the travel choices correspond to replacement, and not to additional trips. As aforementioned in the subsection 4.3.4, this part of the study allows a projection of the potential of commuting trips in BSS to achieve the targets of reductions analysed in section 4.3.2, based on current users. The goal is to get a bigger idea about the inherent effect of this type of travel.

Some of current travel motives are classified as commuting, utilities (journeys to access services or trades), tourism, leisure, physical activities and others like the curiosity of testing the new public bike scheme, as validated by the survey's answers. As it can be seen by the **Figure 5.12**, motives associated with recreational use have the highest shares. These answers show that the current use could provide greater savings if the current users would make their trips in other purposes and the number of latent trips were increased.

After analysing the decrease of GHG emissions already made by the system, with the current share of commuting trips, and understanding the importance of commuting trips in theory, an opportunity to estimate the impact of this type of trips rises.

Commuting presuppose at least two trips per working day, in which weekend days are not considered. The average number of working days in each month and other parameters provided by MobiCascais platform, regarding users and trips made, were also considered. The result is an estimated reduction of about 8.89 t CO_2e per year or 0.74 t CO_2e per month, with current users. The result shows that if current users could consider as regular commuters, it would have a greater impact then the current usage, with a difference of 0.61 t CO_2e per month.

Although the number of users increased, comparing with the first month after the introduction of the new subscription packages, the numbers of users, currently 45, are still far from being enough to complete the reduction goals. The Erro! A origem da referência não foi encontrada. shows the BSS users, which would be necessary to complete the reduction goals of each commitment.

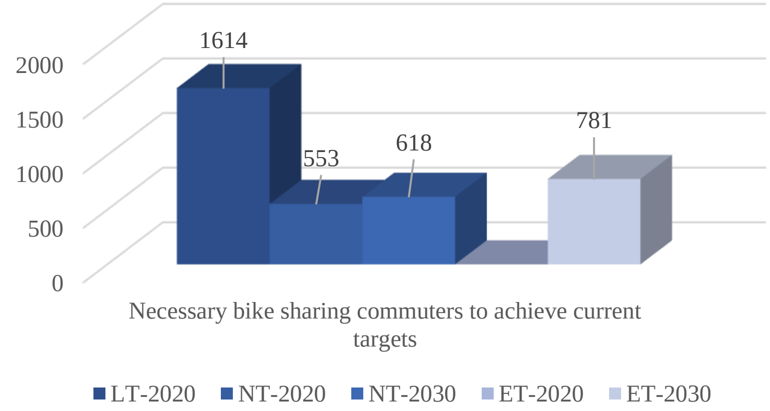

Figure 5.14 - Necessary bike sharing commuters to achieve current targets

A type of practice that does not provide a transition from other transports to bike, but that serves only as a mean to create new trips, should not be highly endorsed. In order to create a more sustainable mobility solution, a goal of the program should be to offer an alternative solution to other modes of transportation. Routine trips are the sort that have a larger impact in GHG reductions.

5.6. BS PROJECTED REDUCTIONS

The results in terms of modal split, according to scenarios created, are presented in **Figure 5.14**, **Figure 5.15** and **Figure 5.16**. This parameter was not affect by the approaches A and B, which differ in considering a decrease in the EF or not.

The results show that considering the weight of each share, individual transportation and walking would be more affected modes. According to ETAC (CM Cascais, 2015a), cars, motorcycles and walking have the highest share in short distance trips, and would have a larger transition to bikes in distances until 4 km.

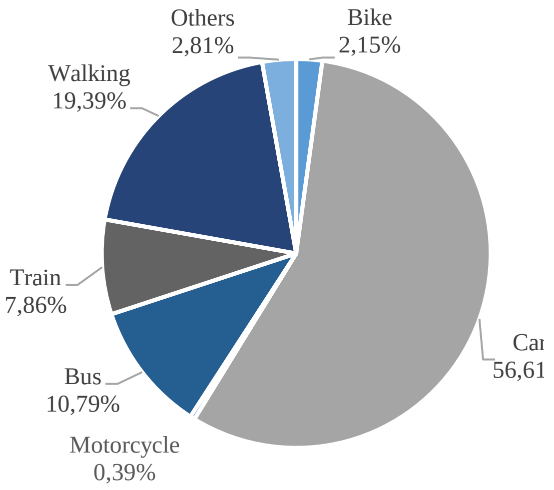

Figure 5.14 - Modal split of the 1st scenario

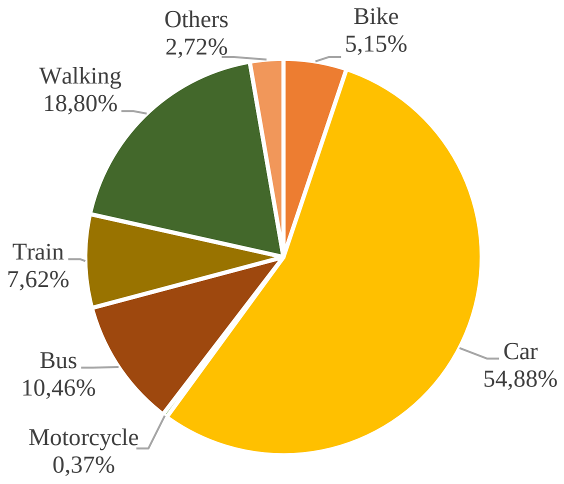

Figure 5.15 - Modal split of the 2nd scenario

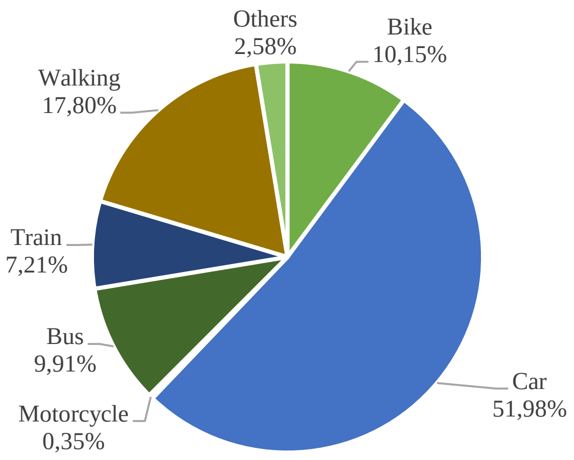

Figure 5.16 - Modal split of the 3rd scenario

The approaches A and B have generated different layers of analysis and possibilities of reductions in GHG emissions. Each approach reflects the effects and relevance of their parameters and the comparison between them expresses the opportunities for GHG reduction due to a change in emission factors. As ICE vehicle are still the prevailing type of transportation in the national territory, the impact of their carbon dioxide releases is one of the principal causes of road transport GHG emissions.

In general, the projections of GHG emissions for 2020, comparing the **Figure 5.17** and **Figure 5.18**, show that approach B offers a greater expected reduction of harmful emissions to the atmosphere. The reduction is verified in both, municipality road transport emissions and inhabitant carbon footprint, expose in **Figure A.6** and **Figure A.8**, in A.4. Appendix – Results and Discussion, and the minimum values reached are noticeable lower that in the approach A, mostly in the longer projections as 2030.The projections made for Cascais inhabitant footprint in road transportation, in both A and B approaches, are presented in **Figure A.5** and **Figure A.7**.

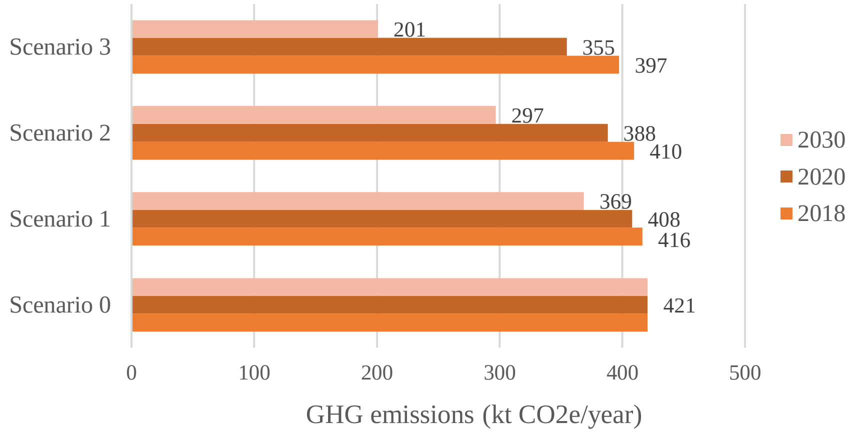

Figure 5.17 - Projections of road transport emissions in approach A

The lower levels demonstrated in approach B are due the projected decrease of EFs, as it can be seen in the **Figure 5.18** below.

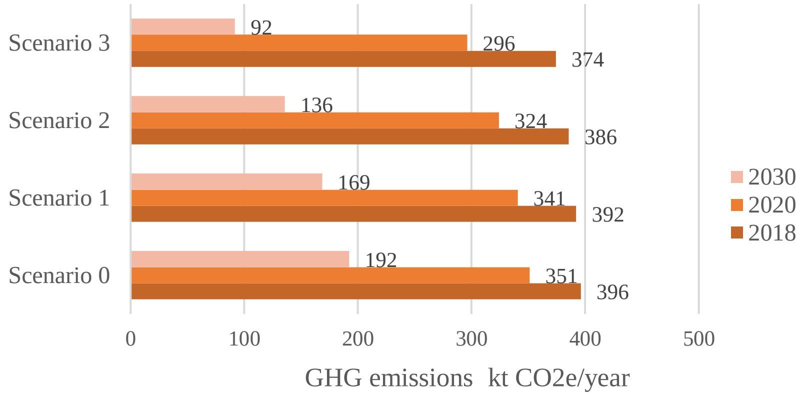

Figure 5.18 - Projections of road transport emissions in approach B

As the progress of EF is integrated in estimations, the possibility of reduction in GHG increases. This outcome confirms that a combination of the two parameters provide a great potential and expectations towards into a more sustainable future.

According to the effects of approach B, a stabilization is more easily achievable over shorter periods, which indicates that a greater reduction can only be accomplished by combining an increase of BS with more efficiency in energy consumption, over several years.

5.7. BS POTENTIAL

The determination of projected reductions and comparing it with the targets previously defined was crucial to understand the results of the projections and the potential of each scenario created.

The yearly projected reductions in GHG emissions of road transportation, using the four previous scenarios, have resulted in **Figure 5.19** and **Figure 5.20**, as the several approaches present different values. The decrease of pollutants emitted depends, in a large scale, on the evolution that emissions factors of vehicles might have over the years. As expected and aforementioned in the previous section, the reduction of GHG emissions reached higher values in approach B.

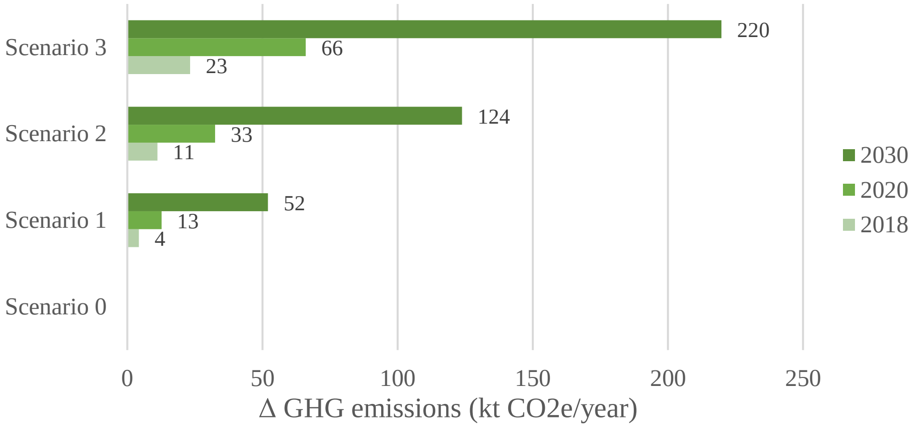

Figure 5.19 - Projected yearly reduction in on-road transportation emissions - approach A

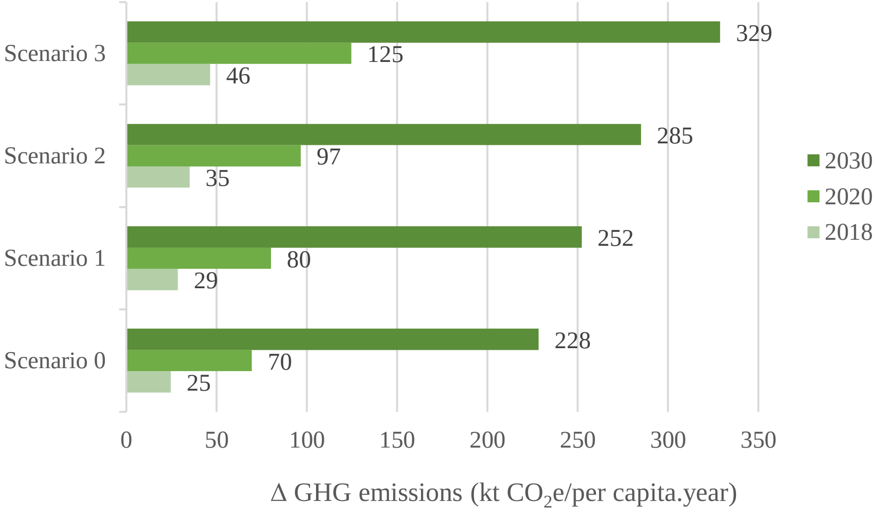

Figure 5.20 - Projected yearly reduction in on-road transportation emissions - B

The same analysis was made relating the yearly reduction of Cascais inhabitant carbon footprint and the results, revealed in **Figure A.9** and **Figure A.10** express the expected outcomes.

According **Figure 5.22**, just the scenario 3 is able to fulfil the local target, as the national goal for 2020 and 2030 might be accomplish by the second and third scenario. Despite the fact that the European target for 2020 could be complete by all scenarios, the one for 2030 would only be achieved by scenario 2 and 3.

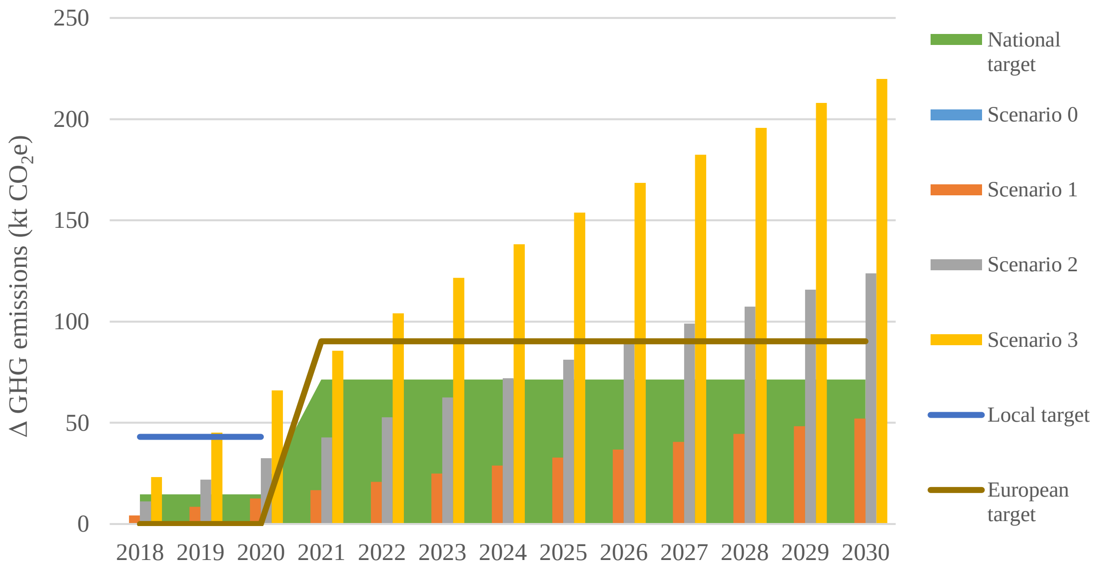

Figure 5.21 - Targets reached in approach A, without EF evolution

The following **Figure 5.22** has reveal the projections of GHG emissions considering the evolution of EF for the next years, and shows the great impact that these scenarios would provide in the municipality decarbonisation. The results indicate that, if the assumptions made in subsection 5.1, for EF decrease over the next years, are correct, the necessary reduction will eventually be completed, in all scenarios. The targets would be accomplished even with a continuous bike share, although an increase in cycling, as substitution trips, would provide greater reductions. The outcomes show the opportunity provided by a modal transition towards cycling and new implementations in the BSS to complete not only established targets but also more ambitious goals at local level.

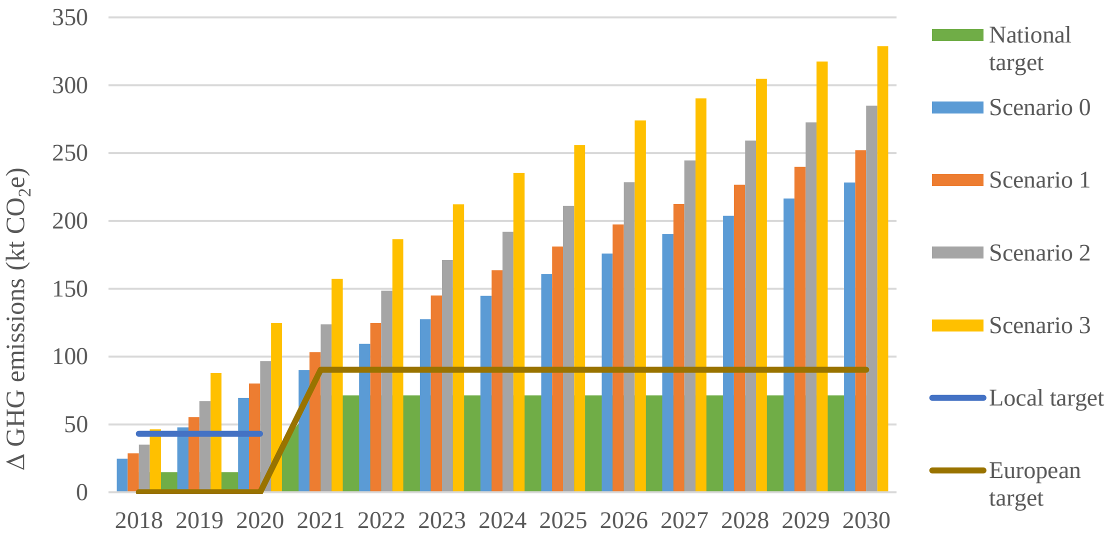

Figure 5.22 - Targets reached in approach B, with EF evolution

The results show that using a WTW approach in the projection of EF decrease, over the years, can provided greater reductions and a bigger impact on the environment than expected, mainly if combining it with a greater increaser in cycling trips.

The replacement of the type of transportation chosen by the population can also be promoted by several factors, as the availability of new cycling infrastructure and innovative transport services as bike sharing. Even though, this analysis indicates the potential of cycling as independent solution, the promotion of integrated mobility can also benefit bike share.

6.

CONCLUSIONS

The results of this investigation confirm that a WTT approach is still not commonly used, due to the difficulty and level of abstraction in the calculations. Well-to-Tank proved to be an approach with relevant impacts not only in EVs, but also in ICE emission factors estimation. As the two dimensions of a WTW analysis depend on different parameters, it also highly depends in variables that have an impact in both approaches. If on one hand, the proficiency of powertrain and energy sources have a larger effect on WTT, on the other hand a TTW approach is more affected by parameters, such as, fuel consumption and possible changes in the GWP of each gas, in ICE vehicles.

The type of fuel and the occupancy rate, in each type of vehicle, have a great influence in both divisions of the Well-to-Wheels analysis. After analysing the different EFs obtained for individual and public transportation, it is evident that a transport with a higher capacity have, potentially, a lower impact in the total share of GHG emissions and in each individual carbon footprint.

According to estimations, the total reduction on the transport sector, in the municipality, was about 51 kt CO_2e, during the period between 2005 and 2017. A decrease that was felt, with more intensity in each inhabitant carbon footprint, due to an estimated growth of 14.3%, in Cascais population. These results show that current targets, made to fulfil the commitments for 2020, have already been reached. Even though, reinforcing local measures, towards a greater environmental sustainability, are still necessary to accomplish stablished goals, for 2030. The reduction of EFs verified over the years may help these requisites, as it is still expected a decrease in carbon intensity.

The current transition in modal share and travel motives have a direct impact on the substituted trips. As more routine trips, such as commuting, would allow a greater replacement of trips, the reduction could be estimated in about 0.74 t CO_2e/month, instead of the current of 0.13 t CO_2e/month, with the same users. The bike sharing system, in Cascais, does not have a representative impact in the municipality decarbonisation, as it is still in its initial phase of implementation and therefore, it is going through a process of growth in use and infrastructure.

The scenarios created, foresing an increase of bike share in the municipality, support a reduction on the environmental impact of local mobility. Transitions trips from different transportation modes to bike, are the ones that provide the opportunity to complete, not just all current targets, but exceed the established reduction goals. Although non-substitution trips may not mean a direct saving in GHG emissions, it might also attract new users. Encouraging a type of displacement that allows a greater modal substitution and the generation of more sustainable behaviours.

The BSS system introduced in Cascais, depending on the way it evolves, can be thought and developed to offer the necessary conditions, not only to complete the challenges already defined but also to serve as launch pad for a more sustainable ones.

Small implementations, based on sustainable solutions, may have some impact, depending on the percentage of modal transition and the type of vehicle replaced, and even help in meeting the current goals. However, the weight of large mobility fleets and the use of vehicles with a high emission factor is still the major barrier to building a highly sustainable future. The strategy to support soft transportation as bike sharing, mainly in the commuting trips, should be define as a priority, because even though some initiatives were taken and a path have been traced, the road is still narrow. Action measures must be adapted frequently and the planning of the new integrated mobility project should be carefully analysed throughout its development.

6.1. FUTURE RECOMMENDATIONS

Although the selected methodology takes into consideration numerous local aspects, the prediction made for 2020 do not consider the intervention of external factors, such as, other mobility options and strategies that could be implemented during that period. Although this investigation allows a better picture of BSS impacts as an exclusive solution, and assess the singular effect of BS implementation around the study area, considering these factors would provide a more realistic evaluation of the study area.

The BSS is still going through modifications and growth. The improvements and adaptations can help this scheme to reach its potential and to be an increasingly appealing alternative. Encouraging the BSS use in docking station closer to commercial and working zones, such as, in areas with great concentration of industry or schools could promote trip motive, such as, commuting and utilities. This consideration also offers a potential study on the topic of this investigation.

Although the assumption that an increase in permitted usage hours would foster a longer and lengthier use could be made, as shown in Figure 5.10 and Figure 5.11, this measure may also jeopardize the current and overall accessibility of current bicycles, mainly if the system is saturated and not optimized. From this perspective, this could demotivate more frequent users for not presenting a consistent alternative.

The GHG emissions saved by the BSS can also be estimated directly from the BSS users, by placing a question before or after using the system. This would allow the investigator to get a greater certainty about the type of vehicle that was substituted by bike. This type of vehicle would have to be associated to an emission factor and data about distance travelled would be more real if it were calculated using a tracking device, placed on bikes.

These emissions saved by the BSS could also be provided directly to BSS users, which would open the possibly of making a more direct awareness about the impact of this information availability. This would also allow another study type of study based on effect of real time awareness in GHG reduction, and in a potential behaviour change.

7.
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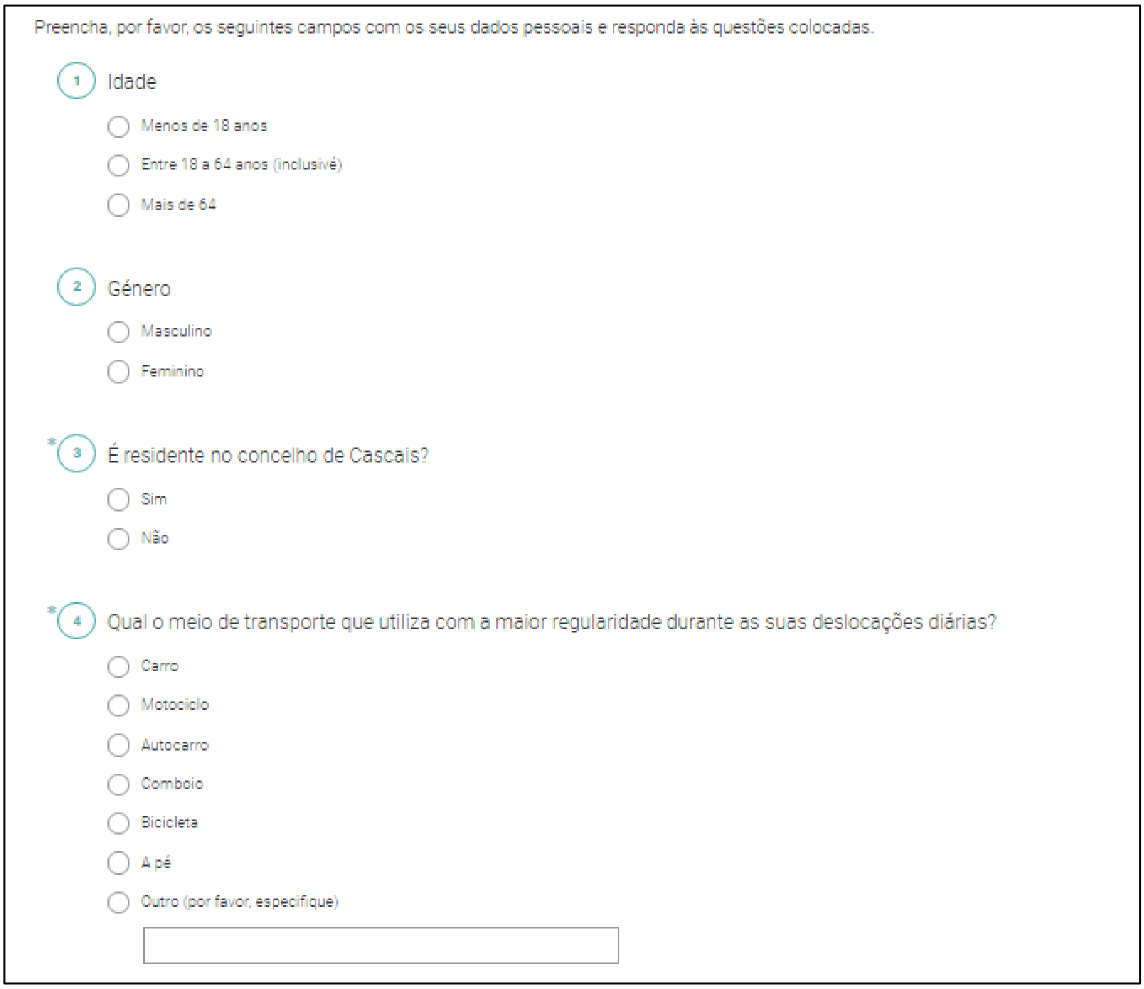
A. APPENDIXES

A.1. APPENDIX – SURVEY



Preencha, por favor, os seguintes campos com os seus dados pessoais e responda às questões colocadas.

1 Idade

○ Menos de 18 anos
○ Entre 18 a 64 anos (inclusivé)
○ Mais de 64

2 Género

○ Masculino
○ Feminino

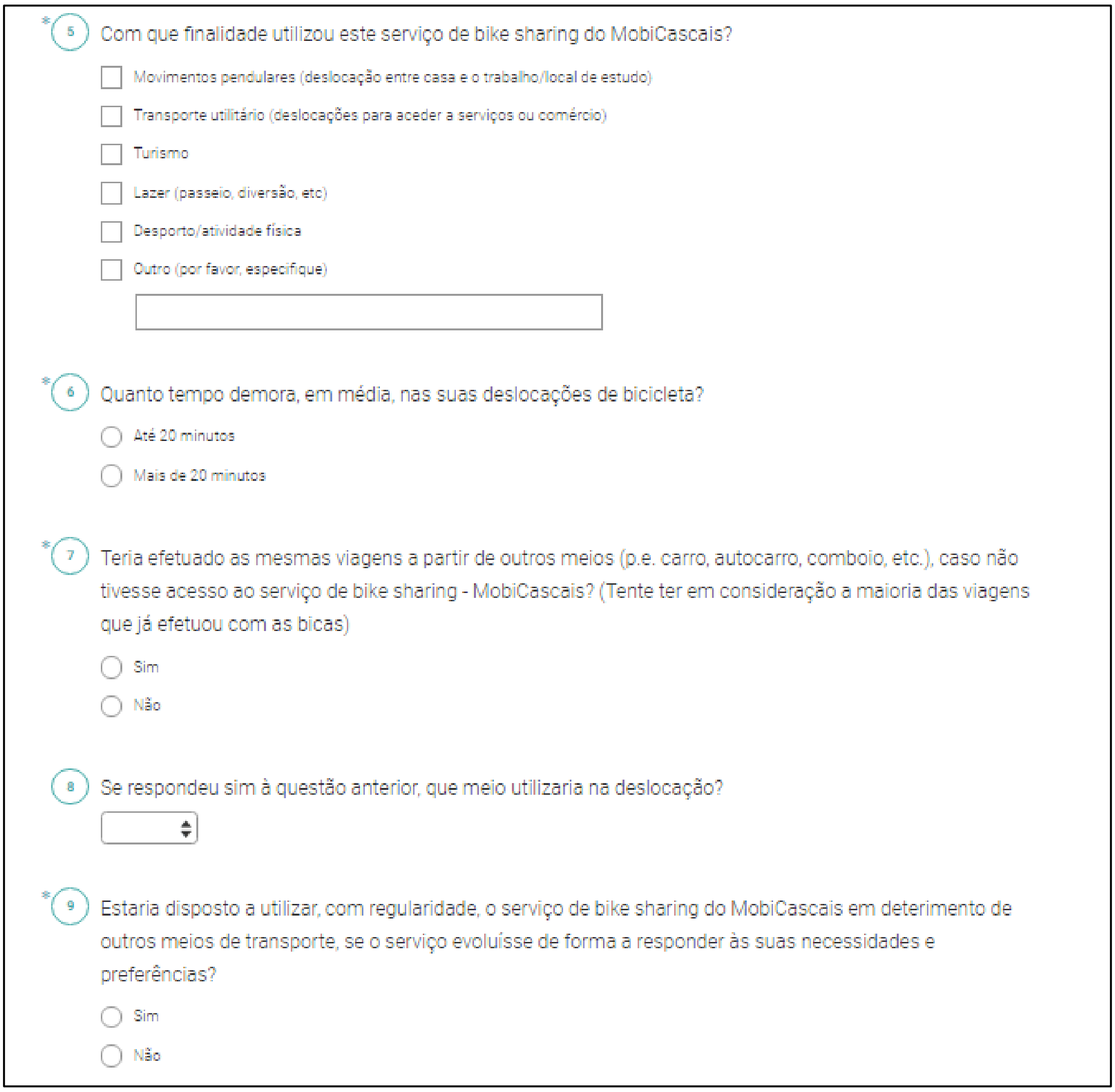
* 3 É residente no concelho de Cascais?

○ Sim
○ Não

* 4 Qual o meio de transporte que utiliza com a maior regularidade durante as suas deslocações diárias?

○ Carro
○ Motociclo
○ Autocarro
○ Comboio
○ Bicicleta
○ A pé
○ Outro (por favor, especifique)

Figure A.1 - Questions of the survey - part1



* 5 Com que finalidade utilizou este serviço de bike sharing do MobiCascais?

☐ Movimentos pendulares (deslocação entre casa e o trabalho/local de estudo)
☐ Transporte utilitário (deslocações para aceder a serviços ou comércio)
☐ Turismo
☐ Lazer (passeio, diversão, etc)
☐ Desporto/atividade física
☐ Outro (por favor, especifique)

* 6 Quanto tempo demora, em média, nas suas deslocações de bicicleta?

○ Até 20 minutos
○ Mais de 20 minutos

* 7 Teria efetuado as mesmas viagens a partir de outros meios (p.e. carro, autocarro, comboio, etc.), caso não tivesse acesso ao serviço de bike sharing - MobiCascais? (Tente ter em consideração a maioria das viagens que já efetuou com as bicas)

○ Sim
○ Não

8 Se respondeu sim à questão anterior, que meio utilizaria na deslocação?

* 9 Estaria disposto a utilizar, com regularidade, o serviço de bike sharing do MobiCascais em deterimento de outros meios de transporte, se o serviço evoluísse de forma a responder às suas necessidades e preferências?

○ Sim
○ Não

Figure A.2 - Questions of the survey - part2

A.2. APPENDIX – CASE STUDY

Table 10 - Climate summary of Lisbon in the last years. Data source: (Weatherbase, 2017)

Parameters	Annual	Jan	Fev	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Temperature (ºC)	17	11.3	12.6	14.3	15.3	17.3	20.3	22.7	23	21.7	18.4	14.8	12.4
Average High Temperature (ºC)	20.9	14.5	15.9	18.2	19.2	21.4	24.8	27.5	27.8	26.2	22.1	18	15.2
Average Low Temperature (ºC)	13.1	8.1	9.2	10.4	11.5	13.3	15.9	17.9	18.1	17.3	14.6	11.5	9.5
Average Precipitation (mm)	725.8	96.8	90.2	51.2	64.7	55.6	17.2	6.1	6.8	28.5	79.8	107.1	121.8
Average Relative Humidity (%)	73.8	80	80	75	70	70	70	65	65	70	75	80	85
Average Wind Speed (km/h)	16	9	16	17	17	19	19	20	19	16	16	14	9

A.3. APPENDIX – METODOLOGY

Table 11 - Bulk emission factors for Portugal and calculation of CO_2e of each fuel type

	Category	CH_4		CO_2		N_2O		Fuel density	CO_2e
		(g/kg fuel)	GWP*	(g/kg fuel)	GWP*	(g/kg fuel)	GWP*	(kg/l)	(g/l fuel)
Car	Gasoline	0.80	28	3160	1	0.206	265	0.745	2411.56
	Diesel	0.08		3170		0.087		0.837	2674.46
Motorcycle	Gasoline	6.35	28	3160	1	0.059	265	0.745	2498.31
Bus	Diesel HDV	0.23	28	3170	1	0.051	265	0.837	2669.99
	CNG	4.50		2750		0		0.712	2047.71

*GWP values for 100-year time horizon from the IPCC Fifth Assessment Report. 2014 (AR5)
Fuel density source: CELE. APA by Galp
Fuel consumption source: 2014 fuel consumption guide

A.4. APPENDIX – RESULTS AND DISCUSSION

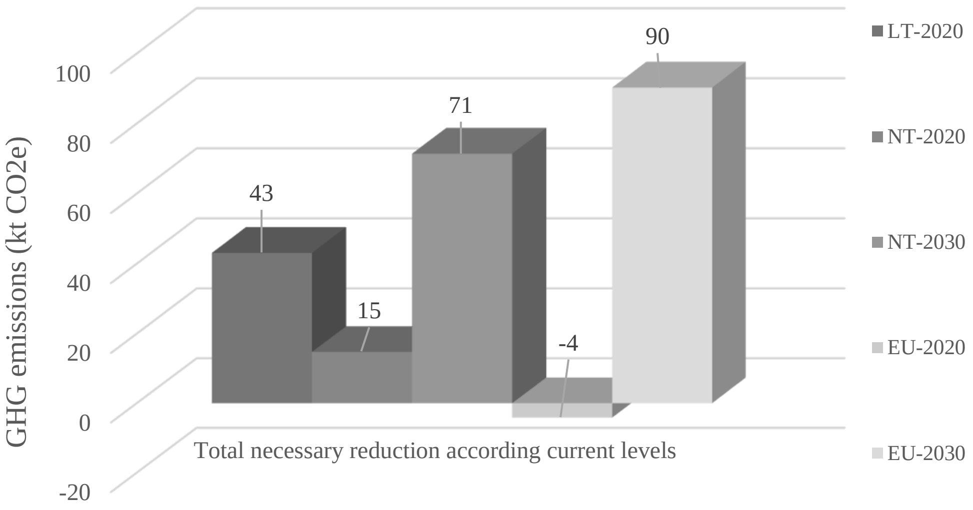


Figure A.3 - Total necessary reduction of GHG emissions, according current levels

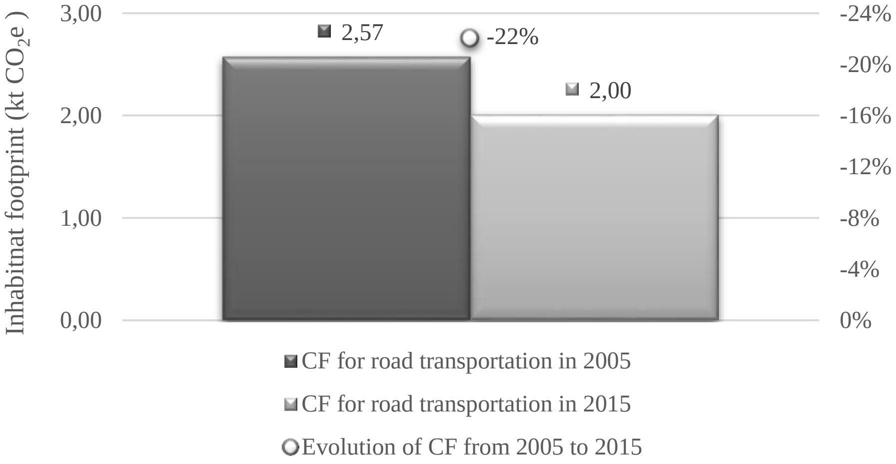


Figure A.4 - Evolution of inhabitant carbon footprint. in Cascais

Table 12 - Amount of bike sharing users

Months (Studied period)	Different users per month	Total gain of users
December	59	225
January	85	
February	104	
March	32	
April	45	

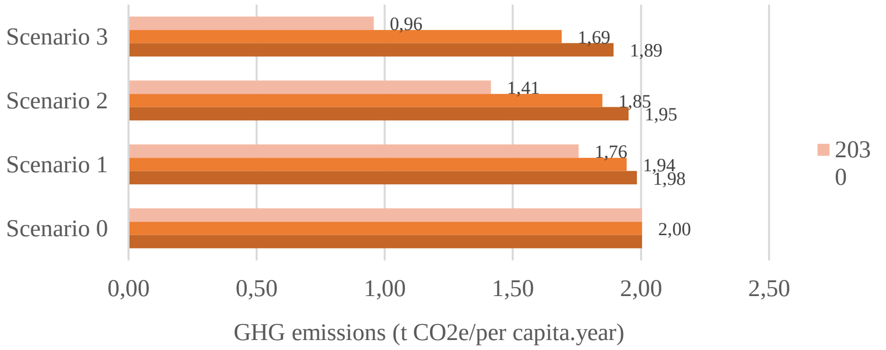


Figure A.5 - Projection of Cascais inhabitant footprint yearly evolution in approach A

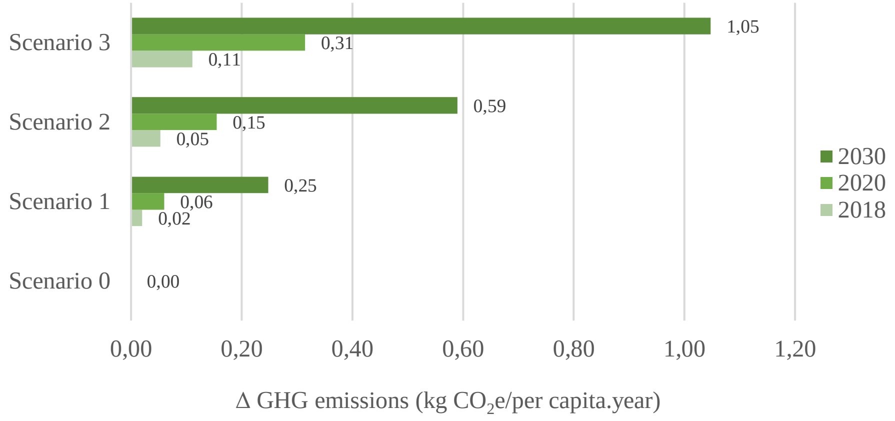


Figure A.6 - Projected yearly reduction of Cascais inhabitant footprint. in approach A

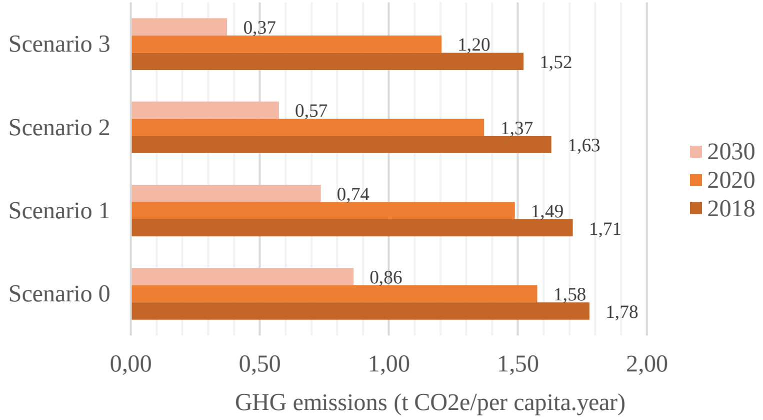


Figure A.7 - Projection of Cascais inhabitant footprint yearly evolution in approach B

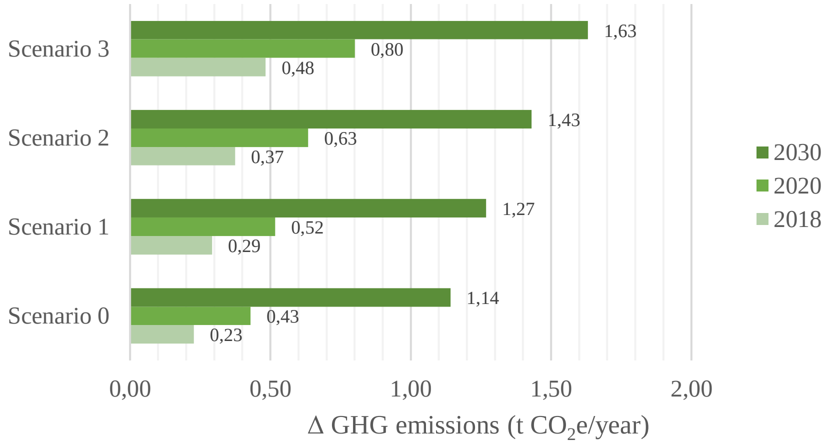


Figure A.8 - Projected yearly reduction of Cascais inhabitant footprint in approach B

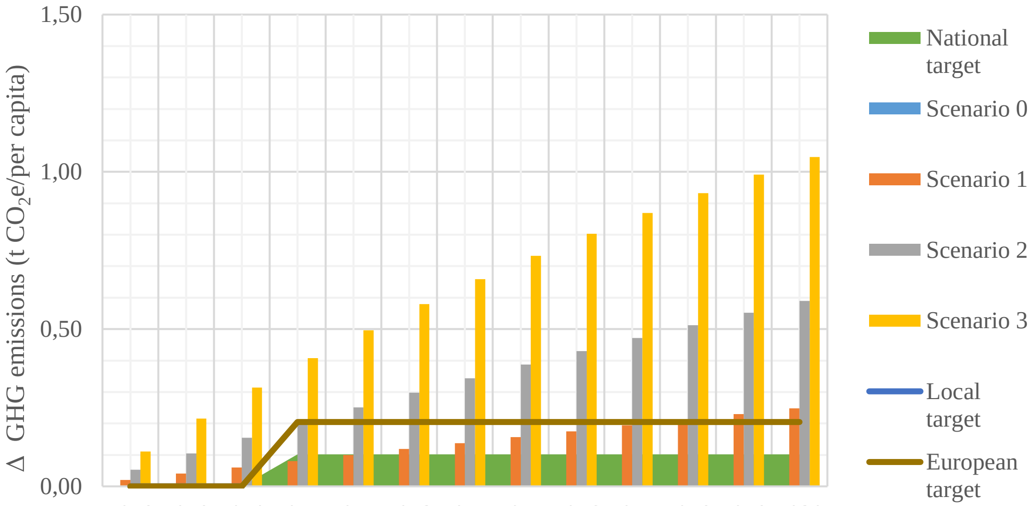


Figure A.9 - Inhabitant CF evolution towards targets. with approach A

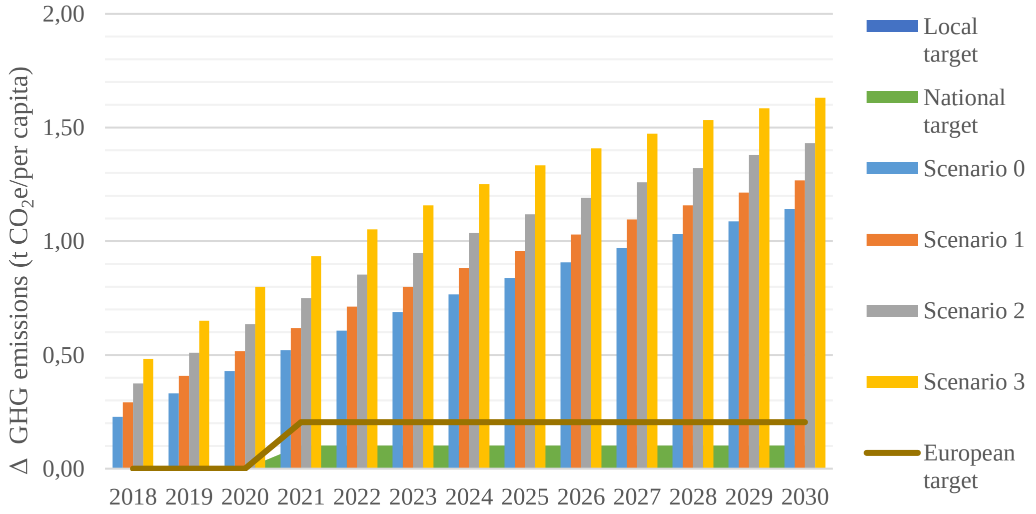


Figure A.10 - Inhabitant CF evolution towards targets. with approach B