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SUSTAINABLE MOBILITY AT FEUP:
COMPARISON BETWEEN TRADITIONAL AND MODERN DATA COLLECTION

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À professora Eliana, que me deu o dom da palavra, da lógica e da criatividade

“A developed city is not a place where the poor have cars.

It’s where the rich use public transportation.”

Gustavo Petro

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Ao João, por ter sido o meu porto seguro em tempos de tempestade.

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A todos que me ajudaram nestes 5 anos e 5 meses.

Um enorme **Obrigada**.

ABSTRACT

Within the context of Urban Management, Mobility is an intrinsic quality to the organization of a city. It dictates the pace and the soul of day-to-day life, reflecting the ideals of a society in question. Being an important source of pollution that mainly affects the atmosphere, its adequate management is crucial in order to diminish the emission of greenhouse gases that contribute to the increase of the carbon footprint and, consequently, global warming. The evolution towards a more sustainable future demands planning based upon the retrieval of real data, to properly support the necessary decisions.

This dissertation presents the case study of the Faculty of Engineering of the University of Porto (FEUP) and the main objectives were the evaluation of the sustainability of the community's mobility and the comparison of two methods for data collection: the traditional method through mobility surveys and the modern method, using the smartphone application SenseMyFEUP, created by a research team of the Institute of Telecommunications, which is inserted in the project FutureCities.

This study went through a Preparation Phase for the creation of the survey, the definition of mobility data necessary to be retrieved by the application and the advertisement of SenseMyFEUP. A Data Collection Phase followed, with two weeks for the survey and four weeks dedicated to the application, culminating in the data processing phase.

With both methods it was concluded that the user rate for the car was superior to 50%, contributing to a carbon footprint between 1,36 and 1,42 kgCO_2equivalent per capita for each trip. An effort is necessary to transfer this tendency towards a more sustainable behaviour, especially among FEUP's professionals. Besides these results, the general community displayed an open mind regarding new sustainable mobility initiatives.

In conclusion, both methods are acceptable for data retrieval, with advantages and disadvantages in each, although the modern method using the smartphone application showed a higher future potential, with the evolution of the technology and the increase in users.

KEYWORDS: Mobility, Sustainability, Carbon Footprint, Data Collection Methods, Big Data, Mobile Application, Smart City

RESUMO

Em contexto de Gestão Urbana, a Mobilidade é uma qualidade intrínseca à organização de uma cidade. Esta dita a cadência e a alma do dia-a-dia, refletindo os ideais da sociedade em questão. Sendo uma fonte de poluição importante que atinge principalmente a atmosfera, a sua gestão adequada é crucial para diminuir a emissão de gases com efeito de estufa que contribuem para o aumento da pegada de carbono e, consequentemente, o aquecimento global. A evolução para um futuro mais sustentável exige o planeamento baseado na recolha de dados reais para uma devida fundamentação de decisões.

Nesta dissertação, apresentou-se o estudo de caso da Faculdade de Engenharia da Universidade do Porto (FEUP), tendo como objetivos principais a avaliação da sustentabilidade da mobilidade da sua comunidade e a comparação entre dois métodos de recolha de dados: o método tradicional através de um inquérito à mobilidade e o método moderno utilizando a aplicação para smartphone SenseMyFEUP, criada por uma equipa de investigação do Instituto de Telecomunicações e inserido no projeto FutureCities.

Este estudo passou por uma Fase de Preparação para elaboração do inquérito, definição dos dados de mobilidade necessários para serem recolhidos pela aplicação e a publicidade ao SenseMyFEUP. Em seguida iniciou-se a Fase de Recolha de Dados durante duas semanas para o inquérito e quatro semanas para a aplicação, e, por fim, a Fase de Processamento de Dados.

Com ambos os métodos concluiu-se que a taxa de utilização do automóvel é superior a 50%, contribuindo para uma pegada de carbono entre 1,36 e 1,42 kgCO_2equivalente per capita em cada viagem. É necessário um esforço para migrar esta tendência para comportamentos mais sustentáveis, especialmente entre os colaboradores da FEUP. Apesar destes resultados, a comunidade em geral mostrou-se aberta a novas iniciativas sustentáveis de mobilidade.

Concluiu-se que ambos os métodos são aceitáveis para recolha de dados, com vantagens e desvantagens, no entanto o método moderno com aplicação para smartphone tem maior potencial para o futuro, com a evolução da tecnologia e aumento de utilizadores.

PALAVRAS-CHAVE: Mobilidade, Sustentabilidade, Pegada de Carbono, Métodos de recolha de dados, Big Data, Aplicação Móvel, Cidade Inteligente

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SYMBOLS, ACRONYMS AND ABBREVIATIONS

CF – Carbon Footprint

GHG – Greenhouse gas

CNG – Compressed Natural Gas

CP – Comboios de Portugal

FEUP – Faculty of Engineering of University of Porto

GWP – Global Warming Potential

INE – Instituto Nacional de Estatística

LNG – Liquefied Natural Gas

LPG – Liquefied Petroleum Gas

STCP – Sociedade de Transportes Coletivos do Porto

UP – University of Porto

1. INTRODUCTION

Sustainability. A word that transforms cities and carries them to the future. A word that connects people, cities, the world itself together, like a throbbing heart. And what turns traditional cities into smart cities of the future? A very important part is its mobility. Considering a city a living body, the way each citizen moves within it resembles blood flowing in each artery, each vein, and, like in any healthy body, it must be efficient, without clots and it must reach any extremity that needs it.

On September 25th 2015, the United Nations set 17 goals (**Figure 1**) as part of a new sustainable development agenda with the goals of ending poverty, protecting the planet, and ensuring prosperity for all. Each goal has specific targets to be achieved over the next 15 years. (United Nations, 2016)

Figure 1 – United Nations sustainable development goals.

Out of those 17 goals, 3 are relevant to mobility:

- **Goal 9:** Build resilient infrastructure, promote sustainable industrialization and foster innovation;
- **Goal 11:** Make cities inclusive, safe, resilient and sustainable;
- **Goal 13:** Take urgent action to combat climate change and its impacts.

A good infrastructure contributes to the development and growth of a country and, from smart mobility to smart cities, prosperity is nurtured by striving for sustainability, pollution reduction and the defiance of climate change. However, the basis of decision making is knowledge and accessibility to information.

In order to properly formulate a plan for sustainable mobility, studies are required to assess the situation and the suitable course of action. Unfortunately, traditional data collection implies long periods of time and associated heavy costs. In Portugal, many mobility decisions are only supported by information given by the Census, which only provides information on work/school related trips. New solutions must arise to meet the needs for supporting data and the requirements of feasible practical applications.

Technology is advancing at an alarming speed, providing an enormous quantity of data in a rate that cannot be processed. It's the age of Big Data. From small quantities of information taken directly from willing participants to huge amounts of complex and unorganized data retrieved automatically in digital processes, the collection of information is rapidly migrating from straightforward and direct methods to an undetected part of everyone's life and become an increasingly prosperous market.

We need to test each step we take towards technology and further away from old methods; therefore, this transition will be evaluated in this dissertation, from traditional information collection through surveys to automatic data collection from smartphone applications.

1.1. MOTIVATION AND OBJECTIVES

Striving for a sustainable urban management requires solid foundation on reliable data collection to construct achievable plans for the future. Mobility, being a core subject in urban systems, entails extensive data to properly characterize its patterns and to evaluate its impact in a city's sustainability.

Mobility evaluations at FEUP are not new and neither are sustainability assessments. However, data collection and processing should evolve to become more exact and less intrusive to increase willing participation in these studies. The main objective of this dissertation is to evaluate the sustainability of mobility in FEUP using carbon footprint as the main tool and to compare traditional and modern data collection to validate its transition. The secondary objectives consist on:

- Studying the different methods of mobility data collection;
- Reviewing the phenomenon of Big Data and its applications in mobility;
- Analysing relations between sustainability and mobility;
- Assessing the potential for a more sustainable mobility of FEUP's community.

1.2. STRUCTURE

This present dissertation was written by following a classic structure and it was divided in seven chapters:

- In the initial section, it is presented and described the theme of this dissertation as well as its objectives and structure of the document;
- The second chapter focuses on literature revision of the state of knowledge on the field of study to serve as a base to the development of this research. The two pillars of this investigation are Sustainability and Mobility, therefore the revision of the art begins with an explanation of sustainability and its tools and then narrowing it to its application to mobility, including its evolution in an urban environment, important indicators, and finishing with the different methods to collect required data for overall mobility and sustainability assessments;
- On the third section, the methodology of the process that led to the results of this dissertation is explained, in particular the preparation phase and the data collection phase, which describe the procedure for the carbon footprint calculation and provide information about the development of the survey and mobile application;
- The fourth chapter shows the results and inherent interpretation and discussion, divided by the mobility results of each method, the sustainability results and the final comparison between the two methods.
- Lastly, the conclusions and further recommendations are displayed in the fifth section, the references in the sixth section and appendixes can be found in the seventh section.

2.
STATE OF THE ART

2.1. SUSTAINABILITY

Sustainability is a concept that has become entwined with planning of the future, since it means the capacity to endure. It is a balance between the use of resources and productivity, allowing the process to continue uninterrupted. The organizing principle of this concept is called Sustainable Development and its definition was firstly conceived by the Brundtland Commission of the United Nations, more formally known as World Commission on Environment and Development (WCED), on March 20th, 1987. Their report, called "Our Common Future", defined Sustainable Development as the *"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* (WCED, 1987).

Sustainable Development stands on three principal pillars: environment, society and economy, where the latest two are restricted by environmental limits. More recently, culture has been introduced in the circles of sustainability as the forth pillar to be considered in local policies in the Agenda 21 for culture in 2002 (UCLG, 2008).

The concept, whether applied to transport or to other human activities, has grown in importance and relevance, leading to the identification of 17 worldwide sustainable development goals by the United Nations on September 25th of 2015 (United Nations, 2016), as presented in the introduction. These goals need the contribution and support of everyone, from the individual person to the government of each country, to be accomplished. It is a concept that needs to influence our mentality as a society, so that our future is how the world wishes it to be.

The first step to achieve that goal is to raise awareness and to educate younger generations to include sustainability as an intrinsic part of their mentality. In response to this need, sustainability in Higher Education has become an important issue to be assessed by the institutions. The first document to consider this matter was the Declaration of the United Nations Conference on the Human Environment, also called Stockholm Declaration, in 1972. In the 19th principle out of 26, it is mentioned the need for environmental education since primary school until adulthood to promote the consciousness and responsibility for the preservation of the environment (UNESCO, 1972).

The world's first intergovernmental conference on environmental education happened in Tbilisi, Georgia, in 1977, generating the Tbilisi Declaration that updated and clarified the Stockholm

Declaration (GDRC, 2015). Since then, the interest for sustainability has bloomed in the 1990's, with conferences and the creation of associations happening around the world.

The Declaration of Talloires, created from an international conference with presidents of 22 universities in 1994, intended to evaluate the role of Higher Education in Sustainable Development and to define a plan of action consisting in 10 points. It was signed by over 400 university leaders in more than 50 countries (Association of University Leaders for a Sustainable Future, 2008).

In 1992, as a product of Rio de Janeiro Earth Summit, Agenda 21 defined in chapter 36 "Promoting Education, Public Awareness and Training" the crucial importance of Education in promoting Sustainable Development and in improving the aptness to deal with environmental problems (United Nations, 1992).

With this new age of awareness, in 2002, the United Nations General Assembly, through its Resolution 57/254, declared a Decade of Education for Sustainable Development from 2005 to 2014 (UNESCO, 2005).

In 2012, the United Nations Conference on Sustainable Development, or RIO+20, resulted in over 700 voluntary commitments and witnessed the formation of new partnerships to advance sustainable development (United Nations, 2015). The Higher Education Sustainability Initiative (HESI) was one of them, now with the membership of almost 300 universities from around the world (United Nations, 2015). Joining this network means committing to the objectives displayed in **Figure 2**.

Figure 2 – HESI's four commitments for sustainability in Higher Education **(United Nations, 2015)**.

As supported by the third commitment, the consideration of Mobility of a University's campus is crucial for Sustainability Assessments and reports, since its impact is considerable for its polluting effects and surrounding urban management. From the need of presenting tangible results to base management decisions on, several tools were created to measure institution performances on social, economic and environmental levels. Regarding transport sustainability, however, environmental issues are usually more thoroughly analysed than other issues (Hidas & Black, 2002), being the Carbon Footprint the main tool for its evaluation of the emission of greenhouse gases, a main problem for transportation.

2.1.1. Ecological footprint

The Ecological Footprint (EF) is one of the most important tools to evaluate sustainability as well as one as the most known for the general public, even though it only considers environmental implications. This procedure was firstly formulated in 1996 by Dr. William Rees and Dr. Mathis Wackernagel of the University of British Columbia, in the book "Our Ecological Footprint - Reducing Human Impact on the Earth", even though Dr. William Rees had been teaching the basics of EF analysis since the 1970's (Rees & Wackernagel, 1996).

This analytical tool calculates the use of resources that weighs on the balance between supply and demand on nature. The supply side is represented by biocapacity, which is considered the planet's biologically productive land and waters, including cropland, grazing land, forests and fishing grounds. Not only they are a source of resources, but, if left unharvested, they can absorb much of the generated waste, especially carbon emissions. On the other hand, the demand consists in the productive area that is actually required to provide the resources we need and to absorb the waste we create, including occupation by human infrastructure due to its impossibility to regenerate resources. This area is known as the Ecological Footprint and it is measured by global hectares (gha), like biocapacity. A global hectare is a biologically productive hectare with world average biological productivity for a given year and it varies from type of land (a global hectare of cropland is smaller in physical area than a pasture land due to its smaller productivity, for example) and from year to year (Global Footprint Network, 2015). To finalize the analysis, the balance between biocapacity and EF needs to be positive to be sustainable.

The Global Footprint Network is a non-profitable organization, founded in 2003, that promotes EF to assess sustainability to aid decision-making. It is the biggest source of scientific data on the subject in the world, maintaining current studies about world's performance, including countries and programs for individuals to calculate their EF (Global Footprint Network, 2015).

According to the Global Footprint Network, Portugal had a biocapacity of 1,5 gha per capita in 2012. On the other hand, the average ecological footprint of each Portuguese citizen is 3,9 gha, which translates to a deficit of 2,4 gha, revealing an unsustainable performance (**Figure 3**).

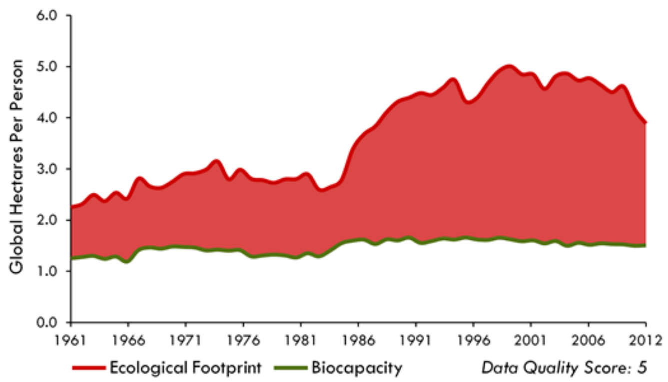


Figure 3 – Ecological Footprint and Biocapacity of Portugal (1961-2012). Source: Global Footprint Network 2016. National Footprint Accounts, 2016 Edition.

Although this tool is being increasingly used, it is widely criticized for its lack of proved accuracy (Wachter, 2008). Most of the data comes from the United Nations statistic sources, but the quality of the results from each country can vary, being scored from 1-6. Portugal, for example, is low on that score (Global Footprint Network, 2013). Transforming every impact into land and sea areas is not selfevident or easily established. The calculations largely depend on the prevailing technologies, meaning that the results can change with the evolution of technology (Wachter, 2008). Nevertheless, EF calculations can be used to provide a general picture of sustainability or the lack of it of a product or a system, which can be helpful for decision makers to identify the main responsible activities for the caused impact related to resource consumption and land use (Castellani & Sala, 2011).

Regarding the activities of individuals, the EF can be decomposed in many components, including food, housing, goods, services and, at last, mobility. The impact of goods or services can be specifically calculated through Life Cycle Assessment, as well.

Due to the recent debate about improving the accuracy of the EF method, Kitzes and colleagues studied the support of Life Cycle Assessment (LCA) to the calculation of specific impacts calculated in EF. By joining the two methods, it provides more exact and supported results, since LCA is more detailed in terms of coverage of impact categories but does not consider the system capacity assessed by EF (Kitzes, et al., 2009).

This methodology was experimented in two case studies in Northern Italy in 2011, applied to tourism activities, where they compared both methods. Being a service, where the main source of impact is related to energy and use of resources, EF could achieve similar results as the LCA, because it is a tool based on consumption. It was concluded that if applied to sectors in which other drivers of impact are predominant, like emission of chemicals, EF has difficulty in making an accurate calculation, requiring the use of LCA since the beginning of the assessment (Castellani & Sala, 2011).

In 2015, the study of this methodology was also attempted using the Polytechnic University of Valencia as a case study to compare EF and LCA methods and results. Being considered an organization, it is possible to calculate the EF of a university, however, its lack of standardization and difficulty of gathering information makes it difficult to use as an indicator. The LCA makes it easy to apply a guideline to follow. Results showed that LCA could guide an EF Assessment methodology where comparability and reliability is possible (Lo-Iacono-Ferreira, et al., 2016).

2.1.2. Life Cycle Assessment

Life Cycle Assessment (LCA) was firstly introduced in the 1970's as an energy analysis and it evolved until it became a complete life cycle impact assessment when life cycle costing models were introduced in the 1980's and 1990's (Guinée, et al., 2011).

LCA is, nowadays, a broad and detailed indicator that evaluates all the associated impacts of products or services throughout all the stages of its life cycle, from cradle to grave, as shown in **Figure 4**. By defining a Functional Unit to base the calculations on and to become a reference to the associated inputs and outputs, the considered system is evaluated from the extraction of raw material and manufacturing, to the use of the product by final consumers and end-of-life

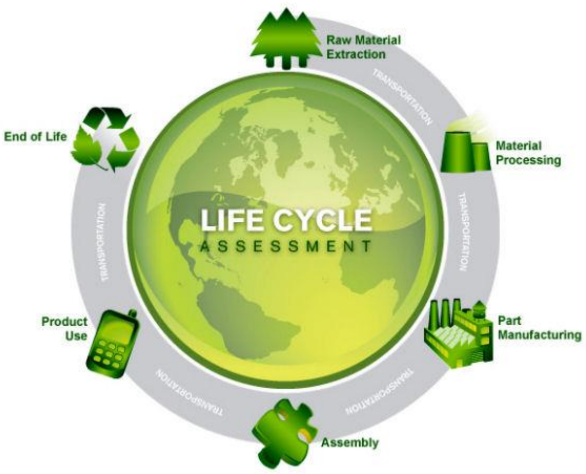


Figure 4 – Process of Life Cycle Assessment **(SolidWorks, 2009)**.

processes, which includes recycling, energy recovery, and elimination through waste disposal in a landfill or incineration (Wachter, 2008). This evaluation befalls on numerous levels of impact including climate change, acidification potential, eutrophication potential, ozone depletion potential, and ground level ozone creation. The Functional Unit can be a car, for example, and for a complete LCA Assessment all the inputs and outputs must be measured since the extraction of the metal for its construction to its end of life. Using the case presented before about the Polytechnic University of Valencia, they defined the university itself as the product system, as seen in **Figure 5**, and the functional unit was a full time student (Lo-Iacono-Ferreira, et al., 2016).

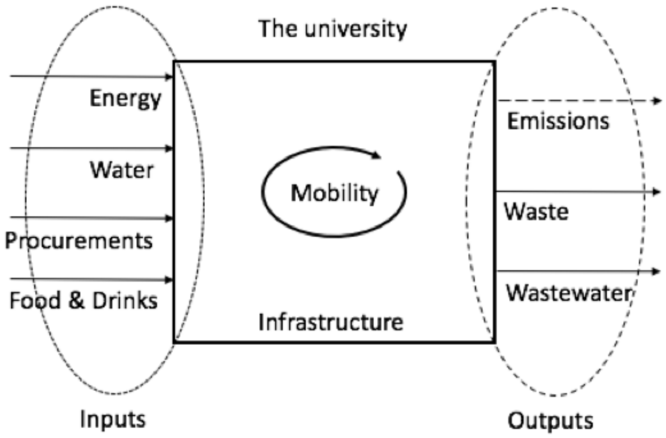


Figure 5 – Input/output analysis of the Polytechnic University of Valencia **(Lo-Iacono-Ferreira, et al., 2016)**.

It is an internationally standardized procedure (ISO 14040 and ISO 14044), which provides a clear guideline for performing LCA calculations. Unfortunately, LCA remains very complex due to its extensive data and should, therefore, be applied preferably to a specific unit or application (Wachter, 2008). This fact makes this tool not suitable for urban mobility studies, especially regarding cradle-to-grave evaluations. For this reason and, due to the need to measure the global warming potential of that activity related to the elevated pollutant gas emissions, the typical tool for sustainable mobility assessments is the Carbon Footprint (CF), which consists in a simplified LCA.

2.1.3. CARBON FOOTPRINT

A Carbon Footprint (also known as Carbon Profile or greenhouse gas (GHG) emissions assessment), is an LCA limited to the analysis of emissions that have an effect on climate change, including carbon dioxide, methane, etc. This limitation makes this method easier to apply on integrated systems, such as an entire house or automobile, facilitating its application on mobility sustainability studies (Wachter, 2008). It allows the calculation of global warming gases emissions from transports and, consequently, their energetic efficiency (Davies, et al., 2000).

The CF measures CO_2 emissions mainly associated with fossil fuel use. In EF calculations, these amounts are converted into biologically productive areas necessary for absorbing this CO_2. The CF is added to the EF because it competes for the use of bioproductive space, since increasing CO_2 concentrations in the atmosphere need to be absorbed. Unfortunately, most CF assessments results in tonnes of greenhouse gases per year, without considering the area needed to sequester it (Global Footprint Network, 2015), which could enrich the assessment.

In order to calculate this footprint, it is necessary to be aware of the Global Warming Potential (GWP) of each gas to be able to add the emissions of different gases and reach a single result on the overall impact on global warming of an activity, often called "CO_2 equivalent emissions". The GWP was presented in the First Intergovernmental Panel on Climate Change (IPCC) Assessment, stating that "It must be stressed that there is no universally accepted methodology for combining all the relevant factors into a single global warming potential for greenhouse gas emissions. A simple approach has been adopted here to illustrate the difficulties inherent in the concept" (Myhre, et al., 2013).

The usual GWP is estimated for a time period of 100 years. Carbon Dioxide is the reference gas, hence the name of the method, and it has a GWP of 1. The latest IPCC Assessment GWP values for the three most important gases (Carbon Dioxide, Methane and Nitrous Oxide) are shown in **Table 1**. Even though the emitted Methane lasts about a decade on average, which is much less that the Carbon Dioxide that lasts for thousands of years, it can absorb a lot more energy. This effect plus the indirect influence on being a precursor to ozone (also a greenhouse gas) is quantified in the GWP.

The complete list can be reviewed in the original report, however only these three gases were considered in the calculation of the CF of this dissertation case study. The inclusion of climate-carbon feedbacks means it is considered the response of the gas to emissions of the indicated non-CO_2 gases (Myhre, et al., 2013).

Table 1 – Main GWP with and without inclusion of climate–carbon feedbacks (Adapted from Table 8.7, IPCC Fifth Assessment Report, 2013)

	Lifetime (years)	Climate–Carbon feedbacks	GWP_{20}	GWP_{100}
Carbon dioxide (CO_2)	-	-	1	1
Methane (CH_4)	12,4	Yes	86	34
		No	84	28
Nitrous oxide (N_2O)	121,0	Yes	268	298
		No	264	265

By quantifying all emissions from each gas, it is possible to apply the GWP and translate to CO_2 equivalent, all the process being in units of mass, not volume, as shown in the formula below (Gillenwater, 2015).

$$\text{Mass of } CO_2e = \Sigma(\text{mass of gas}) \times (\text{GWP}) \qquad \textbf{(1)}$$

The emissions of each gas depend on the activity, being its specific values called emission factors. The default emission factors are averages based on the most extensive data sets available.

In 2014, the average carbon footprint per capita in the world was 4,90 tCO_2e, while, in Portugal, it was being slightly below with 4,60 tCO_2e. On the other hand, considering the contribution of transportation related emissions, Portugal surpasses the value of 0,86 tCO_2e per capita for the world with 1,51 tCO_2e each year, although it remains inferior to the value of the European Union that reaches 1,69 tCO_2e. To calculate the annual CO_2 emissions of transport per capita, the CO_2 emissions of transport from fuel combustion from all traffic in the country that year are divided by the population (World Energy Council, 2016).

As global warming caused by air pollution becomes a universal concern, vehicle emissions are the focus of attention to improve air quality. Electric vehicles have been developed with the purpose of reducing pollution with the disadvantage of increased cost and, in the case of battery powered vehicles, limited range. Hybrid vehicles are also a development in technology, striving for low or very low emissions, including hybrid electric buses (Davies, et al., 2000).

Air pollution is responsible for 310 000 premature deaths in Europe each year, which is more than those caused by road accidents, and the damage to human health is estimated to cost between 427€ and 790€ billion per year to the European economy. Health problems related to air pollution affect mostly the very young and the old and those with heart and lung diseases, being both common causes of death in Europe. On the map below it is shown an estimate of how many months life expectancy was reduced by man-made fine particles across Europe in 2000 and in 2020, after many measures for air pollution have been implemented (European Comission, 2015).

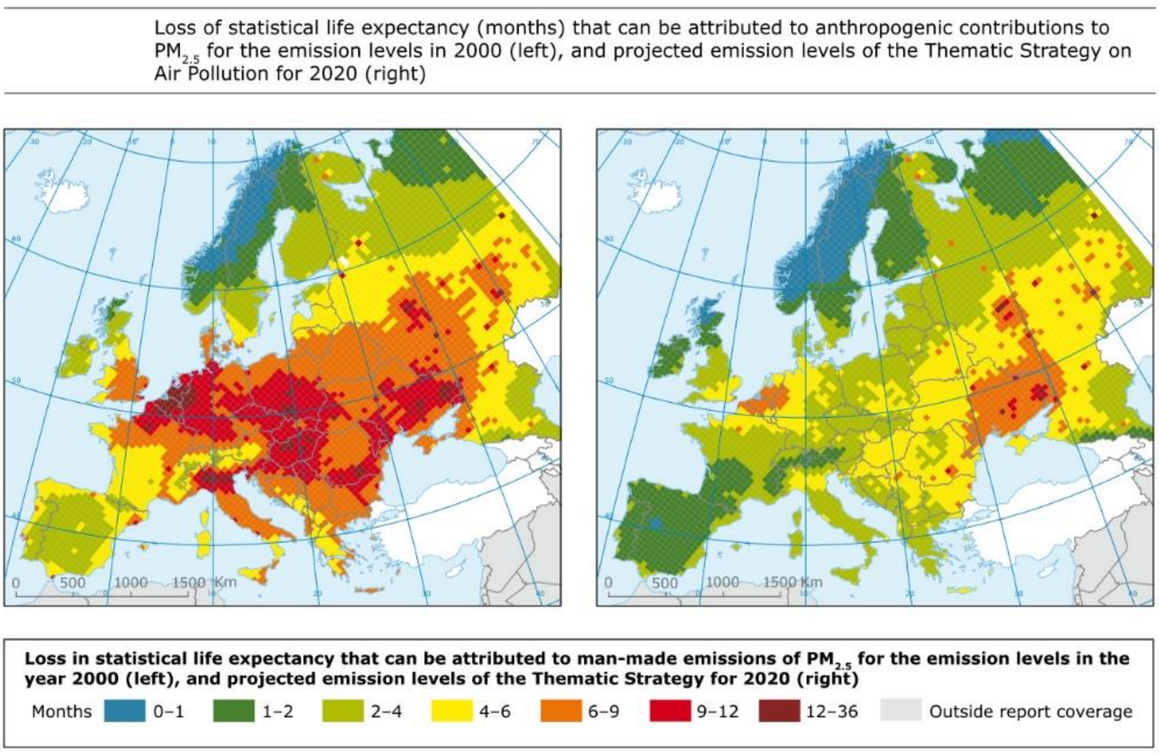


Figure 6 – Loss of statistical life expectancy (months) in 2000 (left) and 2020 (right) **(European Comission, 2015)**.

To be able to combat this danger to public health, many countries around the world, as well as the European Union (EU), have set air quality standards, which include concentration limits to be met by set dates. In order to achieve Air Quality Standards, low emission zones began being implemented, limiting the access to vehicles that do not fulfil with the requirements (European Comission, 2015). The Environmental Protection UK defines the objective for a low emission zone as "to reduce vehicle emissions, in a given geographical area, in order to improve local air quality" (Davies, et al., 2000). There is currently one Low Emission Zone in Portugal, in Lisbon, since 2011 (CLARS, 2015). However, trying to improve the environment with tight regulations regarding transports will always affect mobility and that impact must be taken in consideration and included in urban management decisions.

2.2. MOBILITY

Transport is rapidly becoming the dominant issue in any discussion on the urban environment and economy, due to its influence to the overall management. Urban mobility has evolved and become more important since the first industrial revolution brought forth by the invention of the steam engine. Before this event, raw materials and finished goods were transported by wagons drawn by horses on land and by boats along canals and rivers. In early 1800's, the first commercially successful steamboat was invented by American Robert Fulton and Richard Trevithick, a British engineer, constructed the first railway steam locomotive. By mid 19th century, steamships could be seen carrying freight across the Atlantic Ocean and, on September 15th 1830, England's Liverpool and Manchester Railway became the first to offer passenger services regularly and fully timetabled. In addition, a new process for road construction with macadam was invented around 1820 by Scottish engineer John Loudon McAdam (History, 2009). With the creation of motor vehicles, dust became a problem in macadam roads, so, in 1902, tarmac was invented and used until asphalt was introduced in 1920 and originating roads as we know them today (Benson, 2016).

According to Peter Jones, from the Centre for Transport Studies in UK, the evolution of urban transport policy has gone through three stages over the past half century:

- **Stage 1** – *Traffic growth policies: a vehicle-based perspective;*

  Urban economic growth in its early stages leads to a fast increase in car ownership and use, creating traffic. This was first associated with the development or expansion of a domestic motor industry. The found temporary solution for that problem was the investment in major urban road building programmes and measures to maximise vehicle capacity on existing urban streets, supported by large increases in parking provision, particularly at major trip destinations, which in consequence cuts back the investment on public transportation (Jones, 2014). This balance between offer and demand is not easy, because increasing offer to meet the demand, usually increases demand as well (Davies, et al., 2000). This vehicle-based paradigm is usually supported by those in positions of power and wealth, which are mostly car owners, and the bulk of the population who aspire to car ownership and see road building as a positive sign of economic development (Jones, 2014). This tendency needs to be addressed and the strategy involves the investment on the development of techniques that provide a more quantitative analysis of the relationships between transport and land use. Transportation studies led to the development of three stage aggregate traffic forecasting models, combining vehicle trip generation, trip distribution and traffic assignment modules. It became apparent that unrestrained car use in high to medium land development density was not supportable. As an example, in London, even with proposals for an extensive urban motorway network, the forecasting models were predicting demand levels far superior to the proposed capacity (Jones, 2014). Congestion in the EU costs nearly 100 billion euros, or 1 % of the EU's gross domestic product (GDP), annually, which makes proper mobility management an objective to be achieved. (European Comission, 2015) This provokes an impasse about how to address the pressure growing traffic without road building. To be able to deal with this problem the attention had to shift from the overall unlimited movement in urban areas to the study of individual behaviour (Jones, 2014).

- **Stage 2** – *Traffic containment policies: a person trip perspective;*

  In this next stage, the policy focus on moving people from their origin to destination, in the most efficient manner, regardless of mode choice. The solution to the previous problem of the rapid growth in vehicle demand in a physically constrained area became the transition to new forms of transport. Public transportation use the limited urban space in a more efficient manner and can carry much higher numbers of people per unit area. The shift in modal choice has been encouraged by increasing restrictions on car use, particularly parking controls in urban centres and access restrictions to counter high levels of air pollution (Davies, et al., 2000), like mentioned before with low emission zones.

- **Stage 3** – *Liveable cities: activities and quality of life perspectives;*

  With the third stage, movement becomes secondary to the growing interest to increase the quality of urban life, more like a means to an end, rather than an end in itself. Cycling and walking rise in importance for being sustainable and healthy modes of transport and improving urban space and leisure activities. This new activity-based perspective has introduced new forms of data collection, both in terms of measuring behaviour, like the use of activity-based and time use diaries, and in the types of data concerning provision of what needs to be collected, such as detailed information on the location of facilities and their opening hours, plus information on satisfaction and well-being. This new need for detailed research into daily behaviour has led to major advances in modelling techniques, allowing the implementation of an activity-based approach on urban mobility studies (Jones, 2014).

Throughout the evolution of urban transport, mobility indicators have provided measures for travel demand and urban management. According to Sarmento, "an indicator is something that helps you understand where you are, which way you are going and how far you are from where you want to be. A good indicator alerts you to a problem before it gets too bad and helps you recognize what needs to be done to fix the problem" (Sarmento, et al., 2000).

The most common and important indicators for mobility are distance, time, frequency (number of trips or cargo) and model choice, defined by Bovy et. al., 1993. From these four basic parameters, it is possible to associate more variables to increase complexity and to reach more detailed conclusions. The indicators will be a reflection of the interaction between factors, which can include the land use system and transport system (**Figure 7**) (Silva & Pinho, 2006).

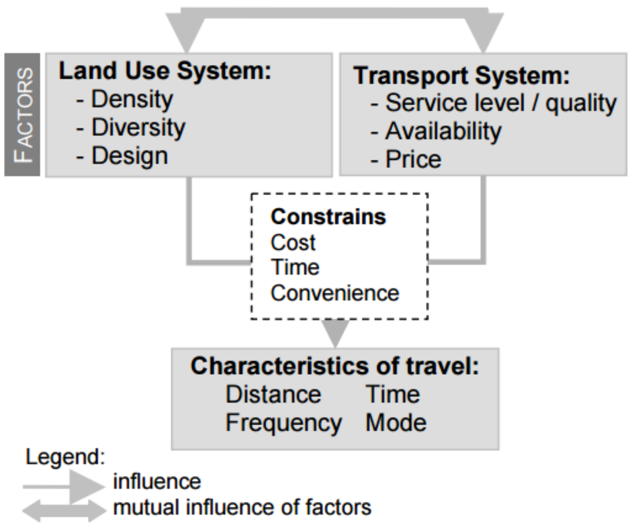


Figure 7 – Conceptual framework of the land use and transport factors influencing travel patterns **(Silva & Pinho, 2006)**.

2.2.1. Sustainable Mobility

According to Hidas and Black (2002), sustainability in mobility means "a system that supports social connectivity and economic prosperity in a fair and equitable manner, without presenting risks to local or global environmental quality and resource use", therefore sustainable transportation is vital to achieve a sustainable city. According to the Transportation Association of Canada, a sustainable transportation system is a system that (Wadhwa, 2000):

1. Meets the access needs of the present generation;
2. Allows future generations to meet their own access needs (which will grow because of economic growth and rising populations);
3. Is powered by renewable (inexhaustible) energy resources;
4. Does not pollute air, land or water beyond the planet's ability to absorb/cleanse (especially CO_2);
5. Is technologically possible;
6. Is economically and financially affordable;
7. Supports a desired quality of life;
8. Supports local, national and global sustainable development goals.

To properly accompany a long-term process such as the development of a Sustainable Urban Transport system, it is crucial to monitor and evaluate progress over time and, if necessary, to use remedial measures and actions. An efficient monitoring process requires well-defined objectives and performance indicators regularly measured and analysed (Hidas & Black, 2002).

The Transportation sector is responsible for about 27% of CO_2 emissions all over the world (Calabrese, et al., 2013). The most important mobility indicators for sustainability are modal distribution and distance of the trips, since it allows the measurement of the influence on air pollution through tools like the carbon footprint. High modal share of non-motorized transport and Public Transport reflects the modal share in favour of low carbon transport (Silva & Pinho, 2006). However, that share must depend on total distance covered by mode of transport and not the number of trips regardless of the length to be accurate in the evaluation of sustainability.

According to the Portuguese Census of 2011 and the modal split of work/school related trips, the car is the preferred mean of transportation in Portugal. About 62% of the population choses the car, either as a passenger or a driver, to carry out their daily activities (**Figure 8**), a trend that is also followed in Porto, where the case study for this dissertation occurs. Since 2001, there has been a transition from public transports to individual vehicles, which does not bode well for the country's sustainability (Instituto Nacional de Estatística, 2011).

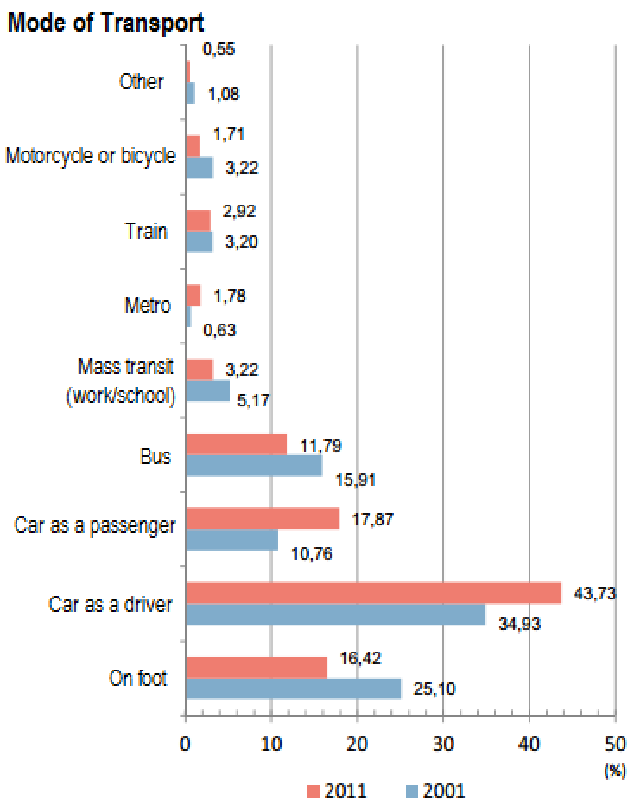


Figure 8 – Mode of transport used in work/school related trips. Adapted from Censos 2011, Instituto Nacional de Estatística.

Since mobility sustainability is directly connected to distance and mode of transport, the strategic tactics need to involve those indicators. Silva and Pinho proposed a methodology of analysis of the sustainability of the land use and transport systems, which are influential factors as mentioned before.

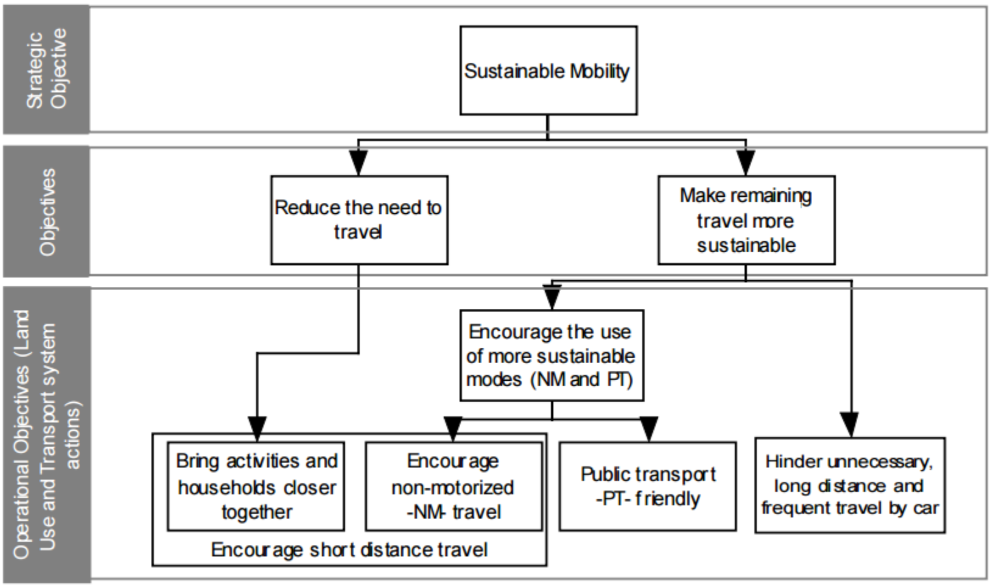


Figure 9 – Objective tree of the methodology of analysis by Silva and Pinho **(Silva & Pinho, 2006)**.

The objectives of that methodology, presented in **Figure 9**, where to reduce the need to travel, by bringing activities and households closer together, and, for the remaining essential trips, to make them more sustainable, by promoting the elimination of unnecessary long distance trips by car and encouraging the use of more sustainable modes. These modes would be public transportation for long distance trips and non-motorized transports for short distances (Silva & Pinho, 2006).

2.2.2. Mobility Data Collection and Processing

To implement measures to improve mobility it is necessary to collect information about mobility patterns and population's behaviour, usually following established indicators. The most traditional method is directly through surveys and interviews, more recently including travel diaries. While surveys usually gather general information about a person's mobility, a travel diary is a collection of real travel information throughout a period of time, usually a week. These methods can consider individual data or household data and generally evaluate the main indicators of mobility: mode of transportation, frequency, time and distance (by considering the destination and purpose of the trip).

England, for example, holds a National Travel Survey every year since 2010, which consists in face-to-face interviews and 7 days of self-written travel diaries, and it stands as the primary source of data on personal travel patterns by residents of England within Great Britain (Department for Transport of the Government of UK, 2016). Associating interviews and travel diaries allows researchers to obtain not only quantitative, but qualitative data to better understand urban mobility. In Portugal, on the other hand, the practice of collecting mobility information is very dim. In fact, the only proper national survey to mobility of resident population was in 2000, and merely to 33 municipalities, which hold 70% of the resident population in the northern region (Instituto Nacional de Estatística, 2002). Other existing attempt to get information in Portugal was through a European project called "The EUROSTATS pilots of long-distance travel diaries" which studied the travel diaries from Austria, Denmark, France, Germany, Italy, Portugal, Spain and Sweden. In Portugal, questionnaires were distributed to 5694 households, again from the northern region, but only about trips longer than 100km (Axhausen, 1997). Another study was conducted in Greater Copenhagen and Greater Porto to perceive how urban structure constrains sustainable mobility choices, by using Structural Accessibility Layer (SAL) and the Qualitative-Quantitative Method for interviews and travel diaries (Pinho & Silva, 2015).

Indicators of survey quality include response rate, correctness and completeness of survey entries, which does not always happen considering that this method is known to be susceptible to erroneous reporting (Brög, 2015). Face-to-face or telephonic surveys achieve highest response rates than email surveys, however it does not exists a consensus on what the acceptable response rate is, as long as it is representative (Cook, et al., 2000).

To measure the incorrectness of a travel diary, Raza et.al. conducted an experiment to compare the answers given to a travel diary, using a smartphone application known as SPARROW, and the information retrieved by the GPS of an offered electric vehicle. The respondents filled in the details of their activities and trips in the application, which also recorded GPS traces of the movements, and then both results were checked for consistency. Most discrepancies occurred when the user forgot to report a trip an electric car trip in the travel diary or when specified wrong start/end times for home, non-daily shopping and social visit activities (Raza, et al., 2015).

Another experience was conducted with online travel diary in Australia, which incorporated many features designed to improve the quality and completeness of data, while aiming to minimise participant burden. It had an optional smartphone app to aid the trip report by using a map that was installed by 45% of the participants. It was revealed that those who installed the app and looked at the map exhibited fewer errors per 100 trips compared to the rest (Greaves, et al., 2015).

With the evolution of new technology, like the smartphones and other location detection devices, the last decade has been the stage of the development of two different fields determined to understand how individuals move in space and time: the traditional field of mobility researchers, who have been working in this field for decades, and the new comers from a variety of disciplines, especially computer scientists in particular due to the crescent source of digital information. They both use different approaches, different methodologies and different datasets. This presents an opportunity for the evolution of mobility data collection and processing by working together for a common goal (Chen, et al., 2016).

From paper, travel diaries are reaching the digital world, which are less prone for errors. Many people around the world share their travel experiences every day, but this informal information goes unprocessed. The digital information differs and separates from the analogical one for its quality and fidelity, its independence of nature of the data, the flexibility for the transport, compression, cipher, communication and manipulation of the basic sources and, especially in the data space and economic demands for the massive store of information (Hoyuela, 2002).

Nowadays, the Internet of Things connects us more than ever, yet the Big Data that constantly produces presents many challenges that need to be tamed so we can reap the benefits of connectivity (Li-MinnAng & PhooiSeng, 2016). The biggest problem with Big Data (massive, less structured, heterogeneous, unwieldy data up to, including and beyond the petabyte range) is that it is incomprehensible to humans at scale. Machines in the cloud are simply tools and they cannot understand the information they process as humans do. They can amplify noise or errors in the data just as easily as amplify signal or provide insight, consequently a human input is always necessary. And yet Big Data keeps getting bigger and unprocessed in a useful manner (Morrison, 2015).

There are pyramids of understanding that people have to build with the data they are generating. Only the apex of each pyramid is accessible to the population at large. There is a lot of work required to process all the data, most of it at the base of such structures. And from it the following challenges arise (Morrison, 2015):

- **Recognition –** Identifying what is what in the data;
- **Discovery –** Efficient ways to find the specific data that can help you;
- **Modelling and simulation –** Intelligent ways to model the problems big data can solve so human inputs can result in useful outputs;
- **Semantics –** Effective and efficient ways to contextualize the data so that it's relevant to specific individuals and groups;
- **Analytics –** Effective ways to analyse and visualize the results of the data;
- **Storage, streaming and processing –** Efficient ways to take human inputs and act on batches or streams of big data to be able to extract insights from it.

The Big Challenge of Big Data is turning it from technology oriented to user oriented, because in the end what truly proves its value is its usefulness. The success of an information system is to transform a data set into comprehensible information (Hoyuela, 2002).

The control of information is the guarantee of power. The problem is no longer based in the control of the access to the information but in the saturation, in the noise, in the indifference, in the interference. In a way, “everyone speaks and nobody is listening”. To solve these problems, researchers in the information technologies created the concept of metadata (or “data of the data”) (Hoyuela, 2002).

The Internet created a new world in the informational economy, allowing connection to users in various platforms (Hoyuela, 2002). The increasing variety of devices and ways to connect to the internet affects traffic and can be seen in the changing device contribution to total IP traffic. At the end of 2014, 40% of IP traffic and 22,5% of consumer Internet traffic originated from non-PC devices. By 2019, 67% of IP traffic and 64% of consumer Internet traffic will originate from non-PC devices (**Figure 10**) (Cisco, 2015).

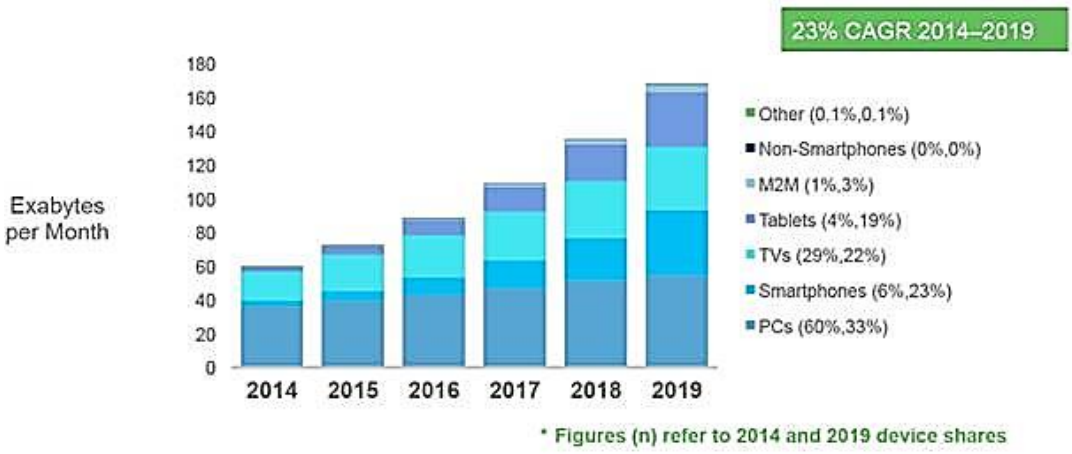


Figure 10 – Global IP Traffic by Devices (Cisco VNI, 2014).

In 2014, according to International Telecommunications Union, around 65% of Portuguese people had access to the internet (International Telecommunications Union, 2016), which constitutes a solid base for data collection needs.

Most online social networks nowadays allow the identification of the location of the user. Facebook and Twitter, for example, exploit the GPS readings of user's phones to tag posts, photos and videos with geographical coordinates. This generates enormous amounts of data, which can be useful for the study of mobility behaviours. Comito, Falcone and Talia attempted to analyse the time and geo-referenced information associated with online posts to detect typical trajectories and discover common patterns, using the tweets in the urban area of London as a case study. By assuming people tend to follow the same routes daily, like going to work using the same roads, they had enough information to model behaviours and identify top interesting locations and travel sequences (Comito, et al., 2016).

Mobile phone data can also be used to develop Origin-Destination Matrices from triangulated mobile phone records of millions of anonymized users, which was attempted in Boston (Alexander, et al., 2015) and Dhaka, Bangladesh (Iqbal, et al., 2015). Unfortunately, mobile phone data lacks information typically available from travel surveys about a respondent and the trip (Alexander, et al., 2015).

Another more direct way of collecting mobility data is through smartphone specialized applications. Mobility apps have been increasing as alternatives to traditional travel diaries. Nonetheless, most still present both characteristics. An application called "MoveSmarter" used automatic trip detection with a web-based prompted recall survey. This app is particularly unique due to its sample size (about 600 respondents) and representativeness of the sample for the Dutch population. After an in-depth comparison between automatic detections and reported trips, most trips were detected correctly without strong biases in trip length or travel time distributions. However, 20-25% of the trips could not be detected due to a problem with inaccuracy when activity times at the trip destination are small, creating lack of distinction between successive trips. Also, most missing trips were caused by inappropriate use of the app or empty batteries, a common problem in mobility applications (Geurs, et al., 2015), unlike "SmartMo". The app "SmartMo" was designed in a multi-stage iterative development process and included a traditional travel survey modified to match mobile devices that could be completed any time the user wished. Trip distance and duration was automatically measured and calculated to prevent inaccuracies due to individual and subjective assessments. Additional map matching algorithms and filter criteria for identifying and eliminating outliers are implemented externally on a server, which in return made the app less demanding from the energetic point of view, since all the calculations were not run by the smartphone (Berger & Platzer, 2015).

Other study by Montini et. al. used a dedicated GPS device to validate the results of the mobility app and to compare the best form of data collection. They concluded that even though meaningful diaries can be extracted from both data sources, if the high resolution data is needed, a dedicated GPS device is more efficient, since they do not have battery issues, which means more consistent data with a constant quality (Montini, et al., 2015).

As proven, GPS-based data collection has gained popularity in the recent years, due to its ability to record accurate time and geographic information and easiness to add extra request for information through integrated surveys. While such methods have many advantages over traditional surveys, they suffer from other limitations such as the dependency of the constant use of the smartphone and the unavailability of GPS signals in certain areas (Zhao, et al., 2015). They face the challenges of mode identification and stop detection with overlapping bus routes, distinguishing waits and transfers from non-travel related activities, and tracking underground travel in a Metro network, so in many situations they use small questionnaires as a support (Carrel, et al., 2015).

In this dissertation a case study using both a traditional survey with incorporated travel diary and a mobility app called "SenseMyFEUP" will be analysed, comparing the two methods and evaluating the sustainability of the joined results.

3. METHODOLOGY

The process applied to this study required three parts with subdivisions to reach the desired results and conclusions: the supporting study of the state of art and preparation of the next phase; the data collection from the mobility survey and the app "SenseMyFEUP" and the final data processing and inherent analysis[1] (**Figure 11**).

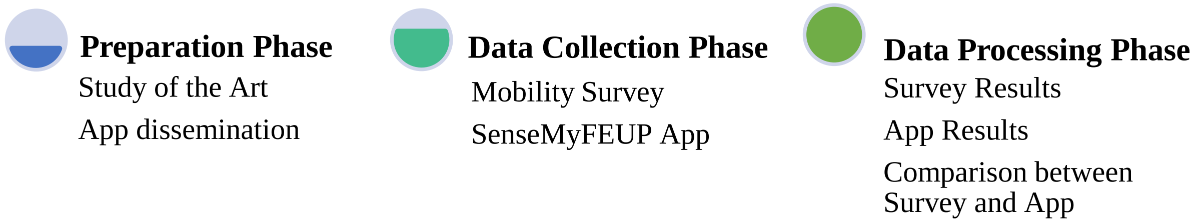


Figure 11 – Schematic representation of the phases of the process for this study.

The case of this study for both survey and mobile application is the Faculty of Engineering of the University of Porto. The University of Porto is the second largest Portuguese university by number of enrolled students, after the University of Lisbon, and has increased its renown and reputation over the years, while at the same time striving to increase its sustainability. In 2015, it harboured 30 066 students, 1 542 staff members and 2 286 teachers and researchers spread among the 3 main campuses and 14 faculties (Universidade do Porto, 2015). From these numbers, the Faculty of Engineering of the University of Porto includes 6 839 students, 340 staff members, 536 teachers and 315 researchers (**Figure 12**) (FEUP, 2015).

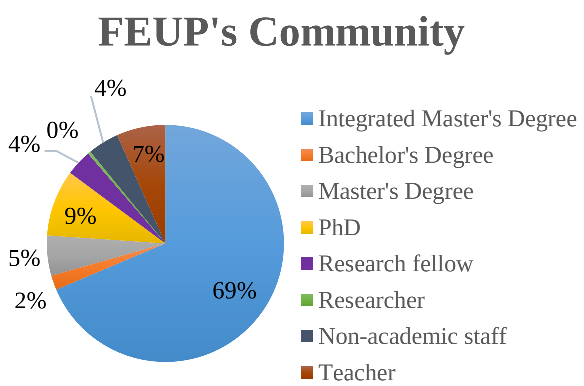


Figure 12 – Distribution of FEUP's community.

[1] The internship of the author of this dissertation in FEUP's Commissariat for Sustainability served as a link between the technology source and the target community, which aided the process and allowed a greater degree of participation and involvement.

Throughout the years, several studies have been carried out to evaluate sustainability and mobility patterns, especially since the creation of FEUP's Commissariat for Sustainability in 2015. The most recent studies include a dissertation about the influence of parking offer in the modal choice of their users by Diogo Silva and a Mobility Study for a Car sharing initiative by FEUP's Commissariat for Sustainability in November of 2015, which will be used for comparison in the results.

3.1. PREPARATION PHASE

The study of the art phase was a common base to both the survey and application. For the survey, the collection of both typical and traditional questions was needed in order to compare with the results from the app and expand further to evaluate the ability of this method to gather reliable information. For the smartphone application, the preparation phase required more work due to the partnership with a team from the telecommunications lab, which was developing the Future Cities Project where the SenseMyFEUP app was included. This cooperation allowed the improvement and the moulding of an existing technology (SenseMyFEUP used the same code of an existing app from the same lab, SenseMyCity) based on mobility and environment indicator's needs. My role was to provide the necessary formulas to calculate the carbon footprint and the exact data that was needed for the indicators of sustainability, which included mobility (distances, time, frequency, mode of transportation and origin/destination matrix).

To assess FEUP's sustainability regarding mobility, it was required data related to the society involved, economy and environment. The society parameter was satisfied by the interaction with the community through the survey and the SenseMyFEUP app, the resulting feedback and conclusions. Regarding economy, the balance of household income/mobility costs was made through the survey, but not with the app, even though in early discussions it was considered the inclusion of that measurement, however that would require a better mode of transportation detection system and some level of intrusion for the user to obtain sufficiently accurate results.

On the subject of environment, the elected tool to measure it was the carbon footprint. The formula for its calculation changed according to the mode of transportation selected for each trip. To calculate the emissions of CO_2 equivalent of the car, motorcycle and bus we used the values regarding Portugal provided by the EMEP/EEA air pollutant emission inventory guidebook from 2013 (Ntziachristos & Samaras, 2013). The substances considered for the calculation were CH_4, CO_2 and N_2O, rejecting CO, NOx, PM and CO_2 from lubricants for having little or too indirect influence in the overall carbon footprint to be considered (Intergovernmental Panel on Climate Change , 2013).

According to the IPCC Fifth Assessment Report of 2013, releasing 1 kg of methane (CH_4) into the atmosphere is equivalent to releasing 34 kg of CO_2 and if instead of methane it was nitrous oxide (N_2O) the equivalent would be 298 kg of CO_2 in the course of 100 years. The resulting CO_2e value was calculated with the following formula:

$$\mathrm{CO_2e} = [\mathrm{CO_2} + (\mathrm{CH_4} \times 34) + (\mathrm{N_2O} \times 298)] \times \mathrm{Fuel\ Density} \quad \textbf{(2)}$$

The next table shows the considered values for the chosen fuels for the different modes of transportation.

Table 2 – Fuel densities for the calculation of the carbon footprint

	Fuel density (kg/l)
Gasoline	0,745 (Edwards, et al., 2014)
Diesel	0,832 (Edwards, et al., 2014)
LNG	0,450 (International Gas Union, 2012)
CNG	0,679 (Luxfer, 2016)

Considering the bulk emissions for Portugal provided by the EMEP/EEA air pollutant emission inventory guidebook from 2013, updated July 2014, in the 1.A.3.b Road transport Section, the resulting CO_2e values were calculated for cars, motorcycles and buses in **Table 3**.

Table 3 – Bulk emission factors (g/kg fuel) (for CO_2 g/kg fuel) for Portugal, year 2005 **(Ntziachristos & Samaras, 2013)**

	CO (g/kg fuel)	NOx (g/kg fuel)	NMVOC (g/kg fuel)	**CH_4 (g/kg fuel)**	PM (g/kg fuel)	CO_2 from lubricants (g/kg fuel)	**CO_2 (g/kg fuel)**	**N_2O (g/kg fuel)**	**CO_2e (g/l fuel)**
Car (gasoline)	70,1	11,7	10,3	0,80	0,03	9,86	3160	0,206	2420,20
Car (diesel)	3,36	13,5	0,47	0,08	0,89	11,31	3170	0,087	2661,27
Car (LNG)									1237,50
Motorcycle	515	4,44	284	6,35	4,28	50,4	3160	0,059	2528,14
Bus	8,2	36,1	2,21	0,33	1,1	3,52	3170	0	2160,05

In order to use the required emission factors, it was necessary to know the fuel consumption of each transport to transform from CO_2e in g/l of fuel to g/passenger.km. While it is easier to acquire that information about personal means of transportation, like cars and motorcycles, public transportation proves itself more difficult to provide it. According to data from the National Statistics Institute (INE), urban public transports consume in average 50,2 l/100 km (Instituto Nacional de Estatística, 2005). This information, however, is too broad and not exact enough to provide a good basis for the rest of the calculations, especially for lacking more current information. For that reason, considering that in Porto most of the transportation via bus is controlled by "Sociedade de Transportes Colectivos do Porto" (STCP) whose fleet is mainly fuelled by compressed natural gas, we used their Sustainable Development Report to obtain the data on their CO_2 emissions. In 2015, each vehicle emitted 1,385 kg of CO_2 for every kilometre covered. The same procedure was applied with the Porto's Metro and train (Comboios de Portugal – CP) information, which revealed that, in 2014, they released 41,674 and 27,03 gCO_2e/passenger.km respectively (CP Comboios de Portugal, 2014). The logos from the three companies are presented in **Figure 13**.

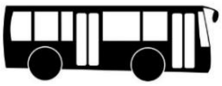
Figure 13 – STCP, Metro do Porto and CP logos.

The results of the emissions from each vehicle need to be divided by the number of passengers to provide a more accurate value of the individual carbon footprint. The occupancy rate of passenger cars in Western European countries, like Portugal, is around 1,54 passengers per vehicle (European Environmental Agency, 2015), however in Greater Porto that rate is lower, consisting in 1,4 passengers per vehicle (Instituto Nacional de Estatística, 2002).

In regard to buses, STCP states that in 2015 the occupancy rate was 13,4% (STCP Sociedade de Transportes Colectivos do Porto, 2015), which, considering that the average capacity for a bus is 90,9 people (STCP Sociedade de Transportes Colectivos do Porto, 2016), means that it usually carries 12,18 passengers per vehicle.

For the metro and the train, the information on the occupancy rates were not required, because the provided data from the reports already took that detail into consideration and further calculations weren't needed. The final emission factors can be consulted on **Table 4**.

Table 4 – Carbon footprint estimation

	Final emission factors (gCO_2e/passenger.km)
 **Car**	**Gasoline:** $2420{,}20 \times \frac{\text{fuel consumption (l/100km)}/100}{1{,}4}$ **Diesel:** $2661{,}27 \times \frac{\text{fuel consumption (l/100km)}/100}{1{,}4}$ **LNG:** $1237{,}50 \times \frac{\text{fuel consumption (l/100km)}/100}{1{,}4}$
 **Motorcycle**	**Gasoline:** $2528{,}14 \times \text{fuel consumption (l/100km)}/100$
 **Bus**	**CNG:** 88,939 gCO_2e/passenger.km
 **Metro**	**Electricity:** 41,674 gCO_2e/passenger.km
 **Train**	**Electricity and Diesel:** 27,03 gCO_2e/passenger.km
 **On foot or bicycle**	0 gCO_2e/km (increase of CO_2 production not considered)
Other means	Not calculated

To calculate the individual carbon footprint through the survey and the app it is required information about the distance travelled with each trip and, in case of the car and motorcycle, the specific fuel consumption, so it is possible to apply the emission factor. According to **Table 4**, the considered order from the most pollutant mode of transportation to the least is as it follows (top to bottom):

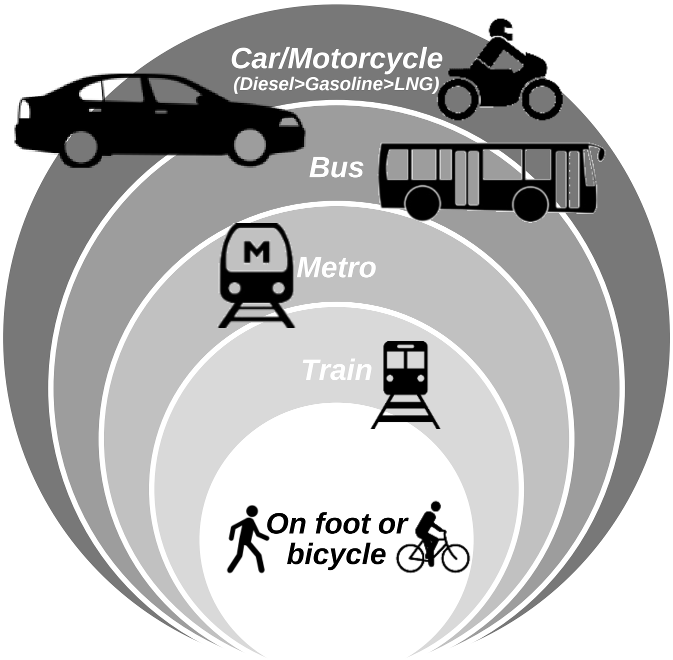


Figure 14 – Order from the most pollutant to the least pollutant mode of transportation per passenger (top to bottom).

It is important to point out that even though vehicles that run on diesel create more CO_2 per litre, they usually can achieve higher fuel economy than similar vehicles that use gasoline, which generally offsets the higher carbon content of diesel fuel.

3.2. DATA COLLECTION

3.2.1. MOBILITY SURVEY

The mobility survey was created using Google Forms (**Annex 1 – Survey**) due to its simplicity in generating questions and answering them from the user's perspective (**Figure 15**). Simple, clean and effective were the key words intended for this experience that is often seen by the participants as tenuous or confusing. This survey was a combination of traditional questions to characterize the sample (occupation, age, gender, household information, income) and evaluate their general mobility habits concerning their trips to and from FEUP (distance, frequency, duration, mode of transportation) and a travel diary to give a consistent one-week detailed information that can be compared with the general answers that were given. The evaluation of sustainability will be based on the characteristics of the sample, their average travelling costs and their carbon footprint, that will be calculated using the data about mode of transportation, distance and fuel consumption in case of using a personal vehicle. With these results, the objective will be to assess the sustainability of FEUP's mobility and the potential to improve.

Figure 15 – Introduction to the Mobility Survey using Google Forms.

Due to an initiative in progress by FEUP's Commissariat for Sustainability and the University of Porto called U-Bike, the mobility survey was sent to all University community with the addition of a question specifically about the susceptibility to the initiative. This served as a previous study to the University of Porto project that applied to the competition called "POSEUR-07-2015-31" which promotes power and conventional bicycles in Academic Communities.

The email to FEUP's community was sent on April 20th and the second email on April 26th, ending the period for answers on April 30th . In total, 340 people answered, consisting of 4,1% of the total community, with several replies with suggestions and ideas about sustainability and mobility. Even though it is a low response rate to a normal Mobility Survey (the ideal being above 10%), it is high if we consider the usual rate for travel diaries, where it is not unusual having only 10 families in a city contributing to the travel diary.

3.2.2. SENSEMYFEUP APP

The mobile application called SenseMyFEUP was developed for Android Smartphones by a research team from FEUP's Institute of Telecommunications led by Ana Aguiar, both a teacher and a researcher. For this purpose, they adapted another app of their creation, called SenseMyCity, which is part of the project Future Cities from the University of Porto. They both use crowdsensing to obtain data from the users, and, in SenseMyFEUP's case, it is more directed to retrieve information about mobility's indicators (mean of transportation, duration and distance of a trip) and use distance and chosen mode of transport to obtain the user's carbon footprint.

The data collection and the associated database was registered in the National Data Protection Commission with the process code 61.805.680. Each user is identified in the database by the hash used by Google Open ID and not even the database administrator could revert it, therefore not being possible to identify the emails of the participants. The users had access to their data through the app's website[2], but they were anonymous to everyone else. The raw anonymous data use individual id to be later processed in mass. All the data will be erased after 3 years.

To validate the mode detection algorithm that was still in progress, the users had to respond to a questionnaire each time the app sensed that they finished a trip, using GPS or other location sensor and detecting the variation of velocity between points (**Figure 16**). The interface of the app showed information about the user's mode of travel, carbon footprint and the comparison to FEUP's average (**Figure 16**).

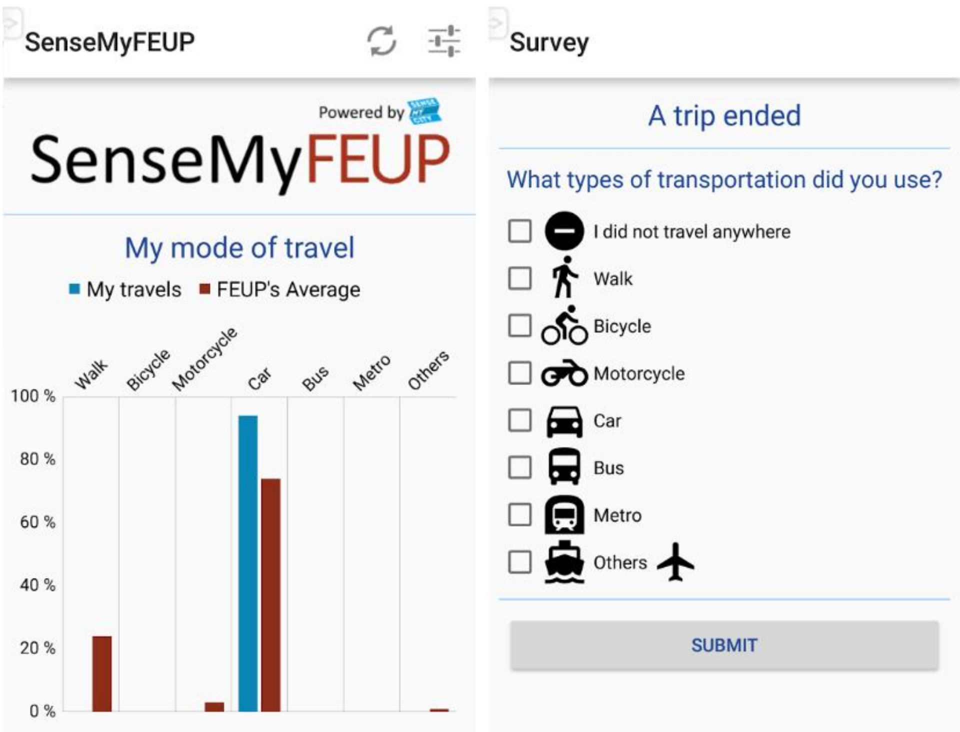


Figure 16 – Interface of SenseMyFEUP in an Android Smartphone.

[2] The official website could be accessed through the link: **sensemycity.up.pt/project/sensemyfeup/** and the data with an interactive map in: **sensemycity.up.pt/sensemyfeup/**

The SenseMyFEUP app was officially released to the public on March 29th and the dissemination period lasted from that date until April 4th, when the data collection for this study started. The dissemination consisted on the distribution of flyers (**Annex 2 – Flyer**) and the exposition of posters (**Annex 3 – Poster**) throughout the faculty. The target audience was all FEUP's community.

The Commissariat for Sustainability sent the first email to announce the app on March 30th, the second email was sent by "Notícias FEUP" on April 4th and the third on April 13th by the Commissariat for Sustainability. It was also created a Facebook page on April 1st to better spread the word and increase the connection with the students in particular. To raise interest, during the period of April 4th to April 29th, a FEUP's sweatshirt was sorted among the app's users each week and a smartphone in the end with the chances of winning accumulating with time since the installation and with each data contribution (**Figure 17**). Due to the impossibility of identifying the exact winner through his or her google email, the winner would be warned through an app notification.

In total, 239 people used the app, but only an average of 100 sent data consistently.

Figure 17 – Example of the FEUP's sweatshirt and the smartphone Motorola Moto G v2 used as prizes during the sample period.

4.
RESULTS AND DISCUSSION

4.1. METHOD RESULTS

4.1.1. SURVEY RESULTS

During our mobility survey period from April 20th to April 30th we received 340 answers which consisted of 4,1% of FEUP's community. The results in bulk for each question of the survey can be verified in **Annex 4 – Survey Results**.

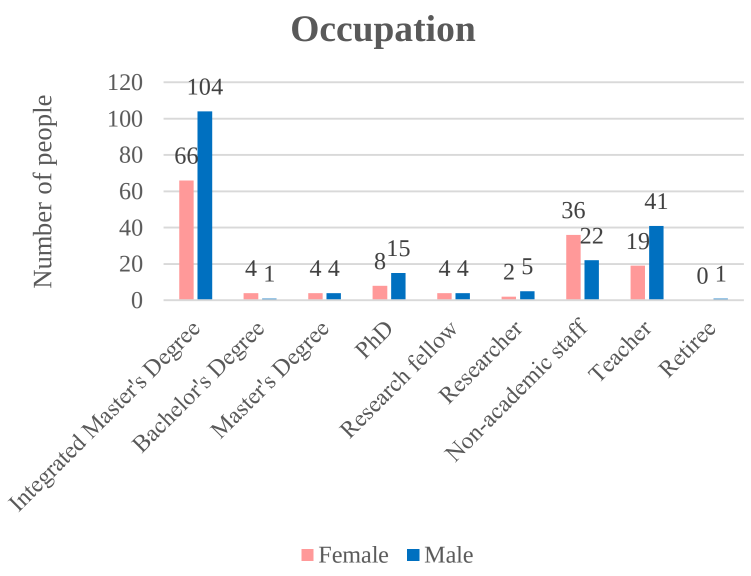


Figure 18 – Sample characterization of their occupation and gender.

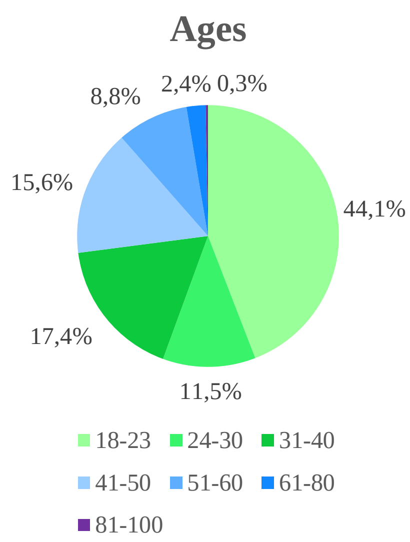


Figure 19 – Sample characterization of their age.

The sample from the survey is relatively consistent with the reality of the community, even considering the small sample size, but with a slightly higher participation from Teachers and Staff. **Figure 18** and **Figure 19** represent the general characteristics of those who answered the survey, being the majority Integrated Master's Students (50%), Teachers (18%) and Staff (17%).

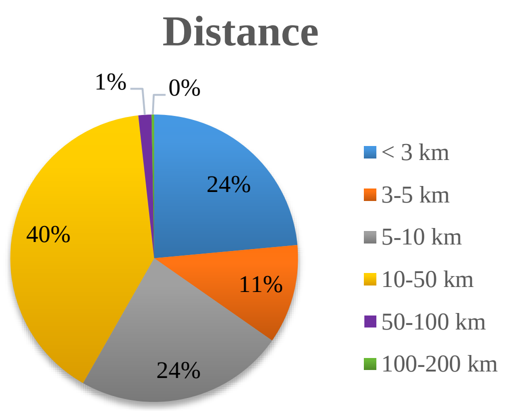


Figure 20 – Distances of the trips to and from FEUP.

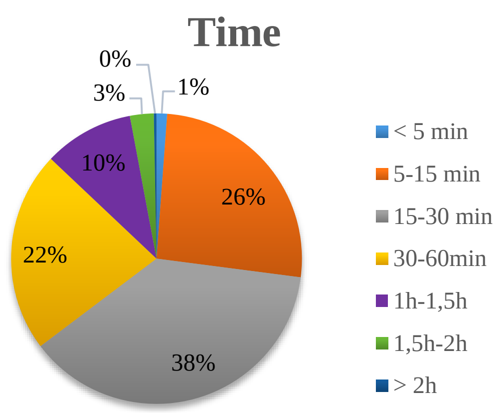


Figure 21 – Duration of the trips to and from FEUP.

According to the survey's results, most trips to and from FEUP are between 10-50 km, 24% are between 5-10 km and 24% being less than 3 km (**Figure 20**), being the overall average distance 14 km. The same trips last primarily between 15-30 min, 26% being between 5-15 min and 22% between 30-60 min (**Figure 21**), with a median of 32 min. Without traffic, red lights or other stops among the way, the average speed would be 26 km/h. This scenario, however, is extremely unlikely, especially with motorized vehicles.

The results for the modal distribution (**Figure 22**) revealed that the car is the main choice for travelling to and from FEUP by 51% of the respondents, which is consistent to the 52% indicated by Diogo Silva in his dissertation (Silva, 2015), but an increase from the results of the Mobility Study carried out by FEUP's Commissariat for Sustainability in November of 2015 where only 40% were car users (Comissariado para a Sustentabilidade, 2015). Public transportation results also differ a bit, with 36% in this survey, 31% in Silva's dissertation and 40% in FEUP's Mobility Study.

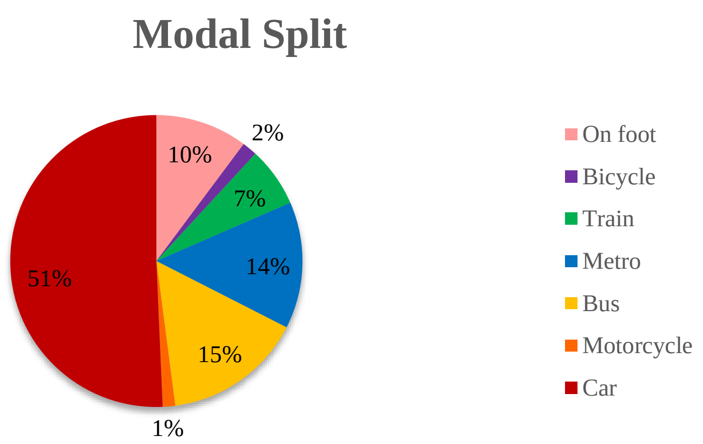
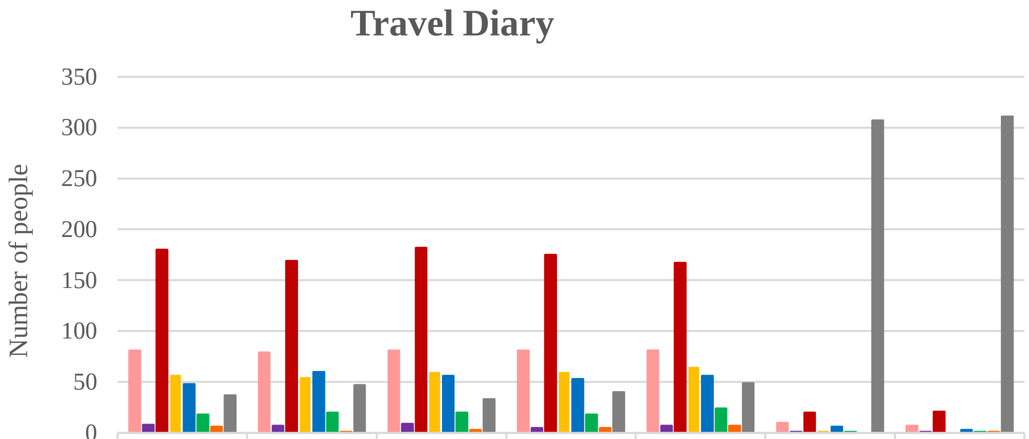


Figure 22 – Modal split of the trips to and from FEUP.

The results for the distribution of mode of transportation are represented in more detail in the travel diary (**Figure 23**). It is important to mention that in the survey besides the travel diary there was another question in which the person would specify the overall preferred transport. Many answers revealed disparities between the answers (for example: saying they prefer to walk but then stating that they used the train every day during the week, meaning they live too far to just walk the entire trip to FEUP), as well as the affirmations about going or not to FEUP during the week. These irregularities were taken in consideration and adjusted to the most probable reality for general assumptions.



	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
On foot	81	79	81	81	81	10	7
Bicycle	8	7	9	5	7	1	1
Car	180	169	182	175	167	20	21
Bus	57	55	60	60	65	2	0
Metro	48	60	56	53	56	6	3
Train	18	20	20	18	24	1	1
Motorcycle	6	1	3	5	7	0	1
Didn't go to college	37	47	33	40	49	307	311

Figure 23 – Travel diary results.

The mobility patterns throughout the week are fairly consistent, with Wednesday revealing a bigger attendance rate and Friday the lowest (**Figure 24**). This implies that in the middle of the week there is a smaller chance of wanting to skip class or similar intentions or a bigger chance of having activities (classes, work, etc) programmed for that day. It also implies that at the end of the working week many students decide to go home early.

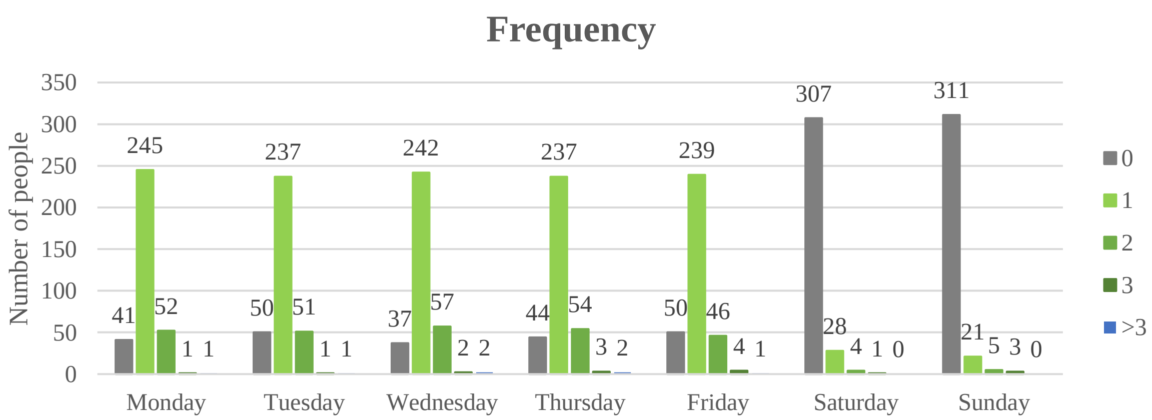


Figure 24 – Frequency of trips to FEUP each day of the week.

Nevertheless, the car wins every day of the week. This phenomenon receives influence from different conditions that need to be analysed. The first condition is distance. **Figure 25** displays a map with the locations of all respondents from where they travel directly to FEUP and specific transport mode.

It is possible to detect a concentration of metro users in Póvoa de Varzim and north of Gaia, close to the lines that service those areas. Train users, on the other hand, come mainly from Espinho in the South, Valongo from the East and Trofa from Northeast, usually stopping at São Bento Station and taking the metro following the D line directly to FEUP. Bus users and car riders are more irregular and many come from places not serviced by metro or train, especially cars if near a highway.

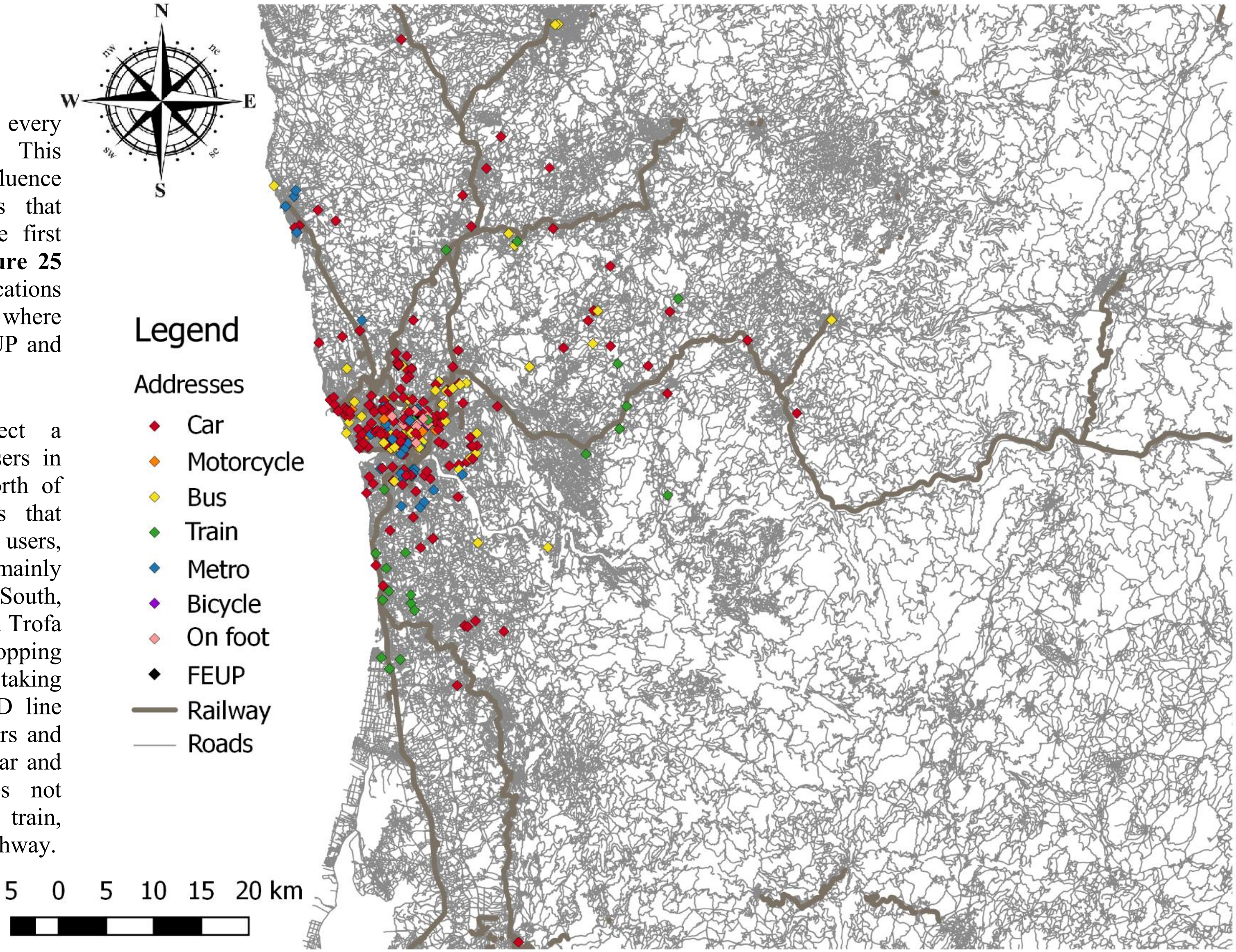


Figure 25 – Map of the locations and the transportation mode

In **Figure 26**, we separate and group chosen modes of transportation by walking distance (less than 2 km), bicycle distance (between 2 and 5 km) and the rest. The walking distance is equivalent of around 24 minutes of walking at a normal speed of 5 km/h. With longer times, people start looking for alternatives, especially in a well-serviced area as FEUP's vicinity. Regarding the decision of the limit of cycling distance, several studies including an European study of cycling habits by John Pucher and Ralph Buehler state that longer distances than 5 km means a significant decrease of bicycle use, being 2,5 km the comfortable average (Pucher & Buehler, 2008). The considered distances were based on those declared by the respondents after a comparison to their addresses and identification and correction of irregularities.

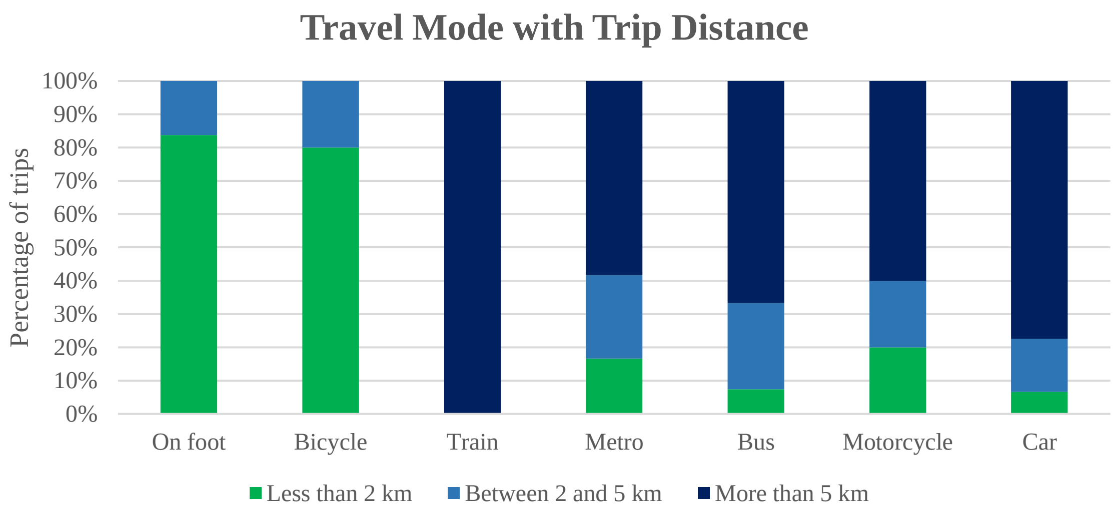


Figure 26 – Influence of travel distance on the choice of transportation.

The graph above reveals that 23% of car users and 40% of motorcycle riders are within bicycle distance. Even more worring is the fact that 7% and 20% respectively could walk to the faculty and decide not to do so. Regarding public transports, 17% of metro users and 7% of bus users are closer than 2 km, which for metro means that they live close to the D line.

On the presented option of using free bicycles from the project U-Bike, according to **Figure 27**, 17% of people who ride the bus, 12% of those who use the metro, 10% of train users and 9% of car drivers allege interest in participating in this iniciative, being 8 km the average distance of the trip for the respondents. A greater number more claim to evaluate the situation when the time comes, with the average distance rising to 13 km, and most people who were not interested were 18 km away from FEUP. This means 8% would change their mobility habits to become more sustainable and 33% would consider it, coming both groups from considerable distances.

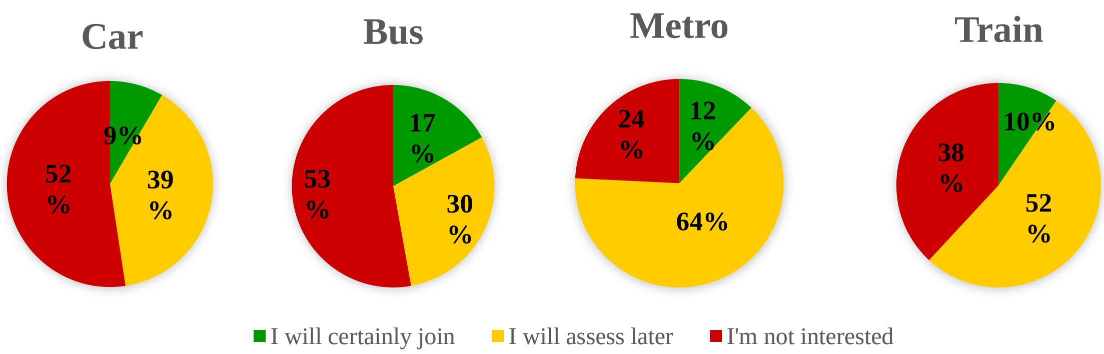


Figure 27 – Responses to the U-Bike question in the survey.

To further assess the issue of distance, a map was created with a visual representation of the area that can be walked with the average velocity of 5 km/h for 3km. This new distance was chosen to include the remaining 16% who chose to walk to FEUP and the 20% that use the bicycle. **Figure 28** is part of the map of **Figure 25** zoomed in to show the required area. Of all the people who live 3 km away from FEUP, 51% decide to walk or use the bicycle, taking less than 36 minutes. Even so, many still prefer to use the car (25%) and the bus (10%). Concerning the metro, this area includes 6 stops: Marquês, Combatentes, Salgueiros, Pólo Universitário, IPO and Hospital São João, being the 3 last ones usually used as the last stop.

The further we go from FEUP, especially starting on 3 km, the more car users are found, being this fact already visible around the area.

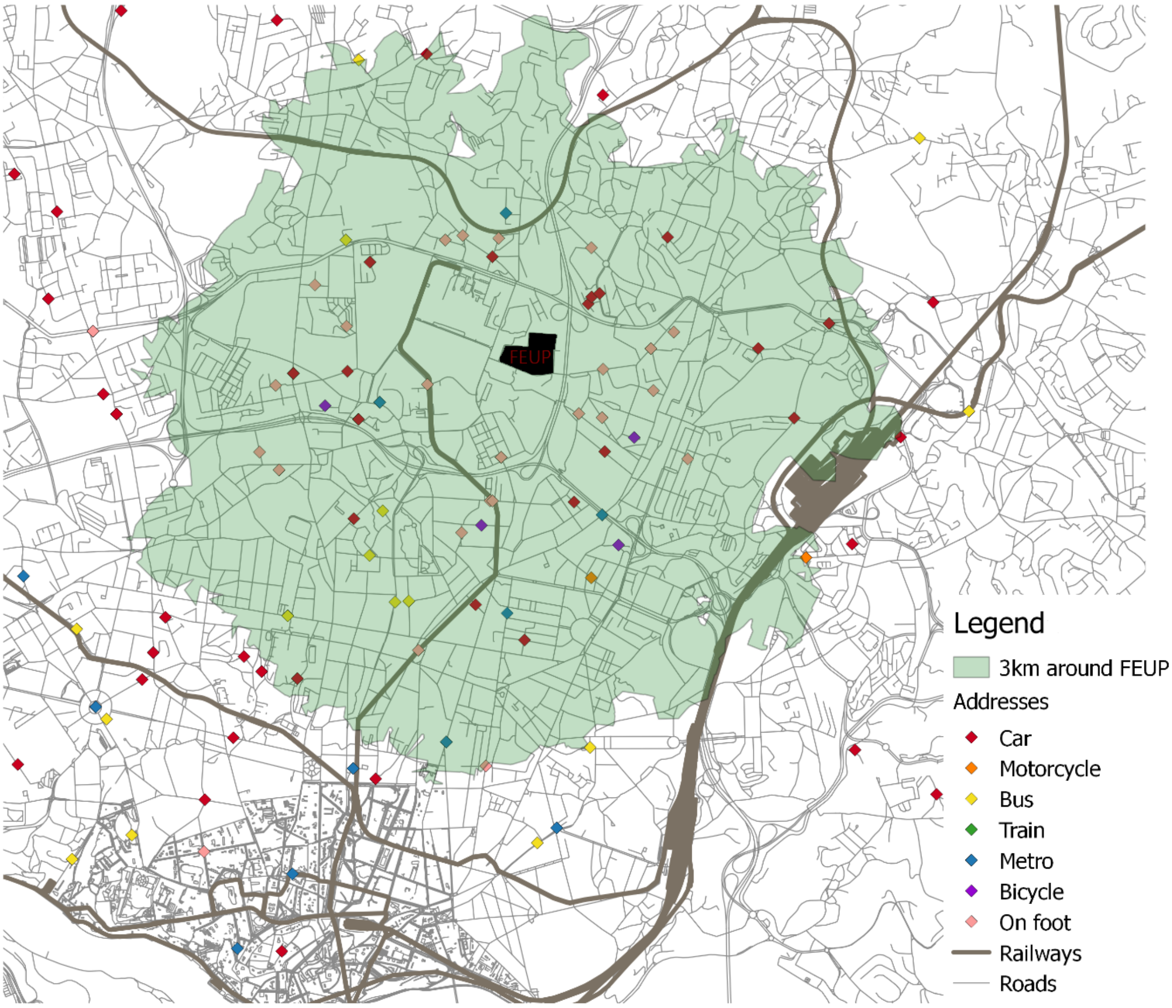


Figure 28 – Part of the map of the addresses and chosen mode of transportation for the trips to and from FEUP.

The influence of one's occupation also weighs heavily on the decision of how to travel around. **Figure 29** shows us that older, more academically achieved people tend to use the car more. The great majority of FEUP's non-academic staff has a higher degree, thus following more closely the mobility tendencies of teachers than those of students or researchers. In reaction to the survey, several people, mostly teachers and staff, felt the need to justify their preference for the car and to emphasize their concern for the environment and their sustainability but regretting the improvement of their habits being impossible due to the conditions of their situation. Within the older, working group of FEUP's community, the probability of having a family and needing to give a ride to other members, like taking children to school or their wife/husband to work, is bigger, thus resulting in the preference for personal vehicles to suit their needs and give them more liberty to maneuver any occuring situation. Public transportation doesn't satisfy these needs due to its limiting schedule and area of service, which can be a deterrent for most people.

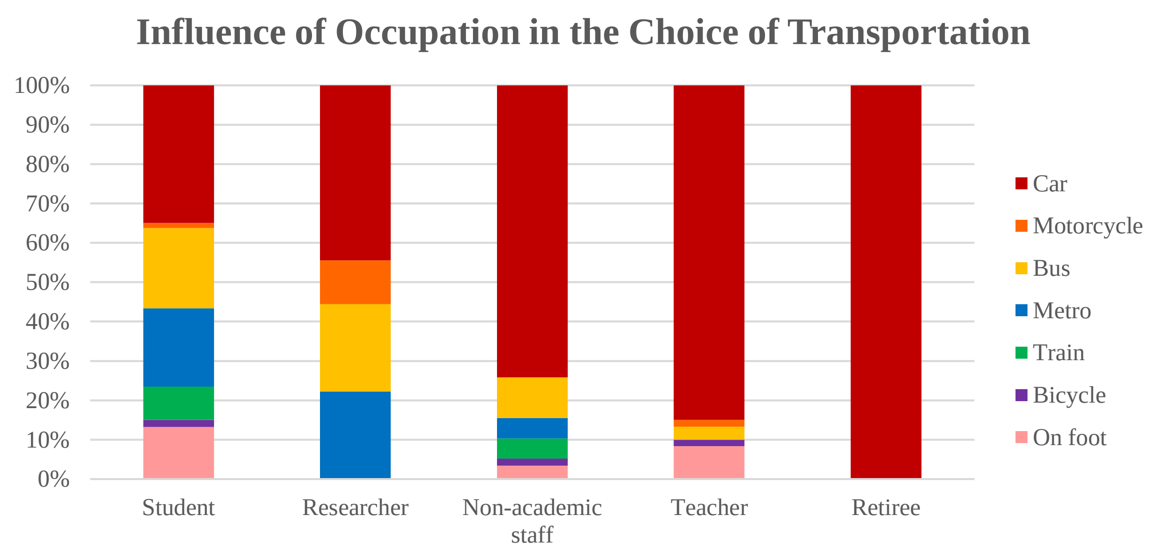


Figure 29 – Influence of occupation on the choice of transportation.

Occupation is intimately related to income, and the bigger the salary, the bigger the tendency to use the car, according to **Figure 30**.

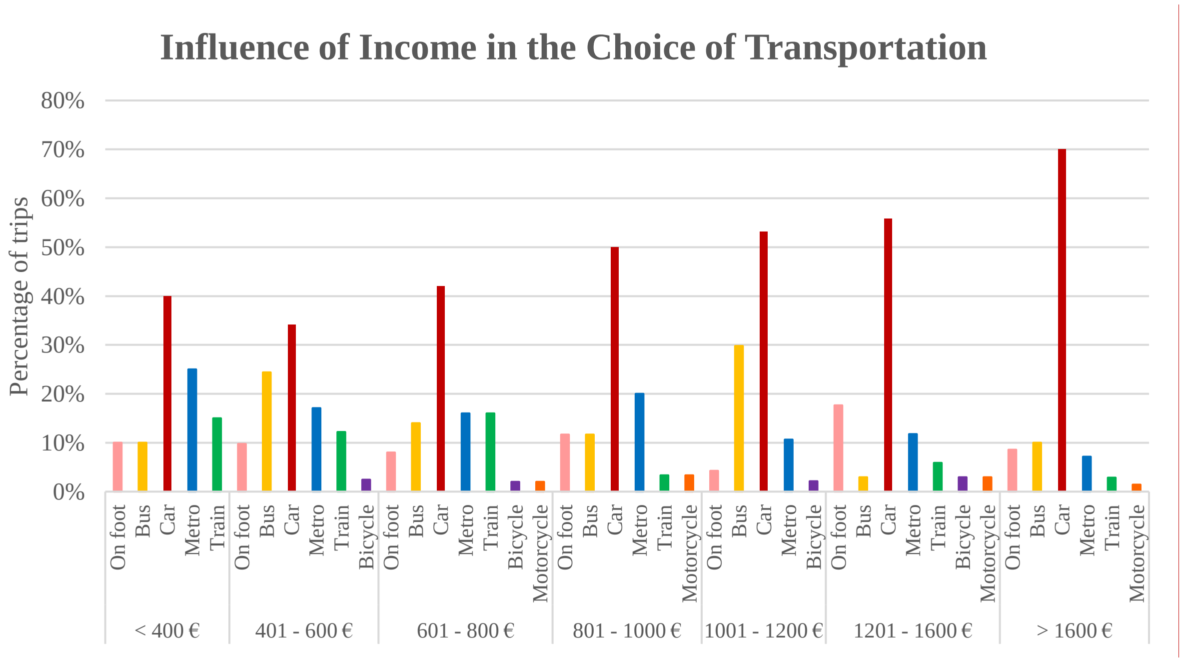


Figure 30 – Influence of income on the choice of transportation.

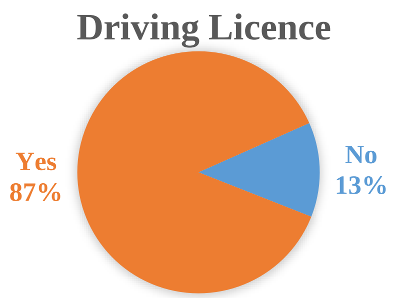


Figure 31 – Share of people who do or do not have driving licence.

Regarding the influence of driving licences on the choice of mode of transportation, as predictable and shown in **Figure 31**, most people have a driving licence, consequently choosing more often the car as their main mean of transportation. From those who do not own a car, 13% still use it as a passenger, even though the most favoured transport is the bus by 42% (**Figure 32**).

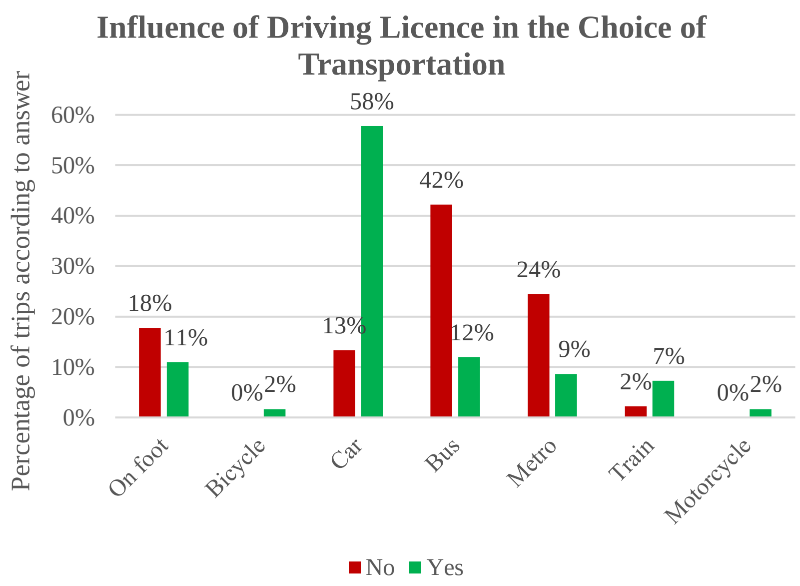


Figure 32 – Data about the influence of having driving license in the chosen transport (percentage of answers).

Comparing the percentages of both situations, the key factor that differentiates them is the train. In every other mean of transportation, with the exception of the car and the motorcycle, the number of people without driving license surpasses the ones who do have it.

The tendency to use the car for long distance trips instead of the train can be problematic because carbon footprint is directly related to the travelled distance. Returning to the analysis of overall modal split, the modal distribution changes a bit when passing from evaluating individual trips to the distribution according to the total of the travelled distance.

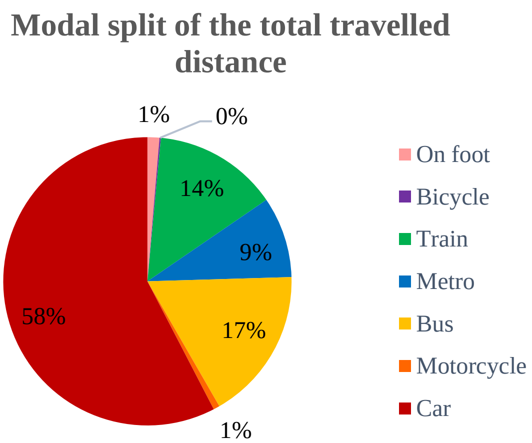


Figure 33 – Modal distribution according to the distance.

From this point of view, the car and train are used for longer trips, passing from 51% to 58% and 7% to 14% respectively in the overall modal distribution, shown in **Figure 33**. Fortunately, the train is the public transport that contributes less to the individual carbon footprint. The car, on the other hand, is the worst decision for long travels regarding sustainability, unless it is shared with more people.

The final considerations on sustainability shall be assessed further ahead.

4.1.2. SENSEMYFEUP RESULTS

In total, SenseMyFEUP had 239 unique users, 8844 answered questionnaires and 290540 processed kilometres. Due to the fact that the mode detection algorithm was not finished at the time of the app's release to the public, the mode was only identified through the answers of the questionnaires. This data was then used by another student to perfect the algorithm for his dissertation[3]. When finished, it proved to have a combined accuracy of 86,71% and precision of 66,61% (in particular metro 84,19%, car 88,71%, bus 59,61% and bicycle 6%) in comparison to the results of just analysing questionnaires. Unfortunately, it was not possible to run the complete dataset with the algorithm, so the results presented here will only be based on the answers given by users and filtered by the other student.

The problem with this process of obtaining results is that there were many discrepancies with the answers given to the questionnaires and other indicators like speed and location. For this reason, most of the data had to be cleansed and irregularities eliminated. For a trip to be validated, the answer to the mode of transportation had to obey the following rules:

Table 5 – Limits imposed for the identification of the mode of transportation

On foot	Median speed < 10 km/h and Max speed < 20km/h
Bicycle	Max speed < 50 km/h
Car	No limits imposed
Bus	Max speed < 120 km/h
Metro	Max speed < 110 km/h (Metro equipment speed limit + 10%)

In addition to this purge, most of the remaining data was not relevant to this study because only trips to and from FEUP are considered. The act of correctly detecting the beginning and the end of a trip proved itself very tricky. A trip was considered terminated after some time of inactivity, which can lead to incorrect assumptions if the user is stuck in traffic or just stopped in the way to school/work to talk to someone. In these situations, a trip will not be correctly identified. Another difficulty was encountered in dealing with intermodal trips, which usually happen with users that live further away. In contrast to the survey results, the average trip distance was only 2,7 km, diverging from the average 13,8 km assessed before. This shows the problem of recognition of an intermodal trip, reflecting in an excess of trips starting and ending near FEUP, particularly Paranhos (**Annex 5 – SenseMyFEUP Results**). The reason why the distance does not reach a similar value to the survey is because the target population was different. The app users were mainly students and few teachers or staff. A detailed characterization of the sample with a connection with individual mobility patterns was not possible due to privacy issues.

[3] A parallel dissertation was conducted by a Master in Electrical and Computers Engineering's student under the orientation of Ana Aguiar regarding the mode detection system of SenseMyFEUP.

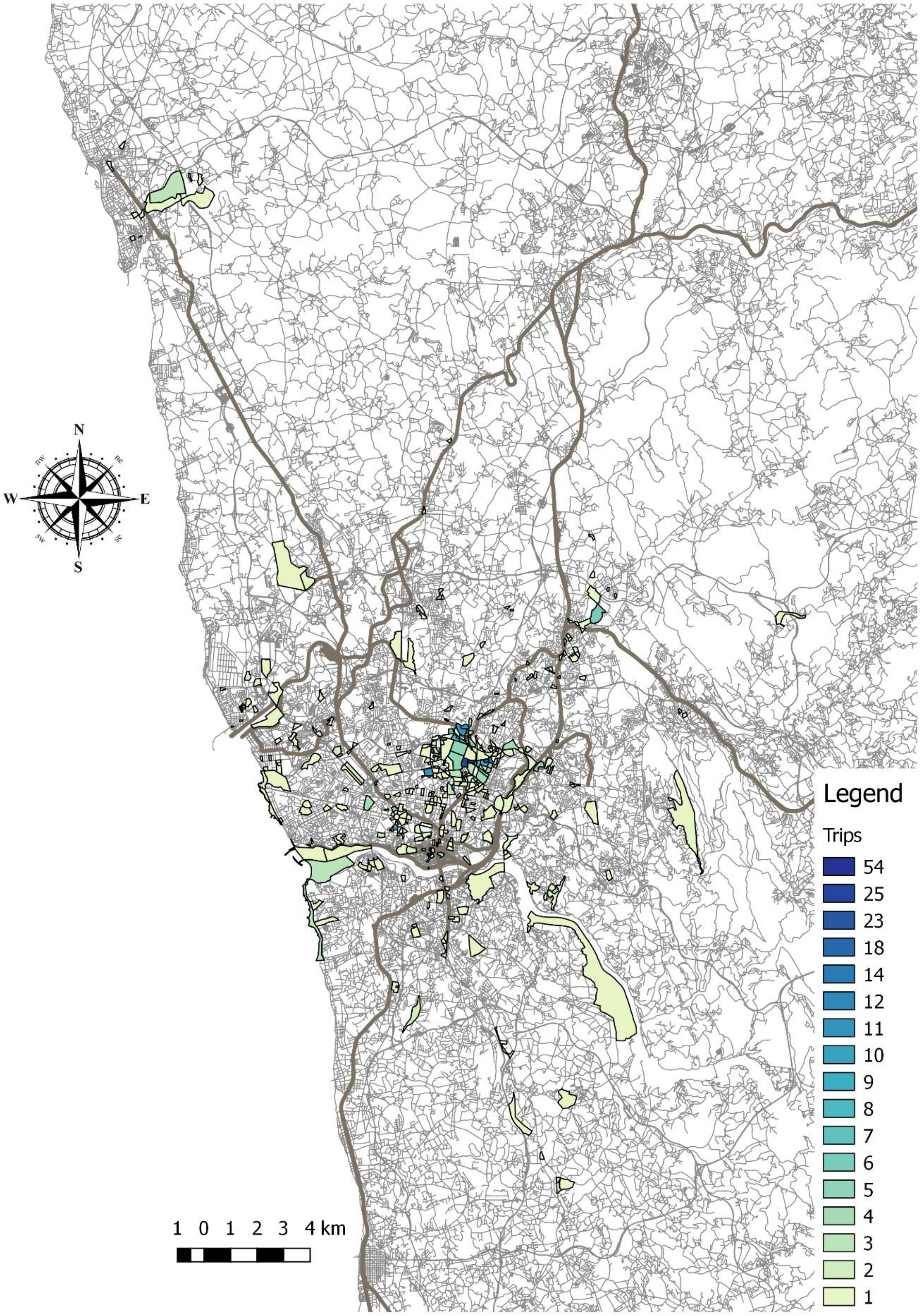


Figure 34 – Map with the number of trips to and from FEUP according to geographic codes.

The map in **Figure 34** represents the number of trips according to the location based on the codes of the Geographic Base of Information Referencing (BGRI - Base Geográfica de Referenciação de Informação) with concentrated numbers near FEUP and extending as far as Póvoa de Varzim.

Most origins and destinations of the trips seem to follow metro lines, like the D line, that connects FEUP and Gaia, the centre being the downtown area of Porto and continuing in direction of Matosinhos. Other locations that encourage the use of train for their distance, like Espinho, are not represented by the sample. The largest concentration of users, however, remains in Paranhos, where FEUP is situated. It is important to emphasize that only the locations that were the origin or the destination of a trip to or from FEUP were considered for the map and not FEUP itself, therefore the concentration of trips of that area should be smaller, unless most people from the sample lived nearby and came to and from FEUP often.

The restriction of information also affected the calculation of frequency of trips by average user because it is necessary to be able to access the exact number of people that sent data during that day to divide the total of the daily trips by that number. The responsible for the processing of the data did not have that access, consequently it was difficult to determine the exact number from the excess of Paranhos trips that correspondent to lunch time occurrences and other small trips.

Nevertheless, a correction to the excess of walking trips was attempted with the elimination of situations in Paranhos with very short distances and long periods of time. Without considering irregular trips, the average distance rises to 6,0 km and the duration of the trip is around 34 min to FEUP and 30 min from FEUP. The difference can be shown in the transition of **Figure 35** to **Figure 36**.

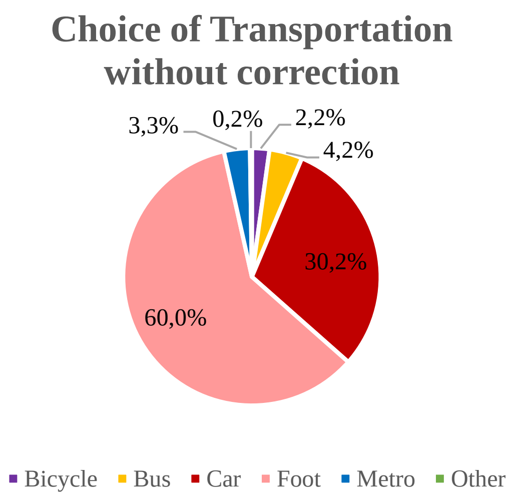


Figure 35 – Choice of Transportation without correction.

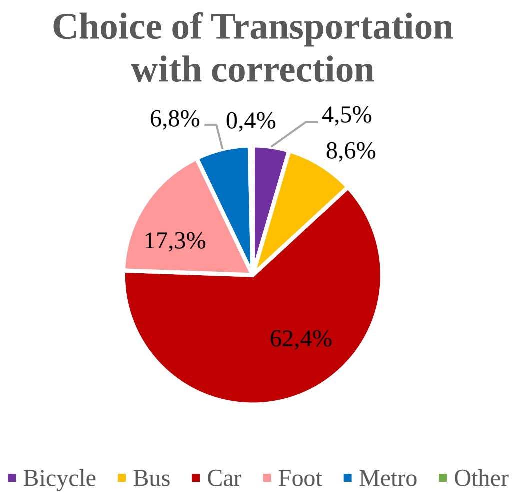


Figure 36 – Choice of Transportation without correction.

With this correction, the modal split is more similar to the survey results, even though the experiment period was different. The comparison between the two methods will be analysed further ahead. The car share is the same as the value defined by the Census 2011 for work/school trips (62%) not only in Portugal but also in Porto, with the rest of modal choices having a similar distribution, except the metro and bicycle, which are more frequently selected in this case study due to the proximity of metro stations and the larger number of short trips.

The official data collection period for SenseMyFEUP was from April 4^{th} to May 1^{st}, including the 14^{th}, 15^{th}, 16^{th} and 17^{th} week of the year.

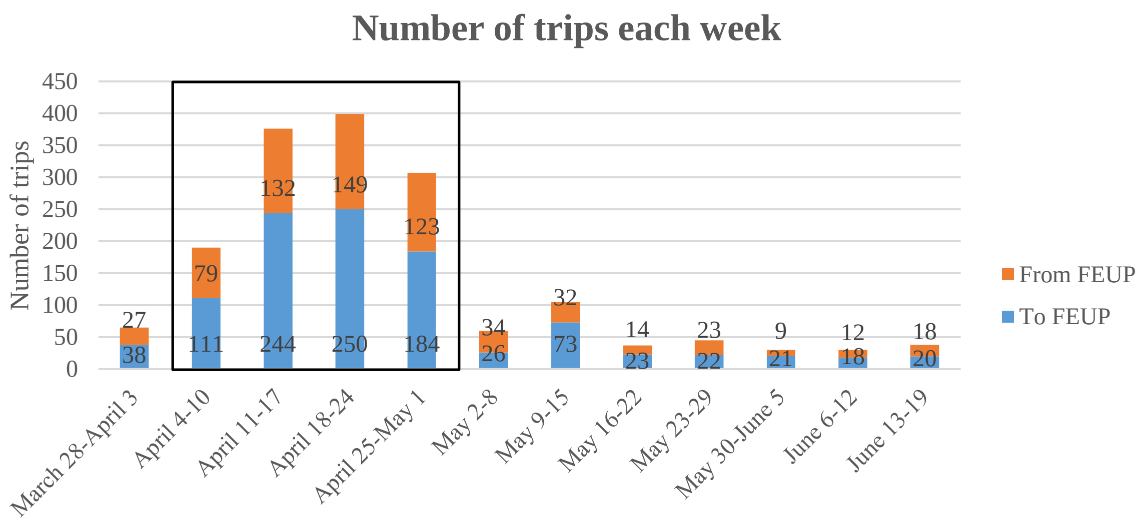


Figure 37 – Evolution of total number of trips each week.

The evolution since the beginning of the trial period (March 28th to April 3rd) can be observed in **Figure 37**, noticing a slow start in the first week of April 4-10th and increasing until the third week, but decreasing in the final week. This decline started to happen in the last week probably because the final winners of the prizes had already be announced and there was not anything else to cling the users and interest them enough to maintain the app installed. After this period, a huge drop was expected, accentuated by the fact that from May 2-8th was Porto's Queima das Fitas, a big event that always happens in the first week of May and when academic activity is reduced, with few or no classes at all. This drop is then softened the next week when normal activities restart.

The modal distribution for each week is expressed in **Figure 38**, with emphasis on the four experiment weeks.

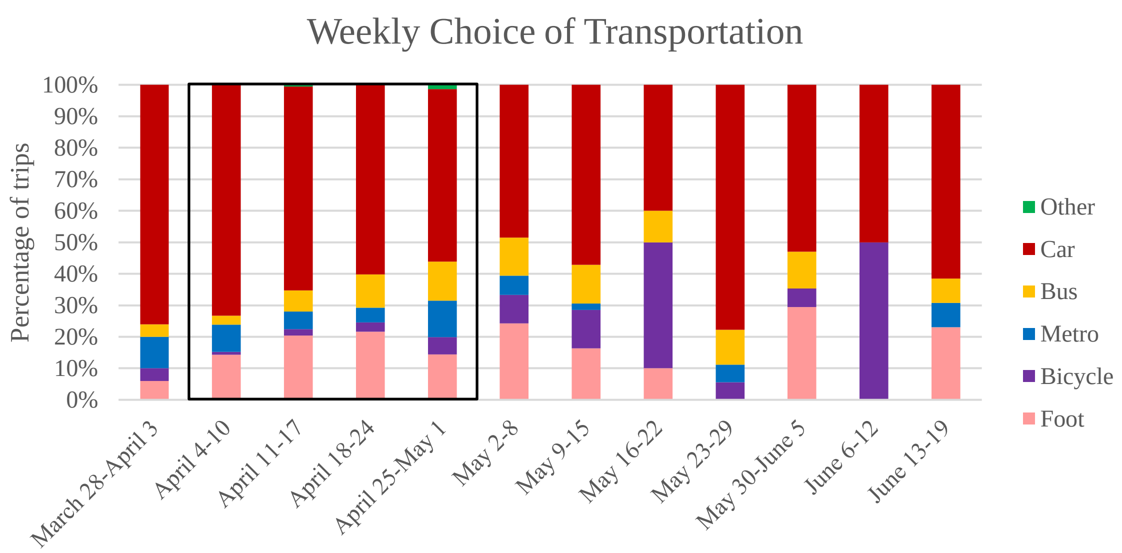


Figure 38 – Weekly Choice of Transportation.

The share of car trips decreases as the amount of users increases, allowing the modal distribution to become more stable and representative. From May 2nd on, the declining user population started disfiguring the correct distribution, becoming useless data when the total weekly trips became less than 50.

Regarding daily patterns, the average number of trips per day is shown in **Figure 39**, revealing an increase during the course of the week until Thursday with a decrease on Friday. In similarity to the survey results, this decrease may be an indication of the students' decision of returning home early for the weekend.

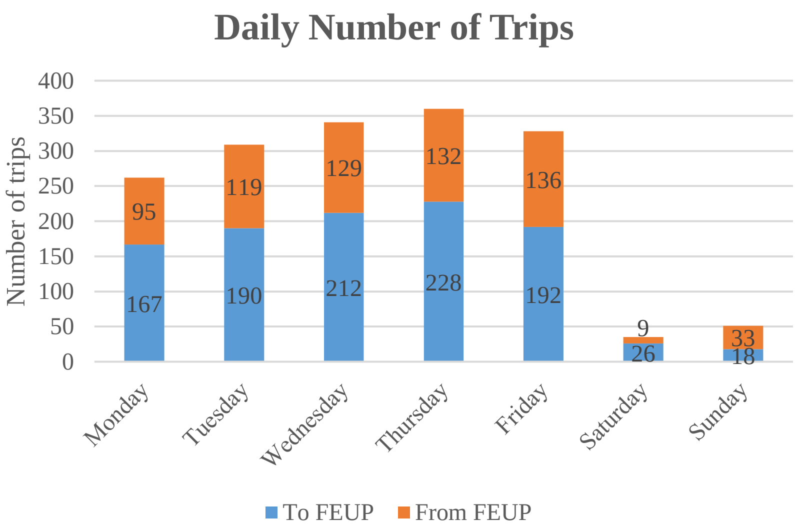


Figure 39 – Daily number of trips

By observing **Figure 40**, the choice of transportation does not vary much with each day, not even between workdays and weekend, unlike the survey results. The lack of teachers, staff, investigators and other heterogeneous elements in a student-predominant user base steer the results away from exact representation.

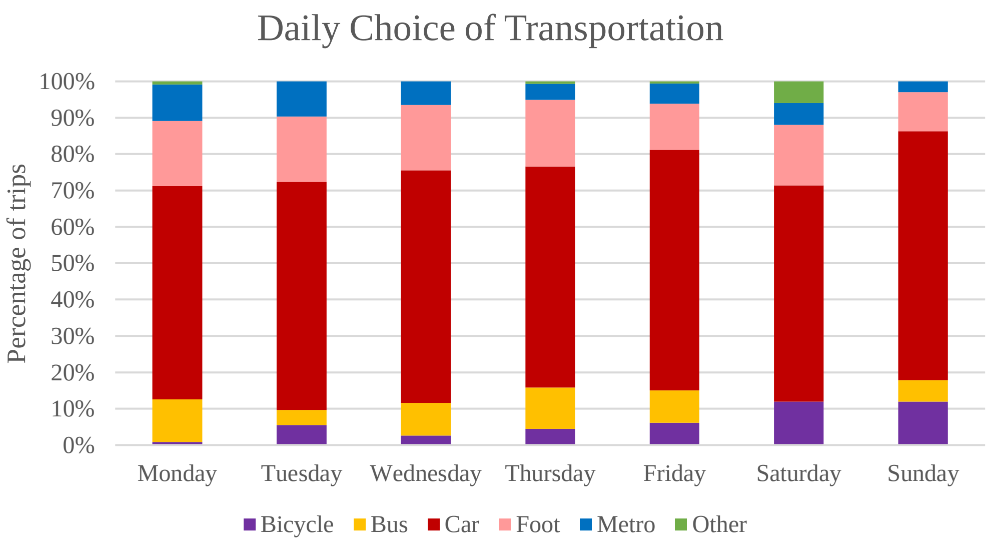


Figure 40 – Daily Choice of Transportation.

In comparison to the survey, the app was not able to collect the same variety of information due to its early stages of development, thus the decreased richness of data and extend of analysis. A comparison between both methods will be assessed further ahead.

4.2. SUSTAINABILITY RESULTS

Regarding economic aspects of sustainability, the community spends on average 45 euros per month on travel expenses that include coming to and from FEUP, according to the survey (**Figure 41**). This type of information was not obtainable with the app.

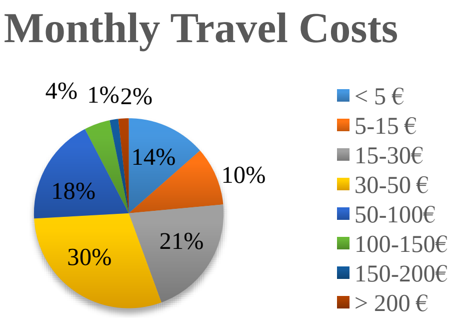


Figure 41 – Survey data about monthly travel costs.

By comparing the answers regarding monthly income with travel expenses, the average person spends around 5% of their share of the household money on their transportation. Even though the average spending between 30-50 euros is common on every level of income, there is a tendency within people with higher incomes to spend more on their mobility (**Figure 42**). This is supported by the fact shown previously: the more a person earns, as he/she becomes older and rises in the professional hierarchy, the more he/she favours the car.

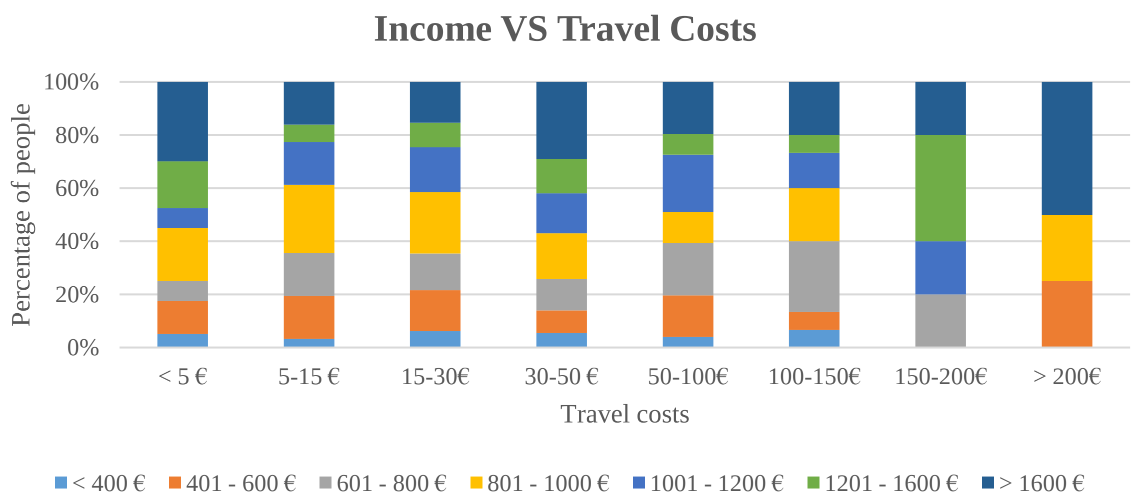


Figure 42 – Influence of income on monthly travel spending.

On a social level, this behaviour was justified by the value of practicality and commodity, which is a harder behaviour to change, and, more importantly, the need to give a ride to other people. Being older and more professionally accomplished means the probability of having a family and living on the suburbs (and not renting a house near FEUP like many students) is higher. The lack of quality in public transportation is also a referred point by most people, which can befall on the practicality factor. Even though many reveal concern about their sustainability, many limiting conditions influence their choice of using the car (**Annex 4 – Survey Results**).

On the environmental side of this behaviour and by reviewing the general results of the survey, it was concluded that our carbon footprint, on average, is 1,36 $kgCO_2e$ per capita in each trip made from and to FEUP, which is consistent to a prevalent car user community. With the app the value is quite similar, reaching 1,42 kgCO2e/trip due to a higher share of car users.

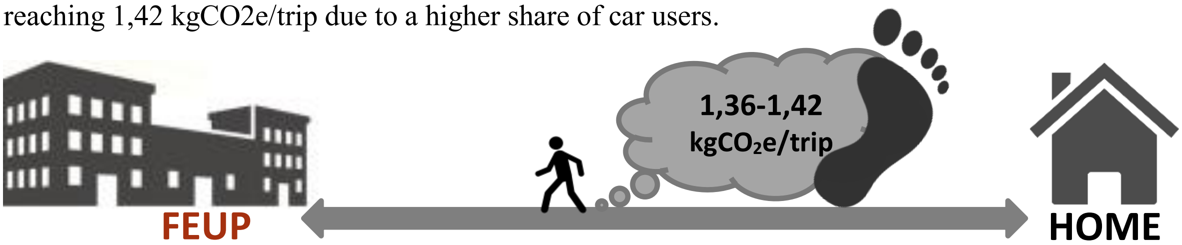


Figure 43 – Representation of the final result of FEUP's carbon footprint per capita with each trip.

Using the survey information on frequency of trips throughout an average week, the emissions were estimated around 14,61 $kgCO_2e$ individually, which translates into 584,50 $kgCO_2e$ during the 40 weeks of an academic year. In 2014, the average carbon footprint per capita in Portugal was 4,60 tCO_2e, with 1,51 tCO_2 being the share related to transportation emissions (World Energy Council, 2016). Even though our results constitute just a third of that value, we have to bear in mind that it was only considered trips from and to FEUP for 10 months. The contributions from other types of mobility will definitely increase, since that school/work travelling only consists of 30% of a person's mobility in the area of Porto according to the Mobility Survey of Resident Population in 2000 (Instituto Nacional de Estatística, 2002). By considering the totality of mobility emissions of 1,95 tCO_2e per person in an year (considering that 0,58 tCO_2e is 30%), FEUP's community not only surpasses the national average, but also the world annual carbon emissions of 0,86 tCO_2e per capita (World Energy Council, 2016).

The only available way to decrease our carbon footprint are options that are within FEUP's reach. Studying the survey's results with more care, we concluded that from the 168 people (51%) who chose car as a preferred mode of transportation, 66 reported that they used any kind of public transport or other alternative for their travelling to or from FEUP in at least one day in their travel diary, meaning there is a feasible substitute to the car. On another note, 20 people use the car for travel distances shorter than 3km, which can be considered a valid walking distance and an average bicycle distance, 10 of those being in common with the previous 66. In total, 76 people (22,4% of the sample) were identified to possess mobility habits that could be easily changed and become more sustainable. If those people decided to use a bus from now on and those within 3 km started walking, for example, the average carbon footprint would become 1,25 $kgCO_2e$/trip, a 8% decrease. Applying on the whole population, around 1795 people in FEUP (22,4%) are easily susceptible to improve the sustainability of their mobility which could be obtained and increased in number with more awareness campaigns, projects like car sharing, and even striving to improve public transportation around campus and in areas poorly serviced. FEUP's Commissariat for Sustainability poses a vital role in supporting sustainable projects and initiatives and spreading awareness in the community. On the other hand, if we consider SenseMyFEUP's results, 42% of car trips to FEUP and 34% of car trips from FEUP were less than 3km. If those trips were on foot, the total carbon footprint would decrease 22% from 1,42 kgCO2e/trip to 1,10 $kgCO_2e$/trip.

Regarding the feedback of the U-Bike initiative, as cited previously, 17% of people who ride the bus, 12% of those who use the metro, 10% of train users and 9% of car drivers allege interest in starting to ride bicycles to FEUP. In total 8% would change their mobility habits to become more sustainable and 33% would consider it. This would mean that if all those who affirmed that they would certainly start riding a bike keep their word, the average carbon footprint would decrease to 1,21 $kgCO_2e$/trip. If we add those who would think about it, the difference would be even more considerable, dropping to 0,69 $kgCO_2e$/trip, decreasing 49% from the actual value.

4.3. COMPARISON TRADITIONAL VS MODERN METHODS

After analysing the results provided by both sources, the survey and the mobile application, it is time to review these methods and reach a conclusion on their effectiveness in obtaining useful results.

The traditional method of studying mobility is simple and to the point, although it has its limitations. It matured through time into a standardized procedure based on surveys, which can take various forms, but always presenting the same base questions to answer key points in mobility: mode of transportation, time, distance, frequency and purpose of the trip. Other information can easily be requested and inserted in the survey, as well as interviews for a more qualitative input.

The downside of this process is related to the length of the survey and the specific, wearing questions that are necessary to cover the information required to be able to gather useful statistics on the matter. The less specific a survey is, the less exact and informative the results will be, but on the other hand it will be faster and not as irksome to people, which can lead to a bigger number of responses. If, on the contrary, a survey is more complex and inquisitive, the opposite would happen. In the end, it reduces itself to a simple balance of extent of information gathered and the willing participation of the people.

Having complementing questions in a survey also aids in minimizing mistakes made by respondents while answering the questions and misunderstanding their meaning or by simple distraction. For example, in our survey, a travel diary was included that could be compared with a generic question about the usual mode of transportation and another about the frequency of trips to FEUP. Some people had inconsistencies in their claims, such as affirming that they used the car on certain day but contradicting themselves next saying that they did not go after all, or declaring their preferred mode of transportation to FEUP is the train and then all the days of the week they just walked. In most situations, it is just a matter of defining which question was the less likely of provide an erroneous response and correcting that mistake to prevent it from contaminating the overall analysis of the results with inconsistent data.

Comparing both methods, there is a clear confrontation about declared mobility and revealed mobility. By relying on a survey to provide data means accepting the inherent errors related to generalization, perception of the respondent and willingness to provide thoughtful answers. An app based on a location sensor system gives more accurate answers, since it does not depend on the user per se to provide the data. This information is not a described behaviour but a perceived behaviour instead.

With the app, the origin of errors are more varied than human mistakes and further information may not exist in order to make an assumption. If it does, it can be a process that is not very user friendly and requires a lot of time if the app is not programmed for that circumstance, like the case of SenseMyFEUP. Being a new app, it requires improvement to deal with unforeseen situations. Older, more commercial apps are, as a rule, more matured and tested, due to the resources available and spent, which results in higher efficiency and result accuracy, which can make irregularities easier to detect and correct.

Regarding SenseMyFEUP, a source of app results errors can be during the answering of questionnaires. Some respondents stated they walked during the last trip, although the velocity sensed by the app was around the 45 km/h. Another common problem was with the detection of the exact location of the user. The source of this error, however, can usually be traced to the phone itself. These represent the various different uncontrolled variables that can potentially cause problems.

Inconsistencies with the location system from the user's phone or online connection can incapacitate the app's ability to work correctly. Each trip must be correctly identified from its beginning to its end and that means movement recognition with variation of velocity. This process can be complicated because many trips are not simple: they can be intermodal, with stops along the way and other irregularities. If the automatic detection mode is not fully operational, questionnaires can be both a source of confirmation to compensate that weakness as well as a source of confusion, errors and frustration from the user's part. Having to answer a question about used mode of transportation every time a trip ends can be tedious if they pop up regularly. With SenseMyFEUP, some users complained that they were too frequent and appearing before even a proper trip ends or considering walking from one classroom to another as a viable trip, meaning the detection was too sensitive. Other people stated the contrary about their experience, receiving few questionnaires compared to the quantity of trips made. Most of this feedback was conveyed to the developers verbally, through email or Facebook page.

Trip recognition is crucial, but most of it relies too much on the user's phone or if the user remembers to answer with each trip without letting them accumulate and probably give wrong feedback for mistaking trips. Another problem associated with trip recognition is the correct trip chaining, which can be a problem difficult to control, especially when public transportation and waiting periods are involved. SenseMyFEUP considered a trip complete when the user seized to move for a longer period than a normal metro or bus stop or the waiting time at a traffic light, therefore if it took longer than usual, like being stuck at a traffic jam or waiting for a bus or a train, the app would not chain the trips correctly. Also, if the location system stopped providing data for longer than 20 min or in a radius of 200 m, the trip would end, which becomes a problem with metro underground tracks. To aid in correcting this problem the help of the user would be necessary to select the registered trips and connect them, requiring a change of the app's interface choices.

The advantage of the app was supposed to be its independence from the constant attention of the user, but unfortunately, being at its early stages, it requires support from the user to validate the information, which is to be expected from an evolving project. As it grows and with a completed and efficient algorithm for mode detection, this app can provide more accurate data with a better, less intrusive interaction with the user by removing the need for questionnaires for each trip. By analysing **Figure 44** regarding the difference of modal distribution assessed by both methods, even though the overall app's results present higher share of car users and people who choose to walk, the results during the same period as the survey are more similar, getting closer to the results from the survey, with the exception of trips on foot. They suffer an increase due to the lack of train users input.

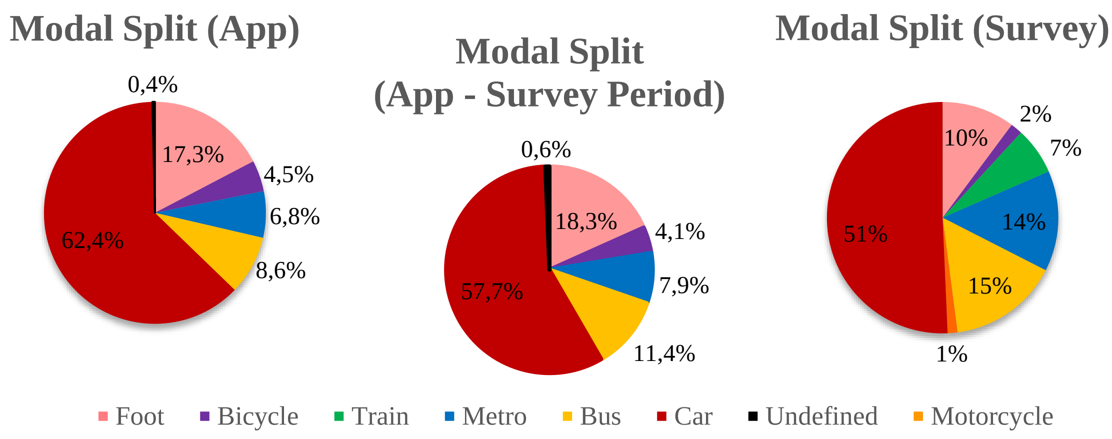


Figure 44 – Modal split of the total results from the app, modal split of the app during the same period as the survey and modal split of the results of the survey (from left to right).

In comparison with the survey, the app data is more detailed and each trip is unique, which is better for differentiation and accuracy, even though privacy prevents the identification of trips to each person throughout time. While in the survey, the distance analysis was based on the answers of the respondents and their opinion, the app automatically retrieved that same information with precise values and added details about origin and destination, not only gathering data on school/work mobility, but its total as well. For more accurate results for the survey distances, it would be necessary to calculate it through the given addresses, which would take a long time to process, and, even so, it would not reach the accuracy of the app because not all school/work trips start or end at home. The closest in detail that a survey can get to a dedicated app is through a travel diary, but that lowers the response rate, therefore the choice between both methods must be balanced by considering the requirements and the resulting consequences.

In contrast to the survey results, the average trip distance from SenseMyFEUP was only 2,7 km and 6,0 km with the corrections, diverging from the average 13,8 km assessed before, even though in both the average duration is around 30 minutes. This difference in distance is not only a reflection of a majority of users being students but also a problem with identifying long distance, intermodal trips, since only cars and buses were correctly identified in long distances, not being able to identify train travelling correctly.

The proper identification of the app's users could not as detailed as the survey's respondents due to privacy issues, which becomes a limitation when associating an individual pattern of trips over the days and contributing to the comprehension of problematic behaviours and their correlation to personal characteristics. This extra knowledge could aid in creating measures to deal with these situations and improve mobility and sustainability in a city.

In **Figure 45**, the results from both maps are combined. Most locations coincide, including the zones surrounding FEUP, the downtown area, north of Gaia, Águas Santas, Matosinhos and Póvoa de Varzim. Survey results go further than those from SenseMyFEUP, because it includes train trips that were harder to detect by the app as an intermodal trip.

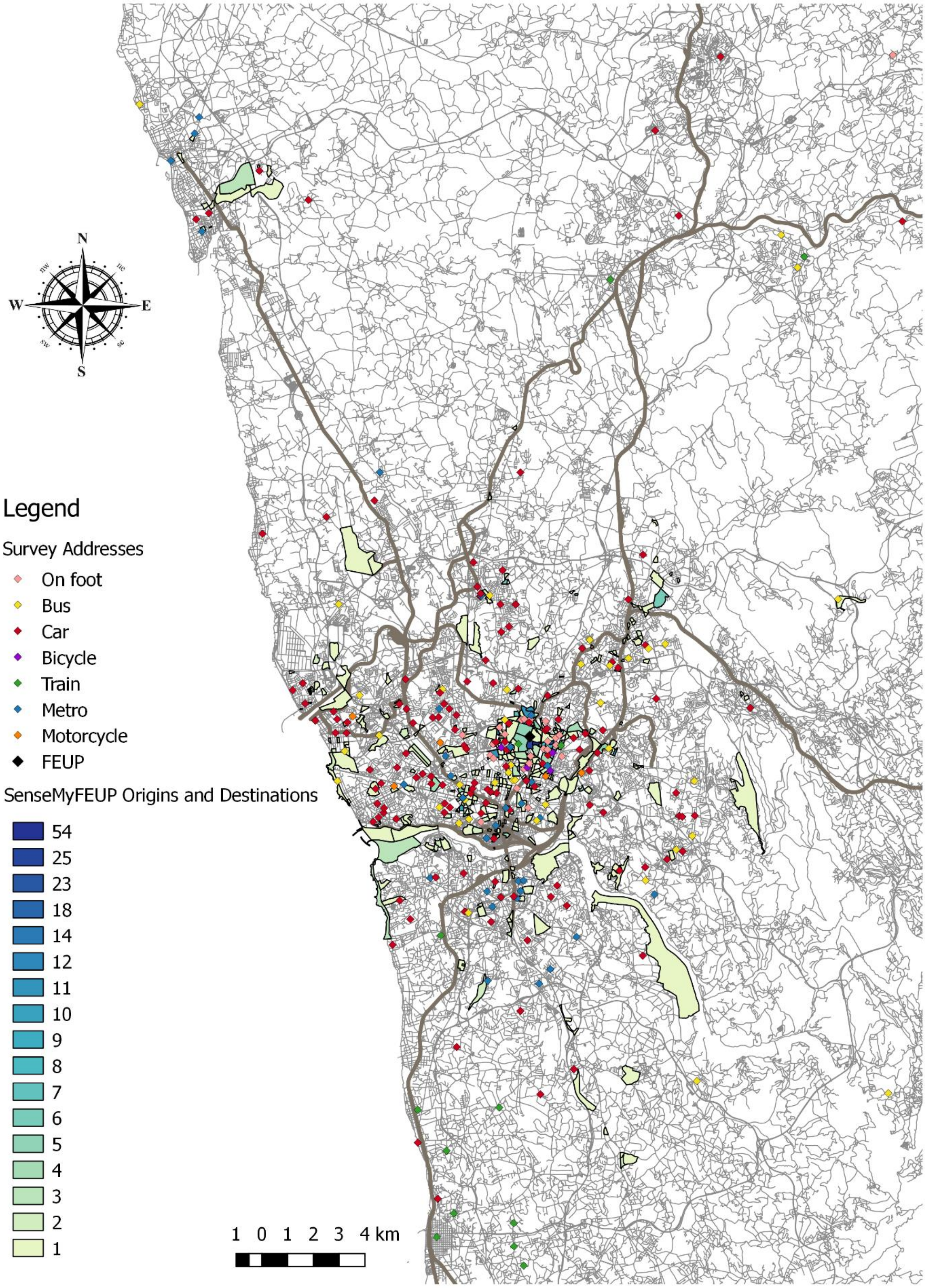


Figure 45 – Map of the combined results of both methods, the survey differentiated by mode of transport and the app by number of trips to or from that location.

The difference of areas between the survey and the app is a reflection of their user coverage and technical limitations. Although the number of responses to the survey was not high due to the saturation of email requests over the years, it was enough to show the heterogeneity of FEUP's community and the diverse mobility patterns. The inherent errors of traditional surveys had to be considered and some answers adjusted according to all information that was obtained, while others had to be discarded when the respondent did not wish to provide the answer to a particular question that he/she found too invasive, particularly regarding the general address. This type of correction occurred in bigger scale with the SenseMyFEUP app due to the big data that was collected. Most of the rejected trips were not related to FEUP and the difficulty to chain intermodal trips contributed to the amount of eliminations. The final sample contained a large number of short distanced trips which, unless most of the users lived near FEUP, is not representative of the whole community. The most receptive people to install the app were students due to their trust and reliance on technology and because they were the principal target of the advertisement and showed more interest in the prizes. Another limitation to obtain a larger number of users was the difficulty to collect data from IOS smartphones due to its restraining impositions on apps that rely on location sensors, therefore only those who owned Android smartphones within FEUP's community could contribute with data.

The problem with trip chaining and modal identification is a crucial step to be overcome and to improve the app. This issue was born from the fact that SenseMyFEUP shared SenseMyCity's programming, which is more directed to traffic management. This presents a limitation to the correct study of mobility because while the identification of how many people go through a certain road is enough for traffic control, for mobility it is insufficient. Mobility requires a complete identification of a trip and all the roads from the beginning to its end to be able to assess behaviour and create measures to correct problematic situations. SenseMyFEUP requires an evolution from SenseMyCity by improving its data collection regarding mobility and, consequently, sustainability.

Regarding sustainability, the survey provided more specific data related to details about personal vehicles, including type of fuel and fuel consumption, both being important for the calculation of the carbon footprint, and also information about social situation and mobility costs. SenseMyFEUP, on the other hand, did not retrieve that information since that would demand more questions for the users and, for now, the intention was to remain simple, using average data to compensate the lack of information. Even though SenseMyFEUP could not evaluate the social or economic parts of sustainability, it is possible in the future to implement ways to retrieve that information by enriching the interactivity with the app.

In the following table, a final collection of advantages and disadvantages from both traditional and modern method according with different main topics are revised.

Table 6 – Advantages and disadvantages from both studied methods.

	TRADITIONAL METHOD (SURVEY)	**MODERN METHOD (APP SENSEMYFEUP)**
COSTS	• Even though the survey did not present associated costs due to the fact that was email based, city or country level surveys require considerable investments.	• The main costs of SenseMyFEUP were the prizes, the payment for the registry in the National Commission of Data Protection and, especially, the costs regarding data storage.

TIME	• Although it requires a smaller amount of time to write a survey, in bigger scale the survey period is a lot more extensive, especially with a larger target community. Door-to-door surveys demand long periods of time and, as opposed to the app, the richness of the data is not increased with a longer data collection period, only the amount answers; • It usually only requires a single fill of the survey, unless it is a travel diary.	• The programming phase requires a lot of work and a lot of time, however, from the moment the algorithm is finished, the data collection is automatic and does not require further effort, unless problems are found; • The period for data collection is continuous until the app ceases to work, contributing with more information each day.
HUMAN RESOURCES	• In this case, the method only needed the contribution of one person, since it was an online survey. However, if it is face-to-face, many teams are required on the field to conduct interviews and questionnaires.	• Making and maintaining an app requires a specialized team with an increasing number of involved people according to the complexity of the app and the collected data.
USERS	• It allows a better access to a larger portion of the population, since it does not exclusively depend on technologies to collect data, which could be a deterrent regarding old-aged people, for example; • The response rate depends of how the survey is conducted (online, face-to-face, by telephone) and the receptivity of those inquired. Face-to-face interviews have better rates, as well as having a target community that is more informed and interested in the matter.	• It is limited by the required technology, which in SenseMyFEUP's case meant that only those who possessed an Android smartphone could install and use the app, narrowing the sample; • It is a more attractive and effective method for the younger population, who rely on a daily basis upon technology and are less likely to regard this method with distrust.

RESULTS	• The collected data is a declared mobility, which is more prone to assumptions; • The provided information is generalized and limited to the questions; • The detail demanded in the survey influences negatively the response rate, which means that travel diaries, even though they collect more information, present lower response rates; • The errors of this method are mainly human, especially during the filling of the survey, due to distraction, imprecision, assumption, lack of memory (in particular regarding travel diaries, which require more details), etc; • Most difficulties lie on dealing with response inconsistencies and unforeseen situations that are not considered in the questions of the survey.	• The collected data is a revealed mobility, which is closer to reality; • The results are more exact and detailed throughout time, with a passive and continuous collection, even though privacy issues can limit some access; • SenseMyFEUP used a questionnaire to identify the transport mode, therefore, in similarity to the traditional method, it had to face human errors in its results; • Technical problems are intrinsic to technology and, especially if the users are not accustomed to this type of apps, situations like having the location sensor inactive, not turning the smartphone on while travelling or wifi problems are common; • The main difficulties of mobility apps are modal identification and trip chaining.

Both methods have advantages and disadvantages and the choice depends on the available resources, the required richness of the results and the target population. The ideal scenario would be to use the strengths of both methods to collect data, especially in larger scale cases, allowing a smoother transition to a new era of mobility information. However, that is not always a viable option and a choice must be made.

5. CONCLUSIONS

The evolution of cities over time has created many challenges to mobility management. The promotion of sustainable modal choices is necessary to encourage the population to choose public transportation over personal vehicles. The constant rise of the quantity of cars roaming the streets, creating traffic and stress, can affect the natural flow of a city, public health and overall sustainability.

The case study, supported by two methods, proved that the community of the Faculty of Engineering of the University of Porto follows the trend of favouring the car over public transportation. Its comfort and practicality in varied situations is still deeply valued, and it affects FEUP's sustainability negatively for being a favoured choice for long distances. The individual carbon footprint for each trip calculated with the data from the survey and the app was between 1,36 and 1,42 kgCO_2e, that translates to 0,58 tCO_2e at the end of the academic year. Even though it is less than the average emissions from transportation in Portugal (1,51 tCO_2e per capita), it does not consider the remaining mobility for the whole year, since the share of school and work trips in the area of Greater Porto only consist of 30% of the whole mobility. Comparing with the world average of 0,86 tCO_2e per capita in an year, the totality of mobility emissions by FEUP's community not only exceeds that value by reaching 1,95 tCO_2e per person but also the national average.

The feedback from the survey demonstrated a wish for change from the community that revealed interest for sustainability, but inability to overcome daily limitations with other mobility choices. More initiatives are required to support this transition, including promoting walking or the use of bicycle for short distance trips, which showed interest from the community according to the U-Bike question, and carpooling/carsharing for people who live further away and have few or none public transport options. Encouraging better supply and quality of public transportation with supporting data about deprived areas is also important to diminish the advantage of the car. It is imperative to diminish the preference for motorized vehicles for short distances and to increase the use of public transportation for longer ones. The dependency on other people regarding modal choice is a problem more difficult to tackle, since it is related to social conditions, like taking children to school for example.

Regarding SenseMyFEUP, even though being a relatively new method of approaching data collection in this faculty, it sparked interest in the community and raised awareness about mobility and sustainability in a new way. Being a recent project, it requires further development to correct problems and increase interactivity with the user to encourage installation and continued use. With a growing user community, Big Data complications related to data collection intensify, requiring efficient programming to retrieve useful information and compile it in an organized way for every type of user, from typical everyday users to specialists in the area. Big Data in Mobility applications stands on four base indicators: mode of transport, distance, time and frequency. From there, new indicators can be evaluated by assembling the required data through proper programming. Evolution and the improvement of data collection quality are a matter of time and dedication, particularly regarding mode detection and intermodal trips identification with SenseMyFEUP.

Both methods provide valid information, but the app has more potential for the future as a developing technology. The traditional method has a more stablished procedure that can be easily followed, but, unfortunately, studying big populations can be costly and take long periods of time. Modern methods through mobile applications require programming, which can also be laborious, especially with non-commercial apps, like SenseMyFEUP. In the end, the results are slightly different: the survey method relies on what respondents say it is true and the app method collects real life information directly from the source, as long as it does not completely based on questionnaires. Each approach has its strengths and weaknesses and the choice to obtain data through one or another belongs depends on the situation, the target population, the final objectives and the available resources. For now, using both methods to balance their strengths and weaknesses is a good choice for the evolution of data collection.

5.1. FUTURE RECOMMENDATIONS

Regarding the traditional approach of mobility data collection, it would be interesting to complement the usual surveys with interviews to better comprehend the behaviours and the reasons behind it. The qualitative understanding in surveys is very limited to pre-determined general answers or open questions that few people usually like to contribute, especially when it is intrusive to their privacy. With a better understanding of the drive behind an action, it is easier to promote new initiatives that combat the source of the problem.

On the other hand, although the experiment with the SenseMyFEUP app was not as successful as desired, it showed that it holds enough potential to expand to an efficient method of data collection of the mobility and sustainability of FEUP’s community and beyond.

In the future, as the app is in constant development and striving to perfect itself, I suggest longer trial periods with the most diverse smartphones possible to make sure it is working to a satisfying level. Promoting the development of a more interactive and interesting interface by creating games, travel route suggestions and other stimulating sharing of information (for example, promotion of carpooling) is also a good step to engage users to install and maintain the app. Pure data collection without upsides for the user is not a successful approach, but relying on prizes to increase users is not a good long-term tactic either without the proper support of an useful and interesting app for the user.

An interesting idea for SenseMyFEUP would be the study of peak hours during the day regarding trips to and from FEUP, especially regarding those that use the car, to be able to suggest adjustments to public transportation (mainly buses) timetables. Another possibility would be to identify the main routes people use, particularly those who walk or ride the bicycle or even those who live near and use the car or other transport, to assess the condition and the security of those paths, especially at night, since insecurity was also one of the reasons some car users used to justify their preference, although they lived near.

With the evolution and improvement of the app to a more user friendly level, SenseMyFEUP will be able to expand to other faculties and universities and be a significant source for mobility and sustainability data.

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7. APPENDIXES

ANNEX 1 – SURVEY

Idade *

A sua resposta

Género *

- Feminino
- Masculino

Profissão ou Ocupação *

- Estudante: Licenciatura
- Estudante: Mestrado Integrado
- Estudante: Mestrado
- Estudante: Doutoramento
- Bolseiro de Investigação
- Investigador
- Docente
- Funcionário
- Outra: ____

Unidade Orgânica/Serviço da UP a que pertence *

Arquitetura	Letras
Belas Artes	Medicina
Ciências	Medicina Dentária
Ciências da Nutrição e Alimentação	Psicologia e Ciências da Educação
Desporto	Instituto de Ciências Biomédicas Abel Salazar
Direito	Porto Business School
Economia	Serviços de Acção Social
Engenharia	Centro de Recursos e Serviços Comuns
Farmácia	Reitoria

Número de pessoas do agregado familiar *

1	3	5	
2	4	6	> 6

Rendimento médio mensal do seu agregado familiar per capita *

Até 400 €	1001 - 1200 €
401 - 600 €	1201 - 1600 €
601 - 800 €	Superior a 1600 €
801 - 1000 €	Não sabe/Não responde

Possui carta de condução? *

- Sim
- Não

Tem carro à sua disposição? *

- Sim
- Não

Indique a rua e o concelho da sua residência habitual nos dias em que se desloca à faculdade *

Por exemplo: Rua de Ceuta, Porto

A sua resposta

Encontra-se deslocado do seu agregado familiar? *

- Sim
- Não

Se responder "Sim" na questão anterior:

Indique a rua e o concelho do local de residência do seu agregado familiar *

Por exemplo: Rua de Ceuta, Porto

A sua resposta

Quais os meios de transporte que utiliza com maior regularidade para realizar as viagens para a residência do seu agregado familiar? *

- Automóvel
- Autocarro
- Comboio
- Metro
- Avião
- Outra:

Travel Diary

Em geral, qual é o seu meio de transporte preferencial nas viagens casa-UP/UP-casa? *

- ○ Automóvel
- ○ Autocarro
- ○ Metro
- ○ Comboio
- ○ Bicicleta
- ○ A pé
- ○ Outra: ____

Na segunda-feira (11 de abril), quais os meios de transporte que utilizou? *

- ☐ Não fui à UP
- ☐ A pé
- ☐ Bicicleta
- ☐ Automóvel
- ☐ Autocarro
- ☐ Metro
- ☐ Comboio
- ☐ Other: ____

Na terça-feira (12 de abril), quais os meios de transporte que utilizou? *

- [ ] Não fui à UP
- [ ] A pé
- [ ] Bicicleta
- [ ] Automóvel
- [ ] Autocarro
- [ ] Metro
- [ ] Comboio
- [ ] Outra: ____________

Na quarta-feira (13 de abril), quais os meios de transporte que utilizou? *

- [ ] Não fui à UP
- [ ] A pé
- [ ] Bicicleta
- [ ] Automóvel
- [ ] Autocarro
- [ ] Metro
- [ ] Comboio
- [ ] Outra: ____________

Na quinta-feira (14 de abril), quais os meios de transporte que utilizou? *

- [ ] Não fui à UP
- [ ] A pé
- [ ] Bicicleta
- [ ] Automóvel
- [ ] Autocarro
- [ ] Metro
- [ ] Comboio
- [ ] Outra: ____________

Na sexta-feira (15 de abril), quais os meios de transporte que utilizou? *

- [ ] Não fui à UP
- [ ] A pé
- [ ] Bicicleta
- [ ] Automóvel
- [ ] Autocarro
- [ ] Metro
- [ ] Comboio
- [ ] Outra: ____________

No sábado (16 de abril), quais os meios de transporte que utilizou? *

- [ ] Não fui à UP
- [ ] A pé
- [ ] Bicicleta
- [ ] Automóvel
- [ ] Autocarro
- [ ] Metro
- [ ] Comboio
- [ ] Outra: ____________

No domingo (17 de abril), quais os meios de transporte que utilizou? *

- [ ] Não fui à UP
- [ ] A pé
- [ ] Bicicleta
- [ ] Automóvel
- [ ] Autocarro
- [ ] Metro
- [ ] Comboio
- [ ] Outra: ____________

Quantas vezes foi à sua UP? *
Se almoçar fora e regressar, conta como mais uma vez

	0	1	2	3	>3
Segunda-feira	○	○	○	○	○
Terça-feira	○	○	○	○	○
Quarta-feira	○	○	○	○	○
Quinta-feira	○	○	○	○	○
Sexta-feira	○	○	○	○	○
Sábado	○	○	○	○	○
Domingo	○	○	○	○	○

Quanto tempo demora a realizar a sua viagem normalmente? Contabilize desde que sai da sua origem (p.e. "porta" de casa) até ao seu destino (p.e. "porta" da faculdade) *

< 5 min
5-15 min
15-30 min
30-60min
1h-1,5h
1,5h-2h
>2h

Qual é a distância aproximada (em km) que percorre na sua viagem?

A sua resposta

Quanto gasta a realizar a sua viagem mensalmente? (passe, gastos combustível...) *

< 5 €
5-15 €
15-30€
30-50 €
50-100€
100-150€
150-200€
> 200€

Utilizador de automóvel

Qual o tipo de automóvel que normalmente utiliza? *

- A gasolina
- A diesel
- A gás natural
- Elétrico
- Híbrido
- Other : ____________

Qual o consumo de combustível médio do automóvel que normalmente utiliza? *

- Muito baixo - Cerca de 4L/100km
- Baixo - Cerca de 6L/100km
- Médio - Cerca de 8L/100km
- Alto - Entre 10 e 15L/100km
- Muito alto - Superior a 15L/100km
- Não sei/Não se aplica

No caso da UP aderir a um Projeto cofinanciado de mobilidade que disponibilize gratuitamente uma bicicleta para utilização exclusiva, como perspetiva a sua adesão à utilização da bicicleta nas suas deslocações diárias? *

- Certamente vou aderir
- Irei avaliar
- Não estou interessado(a)

A baixa sustentabilidade do seus padrões de mobilidade preocupam-no e gostaria de usar modos de transporte mais sustentáveis? *

- ○ Sim
- ○ Não
- ○ Talvez

Se responder “Sim” ou “Talvez”

O que poderia incentivar a mudança para atitudes mais sustentáveis? *

Escolher todas as opções aplicáveis

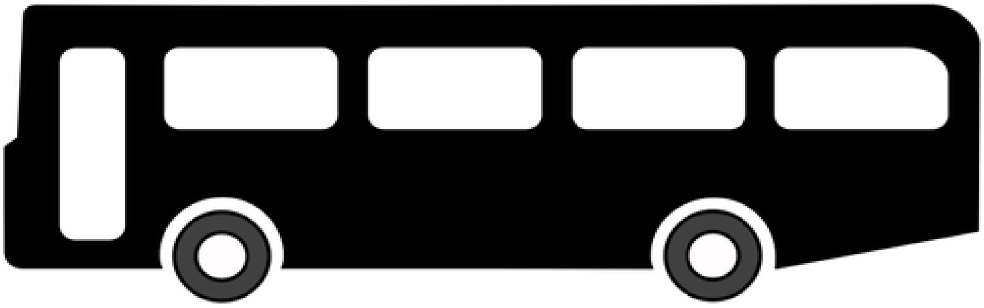
- ☐ Mudar de casa para mais perto da faculdade
- ☐ Redução da oferta de estacionamento na faculdade (aumento das fila de espera para o parque)
- ☐ Ter de pagar pelo estacionamento
- ☐ Melhor oferta/qualidade dos transportes públicos
- ☐ Melhores condições de circulação pedonal (como abrigos das condições climatéricas, melhores passeios, etc)
- ☐ Plataforma de Car Sharing
- ☐ Haver ciclovias de qualidade
- ☐ Armazenamento seguro de bicicletas na faculdade
- ☐ Descontos/compensações monetárias
- ☐ Other: ____________

Se responder “Não”

Qual a razão para a sua inflexibilidade para mudança de modo de transporte para algo mais sustentável?

- ☐ Não o preocupa os impactos provocados pela sua mobilidade
- ☐ Falta de oferta de outras opções de transporte para o trajeto efetuado
- ☐ Escolha de transporte depende de outros (Amigos, colegas ou familiares, como por exemplo dar boleia ou levar filhos à escola)
- ☐ Considera já ser o mais sustentável possível
- ☐ Other: ____________

Utilizador de transportes públicos



No caso da UP aderir a um Projeto cofinanciado de mobilidade que disponibilize gratuitamente uma bicicleta para utilização exclusiva, como perspetiva a sua adesão à utilização da bicicleta nas suas deslocações diárias? *

- Certamente vou aderir
- Irei avaliar
- Não estou interessado(a)

Utilizadores pedonais

No caso da UP aderir a um Projeto cofinanciado de mobilidade que disponibilize gratuitamente uma bicicleta para utilização exclusiva, como perspetiva a sua adesão à utilização da bicicleta nas suas deslocações diárias? *

- Certamente vou aderir
- Irei avaliar
- Não estou interessado(a)

ANNEX 2 – FLYER

Figure 46 – Flyer to promote SenseMyFEUP.

ANNEX 3 – POSTER

Figure 47 – Poster to promote SenseMyFEUP.

ANNEX 4 – SURVEY RESULTS

Idade
Age

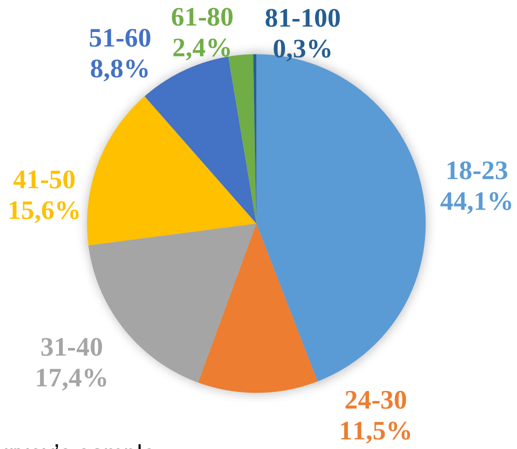


Figure 48 – Age distribution of survey's sample.

Género
Gender

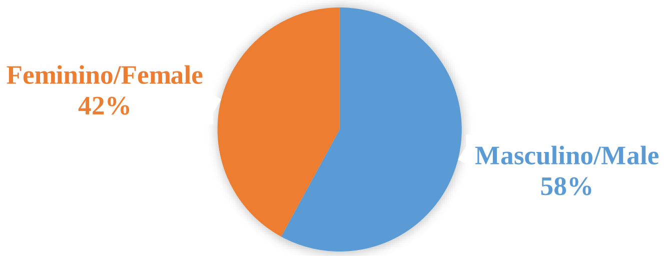


Figure 49 – Gender distribution of survey's sample.

Profissão ou Ocupação
Profession or Ocupation

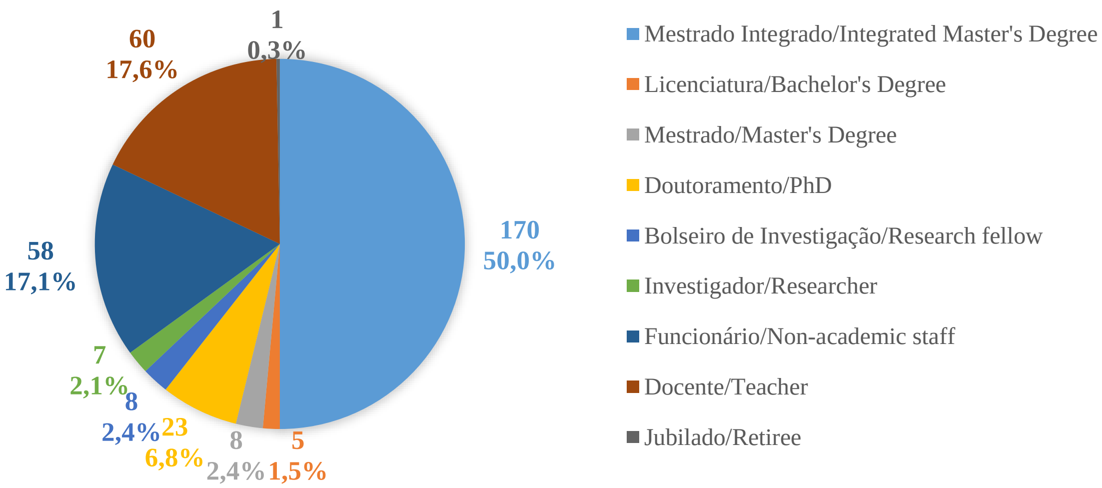


Figure 50 – Occupation distribution of survey's sample.

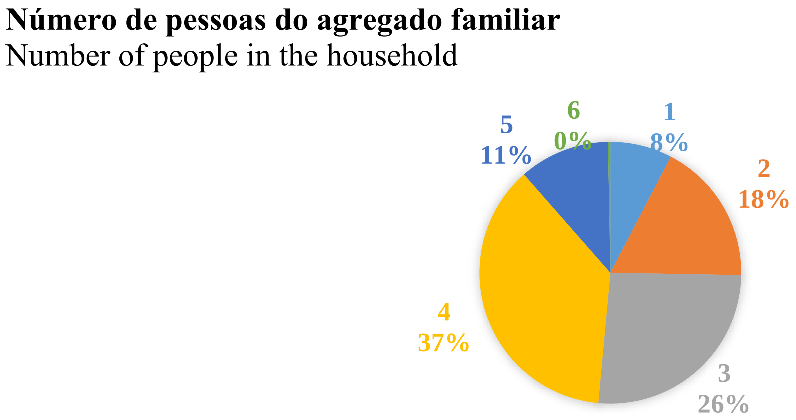


Figure 51 – Number of people in the household of survey's sample.

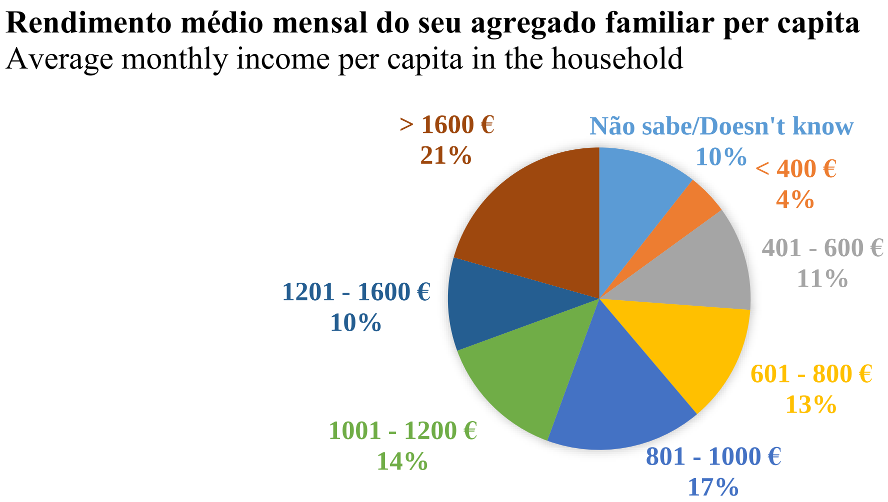


Figure 52 – Average monthly income per capita in the household of survey's sample.

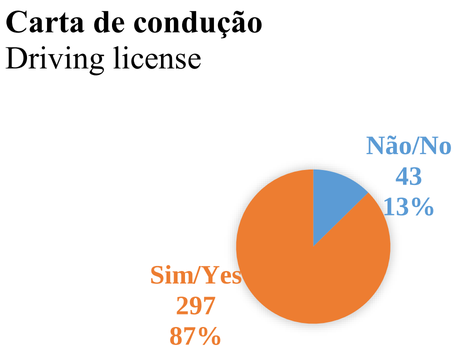


Figure 53 – Percentage of people with and without driving license.

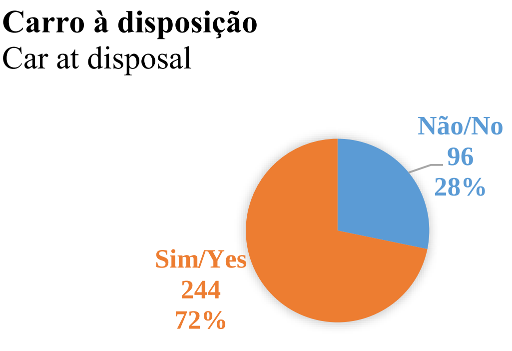


Figure 54 – Percentage of people with car at their disposal.

Deslocado do seu agregado familiar

Living away from family home

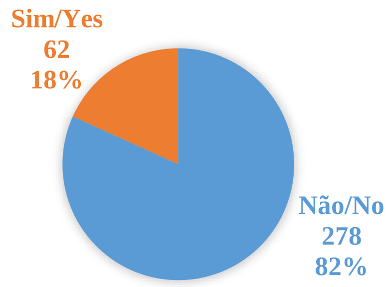


Figure 55 – Percentage of people living away from family home.

Meio de transporte das viagens para a residência do agregado familiar

Mode of transportation to family residence

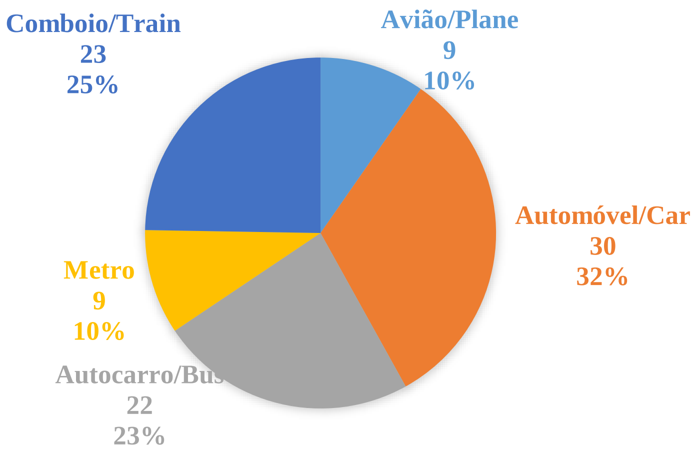


Figure 56 – Chosen mode of transportation for the trips to family residence.

TRAVEL DIARY

Meio de transporte preferencial nas viagens casa-faculdade/faculdade-casa
Preferred mode of transportation for home-FEUP/FEUP-home trips

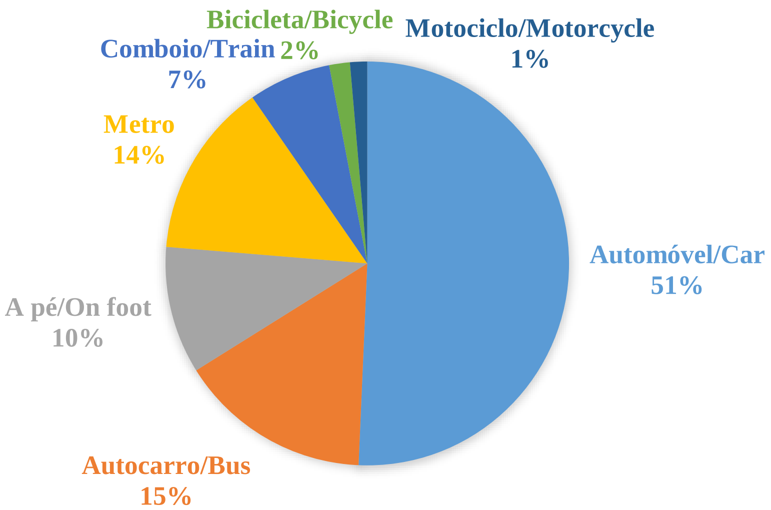
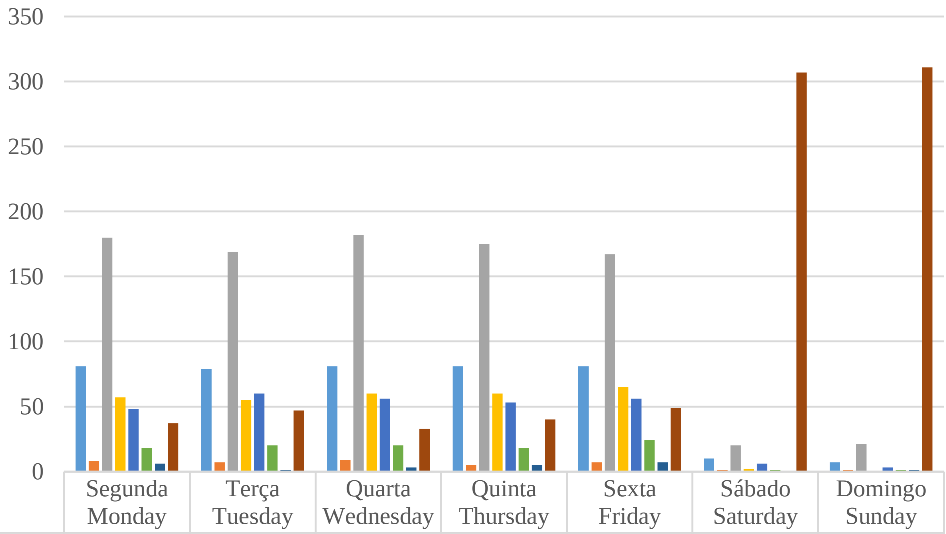


Figure 57 – Chosen mode of transportation for home-FEUP/FEUP-home trips.

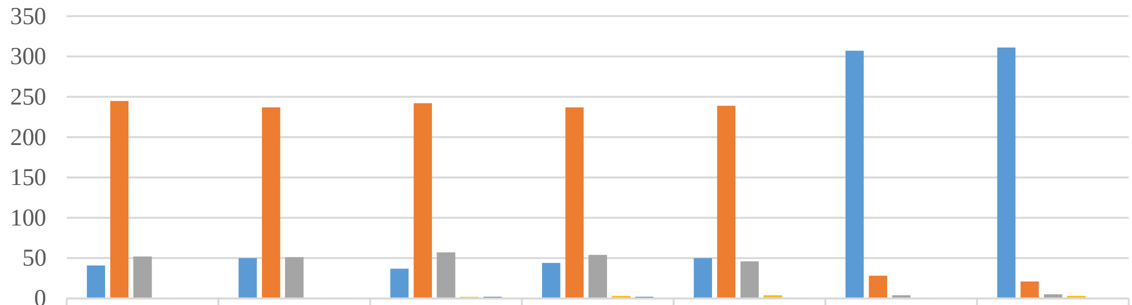
Meios de transporte nas viagens casa-faculdade/faculdade-casa durante a semana
Means of transportation of home-FEUP/FEUP-home trips during the week



	Segunda Monday	Terça Tuesday	Quarta Wednesday	Quinta Thursday	Sexta Friday	Sábado Saturday	Domingo Sunday
A pé/On foot	81	79	81	81	81	10	7
Bicicleta/Bicycle	8	7	9	5	7	1	1
Automóvel/Car	180	169	182	175	167	20	21
Autocarro/Bus	57	55	60	60	65	2	0
Metro	48	60	56	53	56	6	3
Comboio/Train	18	20	20	18	24	1	1
Motociclo/Motorcycle	6	1	3	5	7	0	1
Não foi à faculdade/ Didn't go to college	37	47	33	40	49	307	311

Figure 58 – Chosen mode of transportation for home-FEUP/FEUP-home trips throughout the week.

Frequência das viagens
Frequency of the trips



	Segunda Monday	Terça Tuesday	Quarta Wednesday	Quinta Thursday	Sexta Friday	Sábado Saturday	Domingo Sunday
0	41	50	37	44	50	307	311
1	245	237	242	237	239	28	21
2	52	51	57	54	46	4	5
3	1	1	2	3	4	1	3
>3	1	1	2	2	1	0	0

Figure 59 – Frequency of the trips throughout the week.

Duração das viagens
Duration of the trips

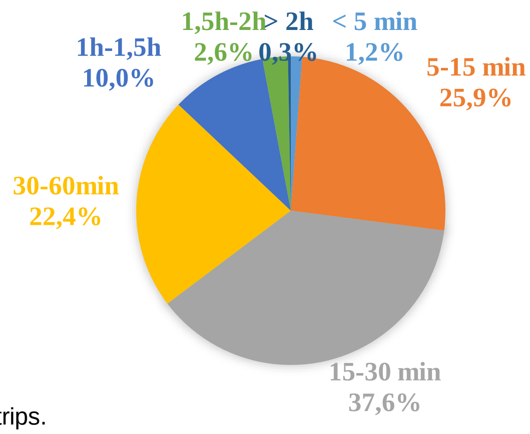


Figure 60 – Duration of the trips.

Distância das viagens
Distance of the trips

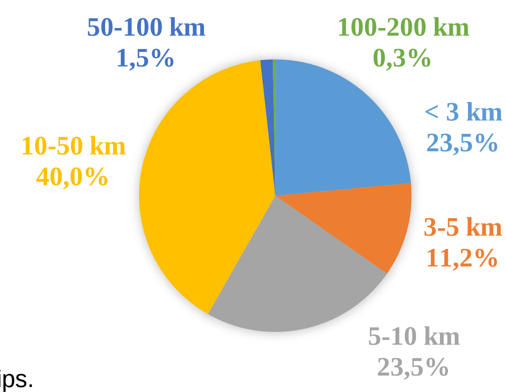


Figure 61 – Distance of the trips.

Custo das viagens mensalmente
Monthly travel costs

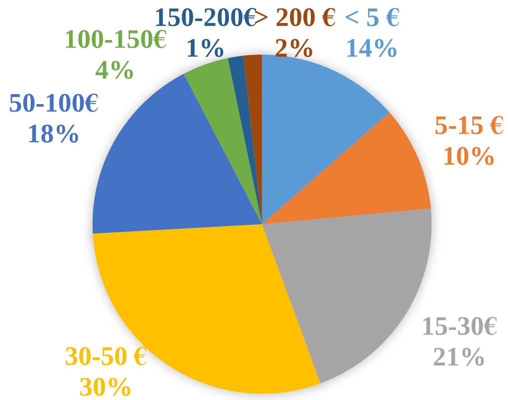


Figure 62 – Monthly travel costs.

Tipo de automóvel utilizado
Type of car used

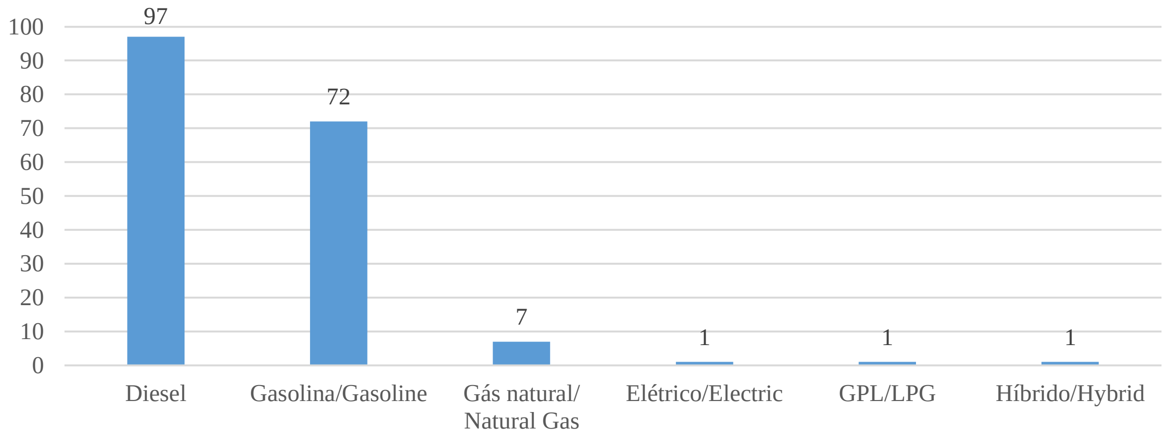


Figure 63 – Type of car used for the trips.

Consumo de combustível médio do automóvel
Fuel consumption of the car

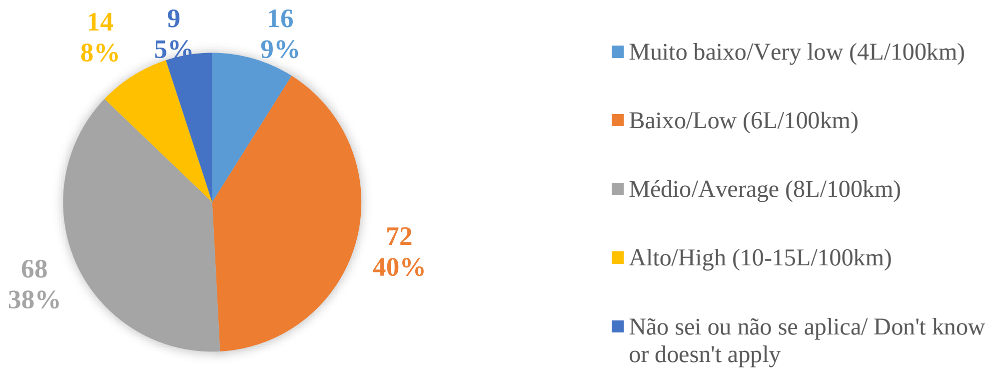


Figure 64 – Fuel consumption of the car.

A baixa sustentabilidade dos seus padrões de mobilidade preocupam-no e gostaria de usar modos de transporte mais sustentáveis?
Does the sustainability of your mobility patterns worry you and would you like to use more sustainable transportation?

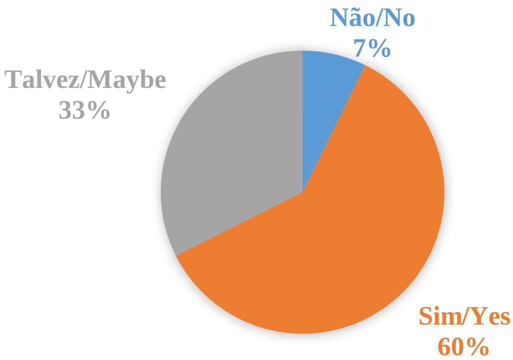


Figure 65 – Percentage of answers regarding concern about sustainability and the wish to change.

Sim/Talvez – **O que poderia incentivar a mudança para atitudes mais sustentáveis?**
Yes/Maybe – What would encourage you to switch to more sustainable habits?

Respostas/Answers	Nº
Melhor oferta ou qualidade dos transportes públicos *Better supply or quality of public transportation*	122
Descontos ou compensações monetárias *Discounts or monetary compensation*	54
Mudar de casa para mais perto da FEUP *Moving closer to FEUP*	44
Plataforma de Car Sharing *Car Sharing platform*	36
Haver ciclovias de qualidade *Existence of good quality bike paths*	34
Armazenamento seguro de bicicletas na FEUP *Secure bicycle storage in FEUP*	33
Melhor segurança e condições de circulação pedonal *Better security and pedestrian paths conditions*	32
Ter de pagar pelo estacionamento *Needing to pay for parking*	21
Não ser necessário dar boleia a outros (Levar filho à escola/Parceiro ao emprego, etc.) *Not being necessary to give a lift to others (Taking child to school/Partner to job, etc.)*	9
Redução da oferta de estacionamento na FEUP *Parking space reduction in FEUP*	8
Balneários na FEUP *Balnearies in FEUP*	4
Nada (Tem carro elétrico, gosta de conduzir, etc.) *Nothing (Has electric car, likes to drive, etc.)*	3
Dinheiro para carro mais sustentável *Money for a more sustainable car*	1
Carregamento de veículos elétricos disponível na FEUP *Charging of electric vehicles available in FEUP*	1
Outros/Others	2

Não – Qual a razão para a sua inflexibilidade para mudança de modo de transporte para algo mais sustentável?
No – What is the reason for your inflexibility to change your mode of transportation to something more sustainable?

Respostas/Answers	Nº
Usar carro é mais prático e confortável *Using the car is more practical and comfortable*	3
Considera já ser o mais sustentável possível *I consider myself to be the most sustainable possible*	3
Falta de oferta ou qualidade de outras opções de transporte para o trajeto efetuado *Lack of supply or quality of other options of transportation*	2
Não o preocupa os impactos provocados pela sua mobilidade *I don't care about my mobility's impacts*	2
Escolha de transporte depende de outros *Transport choice depends on others*	1

Adesão à utilização da bicicleta com o projeto U-Bike
Adherence to the use of the bicycle with the U-Bike project

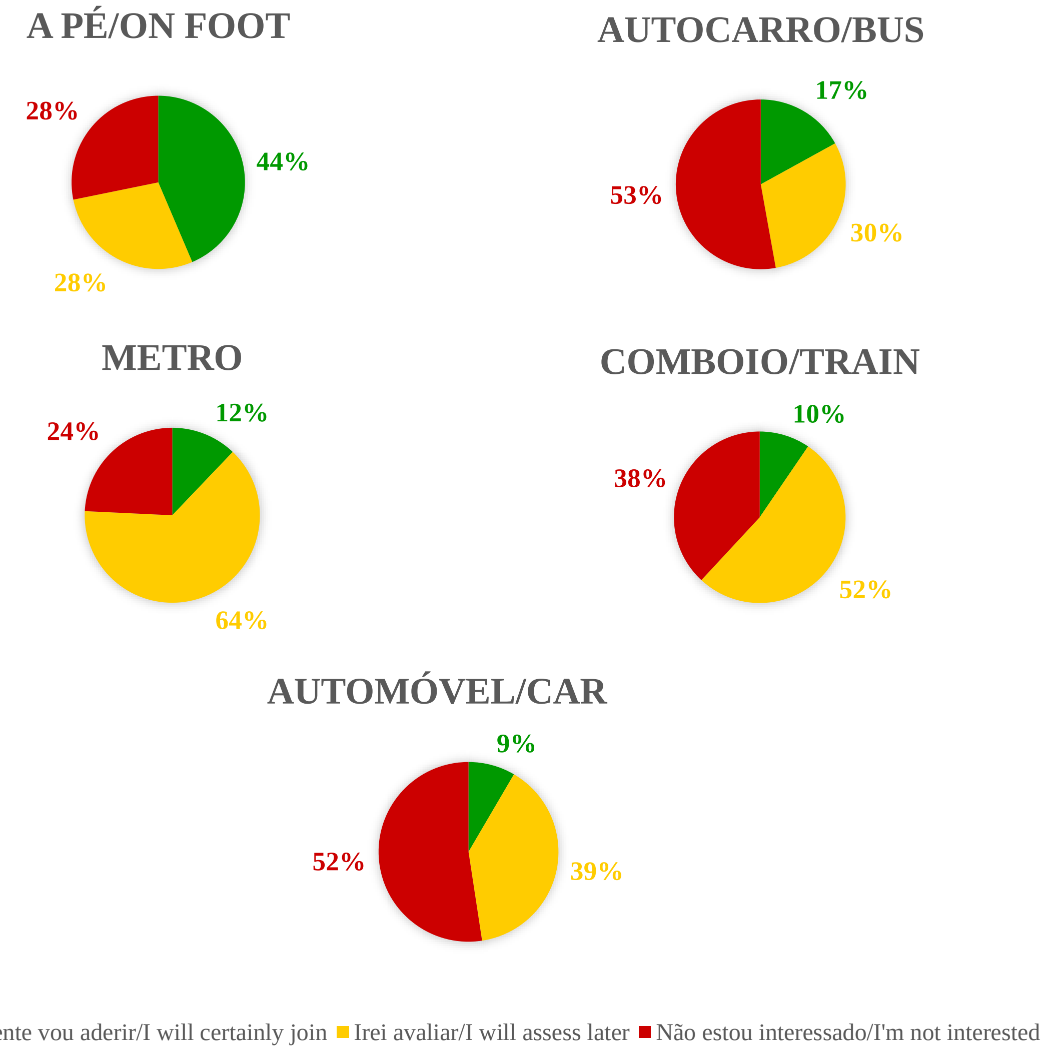


Figure 66 – Level of engagement and interest to the U-Bike project.

ANNEX 5 – SENSEMYFEUP RESULTS

Table 7 – Origins of trips to FEUP

PLACE	NUMBER OF TRIPS TO FEUP						
	Bicycle	Bus	Car	Foot	Metro	Other	Total
Águas Santas	0	0	5	0	0	0	5
Aldoar	0	1	0	0	0	0	1
Alfena	0	0	4	0	0	0	4
Argivai	0	0	3	0	0	0	3
Avintes	0	0	1	0	0	0	1
Avioso (São Pedro)	0	1	0	0	0	0	1
Bonfim	1	0	4	2	0	0	7
Campanhã	0	1	13	0	0	0	14
Canidelo	0	0	3	0	0	0	3
Cedofeita	1	9	11	12	4	0	37
Custóias	0	0	0	0	0	0	0
Ermesinde	0	6	12	0	0	0	18
Fânzeres	0	0	0	0	0	0	0
Folgosa	0	1	0	0	0	1	2
Foz do Douro	0	0	1	0	0	0	1
Gemunde	0	0	0	0	0	0	0
Gondomar (São Cosme)	0	0	0	0	0	0	0
Guifões	0	0	1	0	0	0	1
Leça da Palmeira	0	3	15	0	0	0	18
Leça do Balio	0	0	1	0	0	0	1
Lordelo do Ouro	0	2	1	0	0	0	3
Mafamude	0	0	1	0	0	0	1
Maia	0	0	0	0	0	0	0
Massarelos	0	0	13	1	0	0	14
Matosinhos	0	2	6	0	0	0	8
Milheirós	0	0	5	0	0	0	5
Miragaia	0	0	2	0	0	0	2
Moreira	0	0	0	0	0	0	0
Nevogilde	0	0	0	0	0	0	0
Nogueira	0	0	1	0	0	0	1
Oliveira do Douro	0	0	2	0	0	0	2
Paranhos	12	15	76	618	9	1	731
Pedroso	0	0	3	0	0	0	3
Pedrouços	0	1	5	17	0	0	23
Perozinho	0	0	1	0	0	0	1

Póvoa de Varzim	0	0	0	0	2	0	2
Ramalde	0	0	6	0	0	0	6
Rio Tinto	0	1	9	3	0	0	13
Santo Ildefonso	0	0	6	1	0	0	7
São Mamede de Infesta	1	0	2	34	0	0	37
São Nicolau	0	0	0	0	0	0	0
São Pedro da Afurada	6	0	0	0	0	0	6
São Pedro da Cova	0	0	0	0	0	0	0
São Pedro Fins	0	0	0	0	0	0	0
Sé	0	0	0	0	0	0	0
Seixezelo	0	0	3	0	0	0	3
Senhora da Hora	0	1	1	0	0	0	2
Sobrado	0	0	0	0	0	0	0
Touguinha	0	0	10	0	0	0	10
Valadares	0	0	0	0	1	0	1
Valbom	0	0	5	0	0	0	5
Valongo	0	0	1	0	0	0	1
Vermoim	0	0	5	0	0	0	5
Vila do Conde	0	0	5	0	0	0	5
Vila Nova da Telha	0	0	0	0	0	0	0
Vila Nova de Gaia (Santa Marinha)	0	0	1	0	1	0	2
Vilar do Paraíso	0	0	2	0	0	0	2
Vitória	3	0	10	0	0	0	13

Table 8 – Destinations of the trips from FEUP

	NUMBER OF TRIPS FROM FEUP						
PLACE	**Bicycle**	**Bus**	**Car**	**Foot**	**Metro**	**Other**	**Total**
Águas Santas	0	0	2	0	0	0	2
Aldoar	0	0	2	0	0	0	2
Alfena	0	0	6	0	0	0	6
Argivai	0	0	0	0	0	0	0
Avintes	0	0	0	0	0	0	0
Avioso (São Pedro)	0	0	0	0	0	0	0
Bonfim	0	0	4	2	3	0	9
Campanhã	0	0	10	0	1	0	11
Canidelo	0	0	2	0	0	0	2
Cedofeita	0	2	12	2	2	0	18
Custóias	0	0	1	0	0	0	1
Ermesinde	0	0	8	0	0	0	8
Fânzeres	0	0	1	0	0	0	1
Folgosa	0	0	1	0	0	0	1
Foz do Douro	0	0	2	0	0	0	2
Gemunde	0	0	1	0	0	0	1
Gondomar (São Cosme)	0	0	1	0	0	0	1
Guifões	0	0	0	0	0	0	0
Leça da Palmeira	0	1	17	1	0	0	19
Leça do Balio	0	0	1	0	0	0	1
Lordelo do Ouro	0	0	3	0	0	0	3
Mafamude	0	0	4	0	3	0	7
Maia	0	3	2	0	0	0	5
Massarelos	0	0	12	2	1	0	15
Matosinhos	0	0	3	0	0	0	3
Milheirós	0	0	9	0	0	0	9
Miragaia	0	0	0	0	0	0	0
Moreira	0	0	1	0	0	0	1
Nevogilde	0	1	4	0	0	0	5
Nogueira	0	0	0	0	0	0	0
Oliveira do Douro	0	0	0	0	0	0	0
Paranhos	8	10	51	251	14	0	334
Pedroso	0	0	0	0	0	0	0
Pedrouços	0	0	7	10	0	0	17
Perozinho	0	0	0	0	0	0	0
Póvoa de Varzim	0	0	0	0	0	0	0
Ramalde	0	0	9	0	1	0	10
Rio Tinto	0	0	18	4	0	0	22

Santo Ildefonso	0	1	2	1	1	1	6
São Mamede de Infesta	9	0	12	48	0	1	70
São Nicolau	0	0	0	0	1	0	1
São Pedro da Afurada	0	0	1	0	0	0	1
São Pedro da Cova	0	0	1	0	0	0	1
São Pedro Fins	0	1	0	0	0	0	1
Sé	0	0	0	0	4	0	4
Seixezelo	0	0	1	0	0	0	1
Senhora da Hora	0	1	5	0	1	0	7
Sobrado	0	0	1	0	0	0	1
Touguinha	0	0	5	0	0	0	5
Valadares	0	0	0	0	0	0	0
Valbom	0	0	5	0	0	0	5
Valongo	0	0	1	0	0	0	1
Vermoim	0	0	7	0	0	0	7
Vila do Conde	0	0	1	0	0	0	1
Vila Nova da Telha	0	0	0	0	1	0	1
Vila Nova de Gaia (Santa Marinha)	0	0	2	0	2	0	4
Vilar do Paraíso	0	0	2	0	0	0	2
Vitória	2	0	12	1	3	0	18