# ID 1534 | SUSTAINABLE MOBILITY AT FEUP

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## 1 INTRODUCTION

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 World Commission on Environment and Development (WCED), on March 20th, 1987. WCED 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 (UCLG, 2008).

The transport sector is responsible for 23% of the total GHG emissions, with about three quarters coming from road traffic (Ribeiro, et al., 2007). In addition to this problem, transportation has also other negative impacts on sustainability such as noise pollution, devaluation of public spaces, public health and safety, development and urban sprawl, etc., all of which involve a high cost for societies (Fenton, 2017). Given this situation, the concept of sustainable mobility arises, which can be defined as the one that, responding to people's travel needs, is carried out through sustainable modes of transportation (Portuguese Environmental Agency, 2010).

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 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 becoming an increasingly prosperous market.

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.

Therefore, Big Data shows potential in becoming an important tool in the decision making process of improving mobility systems. It is in this sense that falls the present study, in which the main objective was to evaluate the sustainability of mobility in the Faculty of Engineering of the University of Porto (FEUP) using carbon footprint as the main tool and operationalizing this concept for awareness campaigns on the sustainability of individual mobility intended for the general public and to compare traditional and modern data collection to validate its transition. The secondary objectives consisted 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.

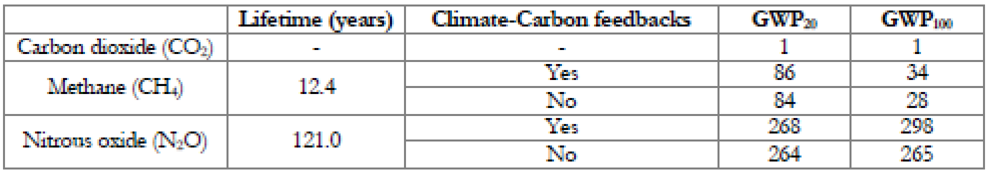
# 2 STATE OF THE ART

## 2.1 CARBON FOOTPRINT

A carbon footprint, is a Life Cycle Assessment (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, Jefferson, Longhurst, & Marquez, 2000).

The carbon footprint measures CO2 emissions mainly associated with fossil fuel use. 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 “CO2 equivalent emissions” (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 carbon footprint calculation of this study. The inclusion of climate-carbon feedbacks means it is considered the response of the gas to emissions of the indicated non-CO2 gases (Myhre, et al., 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 |

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

By quantifying all emissions from each gas, it is possible to apply the GWP and translate to CO2 equivalent, all the process being in units of mass, not volume, as shown in the formula below (Gillenwater, 2015).

$$\mathit{Mass\ of\ CO2e}=\Sigma(\mathit{mass\ of\ gas})\times(\mathit{GWP})\ (1)$$

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.

## 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).

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, Ma, Susilo, Liu, & Wang, 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).

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).

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 (2016) 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, Falcone, & Talia, 2016).

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, Thomas, Bijlsma, & Douhou, 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. (2015) 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, Prost, Schrammel, & Rieser-Schüssler, 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, Ghorpade, & Pereira, 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, Lau, Mishalani, Sengupta, & Walker, 2015).

A recent study by Susilo et al. (2017) used different methods to measure travel satisfaction, which included two types of smartphone applications (a satellite navigation app and a game app), an on-line survey, a paper-based semi-structured questionnaire and a focus group. This resulted in 5275 valid responses from eight European cities and five FIA (Federation Internationale de l'Automobile) national networks. Although this study wasn't focused on mobility data collection, it allowed to conclude that every method has complex advantages and disadvantages when it comes to provide data on travel satisfaction to policy makers (Susilo, et al., 2017).

In this study, 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 dissemination and data collection from the mobility survey and the app "SenseMyFEUP"; as well as the final data processing and inherent analysis.

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 (FEUP, 2015).

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.

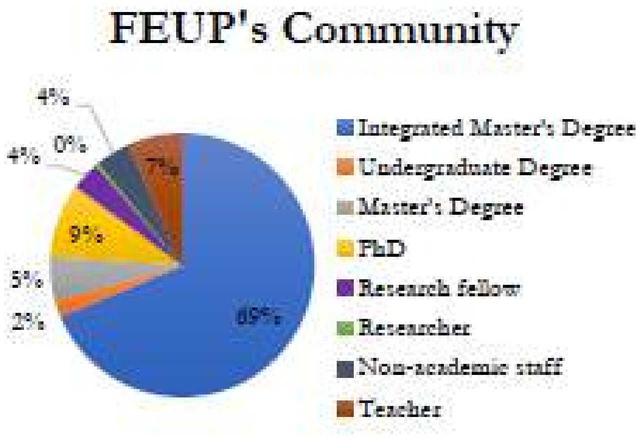


Figure 1 – Distribution of FEUP's community.

### 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 effort 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. It was necessary to operationalize the carbon footprint so it could become an integrated tool of both sustainability and dissemination.

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, which we are focusing on, the elected tool to measure 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 CO2 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 CH4, CO2 and N2O. CO, NOx, PM and CO2 from lubricants were rejected for having little or too indirect influence in the overall carbon footprint (Intergovernmental Panel on Climate Change , 2013).

According to the IPCC Fifth Assessment Report of 2013, releasing 1 kg of methane (CH4) into the atmosphere is equivalent to releasing 34 kg of CO2 and if instead of methane it was nitrous oxide (N2O) the equivalent would be 298 kg of CO2 in the course of 100 years. The resulting CO2e value was calculated with the following formula:

$$CO2e=[CO2+(CH4\times 34)+(N2O\times 298)]\times Fuel\ Density\ (2)$$

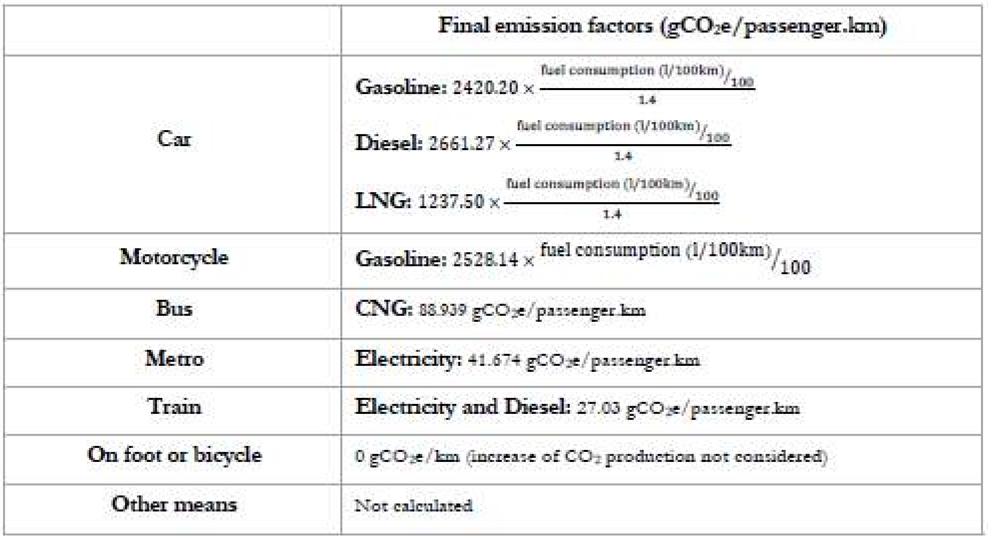
Considering the bulk emissions for Portugal provided by the EMEP/EEA air pollutant emission inventory guidebook from 2013, updated July 2014, in the 1.A.3.b Road Transport Section, the resulting CO2e (g/l fuel) values were calculated for cars, motorcycles and buses.

In order to use the required emission factors, it was necessary to know the fuel consumption of each transport to transform from CO2e 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. 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 CO2 emissions. In 2015, each vehicle emitted 1.385 kg of CO2 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 gCO2e/passenger.km respectively (CP Comboios de Portugal, 2014).

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 2.



| | Final emission factors ($gCO_2e$/passenger.km) |
|---|---|
| Car | **Gasoline:** $2420.20 \times \frac{\text{fuel consumption (l/100km)}/_{100}}{1.4}$<br>**Diesel:** $2661.27 \times \frac{\text{fuel consumption (l/100km)}/_{100}}{1.4}$<br>**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 |

Table 2 – Carbon footprint estimation

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.

It is important to point out that even though vehicles that run on diesel create more CO2 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 PHASE

### 3.2.1 MOBILITY SURVEY

This online 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 sample characteristics, their average travelling costs and their carbon footprint, which 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 of improvement.

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, which promotes electric and conventional bicycles in Academic Communities.

In total, 340 people answered the survey, 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. 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), using 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. 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 being impossible to identify the emails of the participants. The users had access to their data through the app's website, 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. The interface of the app showed information about the user's mode of travel, carbon footprint and the comparison to FEUP's average, so the user could be aware of his or her own sustainability.

The SenseMyFEUP app was officially released to the public on March 29th and the dissemination consisted on the distribution of flyers and the exposition of posters throughout the faculty, considering that the target audience was all FEUP's community.

A Facebook page was created to help disseminate the project especially among the students. To raise interest, during the period of data collection (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. 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 150 sent data consistently.

# 4 RESULTS AND DISCUSSION

## 4.1 SUSTAINABILITY

Sustainability stands on the pillars of society, economy and environment, but this study will focus on the environmental side, considering that the main tool was the carbon footprint. The key variables for its calculation were mean of transport and distance.

For the first variable, shown in Figure 2, the difference from the app and the survey results is based on the different sample of users, although they tend to become more alike during the same time the data was recorded. The car modal share, particularly the one assessed by the app, is similar to the value defined by the Census 2011 for work/school trips (62%) not only in Portugal but also in Porto, with the rest of the 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.

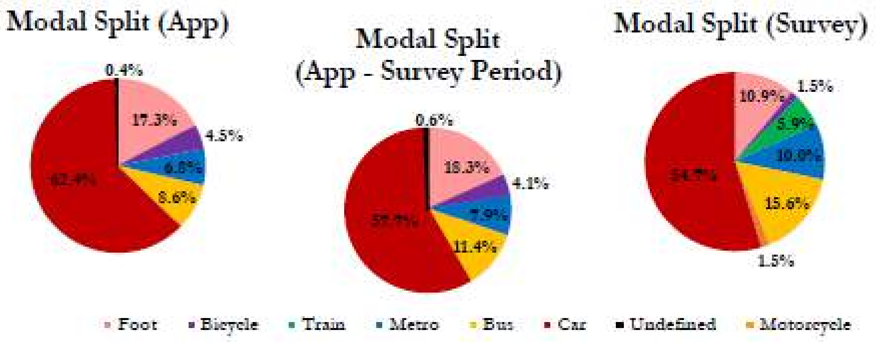


Figure 2 – Modal split according to the survey and the app.

For the second variable, distance, the app and the survey stray from each other in terms of results. While the average trip distance assessed from the survey was 13.6 km, the average shown in the app was 6.0 km, probably due to the difficulty of intermodal trip chaining, which included train travelling, to be discussed further ahead.

With the information of both methods, it was possible to calculate the final carbon footprint. Using the survey, it was concluded that the carbon footprint, on average, is 1.28 kgCO2e 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 relatively similar, reaching 1.42 kgCO2e/trip due to a higher share of car users.

Using the survey information on frequency of trips throughout an average week, the emissions were estimated around 13.80 kgCO2e individually, which translates into 551.99 kgCO2e during the 40 weeks of an academic year. In 2014, the average carbon footprint per capita in Portugal was 4.60 tCO2e, with 1.51 tCO2 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 represents 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 1.84 tCO2e per person in a year (considering that 0.55 tCO2e is 30%), FEUP’s community not only surpasses the national average, but also the world annual carbon emissions of 0.86 tCO2e per capita (World Energy Council, 2016).

There are a few options within FEUP’s reach to help decrease their carbon footprint. Studying the survey’s results with more care, we concluded that from the 186 people (55%) who chose car as a preferred mode of transportation, 25 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, 24 people use the car or public transportation for travel distances shorter than 3km, which can be considered a valid walking distance and an extra of 27 people, if we consider 5km, which could be travelled by bicycle.

In total, 65 people (19.1% 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 5 km started walking or cycling, for example, the average carbon footprint would become 1.21 kgCO2e/trip, a 6% decrease. Applying on the whole population, around 1535 people in FEUP (19.1%) 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. 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 kgCO2e/trip.

Regarding the feedback of the U-Bike initiative, as cited previously, 8% claimed they 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 start cycling keep their word, the average carbon footprint would decrease to 1.20 kgCO2e/trip. If we add those who would think about it, the difference would be even more considerable, dropping to 0.69 kgCO2e/trip, with a 46% decrease from the actual value.

The overall reduction of the carbon footprint can reach 48%, if we combine the population susceptible to change their mobility patterns and the answers for the U-Bike initiative.

## 4.2 COMPARISON BETWEEN METHODS

After analysing the sustainability 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 and their reach to the community.

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, extensive 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 exhausting to people, which can lead to a higher 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.

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.

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 user’s location. 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.

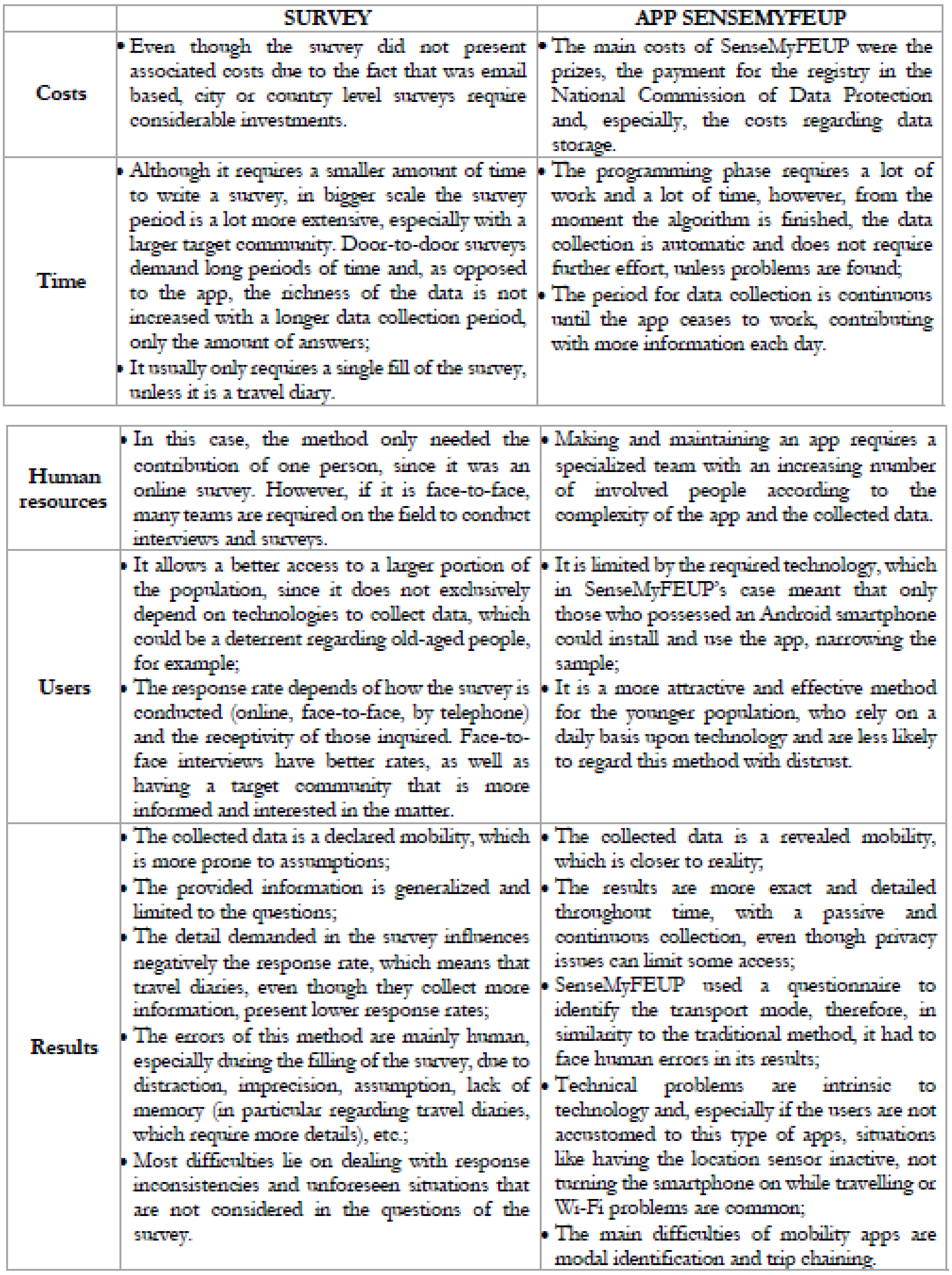
Trip recognition is crucial, but most of it relies too much on the user’s phone or if the user remembers to answer with each trip without letting them accumulate and probably give wrong feedback for mistaking trips. Another problem associated with trip recognition is the correct trip chaining, which 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 200 m radius, 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.

Although SenseMyFEUP faced these challenges, in comparison with the survey, the app data is more detailed and each trip is unique, which is better for differentiation and accuracy. 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.

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.

While the app had more immediate sustainability results which could create awareness about individual habits, the survey didn't offer direct results for the community, although many gave personal feedback revealing their concern about their sustainability, and explaining the limiting conditions that influence their choice of using the car.

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



| | SURVEY | 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 of answers;<br>• 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;<br>• 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 surveys. | • 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;<br>• 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;<br>• 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;<br>• The provided information is generalized and limited to the questions;<br>• 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;<br>• 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.;<br>• 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;<br>• The results are more exact and detailed throughout time, with a passive and continuous collection, even though privacy issues can limit some access;<br>• 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;<br>• 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 Wi-Fi problems are common;<br>• The main difficulties of mobility apps are modal identification and trip chaining. |

Table 3 – Advantages and disadvantages from both studied methods.

Both methods have advantages and disadvantages, with the choice depending 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 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 1.28 and 1.42 kgCO2e, that translates to 0.55 tCO2e at the end of the academic year.

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.

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 by using carbon footprint as a tool. Being a recent project, it requires further development to correct problems and increase interactivity with the user to encourage installation and continued use.

Both methods provide valid information, but the app has a greater 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. 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 is 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.

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# ID 1542 | CAR SHARING AND SOCIO-SPATIAL INJUSTICE

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## 1 INTRODUCTION

Car sharing is nowadays commonly acknowledged as an innovative approach to the transportation problems of urban areas (Firnkorn and Müller, 2015). Scientific literature regularly discusses car sharing related to the context of sustainable mobility and environmental benefits, or in relation to consumer behaviours in the sharing economy rhetoric. The former approach is common in transport studies and concerns strategies to face mobility-related problems in urban context and potential solutions for the environmental impacts of car traffic due to CO2 emissions (Martin and Shaheen, 2011), number of vehicles per household (Martin et al., 2010) and vehicle-kilometres travelled (Firnkorn, 2012). On the other side, social studies are more interested in the changes of consumer behaviour and their implications on society and economy. These publications are mostly based on the shift from ownership to service use lifestyles (Kuhnimhof et al., 2011; Prettenthaler and Steininger, 1999; Schaefers, 2013): the concept of ownership is changing fast and determining lots of consequences on consumers' practices and business strategies (as, for example, the interest of auto companies in short-term rental like a way to balance the loss of purchases; Schwanen, 2016a).

Differently, poor attention has been so far focused in scientific literature to the social impacts of car sharing. This can sound quite surprising: the first car sharing organisation, the SEFAGE (Selbstfahrgemeinschaft, self-riding community), was founded in 1948 in Zürich by a housing co-operative, just to allow people, who could not afford to purchase an own car, to share one (Harms and Truffer, 1998). Shaheen and Cohen (2007) outlines that the main beneficial social impact of car sharing is the possibility for households (in particular, low-income ones) to gain or maintain vehicle access without bearing the full costs of car ownership. Litman (2000) reads it in terms of equity: car sharing can increase equity by improving the mobility options of people who are transportation disadvantaged.

But the spatial dimension can play a crucial role for these supposed social benefits, in particular in urban areas. On the one hand, the distribution of social deprivation problems in the city is not homogeneous, on the contrary it tends to increasingly polarize (especially in times of austerity and economic crisis; Cucca and Ranci, eds., 2016). On the other hand, car sharing services hardly cover all the territory of a city; private companies can choose the area where to operate, or can modulate costs and levels of service (e.g., the density of stations) in different neighbourhood of the same city. If these two spatial distribution patterns mismatch, car sharing can deepen rather than reduce socio-spatial injustice and inequity

As regards the spatial dimension of car sharing services, until now scientific literature has mainly focused its attention on models and tools to assess the market potential for new car-sharing operations in urban communities (Habib et al., 2012). For example, Celsor and Millard-Ball (2007) developed a methodology that supports car-sharing operators and transit agencies to assess the market potential for car sharing in different neighborhoods, according to their characteristics. Wagner et al. (2016) use a set of indicators for the attractiveness of certain areas (based on points of interest in their vicinity, such as shopping malls, movie theatres, train stations etc.) to identify promising regions for an expansion of car sharing business areas. However, the potential negative impacts of these approaches in terms of social inequity have not been considered.