U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

INTEGRATED MASTER'S IN ENVIRONMENTAL ENGINEERING 2020/2021

THEORETICAL FRAMEWORK FOR A USER-SPECIFIC CARBON FOOTPRINT CALCULATOR: TRANSPORT AND BUILDING SECTORS

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Dissertation submitted for the degree of

MASTER IN ENVIRONMENTAL ENGINEERING

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mygreenapp

July 2021

To my sister

"Não sejas o primeiro, sê o que chega mais longe."

M. Cristina Vila, 2021

Acknowledgment

First of all, I have to thank my mentors, who showed me that being a good person and a good professional, are not mutually exclusive traits. They showed honesty and straightforwardness like I never expected to have from a mentor, and it is something that I'll drawn from into who I want to be. They gave me room to make mistakes, had patience to deal with my good and bad moments of productivity, and helped me find a path within this vast topic.

I certainly wouldn't have accomplished this work without my “partner in crime”, Catarina Silva, who understood better than everyone else how challenging this project was, and helped me maintain a sain mind, by debating our subjects, and dealing with me letting off steam. To my friend Rafaela, I honestly thank you for just being there whenever I needed a break, and when I didn't even know I needed them. Our honest talks, music jam sessions, and Python debugging, helped me realize that during these times, there were more things than writing a dissertation.

Thank you to my girlfriend, and her family, who put up with my disappearance and still had the patience to deal with my moments of stress, while having to work on her own thesis. Her love and care helped me a lot in moving forwards with this work, and kept my spirit high.

To all my close friends in college and from “the hood”, I thank you for your advice, understanding, patience, and companionship, even if I wasn't as present as I wanted to. I couldn't have done this dissertation without those bodyboard breaks, trips to the library, English-only speaking days, Zoom hangouts, and other moments that helped me balance work and social life during this pandemic. I would have definitely overload and lost my focus if it weren't for you.

To my dad for letting me have a break, using his home as my office, and giving me space to breathe to just focus and work.

To my mom for the support throughout this journey, and for helping me search for the right words. I hope that I've made you proud by concluding this degree, and you'll finally stop worrying about me becoming “just another employee”.

Ultimately, I must thank my sister, for her support and guidance, for always looking after me as if I were her own child, throughout this dissertation and beyond. Even though I might be shy, sometimes stubborn and pessimist, she was the one who never gave up on me, and always inspired me to be ambitious, caring, and make my own career, based on what makes me happy and fulfilled. Throughout her life's ups and downs, she has shown me that no matter the struggles a person might go through, you can always prevail and be the best in your field, while still being a naturally good human, and the best sister.

Professor Fernando Martins, supervisor of this dissertation is an integrated member of LEPABE – Laboratory for Process Engineering, Environment, Biotechnology and Energy, financially supported by: Base Funding - UIDB/00511/2020 of the Laboratory for Process Engineering, Environment, Biotechnology and Energy – LEPABE - funded by national funds through the FCT/MCTES (PIDDAC).

Abstract

When it comes to climate change and carbon neutrality targets, people are often confused about what to do to reduce their own impacts, especially when everything influences the environment. It is easy for people to get lost in identifying a reasonable option to adopt in their lifestyle. This confusion applies to all dimensions in an individual's routines, such as when wondering what to eat, or what transportation to take.

MyGreenApp is a company that is developing a mobile application, which aims to combine a CO_2 tracker, a sustainable marketplace, and a social network, to promote decarbonization through changes in user's behaviour. The purpose of this mobile app is fully aligned with the global decarbonisation efforts and UN's Sustainable Development Goals.

The work carried out in a business environment aimed to create an extensive framework and guidelines for the operation in two categories within MyGreenApp CO_2 tracker: mobility and buildings. Frameworks for the mobility category were developed based on an extensive literature review, and analysing existent web-based and mobile-based CO_2 trackers. The existing methodologies are somewhat similar but rarely user-specific, which proved to be one of the main challenges in designing the framework, because there are several possibilities and conditions for which the tracker needs to be prepared to operate.

The proposed frameworks for mobility allow adaptation for various types of vehicles, and in multiple conditions, due to their use of embedded mobile device sensors, machine learning programs, and use of APIs, to automate transport detection and carbon footprint measurement based on the user's profile. It also includes real-time CO_2 measurement for electric vehicles, giving an additional factor that is already targeting current trends in electrification of vehicles.

Although construction and energy sectors are amongst the largest global emitters these categories are not typically considered in most carbon footprint calculators. Nevertheless, there is still a lack of a simplified procedure for calculating the carbon footprint of a house for an individual, due to the high volume of information needed to be analysed or collected on site. In an initial phase, the proposed guidelines allow the acquisition of information through the energy certificate and disclosed user's habits, but the goal is to collect as much data as possible to create a multi-layer map. This tool could combine carbon footprint and building characteristics to cross reference with economic, social, and urban planning factors.

Keywords: Carbon footprint; Smartphone; Mobility; Buildings; Calculator; Decarbonization

Resumo

Quando se fala de alterações climáticas, as pessoas normalmente ficam confusas sobre o que fazer para reduzir os seus próprios impactos, especialmente quando todas as ações influenciam o ambiente. Estas facilmente perdem-se no momento de escolher uma opção razoável para adotarem no seu estilo de vida, sem terem de chegar a extremos.

A MyGreenApp é uma aplicação móvel atualmente em desenvolvimento que visa combinar um CO_2 *tracker*, um *Marketplace* sustentável, e uma rede social, para promover mudanças a longo prazo no comportamento dos utilizadores. O trabalho realizado visa criar uma estrutura extensiva e a definição de diretrizes para o funcionamento de duas categorias dentro do CO_2 *tracker*: mobilidade e edificação.

São desenvolvidos diferentes modelos para a categoria de mobilidade, com base numa extensa revisão bibliográfica, e após avaliar as atuais calculadoras de pegadas de carbono, online e de outras aplicações móveis. As metodologias construídas na mobilidade permitem a adaptação a vários tipos de veículos e o funcionamento em múltiplas condições. Isto é possível devido à utilização dos sensores dos *smartphones*, programas de *machine learning* e utilização de APIs. Inclui também a medição de CO_2 em tempo real para veículos elétricos, dando um fator adicional que visa as tendências atuais de eletrificação dos veículos.

Os sectores da construção e da energia não são tipicamente considerados na maioria das calculadoras da pegada de carbono apesar de ser um dos maiores emissores mundiais. No entanto, ainda não existe um procedimento simplificado para calcular a pegada de carbono de uma casa, devido ao elevado volume de informação necessária para ser analisada ou recolhida no local. Numa fase inicial, as diretrizes propostas permitem a aquisição de informação através do certificado energético e dos hábitos do utilizador divulgados, mas o objetivo é recolher o máximo de dados possível para futuramente cruzar fatores económicos, sociais e de planeamento urbano, com o impacto individual e as características dos edifícios.

Declaration

I hereby declare, under word of honour, that this work is original and that all non-original contributions are indicated, and due reference is given to the author and source.

Sign and date

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Notation and Glossary

CF	Carbon Footprint	$kgCO_2$
CW	Cargo weight	kg
DC	Detour constant	km
GCD	Great Circle Distance	km
N	Number of passengers	Un.
PLT	Passenger to Freight Factor	%
PTL	Passenger to Load factor	%
PW	Passenger weight	kg
SCA	Seat Class area	m^2
TF	Total fuel consumed	kg
UCA	User's seat class area	m^2

Greek Letters

∅	Latitude
λ	Longitude

List of Acronyms

AC	Analysed aviation carbon footprint calculator
API	Application programming interface
BEIS	UK Department for Business, Energy & Industrial Strategy
EEA	European Environmental Agency
EMEP	European Monitoring and Evaluation Programme
EPA	US Environmental Protection Agency
GHG	Greenhouse gas
GWP	Global Warming Potential
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICE	Internal Combustion Engine
IPCC	Intergovernmental Panel on Climate Change
RC	Replicated aviation carbon footprint calculator
TFS	ICAO's Traffic by Flight Stage database

1 Introduction

1.1 Framing and presentation of the work

The world is currently facing a pandemic that as shown deep issues in terms of how society adapts to global threats. During the pandemic there was a slow change in behaviour, sometimes due to a disbelieve in science and governments, or even due to an initial laid-back behaviour by the general public. Experts admit that the recovery to a prosperous economy must have in sight a fundamental structural change to the economic system, to prevent the intensification of climate change, therefore prevent the destruction of ecosystems, stop the sea level rise, and achieve net neutrality at least by 2050 (Schnabel, 2020). In order to counteract the worsening of these events, there are many solutions for each sector that lead to the reduction of the greenhouse gas (GHG) emissions and resources consumed. These must be implemented as soon as possible, by governments, organizations, and adopted by people in their lifestyle. Although these alternatives exist, the speed at which this transition is happening does not correspond to what is necessary to achieve the proposed target, and stop the rise of global temperature at 1.5 ºC.

There are two main issues that differentiate the speed with which the world's leading economies have dealt with the two biggest global problems currently, the Covid-19 pandemic and climate change.

With the start of the global pandemic, the number of infected people, and deaths related to Covid-19 began to rise in an exponential way. The news of hospitals almost at full capacity began to spread, and most governments quickly reacted. The consequences of the global pandemic were abrupt and noticeable. Therefore, the urgency for a response was both needed, and supported by politicians, companies, and everyone else.

On the other hand, there has been a gradual increase in the average global temperature, which began with the Industrial Revolution, that started an unregulated release of GHG, back in the mid-18th century. Its impacts are becoming more noticeable due to a higher variance in global temperature, and causing more extreme weather conditions. However, because this increase began to happen over generations, the population in developed countries got used to, and adapted to the new climate conditions.

Secondly, part of the biggest effects of climate change occurs in either developing countries, or in the natural environment. It is complicated for a person to understand all the intricacies that cause these phenomena, as well as create empathy towards a reality in which they have never lived, or observed in person. These factors, lead to a detachment between the main emitters, such as corporations or people in developed economies, and the consequences of their everyday actions, much like the boiling frog syndrome. This theorem explains that if a frog is dipped in boiling water, it will jump out immediately, whereas if the frog had already been in the water while it is heating up it would have stayed in.

These are amongst the main reasons that are delaying the change in dealing with climate change, and cut down on the dependency on fossil fuels. The use of a unit, such as the Carbon footprint, allows to quantify the impacts of actions in different sectors, as well as compare how different alternatives perform in the amount of GHG emitted.

The tracking of the GHG emitted over time allows for an individual, or organization, to visualize and understand what are the actions that have the highest emissions. Depending on how the carbon tracker is programmed, the company that oversees the carbon tracker also receives enough information to provide user-specific suggestions and alternatives (Bekaroo *et al.*, 2020).

During this project, it was done a study on the current carbon footprint calculators which measures individual's impacts in the transport, energy, and edification sectors. The study englobes the methodologies in place, sources of data used, and how these calculators can be integrated into a mobile app, relying on smartphones sensors or not. With this information, it is proposed frameworks for calculating the carbon footprint across the analysed categories. For mobility, the models proposed change based on the type of vehicle, combining different solutions and technologies for each one. The building and energy category framework is a combination of conceptual solutions that are based on a mix of technologies and information, from the user, literature, and other platforms, which helps the user understand their accommodation and their surrounding impacts. These frameworks allow the end objective of providing the tools for the user to decarbonise their lifestyle.

1.2 Presentation of the company

The company that proposed the current study is called MyGreenApp, and it is looking to create a mobile app which interconnects three different services. The combination of a carbon footprint tracker, a sustainable marketplace, and a social network, allows to connect its users and promote a sense of community towards a common goal of an environmentally sustainable future. The information collected from each service will allow to build a deeper profile of the user, and customize recommendations for them to gradually reduce their carbon footprint.

This start-up was founded in October of 2019, by Pedro Teixeira and Bruno Sousa, which are the current CEO and CTO, respectively (MyGreenApp, 2021). At the moment, the application is still under development, and all updates can be checked on its website (www.mygreenapp.org). This dissertation is amongst the projects that is studying how the sustainable marketplace, and the carbon tracker of the app should operate.

1.3 Contribution of the author to the work

The work carried out contributed for a better understanding of the current carbon footprint calculators, and the discovery of the strengths and flaws, to have in mind, while designing the CO_2 tracker. This analysis was done through a comprehensive study of each sector, smartphone technology, and a replication of the structure of other carbon calculators, that are currently in the market. The work developed supported the scheming of the models, with feasible applications, in MyGreenApp CO_2 tracker, and opening opportunities to promote interconnectivity between other services provided in MyGreenApp.

1.4 Organization of the dissertation

This project is divided into a total of six chapters.

The first chapter, the introduction, gives a framing of the different topics and problematics faced in this work, highlighting the development of the carbon tracker and the importance of the work that was carried out. It includes an explanation of the structure of the project, presents the company that supervised it, and sets up the objectives that were defined.

The second chapter, with the context and state of the art, establish an overall analysis on the notion of a carbon footprint, and current carbon footprint calculators, based on a literature review that was carried out throughout the dissertation. The assessment done on the current technologies allowed to further understand what are the main challenges in integrating a carbon footprint calculator into the average smartphone, and subsequently develop the guidelines for calculating the carbon footprint.

The following chapter contains the methodology that was used to build the framework in each sector, based on the parameters, and data sources of the current calculators. For aviation, three main calculators stood out, which have different methodologies. These went through an evaluation and were replicated, to understand which is the best framework to introduce in a mobile app. The remaining models proposed in the mobility category, were built based on theoretical concepts and ideas from other calculators and current trends. For the building and energy sector it is explained the fundamentals of the guidelines proposed.

In the fourth chapter, it is shown the results that were obtained, together with a comprehensive analysis and discussion. It contains the results obtained from the case studies in the aviation sector. It also displays and explains the strategy of the proposed models, including their main sources of information, and how it interrelates with the use of the smartphone. It is listed the different uses and representations that the carbon footprint value calculated can have.

Chapter five reveals the conclusions, and the main takeaway points from the models proposed, and the entirety of the dissertation.

The last chapter is an assessment of the work done, describing the completion of the goals that were proposed, and a self-evaluation on the performance shown. It also includes recommendations and suggestions for a possible improvement of the proposed models, that could be studied with a deeper analysis.

2 Context and State of the art

Climate change has been a notion widely heard by the public over the last couple of decades. As experts began to grasp every aspect of this phenomenon, it became clear what behaviours were responsible for it, and have identified the actions that are needed to reverse this shift in environmental conditions. The emissions of GHGs, began with the burning of fossil fuels, and uncontrolled resource consumption, to serve people's needs and luxuries. With time, this dependency is now present in people's lifestyle and line of business. The measurement of the environmental impacts, into quantifiable parameters forces policies makers, companies, and people to make better and informed decisions, considering economic, social, and environmental factors. The use of a general unit, such as the carbon footprint, or the ecological footprint, allows to unify these impacts, and makes it easier for everyone to understand them (Caro, 2019).

2.1 Carbon footprint

The carbon footprint represents the total amount of GHGs emitted from a certain action, decision, service, or product. This unit allows to compare the impact on global warming, between different actions taken, or products acquired (Youmatter, 2020).

The carbon footprint meaning is often vague, and it differs depending on what it is being analysed (direct and indirect emissions), and what are the boundaries of this study (from the source or controlled by another entity) . Even the analysis to calculate the carbon footprint of the same product or decision, can utilize a wide range of options, cover different aspects, and use different data sets (Ericsson, 2020). This can often confuse people, when the same action can have disparate values being displayed, depending on the calculator's methodology and sources of information.

When the world aims to halve its GHG emissions every decade, to achieve carbon neutrality as soon as 2050, it is even more important to unify these measurements, in order to know the minimal target value of carbon emissions to cut down (Ericsson, 2020).

Highly detailed protocols already exist for measuring and reporting the GHGs emitted, such as the ISO 14064 : 2018, the Intergovernmental Panel on Climate Change (IPCC) guidelines for different economic sector, or the Greenhous Gas Protocol frameworks.

The ISO 14064 is mainly composed of three parts. These specify the guidelines for the development of GHGs inventories, the requirements for the quantification and report of the GHG emissions, and the requirements for the validation of the information collected for the report of the inventories (SGS SA, 2021).

The IPCC refines international methodologies for calculating the GHG emissions, to develop detailed GHG inventories, and for reducing these emissions. This assessment is provided based on regular scientific basis, concerning climate change issues (IPCC, 2021).

The GHG Protocol creates global standardized frameworks to determine, and account for the GHG emitted in the private and public sectors, operating directly with governments, associations, and corporations (GHG Protocol, 2021).

These frameworks appointed outline the core structure and principles for measuring and reporting the GHGs emitted, but only on an organization level rather than an individual scope.

Most of the carbon footprint emissions measurements, rely on factors and formulas that consider just the amount of carbon dioxide emitted (Burton, 2021). However, in every process, resource, or energy consumed, there are more gases being emitted besides carbon dioxide (EPA, 2021).

The gases included in the carbon footprint calculation may also change, based on the quantity, and composition of the emissions analysed. It depends on what the carbon footprint is considering, e.g., it can be a journey, a vehicle, or an event. The GHG Protocol includes within the carbon footprint, a total of seven GHG, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride, and nitrogen trifluoride. These are the same gases considered in the United Nations Framework Convention on Climate Change (UNFCCC) and in the Kyoto protocol (Caro, 2019).

All the GHGs emitted have a significant environmental impact, and strengthen the greenhouse effect. This effect can be converted into a quantitative value, called the global warming potential (GWP), which represents the amount of energy that 1 ton of gas will absorb, during a given amount of time present in the atmosphere (the GWP often is based on a 100 year time period), in comparison to 1 ton of carbon dioxide (EPA, 2020). The GWP for each gas is present in the IPCC assessment reports, being the latest published in the IPCC Fifth Assessment Report in 2014 (EPA, 2020).

The use of a unitary unit allows to directly compare different gases, and it can be used to determine the CO_2eq (CO_2 equivalent) of a mixture of gases (EPA, 2020). The CO_2eq quantifies how much an emission, or mixture of gases, contributes to global warming in a single value (UK Goverment - Defra, 2014).

2.2 Carbon footprint calculators

2.2.1 Global overview

The carbon footprint calculators, or carbon calculators, are tools to ease the calculation of the emissions which are released in different economic sectors, according to different scopes. On the individual level, it is a tool to aware users about their environmental impact, which can also be more fruitful for comparing with carbon footprint values of their peers, such as the average carbon footprint of the inhabitant of your neighbourhood or country (Burton, 2021).

However, this information often lack effect in creating a change in user's habits, due to several aspects as:

- Low consistency in the use of these platforms - This may be correlated with the way these are designed, that do not motivate the user to give regular feedback. Therefore there is no record of how the individual's carbon footprint evolves with time, or what actions have the greatest impact;
- The suggestions provided are too generic - Not every solution is suited for every individual. For example, suggestions about reducing the use of private vehicles, do not apply to someone who does not own a private vehicle. This disconnection between the tool, and its users, reduces the likelihood of a user self-confronting their actions, and create long-term behavioural change (Mallett *et al.*, 2013);
- There can be a big difference between the values obtained for the same action or product - These variations tend to occur, when comparing calculators that are not specific to one sector. The use of different sources of information lead to a difference in the carbon footprint obtained for the same action or travel (Sullivan RK, 2016);

Currently, there is a wide sample of web-based carbon footprint calculators, and mobile apps, that allow the user to do this calculation on the go. The data and formulas necessary for these calculations change, depending on the sector that is being analysed. Most carbon calculators rely on manual input of information by users because their use is only occasional, rather than continuous. Although the user can have a large set of variables to customize, this is not permanently linked to a user's profile (Mulrow *et al.*, 2018).The following figure from a currently available carbon footprint calculator, Carbon Tracker, highlights the simple interface used and how most carbon footprints operate (Bekaroo *et al.*, 2020).

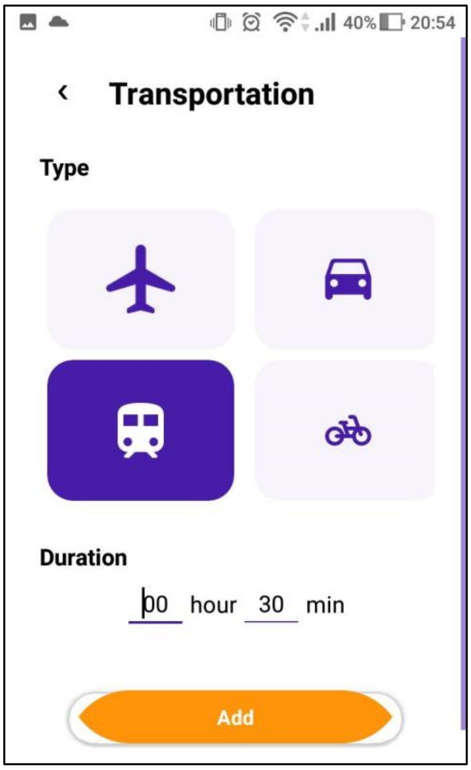


Figure 1 - Screenshot of the app Carbon tracker.

The calculation used is based on generic factors and straightforward calculations, without a valuable output of the footprint calculated. There are more advanced calculators which have a cleaner design and provide targets or suggestions, as the app Capture, which is shown below.

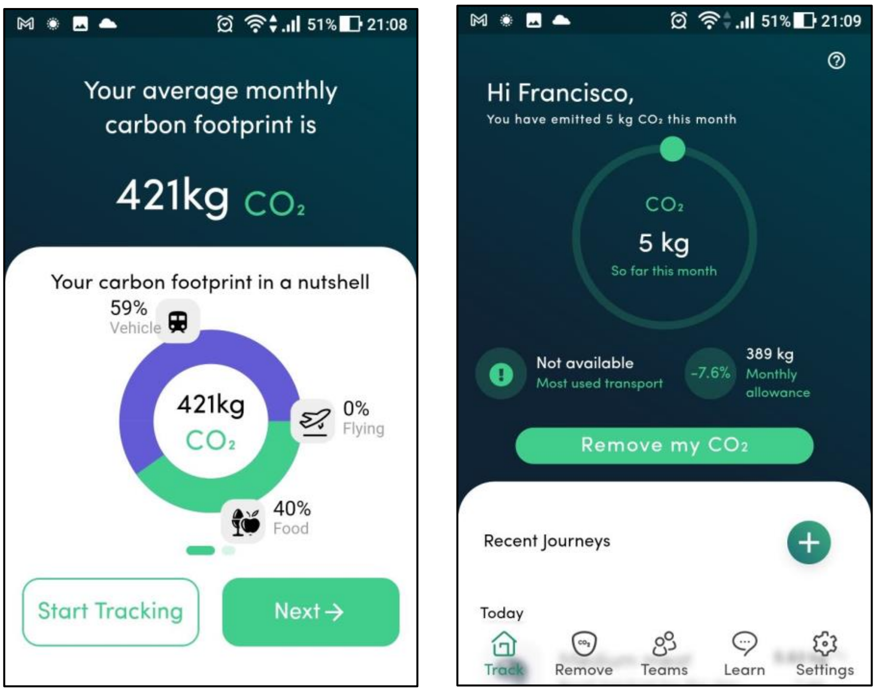


Figure 2 - Screenshots of the app Capture, highlighting the representation of the carbon footprint.

Although this app associates the carbon footprint to a specific user, the input of information is still manual, and does not allow to specify information, such as the vehicle model in which the user travels or the number of passengers with which the users is riding.

The basis of these calculators remains the same, and it can be separated into three segments.

- Inputs – It is where the information of different parameters is inserted into the calculator. It can be manually characterised by the user, automatically collected (using sensors or other apps), or use a mix of both;
- Methodology – The data collected before, is processed to either do routine calculations, using a general formula, or follows a more specific methodology, based on unique conditions, e.g., the country or city in which the user lives, or the type of transportation the user is using.
- Outputs – The carbon footprint determined, can have different representation e.g., mass, volume, or distance travelled. The impact on the user's behaviour depends on how the calculator is designed, and the type of features it has to help the user change its habits. Usually it is offered generic suggestions related to transportation, energy, and diet. Additionally, these platforms often lead to the possibility of offsetting the emissions calculated, in different worldwide projects that mitigate the carbon emissions, e.g., with the investment in renewable energy or reforestation (Donofrio, 2021).

The increase in data traffic, availability of sensors in our mobile devices, and interconnectivity through software, has massified the detection and measurement of almost any user's actions (Ericsson, 2020). This evolution in digital technology has opened the opportunity to automatically calculate the individual's carbon footprint in different sectors (Ericsson, 2020). Newer mobile apps, dedicated to measuring the carbon footprint, rely on the data collected by smartphone sensors or other services (Baumeister, 2017; Sullivan RK, 2016). Some calculators, such as Aerial, Svalna or Tomorrow, can do this calculation with the minimal input, by accessing the credit card information or other connected services, and specify solutions for each user to implement in their lifestyle (Barendregt *et al.*, 2020).

Previous research has even stated that this evolution in technology, has created an opportunity to use data science, and machine learning techniques, to do more than a straight calculation, be engaged with the user and understand its habits, in order for him/her to take action, change habits, and become aware of climate change issues (Mulrow *et al.*, 2018).

The data collected and analysed can also be a strong component in mapping the CO_2 emissions throughout districts and countries, and help strengthen the link between environmental impact, economic, geographic, and social factors (Mulrow *et al.*, 2018).

2.2.2 Mobility and transport

Approximately 95% of all transport is dependent on fossil fuels, which has massively increased the greenhouse effect, and the concentration of particles and gases, mainly in urban areas. This pollution adversely affects people's quality of life, causing severe or chronic respiratory health problems (Germany BMU, 2021).

The direct consumption of gasoline and diesel, in the mobility sector, was responsible for 17% of global GHG emissions, with around 43% of the emissions from this sector originating from passenger road vehicles, in 2018 (Ritchie & Roser, 2020). The electrification of this sector is highly important, but raised another issue, concerning the mining exploration necessary, and electronic residue produced (Balch, 2020).

The use of intelligent and sustainable public transport was slowly increasing before the pandemic. It remains as one of the best alternatives transport to reduce traffic, accelerate urban mobility, facilitate city accessibility, and improve the quality of life in large metropolises (ERTICO – ITS Europe; CERTH, 2019). Another solution to mitigate these emissions would be for a person to work from home, cutting off their need to use any transport. This solution is currently a possibility for various digital jobs, which can be done in long distance settings. This alternative of working from home, or telecommuting, is becoming a reality that many employers are considering adopting, which cuts out the need for daily commuting, consequently relieving urban traffic, and reducing their own emissions, from the employee and the company (Mateus & Lima, 2020).

Each type of fuel has its own chemical composition. Based on the type of fuel used, and the amount of fuel consumed, it is possible to obtain the total amount of GHG emitted. The U.S. Environmental Protection Agency's (EPA) Emission Factor for Greenhouse Gas Inventories contains the emission factors and GWP of several GHGs, that can be used for different types of vehicles (EPA, 2021).

Aviation

Globalisation is one of the factors that has accelerated the pace at which aviation has grown. The aviation sector has eased the connection between cities across the globe, without the need to build roads or railways in between. However, during the pandemic, it was one of the transportation markets with the biggest drop in usability, causing multiple companies to file for bankruptcy. Nevertheless, as countries begin to open their borders, the people's urge to travel is returning and even more strongly because most people had to spend weeks and months confined in their homes. Which even though it revitalizes the aviation market, it is causing the rise in GHGs emitted from the aviation sector once again.

The emissions related to air transport represented 2.5% of the global CO_2 emissions, and 12% of the emissions from the transport sector in 2018 (Ritchie, 2020; ATAG, 2020). The impact of air travels is even higher when considering the release of other GHGs, such as nitrogen oxides, water vapour (sometimes visible in contrails), and particles (sulfates, hydrocarbon, black carbon, and soot) (EESI, 2019).

These emissions have relevant impacts on global warming and can cause severe health problems. Approximately 90% of emissions are released above 915 meters altitude, which increases the impact on the environment due to the proximity of the ozone layer (EASA; EEA; Eurocontrol, 2019; EESI, 2019).

At the individual level, the air travel still has the highest emissions per passenger per kilometre. According to the United Kingdom department for Business, Energy & Industrial Strategy (BEIS), this can vary between 150-255 g CO_{2eq} per kilometre. The emission values depend mainly on flight distance, fuel consumption and load factors. As the distance increases, the high fuel demanding task of take-off and landing decreases, compared with the entire travel (Ritchie, 2020).

The aircrafts used for domestic, and international flights are different. Smaller aircrafts are used for shorter hauls, which have lower fuel burn efficiency and lower load factor (have lower occupancy rates), while for long-hauls, it occurs the opposite. It is up to the airlines to change their fleet, modify trajectories to reduce fuel burn, use lower carbon intensity fuels, and follow other alternative solutions (Graver *et al.*,2020).

When 80 % of CO_2 emissions come from flights of more than 1500 kilometres in flight distance, it is understandable that passengers often do not even have an alternative transport for their journeys (ATAG, 2020).

The solution that is proposed in most carbon calculators, is the option for the user to do a carbon offset of their emissions, or the display of suggestions, such as the avoidance of using domestic flights. Passenger are using more frequently the option to carbon offset their emissions from their air travel (Tirpáková *et al.*,2020).

Private vehicles

The access to a private vehicle has allowed people to have their independence from any timetable or schedule. The use of a public transport may not be preferred because of its significant increase in time spent on a commute, due to detours, delays, and other problems that can often occur (DG MOVE, 2019).

In 2018, the use of road vehicles represented approximately 45 % of global CO_2 emissions from transport worldwide (Ritchie, 2020). In the UK, most of these travels can be done using other alternatives, when considering that roughly 60 % of 2-to-3-km travels are done using a car (Timperley, 2020).

There are different alternatives for the users to adopt, but even the cities are mainly built for the use of a road vehicle. Only in recent times, there has been a higher adaptation in urban planning to include bus-only paths, or even space for the use of bicycles and scooters.

The automotive sector is having a shift in trends towards the use of battery electric, and plug-in hybrid electric vehicles, which ultimately alters the way the carbon footprint is analysed for these vehicles (DG MOVE, 2019). For this type of vehicles, instead of calculating based solely on the fuel, it is necessary to consider the electricity that is being consumed, and its carbon intensity. The carbon intensity varies with time, and changes between regions or neighbouring countries. No matter the type of vehicle, it is its usage phase which has the highest GHG emissions, so the impact of the batteries production is not considered in these calculations.

The publicly available online calculators and mobile apps generally use emission factors to calculate the carbon footprint of a trip. These factors can be categorized by the country in which the user travels, the type of vehicle the user drives, or the type of engine used. These emission factors are generally an amount of GHG emitted, per distance travelled, or time spent in a commute (Bekaroo *et al.*,2020).

Public transportation

After COVID-19, the use of public transportation has seen the biggest drop of occupancy in decades. According to a recent survey, people expect to use more private vehicles instead of public transportation due to the fear of contamination, especially in buses and in bus stations (Euroconsumers, 2020). This effect caused a major setback for reducing the carbon footprint of transportation in general, within the next years.

In 2018 the railway sector accounted for approximately 1 % of transport-related carbon emissions (Ritchie, 2020). On a global spectrum, over a quarter of the rail lines worldwide is electrified, whereby in Western Europe 57 % of rail lines has already been electrified (SCI Verkeher GmbH, 2018). Most recently, the average UK passenger has a carbon footprint of 35.1 g CO_{2eq} per (passenger.km) in 2019-20 (UK Office of Rail and Road, 2020).

Even with the expansion of roads, railway system, and airlines since 2014, the maritime passenger transportation has seen an increase in seaborne passengers embarking and disembarking in ports, within Europe, due to the recovery of the global economy. This led to an increase in cruise passengers as well as regular passengers travelling within national borders, and constitutes most of seaborne passengers in EU countries (Eurostat, 2021).

The shipping sector, which includes the transport of freight and passenger, was responsible for 1.7 % of the global GHG emissions in 2018, but most of these transportations come from freight transport (Ritchie & Roser, 2020).

The carbon footprint of these journey done using public transportation use generic emission factor, that are categorized based on the country in which the user travels, the size of the vehicle, or the distance travelled.

Micromobility

There are other means of transport that are having an increase in daily use, such as e-scooters and other electric devices, e.g., electric skates or monowheels, which are viable alternatives to guarantee an easier, and quicker small distance travel (average ≤4 km). Specifically, the e-scooters market is projected to increase within the next decade, in Asia, Europe, and North America, as their prices decreases, and its popularity rises with scooter sharing services (Grand View Research, 2020; Esferasoft Solutions, 2020).

The use of micromobility devices also increases access to public transport because it accelerates short distances, which people would not consider in their commutes, consequently people adopt other habits, and reduce their transport-related carbon footprint.

Just as for regular electric vehicles, there is a significant ecological footprint to consider due to the use of rare metals in internal electronics and battery, and their lifespan, which increases the electronic residues produced (Balch, 2020).

The lithium used in these batteries is becoming the image of the energy transition, but its exploration in Australia, Chile, China and possibly Portugal, can cause accumulation of highly toxic wastewater that reaches the watershed through soil infiltration, air pollution due to its refinement, and the destruction of natural environments (Balch, 2020). Ultimately, when using these devices, the carbon footprint associated with the uses of these devices, is linked to the electricity consumed, and its carbon intensity. Some scooter sharing brands already calculate the carbon footprint of the user's journeys. The calculated value is used to show the reduction of GHG emitted if the user had used an average fuel car.

Active travel

Where possible, one of the alternatives frequently suggested to reduce the use of motorized transportation, especially private vehicles, is to adopt active travel, such as walking or cycling. It is not often estimated the GHGs associated with these commutes, because it requires a comprehensive analysis, on the type of exercise, energy expenditure and in-take, and dietary habits. The GHGs emitted throughout the food production are also a complex category to analyse, due to the different food types, wide variety of food production and harvest, and different travel patterns involved (Mizdrak *et al.*,2020).

2.2.3 Building and energy

Building sector

In a world that is tending towards smart and sustainable cities, the construction of buildings is no longer as haphazard as it once was, especially due to a better understanding of city planning, and better construction techniques.

During obligatory confinement, many companies had to adapt, and send their employees to work from home, to maintain business as usual within the lockdown conditions. With the economy slowly coming back "a new to normal", many companies and employees are preferring to retain this hybrid work model for some jobs areas. This alternative allows employees to eliminate the time spent commuting, have looser working hours, reduce workplace distractions, and have a more comfortable environment. Meanwhile, the employer saves money spent per employee, has the possibility to employ people that live further from the main office, and can expect an increase in productivity from their workers (Murphy, 2020; Mateus & Lima, 2020).

This drift in mentality about where a person should work, has made people prioritize other factors when choosing where to live (Mateus & Lima, 2020). Future homeowners are beginning to also consider the comfortability of their future home, such as the building materials used for construction, the energy efficiency, and a useful location, e.g., near a public transport station, or in the city's periphery rather than in the middle of urban areas. The question now is more often related to the comfortability within their future home, rather than just price, being near work, or larger dimensions (Accenture - The Dock, 2019).

There are legal standards in place that are enforcing newer homes to be more energetically efficient, based on newer materials, which require fewer resources to produce or extract them, and newer construction techniques, that take advantage of the building's location and average weather conditions, to ensure a better comfortability to its users (Global Alliance for Buildings and Construction, 2020).

The latest planning and land management plans are looking to integrate more green areas in high density cities, and merge the edification with the city's main communication routes and utilities. When considering all the phases involved in a building's life cycle and the different housing types (residential and non-residential), the edification sector represents roughly 40 % of global emissions (Global Alliance for Buildings and Construction, 2020).

The emissions from a house's life cycle come from several stages in a cradle-to-gate analysis, but the phases that have the highest impact concern the product (extraction, production, transportation, and installation), and the use phase, that last throughout almost the entirety of a building's lifetime (HMC Architects, 2019).

The material's emissions are called "embodied carbon", and the changes to its emissions rely heavily on the companies that produce them to adapt, and reduce resource consumption, such as water (HMC Architects, 2019).

Although most people do not have a direct role in the construction process of their future home, there are aspects concerning the construction features that highly affect the energy consumption throughout its operational phase. The emissions from the operational phase are dictated by how the building is constructed, the occupation type, building location and orientation, and the energy mix that is being supplied (HMC Architects, 2019).

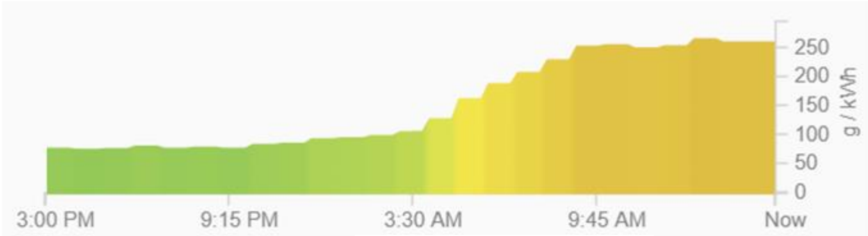
The emissions associated with the built environment, are not analysed in these carbon calculators, due to its high complexity, and variety of parameters that change with time and location. Nevertheless, the building sector is still among the biggest contributors to a society's emissions, because it affects, directly and indirectly, the emissions produced in other sectors, such as energy, transportation, and within the buildings themselves (HMC Architects, 2019).

The carbon footprint of real estate is defined as the emissions that are associated with its activities and operations, which are related to energy that is either consumed directly from the grid, acquired (with the purchase of gas tanks), or produced e.g., using solar panels (HMC Architects, 2019).

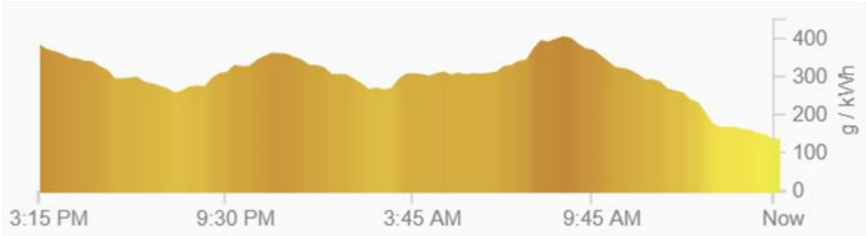
Energy sector

The electricity that reaches the power outlets can be supplied from different sources, which are either renewable or non-renewable, and can even be supplied by different neighbouring countries. The characterization of the main sources of energy in the electricity consumed is called, energy mix, and it is this mixture that defines the amount of GHGs emitted per electricity consumed, or the carbon intensity (gCO_{2eq}/kWh). The carbon intensity has fluctuations throughout the day, and changes mainly due to the weather conditions, and consumption demand. The goal in these electric grids is to obtain the maximum amount of energy produced from renewables, which reduces the carbon intensity.

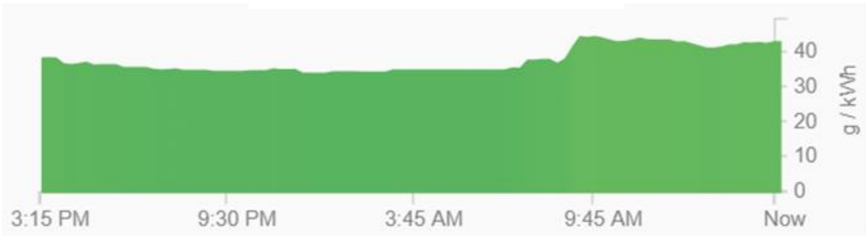
Figure 3 displays the carbon intensity values throughout 24 hours in different countries, and it is proof that the carbon intensity does not follow a strict pattern. For countries closer to the equator, such as Portugal, the production of renewable energy from solar and wind power technologies is more profitable, but does not assure the same stability in carbon intensity, as seen in countries that produce nuclear energy, such as Sweden, and still have most of the energy produced from renewables.



Portugal



Australia (South Region)



Sweden

Figure 3 - Recorded carbon intensity for a timeframe of 24 hours, in different countries (Retrieved June 15, 2021, from www.electricitymap.org).

Almost all calculators which have the calculation of the carbon footprint for the electricity consumed, requires manual input by the user, regarding the monthly electricity bill, to confirm the amount of electricity spent, and/or gas bought within a certain timeframe, except of utilities companies carbon calculators (Mulrow *et al.*,2020). Then each amount is multiplied by their corresponding emission factor. The emission produced from the consumption of gas, may be detailed by the user, by defining the gas acquired (butane, natural gas, or other).

There are a few services that operate with companies to measure their electricity consumption with a high detail, such as the app EDP Zero, which describes what amount of energy is being consumed by their appliances, and even calculates their GHG emissions. On the individual level there is no mainstreamed recording or detection service of when the user is consuming electricity, or what appliances are consuming it, without depending on specific paid services or high-end devices. The carbon intensity that is considered in these calculations, is based on previous average values of the carbon intensity of the country's electricity.

2.3 Use of smartphone sensors for estimating carbon footprint

The use of smartphones has become common, with the increase in utility brought by mobile apps, internet accessibility, and a decrease in price of these devices (Silver *et al.*,2019). People have become used to receiving information and entertainment in a short time, automatically, and prefer it to be user specific. For a new mobile app to be adopted by users with a high level of popularity, firstly, it should not require a sizable change in behaviour (the least inputs and requests) and if possible, it should have the least impact on the battery life.

The use of sensors, such as image sensor, GPS signal, accelerometer, gyroscope, magnetometer, ambient light sensor, microphone, and others (depending on the smartphone) are vital to minimize the frequent manual input of information by individuals, and make the interaction between the user and their smartphone more intuitive (Huawei Device Co., 2021; Majumder & Deen, 2019).

In the context of this work, the use of smartphone sensors is important for automatically detecting the transportation mode and for gathering information of the commute. The information collected by smartphone sensors is used to calculate the individual's carbon footprint. This gathered data also allows to build a user's profile and specify suggestions given, and therefore, promote changes in user's behaviour.

During these travels, there is a continuous recording of a wide spectrum of information, using a mix of different sensors. These sensors allow to characterize the mean speed (with GPS), vibration frequency, linearity, linear acceleration, and magnetic field. The mix of data collected allows to train or test classification machine learning programs that classify the user's status or mean of transportation (Lorintiu & Vassilev, 2016; Mantellos, 2020).

If pre-processing criteria and formulas are applied, the accelerometer receives data that can be converted into linear acceleration. This method allows to determine linear acceleration while reducing the use of GPS signal. The use of an accelerometer as the mains sensor can guarantee data gathering even where the GPS might not work properly, as inside tunnels or in underground systems (Lorintiu & Vassilev, 2016).

The detection of the transport in real time can only be possible using machine learning programs and use of previously recorded data sets. There is a full field of research and study surrounding machine learning based decision methods, mainly related with Random Forest classifier and decision trees. To sum up, the accuracy of the detection is affected by the categories considered, how they are distinguished, the amount/quality of data used to train the model, and how the smartphone is stored during the commute, e.g., in the user's hand, purse, backpack, or pocket (Nabi, 2018; Lorintiu & Vassilev, 2016).

There is also a use of post-processing conditions which help classify the transportation, reduce the detection time, and minimize possible mistakes (Lorintiu & Vassilev, 2016). Here are some examples of those conditions:

- A user cannot change between vehicles, without a transition phase (Lorintiu & Vassilev, 2016). A user cannot switch from a bicycle to a rail vehicle immediately without walking;
- Once the user is in a certain vehicle, he will remain in that vehicle for at least a certain amount of time. For example, a user cannot use a public transportation for only 1 minute (Lorintiu & Vassilev, 2016) ;
- For some transports, as for public transportation, it is possible to set an expected waiting time before using a vehicle (Manzoni *et al.*,2020).

A calibration of the smartphone is often necessary, to decrease classification errors and get the internal noise of the accelerometer, thus ensuring better performance in transport detection. There is a crucial choice as to which sensors to use for data collection. It is based on the energy required and the frequency of its data gathering. In recent research it was mainly used a combination of accelerometer, magnetometer, and GPS (Manzoni *et al.*,2020; Kloeckl, & Ratti, 2010; Mantellos, 2020; Lorintiu & Vassilev, 2016; Slamek, 2017).

For a carbon tracker to operate, it should use lower energy demanding sensors for information collection, to reduce the impact on the battery life, and the smartphone's processing power (Lorintiu & Vassilev, 2016).

3 Methodology

The functioning of a carbon footprint calculator, or carbon tracker, relies on its data sources, and the framework that is set, which can be represented in a flowchart. Both factors dictate the credibility of the values calculated, the versatility of the carbon tracker in different scenarios, and how easily it can be used by the consumer.

There is a gap between the analysed web-based calculators, and the way these can be adapted into a mobile app, while taking advantage of being integrated into a smartphone. The review of these existing calculators allowed to build the proposed models.

The mobility sector has categories with different numbers of parameters needed to calculate the carbon footprint. Therefore, for some areas, as in aviation, the calculation was replicated following current emission calculators. This step allowed to compare formulas, data sources, and to understand the best solution to be implemented in the carbon tracker. The calculation is simpler for the remaining categories due to the use of rigorous emission factors.

The guidelines for calculating emissions from the building sector on an individual basis have been established to create a CO_2 tracker that goes beyond energy consumed, but also considers the emissions of the building in a community setting.

The goal of these proposed models was to allow the use of modern solutions and technologies, but without relying on overly complicated parameters, conditions, and data acquisition.

3.1 Model layout

The frameworks proposed describe how the carbon tracker should operate, within the mobility category. As shown in the example displayed in Figure 4, the operation of these proposed models is divided into 3 phases, arranged in a flowchart, between the moment a user interacts with the application or detects an action, and the final calculation, which always has the output of a carbon footprint in kg of CO_2 per user.

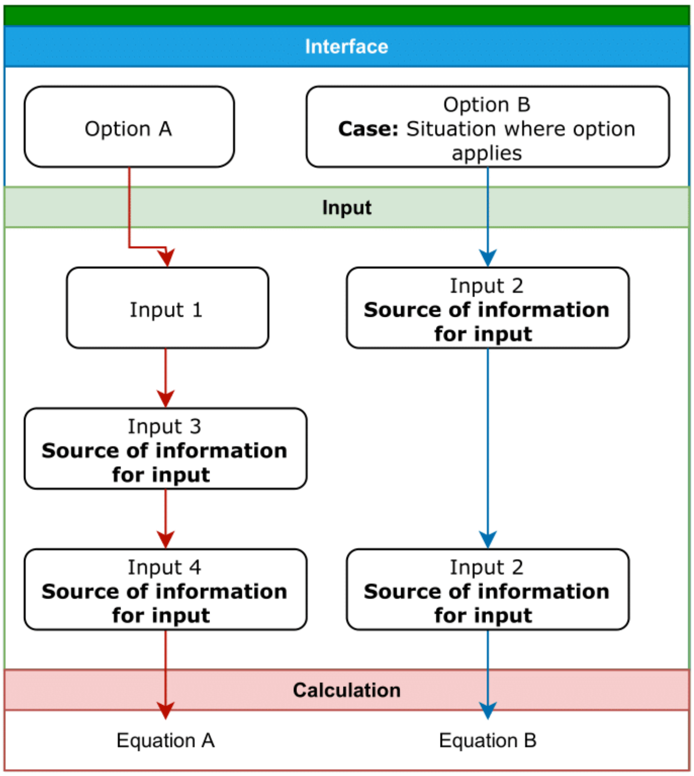


Figure 4 – Example of a proposed model layout.

- Interface – This phase covers the different options for how the carbon tracker is triggered, and in what conditions it should be used. This step may include possible manual input of data by the user, a photo of a ticket, the detection of the transport using smartphone sensors, or even using the data provided by another app, or online service. There is no preferred option, but it is up to the user to decide what best suits him, and his/her lifestyle;
- Input – Different parameters listed needed to quantify the carbon footprint. The information for these parameters can be provided by users (even from the interface stage), measured in real time by sensors, or given by other sources (databases or through APIs). Throughout this stage, the flowchart may have different routes or solutions based on the interface option that began the process.
- Calculation – It contains the formulas that should be used. The indicated formulas are based on other calculators and/or current regulations.

The most viable solution should always be used, e.g. due to better access to information or lower costs. As expected, the value obtained from all these models is the carbon footprint, in the kgCO_2 or kgCO_2eq. Nonetheless, the end calculated value can have different uses, which are transversal to all analysed sectors and sub-sectors. The suggested uses, or outputs, are applicable to every model, and it is based on current calculators, research, and current trends.

3.2 Data use

No matter the blueprint used in the carbon tracker, it is vital to understand what data should be used in the calculations. The data needed to calculate the carbon footprint in mobile apps, can be provided by:

- Real time data - Information collected in real time and immediately accessible, using embedded smartphone sensors, or other online services. In the transport sector, the information may include real distance travelled, electricity consumption of an electric vehicle, fuel burned by a gas vehicle, number of passengers, among others. Regarding the energy sector there is e.g., real time energy consumption or hourly rate applied. The characteristics of the building do not need constant data collection, because the required parameters for the carbon footprint are based on its construction materials.
- Assumed factors – These are estimated or measured values, by certified organizations, such as the United States Environmental Protection Agency (EPA) or the BEIS. These factors are unitary values that can be applied to different scenarios. It can represent an amount of emissions released by a certain action, per time spent, per distance travelled, or per user;

Considering the probability of some scenarios, and the type of information necessary, it is not always possible to estimate the carbon footprint, using only real time data. Even the manual input by the individual, may not be the best solution, because these inserted values may not correspond to reality, because there are based on a subjective perspective. When the use of real time data is not enough, or it is not reasonable to do a manual input of information, the use of assumed factors can ensure the estimation of the carbon footprint. The data recommended in the proposed models, is based on its accessibility and robustness. In most cases, the data proposed is the same as used in other carbon footprint calculators currently available and reviewed.

The access to clear and real time data should always be the priority. From the company's point of view, obtaining this information will either require a direct connection to another service or data provider, e.g., through an airline or car-sharing service, API (Application programming interface), or request the user to manually enter the necessary information.

3.3 Transport Sector

The carbon footprint for transportation should be estimated based on the vehicle model, weather conditions, driving habits, traffic conditions, quality of the road, among other factors. These parameters vary, depending on the individual, people’s culture, city’s road structure, and even climate. However, the analysis performed has allowed to understand that it is not possible to estimate or calculate using all this information, for all types of vehicles.

3.3.1 Aviation

The calculation of emissions from aviation is not as straightforward as for other transports, due to having more variables involved, as the cargo transported, the changes in altitude, or seating classes. Organizations and airlines use different methodologies to estimate the emissions from their travels, but it is often concealed to reduce the possibility of it being replicated in other platforms. This causes a lack of transparency in the methodologies used, which consequently does not ensure scientific rigour in most carbon footprint calculators (Baumeister, 2017).

In this dissertation three existing calculators were replicated, with different methodologies, to pinpoint the procedure that should be implemented in a mobile app, and provide the best available solution for the carbon footprint tracker to function in this sub-category.

ICAO Carbon Emissions Calculator

The International Civil Aviation Organization (ICAO) is a specialized agency of the United Nations (UN), that focuses on aviation. Its main purpose is to maintain and support diplomatic interactions, and to create regulations for aviation safety, security, and environmental protection (ICAO, 2021; IHS Markit, 2021).

ICAO created their carbon emissions calculator to connect passengers to different carbon offset programmes (ICAO, 2021). As shown in Figure 5, the user can input several variables, which are the cabin class, the departure/arrival airports (per flight segment) and the number of passengers travelling (ICAO, 2018).

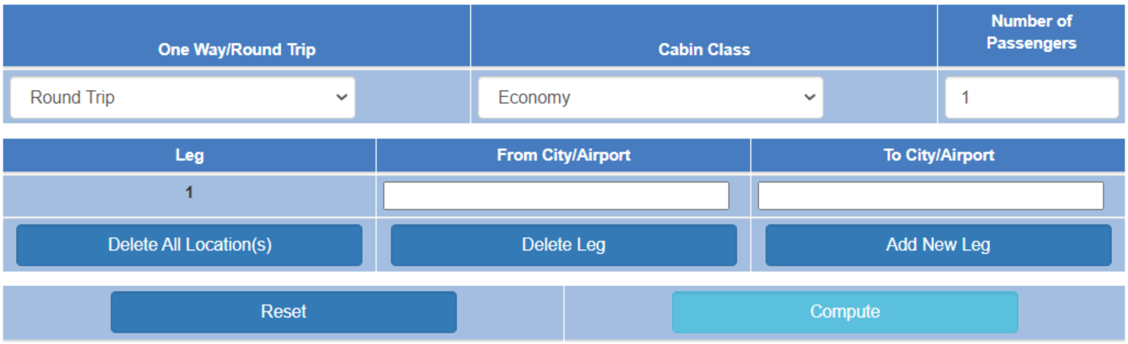


Figure 5 - ICAO's Carbon Emissions Calculator interface, with input variables (Source: ICAO, 2021).

According to the most recent methodology available (ICAO, 2018), here are the parameters considered in their calculation:

- Passenger to freight factors (PTF) – Ratio between the number of passengers and the tonnage of mail and freight transported. These factors are present in the Traffic by Flight Stage database (TFS) and depend on the route considered (ICAO, 2018);
- Passenger to load factors (PTL) – Ratio between number of passengers transported and number of seats available in an aircraft. These factors are present in the TFS database, and depend on the route considered (ICAO, 2018);
- Great Circle Distance (GCD), in kilometres – Distance calculated between the departure and arrival airports based on the coordinates of both airports. This distance is corrected by a factor, based on the location of the two airports, in order to consider detours (in altitude and trajectory) from the straight line between the two airports. This increase can be between 50 kilometres, and 125 kilometres, depending on the distance between both airports (ICAO, 2018);
- Total fuel consumed (TF), in kilograms – The fuel consumption varies with the GCD calculated. This consumption can be calculated through ICAO's Fuel Consumption Formula. Each aircraft model has its own formula based on a group of factors that include the passenger load factor, air traffic, and cabin class flown. In the end calculation, this parameter is the weighted arithmetic mean, based on the frequency the aircraft model does the connection between the airports;
- Number of seats (N) – In this method, the number of seats is not the actual number of seats for every aircraft. It is a calculated number of economy seats, which can fit inside a given aircraft cabin model using a standard cabin layout and dimensions. This process allows to adjust the value of emissions obtained using a factor, if the cabin class selected by the user is "Premium class".

The parameters mentioned are used in Equation 1, to calculate the carbon footprint, per flight. The value 3.16 corresponds to the number of kilograms of CO_2 released by burning a kilogram of fuel.

$$CF = 3.16 \times \frac{TF \times PTF}{N \times PTL} \tag{1}$$

ICAO's factors are based on historical data, and not the present-day conditions. Even the calculations are based on mean values, from different aircraft models. This methodology focuses on the origin and destination airports, and not to a specific air trip provided by an airline company (Baumeister, 2017).

The same data used by ICAO is used for the replication of this calculator, which is publicly available in ICAO's Carbon Emissions Calculator Methodology report, from 2018. However, as seen in previous revision articles, and reports, there is a significant difference in using assumed data and real data, in the aviation category, which can cause major deviations in the result (Jardine, 2009; Baumeister, 2017).

The GCD was calculated using Haversine's formula, seen below, in every replicated calculator (Burnside, 2021). The formula uses the latitude ($\emptyset$) and longitude (λ) of the departure airport and arrival, and the earth radius which is approximately 6371 kilometres. The coordinates of the airports analysed are found in the Ourairports database, which is an open access database created in 2007.

$$GCD = 2 \times 6371 \times \arcsin\left(\sqrt{sin^2\left(\frac{\emptyset_2 - \emptyset_1}{2}\right) + \cos(\emptyset_1)\cos(\emptyset_2)\sin^2\left(\frac{\lambda_2 - \lambda_1}{2}\right)}\right) \quad (2)$$

The factor used in ICAO's calculator to correct the distance travelled to account for possible detours during flight. was not used in the replicated models, because the distances calculated, using Haversine's formula, were already close to the distances obtained in ICAO's calculator.

All the information used for the replication is present in the ICAO's Carbon calculator methodology report. The major detour from the methodology used by ICAO was the number of seats considered. As mentioned before, the number of seats considered is not the real number, but an amount calculated based on the dimensions of the cabin, and the seats. To replace this value, it was used the real number of available seats, per aircraft model, to keep it as faithful to the real settings as possible. This information is present in online sources, such as SeatGuru and Seatmaestro.

The total fuel consumed in each stage, englobes all the aircraft models that travel in each route, based on the frequency in which they travel between the two airports. The information regarding these statistics is in the TFS database. During this project, it was not possible to get access to the TFS database, because it has paid access. Therefore, for the replicated calculator, it is considered a simple average of the fuel consumption, based on the number of aircraft models that do the route.

myClimate Flight Emissions Calculator

If the user does not know any information about the travel, because it is not displayed in the purchased ticket, or it is not even publicly available, ultimately, it is necessary to assume certain estimated values. myClimate's calculator is an example of a calculator strongly based on pre-established factors. The calculator was used to test the reliability of using assumed factors, and to analyse the deviation from the emission values obtained in other calculators.

The myClimate calculator requires the input of the airports of origin and destination, including possible connecting flights to other airports in between, as well as the number of passengers considered, and the cabin class in which the passenger is traveling (myClimate, 2019).

The flight distance is the sum of the GCD, that is calculated based on the coordinates of each airport, and a factor (DC), which is a correction for the detours that frequently happen during air travels. The factors used in myClimate's calculation change based on the flight distance and are shown in Table 1. These can either be associated with short-haul (flight distance below 1500 km) or long-haul (flight distance above 2500 km). If the flight distance obtained sets outside these two intervals, it is used a linear interpolation to determine the emission value (myClimate, 2019).

Table 1 - Parameters used in myClimate carbon emissions calculation (Adapted from: myClimate, 2019).

Aircraft type	Nomenclature	Generic short-haul	Generic long-haul
Average seat number	S	158.51	280.21
Passenger load factor	PLF	0.82	0.82
Detour constant	DC	95	95
1-Cargo factor	1-C	0.93	0.74
Economy class	CW	0.96	0.8
Business class weight	CW	1.26	1.54
First class weight	CW	2.4	2.4
Emission factor	EF	3.15	3.15
Preproduction emission factor	P	0.54	0.54
Multiplier	M	2	2
Aircraft emission factor	AF	0.00038	0.00038
Airport/infrastructure emissions	A	11.68	11.68
A	a	0	0.0001
B	b	2.714	7.104
C	c	1166.52	5044.93

In Equation 3, the variables *a*, *b*, and *c*, allow to do a nonlinear approximation of the fuel consumption from an aircraft. It is possible to obtain the emissions for the travel, airport activities, and production of the aircraft using Equation 3, the flight distance, and the corresponding factors (myClimate, 2019).

$$E = \frac{ax^2 + bx + c}{S \times PLF} \times (1 - CF) \times CW \times (EF \times M + P) + AF \times x + A \qquad (3)$$

The myClimate methodology follows strict guidelines for calculating carbon emissions. The formula used, does not allow the use of information regarding the airline in charge and its aircraft. Therefore, there is no chance of distinguishing options or alternatives for users, beyond reducing the flown distance. This suggestion goes even against the recommendation of avoiding domestic flights (Ritchie, 2020).

For aviation, most carbon footprint calculators consider direct emissions, linked to the direct consumption of fuel during each stage length. Assuming the emissions connected to the production of the aircraft or to the activity in an airport, introduces a relative error, due to the high number of variables that must be estimated.

The replicated model uses the same parameters, shown in Table 1, and the same formula.

Finnair Emissions Calculator

Finnair is the biggest Finnish airline company founded in 1923 (Finnair, 2021). In recent years, it has sought to improve its sustainability in air flights, with the measurement of real fuel burn for each flight and other practices. Finnair has altered its trajectories and procedures, leading to a reduction in costs, and an overall improvement of its financial results (Finnair, 2021).

Therefore, Finnair created a tool for its customers to visualize their own carbon footprint, solely based on the airport of departure and arrival, using the following parameters (Finnair, 2021):

- Pax weight (PW), in kilograms – It is obtained by adding the weight of passengers, their cabin baggage carried, and checked-in baggage weight, following the information in the check-in system. Weight factors are used for the weight of the 0, depending on the type of passenger: child = 35 kg, female 70 kg, male 88 kg, infant 0 kg (Finnair, 2021);
- Cargo weight (CW), in kilograms – Weight of cargo and mail transported in a flight. This information is only accessible to Finnair (Finnair, 2021).
- Fuel consumption (TF), in kilograms – This value is estimated according to the weight of passengers, cargo transported, and distance travelled (Finnair, 2021). The consumption of fuel throughout a flight can be divided into two different groups of phases, the Landing/Take-Off phase (LTO), and Climb/Cruise/Descent phase (CCD). The entire LTO lasts about 30 minutes, and the engine thrust in each phase is defined by ICAO's standards. Meanwhile, the emissions released during the CCD depend on the aircraft

model and the total distance travelled between airports (EESI, 2019; EASA; EEA; Eurocontrol, 2019).

All information is based on Finnair's air transportation records from the previous financial year, which is updated four times yearly (Finnair, 2021). Ultimately, the parameters are applied in the following formula, to calculate the carbon footprint, in kg CO_2/pax:

$$CF = \left(\frac{TF}{PW + CW} \times 100\right) \times 3.15 \tag{4}$$

There are two values multiplied:

- 100 kg, to account for the average total weight accountable by a single passenger (including luggage);
- 3.15 is the mass ratio of CO_2 per fuel consumed,

When comparing with other calculators, and as mentioned in previous research, this is one of the calculators that comes closer to represent real life conditions, and calculate the exact value of emissions. This is only possible due to the use of real time data, and its data reliability (Baumeister, 2017).

For the replication of the calculator, it had to be used alternative sources of information for every parameter. In Table 2, it is characterized the information used in the replicated model of Finnair's calculator:

Table 2 – Parameter's information sources in Finnair replicated model.

Variables	Information Sources
Distance	GCD (Haversine Equation)
Load Factor	ICAO's Factors (ICAO Methodology)
Freight Factor	ICAO's Factors (ICAO Methodology)
Fuel burn data (Aircraft model)	EEA/EMEP – Master emissions calculator (2019)
Seat mapping (Occupancy and dimension)	SeatGuru or Seatmaestro

Originally the calculation is heavily based on the weight transported. Therefore, the type of passengers being transported in the replicated model had to be generalized. It is assumed that half of the passengers are male, and the remaining passengers are female. The weight for each type of passenger is the same as indicated by Finnair.

The major detour is related to the freight and mail, which is being transported. The remaining space occupied by passengers' luggage, is often used to carry additional cargo. The increase in total weight transported affects the fuel burned but, as with other carbon footprint calculators, these emissions should not be linked to the passengers.

Some airlines, such as Finnair, have started to record the fuel burned during each flight, to change trajectories and procedures, and therefore reduce spending's in the long term. Because this information is not publicly available, it was used the EMEP (European Monitoring and Evaluation Programme) /EEA's Master Emissions Calculator, from 2019, to estimate the fuel consumed. This tool currently covers 575 aircraft models, and based on the total travelled distance, it can calculate the amount of fuel burned and the GHGs emitted (EASA; EEA; Eurocontrol, 2019).

3.3.2 Private vehicles

The use of private vehicles gives more control to the user's travels and respective emissions. The user can easily decide which route to take, and their driving habits (aggressive, passive, or defensive driving), which consequently affect the fuel consumption. The fuel consumption can change also due to traffic, weather, type of road, and the conditions of the engine (Shaw *et al.*, 2019).

When it comes to the use of road vehicles, the calculation of the carbon footprint can often be similar across the different carbon calculators. However, when considering its integration in a mobile app, there are some differences in the methodology to apply. This methodology changes, based on two different aspects, the type of vehicle in use, and the type of fuel.

The calculation of the carbon footprint for the use of private and public road vehicles can be identical. However, the availability of their respective data sources is different, which changes the possible solutions and future methods that can be applied. There is also a difference in framework, based on the type of fuel the vehicle has, due to the information needed. Currently, the market is shared by two different type of vehicles, battery electric vehicles, and standard internal combustion engine vehicles (ICE).

Nevertheless, Equation 5 describes the type of calculation that can be done across all road vehicles emission values. The parameters needed for this calculation are the measurement of the distance travelled (*d*), the fuel emission factor (*f*), in gCO_2/l or gCO_2/kWh, and the number of passengers (*N*).

$$\frac{d \times f}{n} = CF \tag{5}$$

A replication of any calculator for these vehicles was not done, because the methodology used for the different carbon calculators remains the same. The biggest difference in the results obtained come from the sources of information used. The reliability of the information is what defines the accuracy of the calculated emissions. The mean through which the information is collected is also based on the possible changes in behaviour that can happen with the use of private or public vehicles.

Private fuel vehicles

The main objective of the proposed framework for this type of vehicle is to calculate the emissions, using the actual conditions of the trip whenever possible, in addition to the distance travelled. This approach gives the user more options to change the behaviour, besides reducing the distance travelled, or using public transport. Considering the variables at play, the calculation of the carbon footprint is not as straightforward as using a formula, so it requires third party programs, and more complex models to calculate the instant fuel consumption, based on the user's driving habits.

This option may not be achievable at first, due the necessity of calibration, or an API connection, among other hurdles. In this case, it is recommended the use of the actual standard emission factors, based on the vehicle's model, and manufacturer. The framework is designed around these two levels of measurement.

Private electric vehicles

Besides the ecological footprint associated with the construction of electric vehicles, these still have GHG emissions connected to the electricity consumption, throughout their remaining lifecycle (Balch, 2020).

The energy mix is rarely the same, and this will have an impact on the individuals carbon emissions when using electric vehicles, and must be considered when calculating it. To correctly link the carbon intensity with the electricity used in each commute, firstly, it is necessary to define, or detect, when the user is charging its vehicle. If possible, this step should require the least manual input, to interfere as little as possible with the consumer's daily routine. The connection between an energy mix from the charging time, and the energy spent in a commute, has been a recent consideration in a few mobile apps, such as in the app EVIO. This association matters more, especially in countries that mostly produce wind and solar energy, which have high variations in the energy mix throughout the day.

3.3.3 Public Transportation

Ideally, the methodology used for public transportation (including road, rail, and maritime public vehicles) should use a database that includes the majority of the vehicles used by different public transportation companies, all around the world. However, for public transportation, it is not possible to use the same methodology as for private vehicles. The main differences between the private and public use are surrounding the vehicle detected, and the number of passengers transported in each travel (Mulrow *et al.*, 2018).

For a private vehicle, it is more accessible to obtain data about the model and maker of the vehicle. Most public transportation companies usually have a diverse fleet that allows them to provide different models for the same trip, especially when it comes to road vehicles, such as buses and taxis. These vehicles can also have different fuel sources, or custom changes to its main structure. Due to this wide range of conditions, it is necessary to have a predefined fuel source to characterize frequent commutes. If the user detects any singular changes from regular commutes, it can change the fuel used in a specific commute.

If the user travels in an electric vehicle, the procedure should follow the same guidelines as for the private electric vehicles. There are two problems that prevent from following that path. Once again, the average energy consumed for different battery electric models are rarely publicly available for public transport models, and the energy charging period time is unknown. The number of passengers transported in a certain travel could be easily changed by the user on the app, but it is not reasonable to ask for the user to constantly guess the average number of passengers present in their commute. The average number of passengers being transported during a commute can drastically change throughout the day and travel. To the extension of the research done for this work, unlike the aviation sector, there is still no centralized database or defined specific emission factors for different realities and countries. Most of the needed information can only be measured and retrieved by each company, which limits the information available to use in this carbon tracker.

Public Road vehicles

There are different realities to consider nowadays in this category, which include buses, taxis, and shared vehicles, which operate using different online platforms. The proposed framework aimed at dealing with different possible scenarios, while maintaining the calculation basis used for private vehicles, shown in Equation 5.

For larger vehicles, e.g. buses, it may not be possible to identify its maker, and model, due to the difficulty for the user to identify the vehicle, or register the information needed. To cover this hurdle, in the model, it included the use of pre-established emission factors, based on the vehicle in which the user is travelling in.

Following the same procedure as for other public transportation emissions calculators, the use of emission factors allows to ease the calculation, and data acquisition. The same calculation and data source will be applied for the remaining transports.

Railway vehicles

In the railway sector, there is still a spread of information across different databases, online information, and company's private statistics. Ideally, the process should be completely automatic, but just as in other public transports, there is a wide range of scenarios, and variables, necessary to estimate with great accuracy the carbon footprint of each passenger.

Today there are different rail systems, which can operate under different conditions, and with various vehicles models. There are too many variables in a train trip, which are difficult to evaluate with the available information. For example, the number of passengers carried changes along the route, and throughout the day, especially on the smaller and local rail system.

Large urban areas, that concentrate a significant amount of population, can have simultaneously a metropolitan, metro, and/or subway systems. These often travel underground, which makes it harder to measure the distance travelled using only the GPS. The biggest difference between the framework for rail transport, and other public transport are the inputs, and parameters to be considered.

Maritime transport

The use of public maritime transportation, such as ferries, is a reality to millions of passengers who use them daily. Just like the railway system, there are different realities across the world, but few countries have estimated their internal transport emissions, or reached an emission factor based on national circumstances.

The information necessary for the calculation of the carbon footprint for the use of maritime transports does not have the same availability of information as in aviation or road sector. Therefore, the proposed model follows almost the same methodology as for the railway system, with the use of emission factors to ease the calculation and fasten its report.

3.3.4 Pedestrian mobility

When looking at the transport sector, usually the GHGs emissions considered are linked to the direct or indirect use of fuel for a certain distance travelled. The same analysis can be applied to each person's daily activities and the resources consumed to obtain that needed energy. Even though the emissions are not direct, it allows comparison with other means of transportation, and shows a true scale between the impacts of each alternative.

3.3.5 Micromobility

When comparing the emissions of the devices used in micromobility, next to other vehicles, the factor with the greatest impact on the carbon footprint is the carbon intensity of electricity. It becomes difficult to replicate the procedure done for electric vehicles with such electric devices, because there are new models being released with different features, and there are no databases that concentrate close to all possible devices.

3.4 Building and energy sector

So far, there is no standardized method to calculate the carbon footprint which assess the entirety of a building's lifecycle (Braulio-Gonzalo & D. Bovea, 2019). There has been made specific and highly detailed analysis to unique buildings, or edification in a specific area, using globally accepted frameworks. These frameworks are designed to rank an infrastructure's environmental performance based on its construction, and it is widely used in the construction sector for newer buildings (Fenner *et al.*, 2018).

The programs most used in analysis for research purposes, and for real life certification are the LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Methodology) (Prologis, 2021). Although they have high quality procedures to do an environmental evaluation, these highly demanding methods would not be feasible to apply in an app, with a wide number of users (Braulio-Gonzalo & D. Bovea, 2019). Both methods have advantages and disadvantages, but the major difference comes from how the buildings are assessed, where BREAM uses licensed experts to examine the building in person, whereas in the LEED method, the professional evaluate the building based on the data collected and sent by the building's design team (Prologis, 2021).

Both are valid ranking methods, but even the data collection used in each one is not feasible to apply in the app, due to the exhaustive amount of data needed to collect in person, or by the user (Braulio-Gonzalo & D. Bovea, 2019). It would represent either a major financial expense or a possible error in the data collected due to subjective user analysis.

In this project it is indicated three means for the carbon tracker to operate in the building and energy category. These methods are not mutually exclusive, which means they can all operate to provide a wider analysis of the user's carbon footprint.

The proposed model is a mixture from the tools and information that are currently available. The purpose of the data collected, and calculated is to develop this information even further, leaving room for the development of a complex map, with the carbon footprint of each user from just the building sector or all sectors. More information may be requested from the first users to start up this mapping, such as the energy certificate of their housing or additional information. Additionally, with the use of data science theory and machine learning algorithms, it should be possible to start estimating other user's building's carbon footprint, based on solid and real information.

There are studies and organizations trying to create highly detailed carbon emission maps, such as CarbonTrace, which uses satellite images and neural networks to determine carbon emissions hotspots. The main difference is that the proposed map for MyGreenApp to develop would focus more on the individuals and households.

4 Results and discussion

4.1 Aviation

4.1.1 Case Studies

When using current carbon footprint calculators, it is common to get different results for the same trip (Baumeister, 2017). Therefore, during this work there was an attempt to replicate the methodologies and calculations of three analysed calculators selected from the aviation sector, using Excel. The replicated models can now be used as a tool to build up the carbon tracker, because it contains and explains all the step and information sources needed. Part of the replicated calculators can be seen in Appendix A, where the inputs are described and displayed.

The three selected calculators made it possible to understand the type of methodology to implement in the MyGreenApp CO_2 tracker, define what type of parameters should be used, and pinpoint the sources of information.

Each of the three calculators was tested using three flights with the same departure, stop-over and arrival airports. The flight's details are present in the Table 3.

Table 3 - Analysed flights for the carbon footprint calculation in aviation.

Flight	Departure Airport	Stop-over Airport	Destination Airport	Distance travelled (km)
1	Helsinki	-	Amsterdam	1525
2	Frankfurt	Helsinki	Dubai	6078
3	Beijing	Helsinki	Tel Aviv	9556

There is still a difference between the information used by the analysed calculators, and what is currently accessible for the present dissertation. In some cases, it was not possible to obtain data from the same source as the analysed calculators, due to the access being restricted.

The carbon footprint, in kilograms of CO_2, obtained by each calculator, and their respective replicated model are shown in Table 4.

Table 4 - Carbon footprint for the flights analysed, with the average value per flight.

Flight	ICAO ($kgCO_2$)	myClimate ($kgCO_2$)	Finnair ($kgCO_2$)	Average ($kgCO_2$)
1	144	284	135	188
2	428	1000	499	642
3	479	1600	656	912

The result of each analysed calculator (AC) is directly compared to the result obtained in their respective replicated calculator (RC). To understand the success obtained in replicating each one it was calculated the relative error, using the next formula.

$$\frac{|CF_{RC} - CF_{AC}|}{CF_{AC}} \times 100\% = Relative\ error \quad (6)$$

To check how close the carbon footprint obtained through the analysed calculators is to the average value, the same basis of calculation the determine the relative error was used to measure the variation to the average value. However, instead of using the CF_{AC} of each calculator, it was used the average carbon footprint value of all analysed carbon calculators.

ICAO Carbon Emissions Calculator

The ICAO's calculator has one of the most complete methodologies out of three analysed calculators, and has the most accessible information. As mentioned before, some information from this methodology was used in Finnair's model. Therefore, it was important to understand the usefulness of the parameters used in Finnair' analysed calculator, and the factors used for replicating them. Table 5 displays the carbon footprint obtained in the analysed flights, in the respective replication, the relative error between these values and the variance with the average values for each flight, displayed previously in Table 4.

Table 5 - Comparison between the values obtained in ICAO's carbon calculator, replicated calculator and average values.

Flight	ICAO ($kgCO_2$)	Replication ($kgCO_2$)	Relative error (%)	Variance from average (%)
1	144	149	3	23
2	428	515	20	33
3	479	591	23	47

The difference between the carbon footprint obtained through ICAO's calculator, and the replicated model, is reasonable and it increases directly with travel distance. This difference can be associated with at least two factors, as described below.

Firstly, there is a higher discrepancy between the number of seats being used in both calculators, as the distance increases. The characteristics of the seating map, for a larger aircraft models, used in long hauls flights, are different from the smaller aircraft models, used in short haul flights. For longer flights, the seats are more distributed among seat classes, and are generally larger than the regular economy class seats. In Figure 6, there is an example of two aircraft's seat compositions and dimensions, in inches, retrieved from one of the recommended sources of information for seating maps.

(a) Airbus A320 (320) Layout 1

Seating details — Seat map key

	Pitch	Width	Seating details
Business	30	18	28 standard seats
Economy	30	18	126 standard seats

(b) Airbus A350-900 (359) Layout 1

Seating details — Seat map key

	Pitch/ Bed Length	Width	Seating details
Business	60 / 78	28	42 flat bed seats

	Pitch	Width	Seating details
Premium Economy	38	19	24 recliner seats
Economy	32	18	187 standard seats

Figure 6 - Seating maps per aircraft model a) Airbus A320 b) Airbus A350-900 (Retrieved June 10, 2021, from www.seatguru.com).

The Airbus A320 was the aircraft model considered for the calculation of the carbon footprint in flight 1, which has a total of 154 seats. The Airbus A350-900 has a total of 253 seats, and was the aircraft considered for the calculation of the carbon footprint in flight 3, for the stage flight between Beijing, and Helsinki.

In comparison to the Airbus A350-900, the Airbus A320 has smaller seats to transport more people, because in shorter flights comfort is not so important. The larger seats, used in Airbus A350, allow more comfortable travels, appreciated in longer flights. As mentioned before, these changes in seat dimensions, and consequently their number, are not considered in ICAO's calculator, which means that the number of seats used for this case study can be much lower than what is being used in ICAO's calculator. Therefore, the carbon footprint associated with each passenger is higher than what is calculated by ICAO.

Secondly, in ICAO's calculator, the average fuel consumed in each stage, englobes all the aircraft models that travel in each route, based on the frequency in which they travel between the two airports. Since it was not possible to consider these frequencies for each aircraft model, the average fuel consumed used in the model will be higher than that obtained by ICAO. By calculating fuel consumption based on an average, it is increasing the representation weight of less efficient aircraft models, which are less frequently used.

myClimate Flight Emissions Calculator

The results shown in Table 6 correspond to the sum of the GHGs emitted from the air travel, airport activities, aircraft production, and jet fuel preproduction.

Table 6 - Comparison between the values obtained in myClimate's carbon calculator and the replicated calculator.

Flight	myClimate ($kgCO_{2\ eq}$)	Replication ($kgCO_{2\ eq}$)	Relative error (%)	Variance from average (%)
1	284	308	8	51
2	1000	942	6	56
3	1600	1474	8	75

There is still a difference between what is obtained in the analysed calculator and the replicated method, even when using the same factors present in myClimate's methodology. It was not possible to determine the source of the deviation between the values. Although the average error percentage obtained in this calculator is one of the lowest when compared to the other replicated calculator, this is attributed to a simple calculation based on general factors, which are relatively simple to perform because there is not much restricted information.

In fact, when comparing with the actual results obtained in the other calculators, shown previously in Table 4, there is a higher disproportion in the results. This variance highlights the difference in precision between using factors and real information, which strongly confirms this is not the best option to apply in the carbon tracker. There is also the limitation in how this methodology could be used to represent real life travels, because the parameters utilized do not change based on the aircraft model or actual occupancy.

Finnair Emissions Calculator

Most of the information used in Finnair's carbon emissions calculator is concealed. Much of the information used for replicating it, had to be assumed data from other sources, such as ICAO. Nonetheless, the results obtained and presented in Table 7 have a relative error near what was obtained in the remaining calculators.

Table 7 - Comparison between the values obtained in Finnair's calculator and the replicated calculator.

Flight	Finnair ($kgCO_2$)	Replication ($kgCO_2$)	Relative error (%)	Variance from average (%)
1	135	141	4	29
2	499	535	7	22
3	656	718	9	28

The use of ICAO's Load and Freight Factors, allowed to replace the missing data, regarding the actual total weight that is transported on the aircraft, without causing a major disparity between the results. The used procedure to replicate Finnair's calculator, could be the best methodology to use in MyGreenApp CO_2 tracker, but it is still suggested a larger sample of tests (in the order of dozens, best if hundreds) to verify it.

The emissions calculated by Finnair's calculator are distributed by the total weight transported. This methodology has a high dependency on the information that can only be provided by each airline, such as, the type of passenger, the occupancy, the cabin weight, and the check-in baggage weight.

It would most likely not be feasible to implement this type of procedure, used by Finnair' calculator, in a mobile app due to the high number of users, and the high volume of information to cover all scenarios. However, it is recommended to confirm this possibility with a software development specialist or team, or even directly with different airline companies. Nonetheless, the use of real data is preferable, even if provided by Flight Data APIs.

4.1.2 Proposed framework

The model proposed for the aviation sector is shown in Figure 7 and it presents some complexity. This is due to the existence of more variables than in the remaining sectors, and because it cannot rely on smartphones sensors. Generally, the use of smartphones is not allowed during air travels, which cuts off the possibility of using onboard smartphone sensors, to automatically detect the air travel, or measure any variable during it. However, these sensors should be used to confirm the air travel undertaken, by obtaining the location before and after the travel. This is an additional feature to validate the information being entered into the CO_2 tracker, as the time spent or the destination and arrival airports, and to ensure that the user is accountable for their transportation impacts.

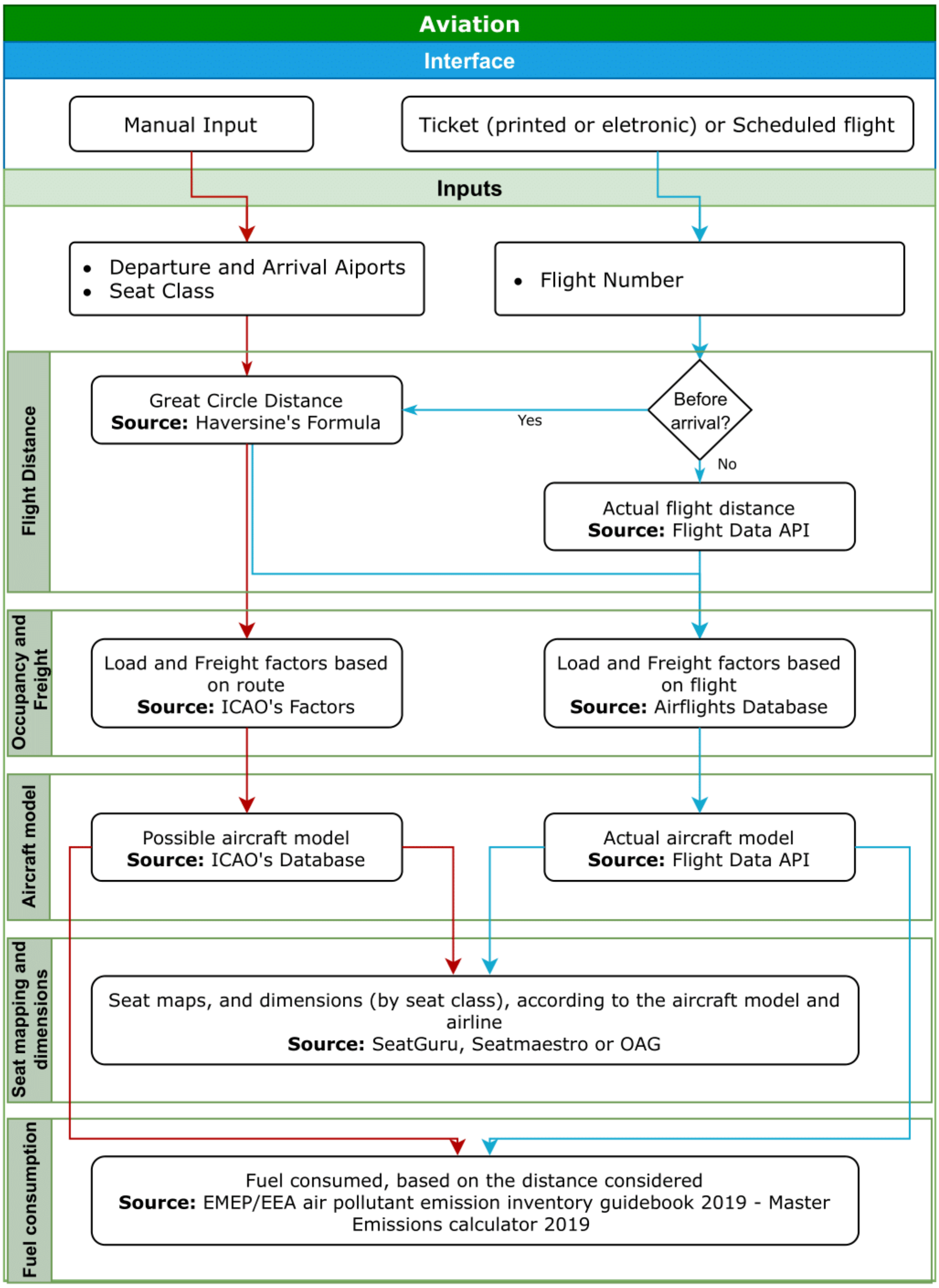


Figure 7 - Proposed model for the category of Aviation.

In the proposed framework, there are two ways to kickstart the calculator, which are stated in the Interface phase. Both can be done before or after the travel has been done, and will define the source of information for the variables being used.

One alternative is based on the route chosen by the user, based on the airports chosen. The option should be used before any type of travel, and allows him/her to have general view over the impact of a given air travel. It lets the carbon tracker provide information without depending on an already scheduled flight, which gives the user the possibility to calculate the carbon footprint way ahead of the actual journey.

The selection of departure and destination airports can also allow the app to give a range of options or suggestions, based on scheduled flights between the same airports. It should recommend possible routes, alternative transports, or aircraft models with lower emission standards. This overview can help the user decide what transport to take, and balance it between the emissions released, the cost, and the time spent. For example, for a domestic flight, if there is a rail system that allows the same journey to be made, it can be suggested as an alternative to travel. For international flights, without alternative transport, the user should be able to compare between different offers, from different airlines, with their respective carbon footprints, as it already occurs in some online services such as Skyscanner.

In the airline industry, every scheduled flight has a corresponding flight number to identify it. Nowadays, there are plenty of Flight Data APIs, such as FlightAware, Aviationstack, or Trawex, which can display the information of specific flights for free. Within these, the user can get information regarding any flight recorded or scheduled. The information usually displayed is the flight distance, the airline in charge, the actual aircraft model, and the expected time travel. Flight data APIs allow to gather this data, and can be valuable in MyGreenApp's CO_2 tracker.

As stated before, the variables sources of the parameters in the Input phase change based on how the process began. If the carbon footprint is being estimated before landing, the flight distance should be calculated, using the Haversine equation. And

However, if the user has a flight number, the pre-flight estimated distance should be the one found in the Flight Data API. This distance is often under the terms "direct flight", "direct route", "straight line" or "planned route". If the user makes the journey by air, the flight distance must be the actual flown distance, which is updated in the chosen Flight Data API. This information is valuable to calculate the fuel burned for each stage flight.

Following this step, it is necessary to know how the occupancy changes in different flights, to correctly attribute the carbon emissions of an airplane to the passengers that are travelling within. Giving the fact that the actual occupancy for each flight is accessible only by the airline in charge, the alternative solution is to use assumed factors, depending on the route or the specific flight. The carbon footprint allocation is estimated based on the two parameters used in some of the analysed calculators: load factor and freight factor.

For analysing the route it should be used the load and freight factors that have been characterized by ICAO, based on yearly data. The most recent factors are presented in the TFS database. As a last resort, these factors can also be found in the ICAO Carbon Emissions

Calculator Methodology (version 11, June 2018), which uses data from the year 2016, being the same factors used for this project.

For the analysis of the flight there are other airflight databases that are more accurate, and use newer information for quantifying the load and freight factors, such as OAG Traffic Analyser, or International Air Transport Association’s (IATA) Monthly Traffic Statistics.

There can be different aircraft models for the same route. These aircraft models define the maximum number of people to be carried, as well as the fuel consumption throughout the flight. As mentioned before, if the user has a corresponding flight number, the aircraft model should be the one indicated for that trip. Otherwise, it should be used ICAO’s TFS database, to compile all the models that fly the same given route, based on the air traffic history. The models compiled will help estimate the fuel consumption through a weighted arithmetic mean, based on the frequency that each aircraft model does the route, just like in ICAO’s methodology.

Due to the fidelity demonstrated in the replicated calculators, it is recommended the use of EMEP/EEA’s Master Emissions Calculator from 2019, or the most recent version available, to estimate the fuel consumed. The database of aircraft models used in this emissions calculator, can and should be extracted to be used in the CO_2 tracker.

The capacity and distribution of each seat class changes depending on the aircraft model, and airline. The different compositions can have slight changes over time, but almost every iteration of seat map is fully described (including seats dimensions and accessories) in the SeatGuru or Seatmaestro platforms, or OAG’s seat database.

This mix of sources allow the option for the user to visualize the carbon footprint associated with a travel, from two different perspectives.

- Predictive point of view - where based on a certain route or flight suggested by the user, it can compare with different airlines or aircraft models, their respective carbon footprint, giving the ability to choose which plane ticket to acquire;
- Post travel analysis – Even if you choose a travel with the lowest emissions per distance, the user can see afterwards (based on the representation that MyGreenApp goes for) the impact a single flight travel, while comparing with other means of transport or sectors present in their daily life.

The formula used depends on the access to the seat dimensions for each seating class. The access to the seat’s dimensions allows to have an alternative for distributing the carbon emissions of an air travel among the passengers seated in different conditions.

Firstly, if the seat dimensions are not available, the calculation proposed is based on the Equation 1, used in the current methodology of ICAO's Carbon Emissions Calculator and parameters tested in previous research (Baumeister, 2017). As mentioned previously, the information used to concern the aircraft will be different depending if the CO_2 tracker is analysing a scheduled flight (based on the flight number), or a route designed by the user. The sources of information should be the same as the ones displayed before, in Table 2, if there is no defined flight number.

However, the use of this formula does not allow to attribute the emissions per passenger, according to their seat class. In ICAO's calculator, it is used an assumed factor to correlate different cabin classes. This is only possible because it is presumed that all seats are economy class, and the number of these seats are based on the aircraft model's cabin dimensions. The difference due to the allocation based on seat class may be lower, with smaller, and less efficient aircraft models. Still, this gives the opportunity for the user to visualize and understand the difference of a simple choice, in their emissions.

If the seat dimensions are publicly available, the proposed formula to use is slightly different, with the addition of the factor of the area of each seat, according to each seat class area (SCA), and the user's seat class area (UCA), both in m^2.

$$CF = 3.16 \times \frac{TF \times PTF}{\sum(N \times PTL \times SCA))} \times UCA \tag{7}$$

In theory, this proposed formula allows to directly correlate the carbon footprint of each passenger with the class seat they are flying in. No research has been found to corroborate this method. For now, it is only a suggested alternative to compensate the lack of information, regarding the weight of the passenger, luggage, and seat, as discussed in Finnair's calculator.

4.2 Private Vehicles

The estimation of the GHGs emitted from the use of a private road vehicle has frequently been a topic of discussion throughout the last decade. The estimation can be achieved using onboard technologies, external devices, smartphone sensors, online services, or with the use of standards. The degree of accuracy changes between each solution, but the key for this framework was to develop a model that could work with different vehicle models, and in different conditions.

4.2.1 Private road fuel vehicles framework

Figure 8 displays the framework for this subcategory, which can be initiated through the automatic transport detection, or with the manual confirmation from the user, when the commute starts. The manual input may allow to slightly increase the battery life, but it forces the user to signal it, each time it begins a journey.

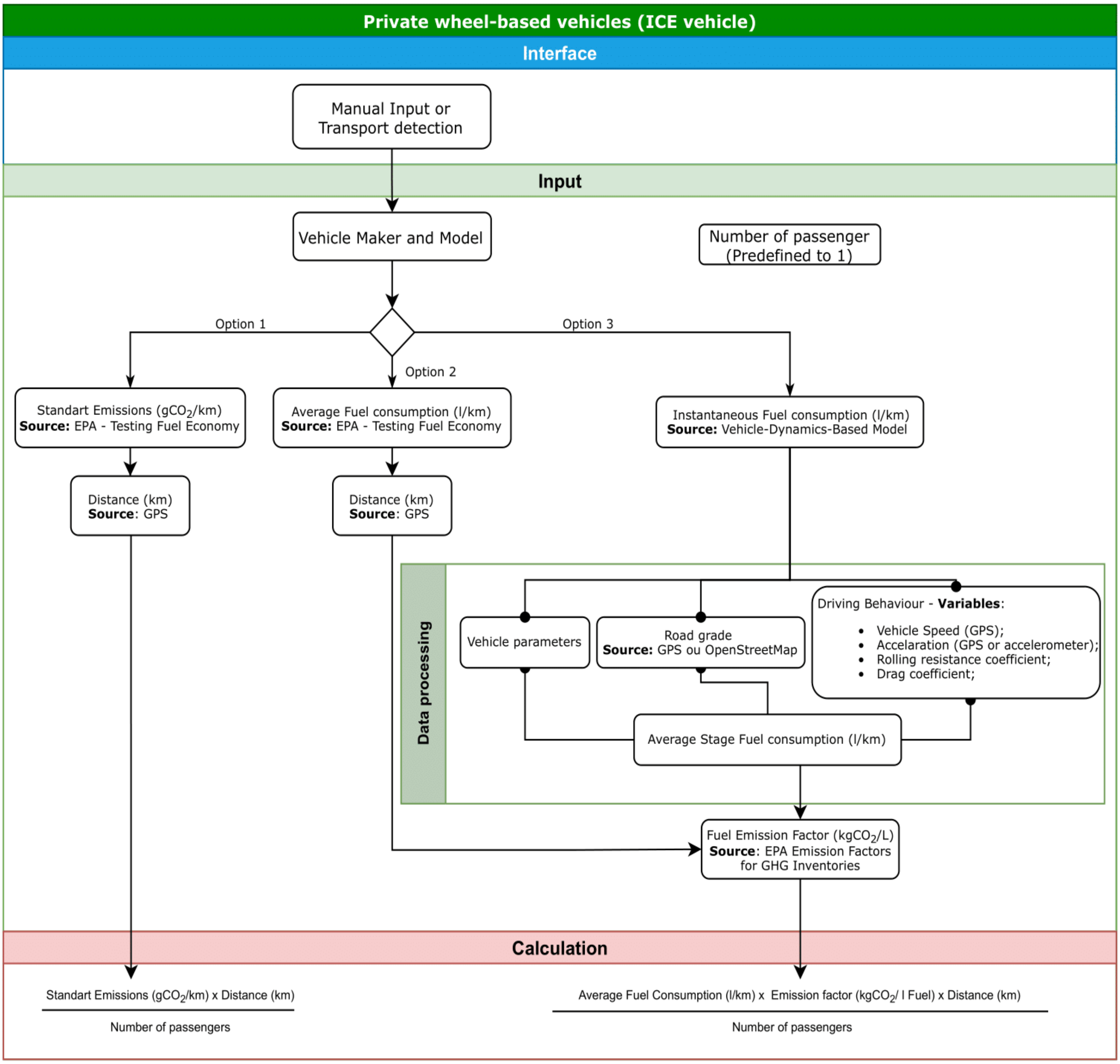


Figure 8 - Proposed model for the category of private ICE road vehicles.

Firstly, it requires the vehicle's maker, and model (car or motorcycle) that the user will be travelling. The input of information can be inserted by the user, either directly, or through the vehicle's license plate. The access to the license plate information eases the input of this information, even for the use of public transportation, by only requiring a single and directly visible information. The information necessary should already be connected to each license plate, and exists in a centralised database, depending on each country, and if it is possible to gain access to it.

The distance travelled should be measured by the GPS signal, as it provides accurate recordings, and it is being used for a longer period. It is also important to consider the number of passengers, towards motivating people to share their personal vehicle, and to avoid using their private vehicle for individual travels. It is not the best practise to constantly ask the user to insert the number of passengers present in a commute. Therefore, for these calculations, the number of passengers should be predefined for only one passenger. After each recorded travel, this number can be changed by the user.

The fuel consumption standards (L/km) or vehicle emission standards (g/km), have been measured for every maker and model vehicle. Right now, most of these numbers are available in the EPA's test data on cars used for testing fuel economy, going all the way to 1984 (EPA-United States Environmental Protection Agency , 2021). If there is a model not included, it is recommended the use of the factors provided by in the United Kingdom BEIS department, for passenger cars. The use of these factors corresponds to the "Option 1" shown in the model.

It is possible to calculate the impact of a certain user's driving habit, using smartphones sensors and directly calculate the fuel consumption. For now, this is still an experimental procedure, as it requires calibration and has only been applied in a specific set of conditions (Shaw *et al.*, 2019). Further down the line, the implementation of this level of detail could help provide more suggestions, to alter the user's driving habits, even slightly, and create a reduction in emissions from their mobility. This alternative is laid out when choosing "Option 3" of the suggested calculator. It could be a strong component to consider in the future for MyGreenApp's CO_2 calculator, to help stand out from other mobile apps of this sort. For now, it is only a hypothesis that requires specific data collection, and procedures. That is why in Figure 8 there is only a category of itself named "Data processing".

Lately, there has been development in a predicative measurement of these emissions. Models such as RouteE and the Google eco-friendly route finder collect a wide range of data concerning the road, and real time traffic, to then suggest an alternative route for the user to follow, that will emit the lowest amount of carbon. The integration of both these options to measure the carbon footprint (pre and post travel), are vital to give the user a better sense about their current impact, and suggest corresponding alternatives (Wilson, 2021; National Renewable Energy Laboratory, 2021).

4.2.2 Private Road electric vehicles framework

As mentioned before, the procedure for electric vehicles must be different from regular ICE vehicles, due to the nature of its fuel. The identification of the vehicle maker and model follows the same guidelines as for ICE vehicles. However, there is a time variable that as to be defined, to proceed with the carbon footprint calculation.

The charging period should be defined by the user. It can indicate the average length of time, which the vehicle is frequently being charged (e.g., between 20:00 and 6:00). Based on this period, it is calculated the average hourly carbon intensity, using the available data in open access platforms, as the electricityMap, or through an API that can have different sources. If MyGreenApp's carbon tracker can establish a connection to the users spending, through the credit card information or online banking, it is feasible to detect transactions associated with the public charging of electric vehicles (in outdoor charging stations).

For this specific sector, it is recommended the use of standard energy consumption factors (Wh/km), measured for each vehicle model. These factors are publicly available, in the EV-database. It is possible to calculate the total energy consumed for a specific travel using the average consumption of electricity for each vehicle model, and the distance travelled (obtained through the GPS sensor). With this procedure done, it is possible to directly connect the electricity consumed with the recent average carbon intensity recorded, following the calculation suggested in Figure 9.

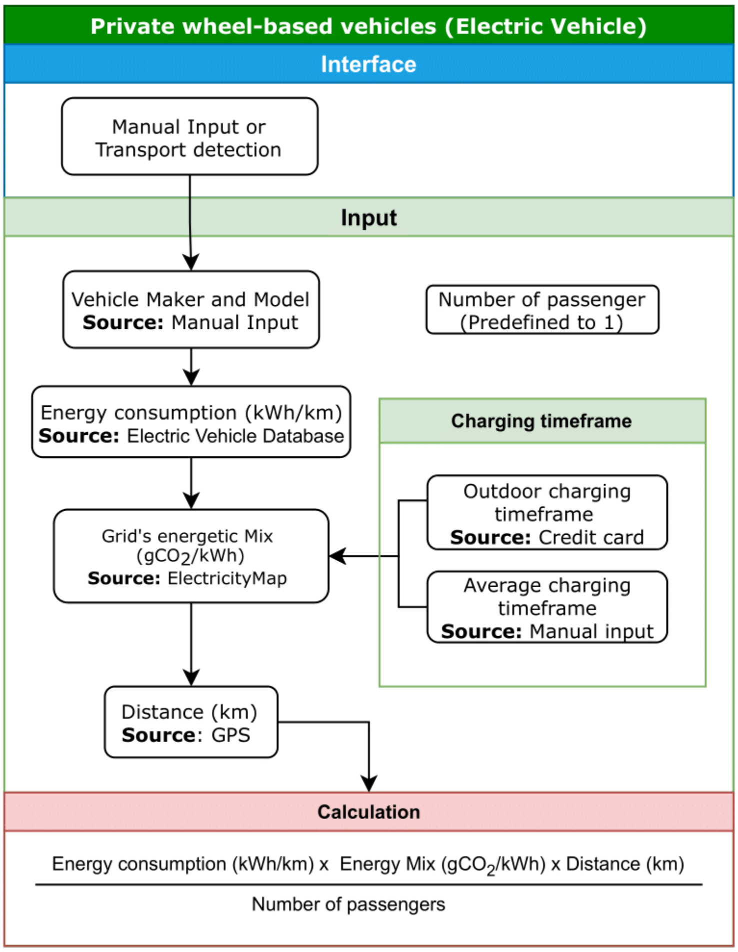


Figure 9 - Proposed model for the category of private electric vehicles.

Ideally, the energy consumption should, once again, be associated with the driving habits of the user. Nonetheless, the estimation of the energy consumption, using smartphone sensors, still needs more research. One possible option to be implemented, is the connection to other mobile apps, or software, directly connected to the vehicle (e.g., Tesla's mobile app). The changes in the users driving habits, using an electric vehicle, do not have such a justifiable impact reduction, as for ICE vehicles, due the scale of the carbon intensity in both fuels.

4.3 Public transportation

4.3.1 Public road transport framework

Nowadays, the use of a shared vehicle can be associated with different solutions, from the use of public transport service (such as public bus), the service provided by a private company (such as Uber, FreeNow or Grab), or a simple carpool, provided by a friend or a family member. The proposed model, shown in **Error! Reference source not found.**, covers these scenarios. It can b e divided into two major groups, carpooling, which is depicted in red and green lines in the model, and larger public transport, represented by the blue line.

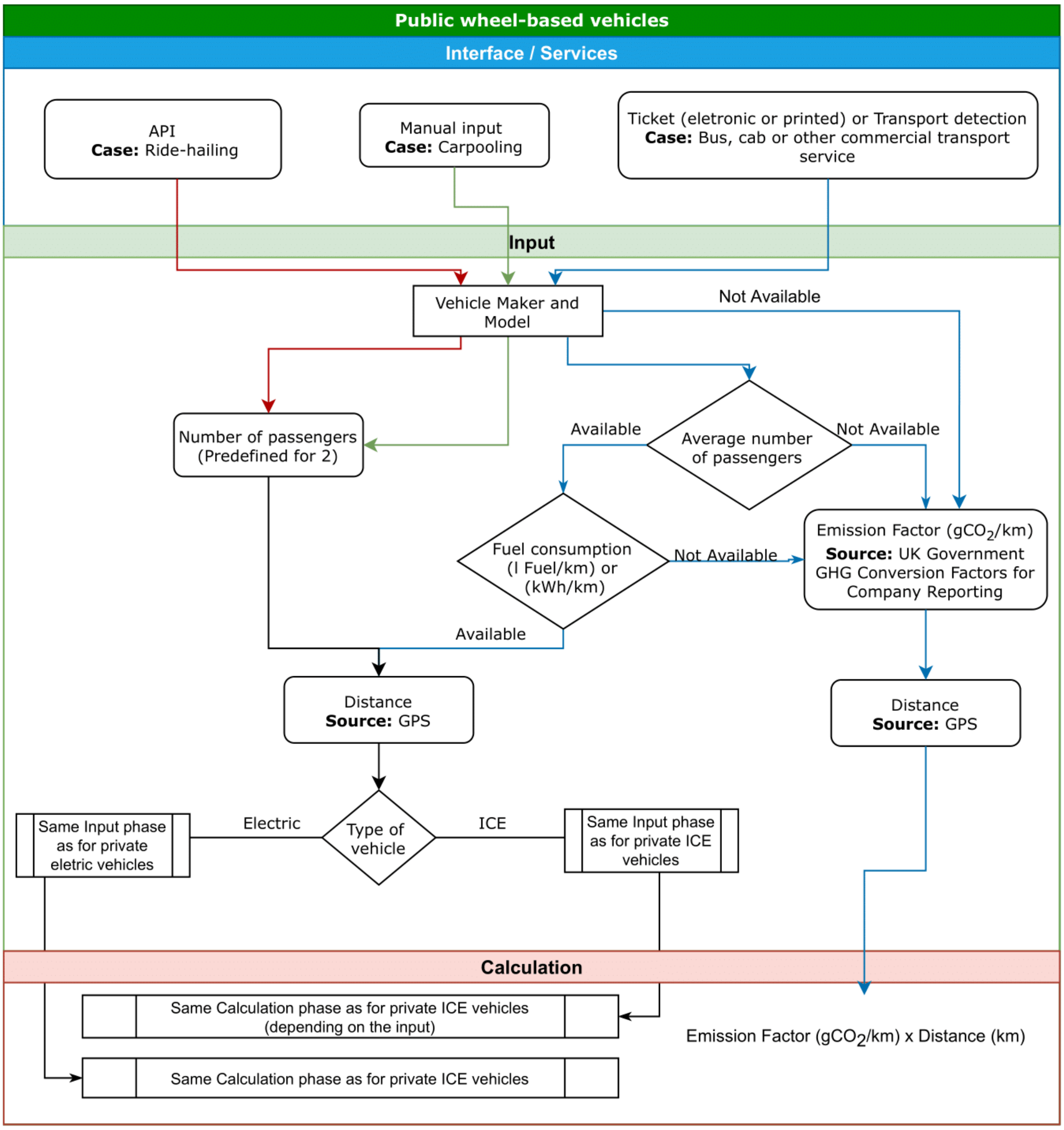


Figure 10 - Proposed model for the category of public road vehicles

Within the carpooling service, the input of data will either be automatic, or manual. Both follow the same methodology previously suggested for private vehicles stated before (electric or ICE), in which requires the vehicle's maker and model.

The manual input uses the same input solutions stated before for private vehicles, where the user is asked to directly insert the information themselves, or through the license plate. On the other hand, if a mobile app already exists for the service used, the information should be directly collected from it. This will depend on the API conditions, and the amount of data that is already collected by the original service provider. It is crucial that there is at least, the recording of the vehicle's maker and model, the distance travelled, and/or the number of passengers present in the commute.

When carpooling, to minimize the manual input required from the user, the number of passengers should be already predefined, this time for two passengers, the driver, and the passenger itself. The remaining model follows the same methodology as for private vehicles (ICE or electric), in which there are different procedures for each type of fuel.

When traveling by a commercial transport service, one of the possible inputs is for the user to report the travel before it occurs, by scanning the acquired ticket. This type of input is not suitable for all scenarios. There are people that, e.g., use the bus daily and already use a pass or subscription. In these scenarios, it is better to set an automatic transport detection that pinpoints the several moments in which the users do this type of travel. For this case, even doe the vehicle specs or number of passengers may not be specified, the use of an assumed emission factor eases both the calculation, and the use of the app.

The information that is more important for calculating the carbon footprint is the number of passengers, and the emission factor of the vehicle in which the user is travelling. If for any type of service, any information is unobtainable or it is not possible to specify the vehicle, it is always recommended the use of the respective emission factors, provided by in the UK BEIS department, for buses and taxis.

4.3.2 Public rail-based transport framework

The use of rail vehicles is one of the recommend transports, due to its efficiency and low emission values. Within the public rail-based vehicles, the main option that kickstarts the carbon tracker, is displayed in the interface section in

Figure 11, and depends solely on the transport detection.

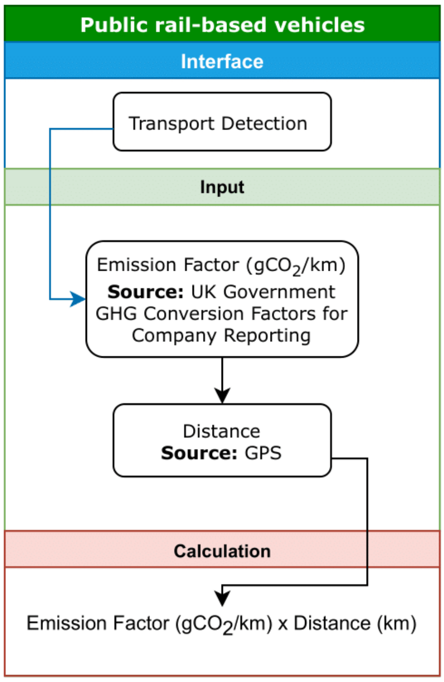


Figure 11 - Proposed model for the category of public rail vehicles.

Although that are travels that require the acquisition of a ticket, usually the information that is needed for the calculation is not present in it. There is a possibility that for longer rail trips (usually done by high-speed trains) this information can be found in a rail transport API, such as tfRail API, but it still requires more study to comprehend what information is truly available in these platforms, and what services are covered by it. The information about the vehicle would allow to obtain an emission standard of its maker and model, but this information is not easily accessible by the user, and the use of a pre-established factor fastens the methodology, without dealing with the constraints necessary, such as the type of fuel, the electricity consumed, or the number of passengers present. For this reason, the process will lead to the use of the respective railway vehicle emission factors, presented in the UK BEIS department.

4.3.3 Public maritime transport framework

The use of marine vehicles is most often used for the transport of cargo. However many people depend daily on such vehicles to cross rivers, or large lakes, to reach their destination. The proposed model for this sector, in Figure 12, follows the same methodology as for the railway system, shown previously, with the addition of the option to include the information regarding the vehicle that the user is on, if it is available. This option will most likely be used when using a private sea vehicle, such a dinghy, a boat, or even a jet ski, or in any other situation where the emission standard of the vehicle is quickly accessible.

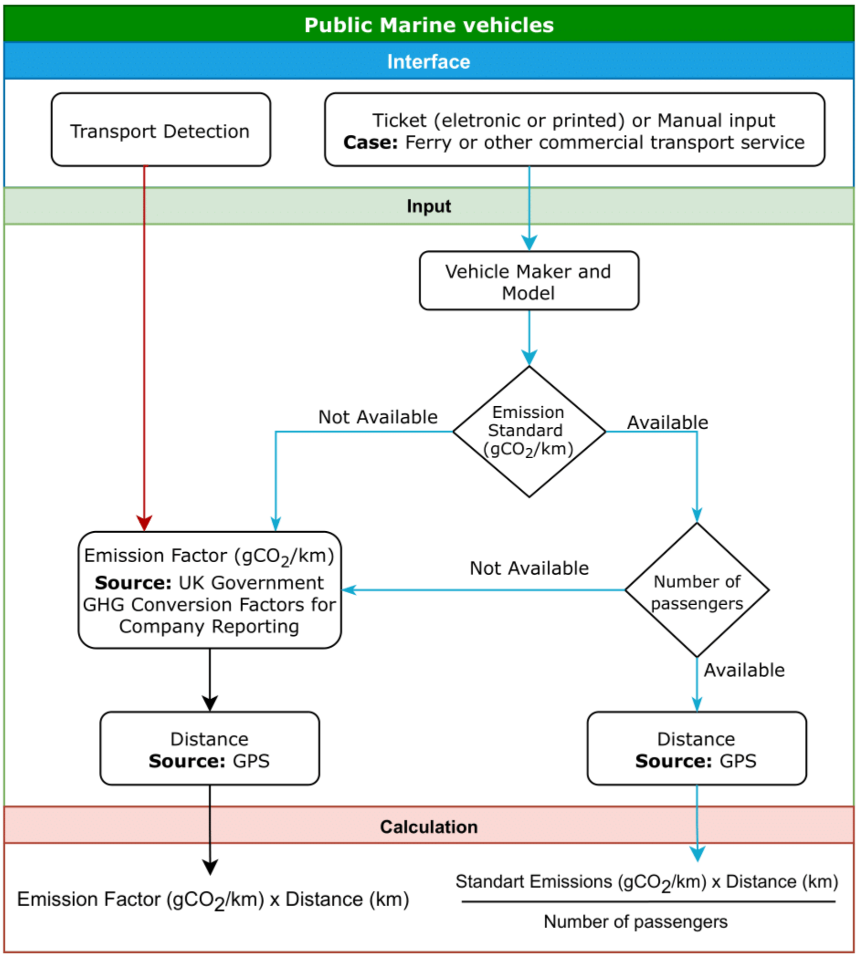


Figure 12 - Proposed model for the category of marine vehicles.

There are people that own a marine transport, often for recreational use, and for these cases, it is not possible to apply the same factors used for the public sector (whatever the size, and power of the ferryboat). The user should insert the information manually regarding the vehicle it uses.

The transport detection should be based on the user's location, but if the user prefers to minimize the battery consumption, it must do so through a manual input, each time it begins a travel by sea.

4.4 Pedestrian mobility framework

The goal of considering the carbon footprint of each commute, even if on foot, is not to place any judgement on every single movement a user might do, but it connects their daily impact to the global spectrum of GHG emissions. The calculation of the carbon footprint of a locomotion allows to compare with other means of transportation, and it is reliant on the user's habits, and diet.

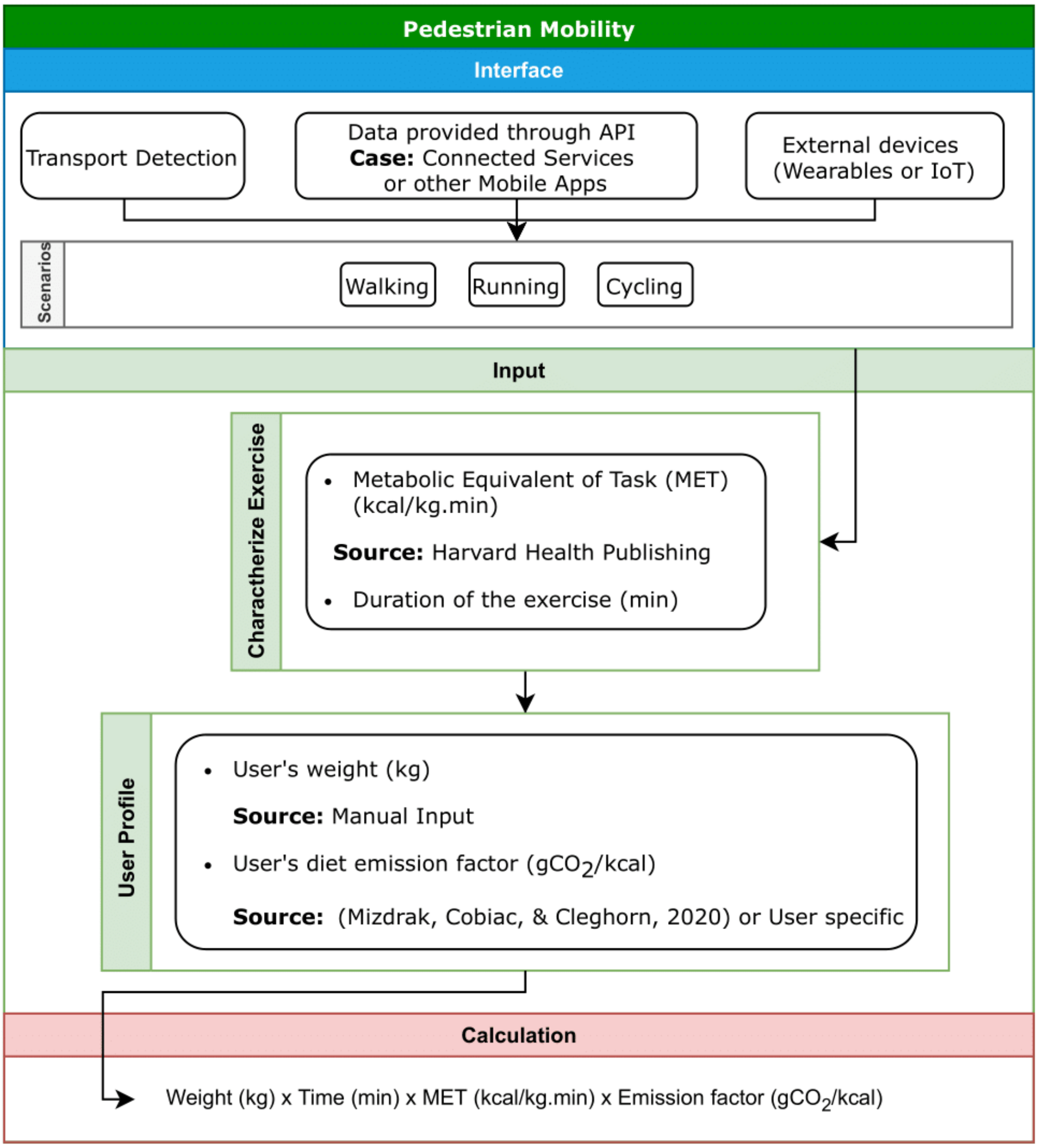


Figure 13 - Proposed model for the category of pedestrian mobility.

Our health is becoming even more connected to everyday technologies. The data collected by external devices, such as smartwatches or health bands, and often stored in mobile apps, is at the core of the proposed model displayed in Figure 13, which are all present in the interface section of the framework (Mizdrak *et al.*,2020).

Even if the user does not have these types of devices, it can be detected by the transport detection program. The conditions, and parameters set to distinguish each activity, such as the vibration amplitude of the smartphone, are crucial to ensure correct detection. The methodology requires the characterization of two factors: the user, and the activity as displayed in the input section. The calculation is based on the energy consumed, in kilocalories (Mizdrak *et al.*,2020).

The measurement of the caloric expenditure is already a procedure used in different mobile apps, related with physical activities or health. There is a metabolic equivalent of task number

(MET), which represents a ratio of energy cost for different activities, related to a simple activity, such as sitting or resting. This value increases with the higher demand in metabolic activity, and oxygen consumption (Roland, 2019; Wood, 2008).

The energy spent must be restored through the food consumed. This is where the emission factor associated with the user's diet comes into play, as shown in the equation used of caloric expenditure.

Understanding how to correlate an everyday diet with a personal carbon footprint, goes beyond the purpose of this dissertation, but this methodology creates a bridge between the information used in two major sectors of MyGreenApp's CO_2 tracker, mobility, and nutrition. With this tracker, it should be possible to someday estimate the user's own emission factor from its diet. If there is an instance where that user specific values are unobtainable, it is recommended the use of emission factors, based on calories spent, which were measured in recent research based on the economic level (Mizdrak *et al.*,2020).

4.5 Building and energy

The calculation of a person's carbon footprint from the building sector is still a new field of study, and it requires high amount of data to correctly assess it. Nevertheless, the proposed solutions, allows to transmit information towards the users, using different techniques of representation and calculation. The mixture of these solutions may be a kick-starter for other carbon calculators, or researchers to streamline the building sector carbon footprint calculations, to be useful and easy to estimate for the individual.

4.5.1 Energy consumption

Ideally, user's electricity consumption should be measured in real-time, using smart appliances, or smart plugs, connected to as many devices as possible. This method would allow to differentiate the consumption for each appliance, link the correct carbon intensity value based on the period in which they operate, and provide more custom suggestions based on their habits. However, it is not reasonable to assume every household must have these devices connected to every appliance, or to expect users to share such detailed information about their consumption.

One solution for calculating the carbon footprint of the operational phase of a user's home, is by acquiring the user's electric bill, and monthly gas spending, following the same methodology as used in other calculators, but minimizing the manual input.

The electric bill allows to determine the monthly energy spending. The month's average carbon intensity can be obtained using the same information as used for electric vehicles, with the use of an API connection with electricityMap. The gas spending should be inserted manually by the user because the information regarding the energy spent or volume of gas consumed, can come from different sources, such as an invoice, or the direct purchase of gas cylinders. Depending on the type of gas, usually methane, it should be used its average emission factor for calculating its emissions, which can be found in EPA's Emission Factors for Greenhouse Gas Inventories.

Finally, we can know how many people live in that house and obtain an estimation of the carbon footprint per user linked to this activity.

4.5.2 **Categorization**

A person can be ranked based on their expected carbon footprint, which are dependent of the residence, and the country in which the person lives. The use of categorisation of user's carbon footprint allow to provide a sense of an objective to accomplish to each individual. It also allows to directly compare between user's carbon footprint inside and outside different neighbourhoods.

According to PORDATA, the average Portuguese carbon footprint, was of 6000 kg CO_2 per capita per year in 2018, considering carbon dioxide from fossil fuels and biomass (PORDATA, 2021).

The construction sector is responsible for 38% of global emissions, of which almost 45% come from residential buildings, as seen in Figure 14, according to the Global Alliance for Buildings and Construction.

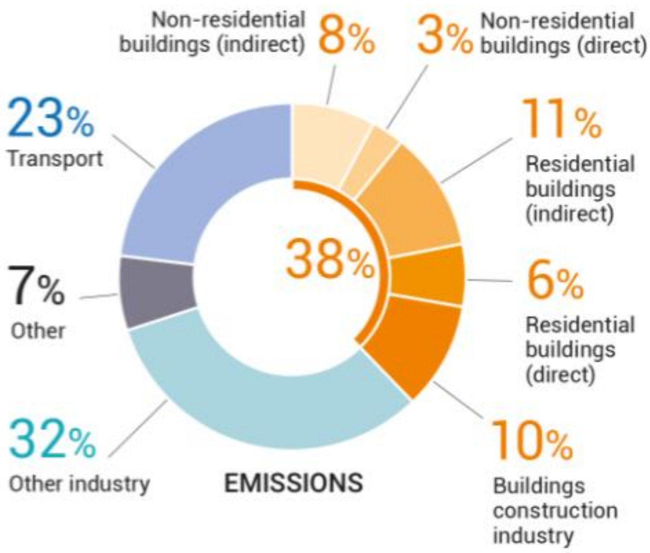


Figure 14-Global Emissions with the characterization of the building sector emissions (Source: Global Alliance for Buildings and Construction, 2020)

Assuming the average Portuguese follows the global trend of CO_2 emissions, it is possible to estimate that the average carbon footprint of residential buildings by the average Portuguese is approximately 85 kg per capita, monthly.

This gives a rough standard of the average value of emissions from residential buildings, and helps create three categories. The boundaries of each category can be modified, based on either the countries average housing energetic efficiency, or population habits. For this study, the limits set for the medium category in emissions, from the building sector, is based on 50 % (425 kg) and 150 % (127.5 kg) of the average carbon footprint value from residential building, for the average Portuguese.

Table 8 - Carbon footprint categories for building and energy sector.

Limits (kg CO_2 monthly per capita)	Category	Colour
>127.5	High	
≤127.5 and ≥42.5	Average	
<42.5	Low	

Table 8 displays the categorization that can be applied to an individual, and the type of representation of its impact, which is easier to assimilate by users, and can promote faster adoption of other energy consumption habits.

4.5.3 Factor based measurement

The consumption of energy is important, but it is intrinsic to the user's habits. There are other factors, such as location, that affect the user's overall carbon footprint, regarding building characteristics or their surroundings.

The use of pre-established factors from the literature, allow to create the steppingstones towards a more complex and detailed analysis of the edification sector, based on the location and housing characteristics. These values were compiled by Fenner *et al.* from other studies that analysed the carbon footprint of buildings in Germany and France, ending with a yearly emission factor based on the house's area (Fenner *et al.*, 2018).

The information regarding the energetic efficiency and housing area can be assessed trough the house's energetic certificate. This document requires a payment, and it is most often only needed for selling or renting a home. If the user is not willing to pay, it could be used the same type of in-person information gathering, that was used by Fenner *et al.*, following the guidelines of ISO 16745 (Fenner *et al.*, 2018). This method could be a possibility if MyGreenApp makes it available only for a subscription service, which could support the financial spending of in-person data collection.

Combining the carbon footprint, and the house's location and characteristics, it should be possible to outline a map, which can be a tool to cross reference with economic and social factors, and can be a service to develop other environmental studies. If this map were to be open source, it would be a way to increase the speed with which information is acquired, and it would be a way to connect the application with its customers.

4.6 Outputs

Carbon footprint representation

The other issue with the concept of a carbon footprint is the way that is represented. The idea of a carbon footprint, and its impact, must be more perceptible besides displaying the brute quantity of emissions. It is important to manage how it is represented visually (graphics, schemes, or in figures) and how the user can percept the quantity of its emissions.

To represent the carbon footprint, the EPA has developed a GHGs Equivalencies Calculator (EPA, 2021). This calculator can convert an emission into several other units that might be more perceptible, for example:

- The number of smartphones charged;
- Barrels of oil consumed;
- Miles driven by the average passenger vehicle;

Such units could be the basis of the representation MyGreenApp decides it is best, or how the user chooses to represent their carbon footprint.

Suggestions and/or Alternatives

The calculation of the carbon footprint should lead to an overview of which sectors have the highest impacts. It should be possible to customize solutions and suggestions based on the profile built for each user based on his/her own habits.

One of the outputs in current calculators usually is the option to offset their emissions, but this action still does not mitigate or cut the emission itself. As stated previously the other type of output that is offered by current calculators are generic suggestions which may not suit everyone, so it is highly important to assure the suggestions given to each user resonates with them. This might be possible using machine learning algorithms to study individual's habits, patterns, or behaviours.

Carbon offset

There is a rising trend in voluntarily supporting a current project, such as the installation of solar panels, reforestation project, or social projects, in order to compensate the GHGs emitted from e.g., traveling or acquiring a product. Carbon offsetting helps mitigate and absorb the GHGs emitted, and especially the aviation sector has seen a rise in the use of carbon offset solutions. Many airlines, such as Qantas, Air Canada, and Finnair, mediate the contact between the customer and certified carbon offset programs (Tirpáková, Socha, Hanák, & Šváb, 2020).

It is important that MyGreenApp ensures that certified carbon offset programmes are displayed, but also that the user is aware that carbon offsetting does not instantly offset the GHG emitted by an action taken today. For example, in reforestation projects, it is often necessary for a forest to adapt and grow up to 50 years, to absorb the emitted GHGs by the user's action to the same level as a normal forest. While carbon offsetting is a means that can be done quickly via smartphone, the best solution is a real change in behaviour.

Gamification and Target Setting

Given the fact that this carbon tracker will be integrated into an app, with its own social network, this creates the ideal conditions to adopt gamification concepts. Gamification is an important key to persuade people to make changes in their lives out of their own volition, through competitiveness or collaboration between users, to reduce their carbon footprint. This concept has already been adopted in carbon footprint related mobile apps, such as GreenApes, and Rvolt, attributing digital rewards in their platforms, or real prizes based on the user's accomplishments.

This incentive can even be accelerated based on targets set for, or by the users. Here are some examples of possible objectives, or "missions", that can be set for each user based on their surroundings:

- "You have a 15 % higher carbon footprint than the average person in your country. Reach this carbon footprint value.";
- "Based on other users in your area, you have the highest carbon footprint in household energy consumption. Try adopting these measures to reduce it.";
- "Achieve the lowest carbon footprint on your journey ever recorded, by using another mean of transport.";

based on their social network, but it will also depend on the information the users are willing to share with other users,

- "Your friend Catarina has a lower transportation carbon footprint for similar transportation habits. Hit the same or lower carbon footprint as her.";
- "Invite three users to a local beach cleaning event.";
- "There are two friends of yours who do the same daily commute as you, but are using the bus. Join them at least one time.";
-

or based on global targets,

- "EU has promised to cut 55 % of their emissions by 2030, compared with the emissions of 1990. For you to fulfil the same goal here is the reduction you should have, each month till then.";
- "The UK has announced it plans on reducing 78 % of their CO_2 emissions by 2035. Achieve at least half of this reduction (39 %) in your monthly carbon footprint";

The rewards obtained by accomplishing these missions, are defined by MyGreenApp. Depending on how the three services are connected and operate, there should be a mix of digital rewards, such as points or badges, and real prizes, e.g., a discount on a product in a store in the marketplace.

Self-confrontation and peer pressure

Using its services, one of MyGreenApp's goals is to help users to understand their current impacts, to show some available and sustainable alternatives, and to understand the importance of taking actions to motivate them to make long-term changes in behaviour. As mentioned before, the carbon footprint is a value that can be hard to understand, especially for people who do not have much experience or knowledge in climate change sciences (Mallett *et al.*, 2013).

With the use of gamification concepts, social network, and the correct representation of the carbon footprint, it is possible to convey not only quantitative information, but also emotional impact, which is more impactful. The user should have an individualistic or collective perspective on its impact, depending on the type of information that is displayed and how it is conveyed. Emotions such as guilt, over the size of their own carbon footprint, or shame, over their carbon footprint in comparison to their group of friends, can be highly influential in long term changes in behaviour (Mallett *et al.*, 2013).

This psychological aspect is a matter that should be considered when deciding how to convey information or suggestions.

5 Conclusion

People may be reluctant to share information from smartphone sensors or other personal sources, due to privacy issues or to save the battery lifetime. Thus, the key in designing an app like the one MyGreenApp aims to achieve, is to make it easy to use through a user-friendly design, and connectivity with other apps and online services. This allows to perform automatic data collection, as well as turning the carbon tracker not only into a measurement tool, but also an engaging service, that can give user-specific suggestions or be useful in other outputs.

Accurately determining GHG emissions and carbon footprint should be a top priority in building this tracker, but it is also very important to ensure that people resonate with what is being shown. The interconnectivity with social media and the sustainable marketplace will be the key to help MyGreenApp standout from other current carbon calculators, and will help merge environmental awareness with people's habits.

The transportation sector is a highly scrutinized industry for calculating the carbon footprint, especially with the rise in people’s environmental concerns, with such trends as the use of electric vehicles. When it comes to private ICE vehicles there is still room for development in the technology to measure instant fuel consumption. Although the public transportation sector is usually what is recommended for users to adopt, there is still lack of available information to improve the CO_2 estimation from these vehicles.

The carbon footprint assessment for the building and energy sector per user is a newer field of study, that is rarely considered in other carbon calculators, leaving an opportunity for MyGreenApp to obtain a competitive edge over other calculators. Considering the new labour and mobility trends accelerated by Covid pandemic, the construction of a multi-layer map as the one suggested would create a leading tool for research in this field, to assist users to make wiser and environmentally friendly choices. With a stronger development and collaboration with municipal entities it could possibly a key component in urban planning.

The use of data science and machine learning to analyse the information collected in the carbon tracker, and all services provided, opens an opportunity for research purposes and uncover patterns in user’s habits and environmental impacts.

Ultimately it is not possible to manage what is not measured. The development of the carbon tracker outlined by MyGreenApp should be encouraged and supported, because it is fully aligned with the current environmental emergency we live in. This development supports the global needed effort to reach carbon neutrality by at least 2050, by giving individuals and organizations, a tool to calculate their carbon footprint quickly and automatically.

6 Assessment of the work done

6.1 Objectives Achieved

There is a leap between a conceptual framework and real-life programming of this CO_2 tracker, the proposed models, calculations, and theory highlighted throughout this dissertation. Still this document can function as a solid foundation for the construction of a unique and innovative CO_2 tracker, because it sums up several aspects important in its development, and propose feasible solutions.

Just as it was set by the company, the proposed models in the mobility sector operate making the most out of the smartphone sensors, and latest technologies, in order to automate the measurement of GHG emissions, and other parameters needed. The construction and energy sectors were more complicated to understand, and the guidelines set out in this work can only be a basis for a very complex framework.

6.2 Final Assessment

The developed work was more theorical than I wished for, but given the conditions this project was done in, it was the right project for me to tackle with a wide and uneven medium of carbon footprint calculations, and GHG measurements across different sectors. I did my best to also consider some basic informatics, while constructing these models to ease future developments from MyGreenApp. I recognise there are many areas and technologies that I could have analysed and referenced, but still tried to provide a concise and useful document.

The work developed concerning the building and energy sectors left much to desire, but it might be the steppingstone towards. It is still necessary more study and experiments (with data collection) in the future to streamline a process that can have a useful outcome, without making data collection tiring for the user or requiring great expense to the company. There is a growing necessity in using data science to analyse high volumes of data as the ones that might be needed to collect and store. There are multiple uses that this tool can have for organisations, but it is necessary to understand how a global use app such as MyGreenApp can be used or reworked to be incorporated into an enterprise environment.

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Appendix A - Developed Aviation Calculators

The replicated calculator were created with the intention to be used later on during the software development of the CO_2 tracker. Each calculator was created in its own excel file, with diferent sheets to separate the inputs, calculations, and aditional data needed to determine the carbon footprint. Figure 15 shows the Inputs that are represented in the sheet used in the replicated myClimate carbon emission calculator.

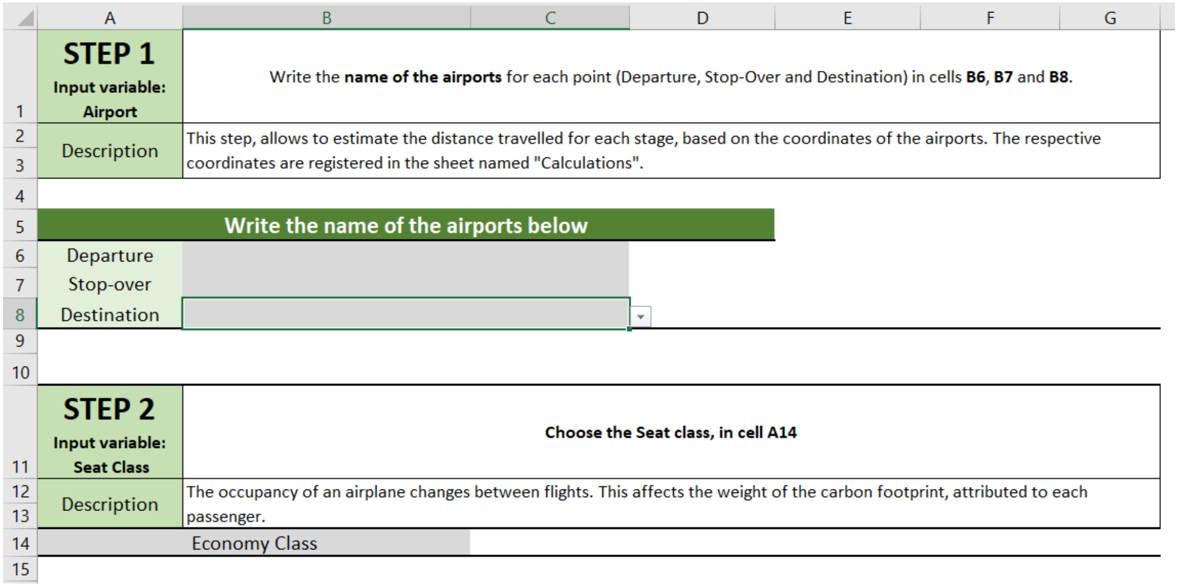

Figure 15-Inputs of the replicated myClimate Calculator, in the excel layout.

The following figures 16, 17 and 18, display the different parameters considered in the Inputs for the replication of Finnair's carbon emissions calculator. Each group of parameters has its own set of steps to help other people to use the excel file designed.

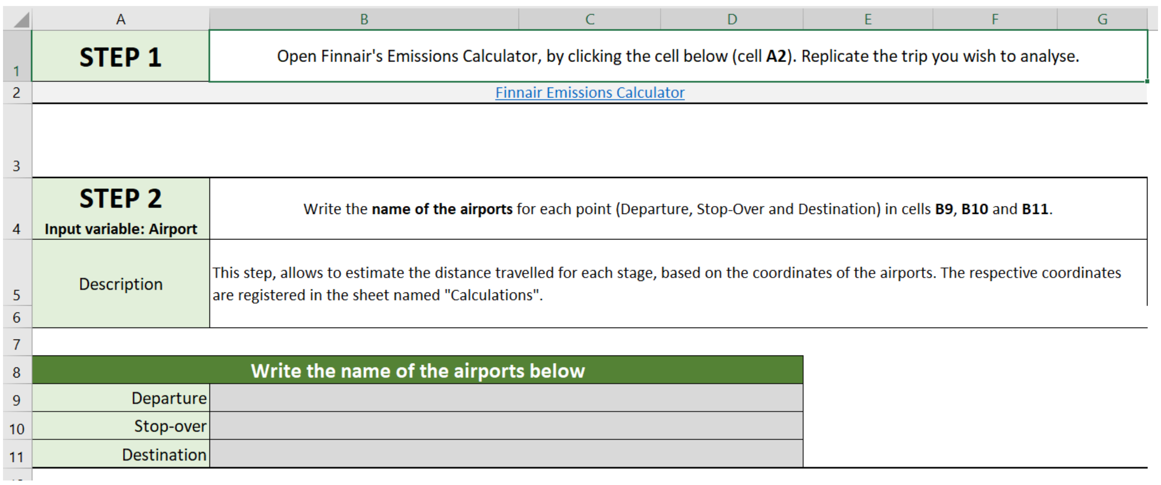

Figure 16-Inputs related to the airport's location used in the replicated Finnair's calculator, in the excel layout.

	A	B	C	D	E	F	G
14	**STEP 3**	Using Finnair's Emissions Calculator, **write the different aircraft models** used for each stage (in cells **B25:B27 and B29:B31**). Check **Figure 1**, in this sheet, for an example of the models displayed in Finnair's Calculator.					
15	**STEP 4**	Click one of the links, in the cells below (cells **C16** and **E16**), to **check the seat composition** for the aircraft models indicated before (in Step 3). **Write the seat composition** indicated for each model, according to the seat class.					
16		Use one of these **options** (on the right):	Seatguru		Seatmaestro		
17–18	Description	Each aircraft model, has different fuel consumptions and seat compositions. These steps allows to compare the carbon footprint among different options for the aircraft model to travel.					
19							
20	**STEP 5** **Input variable: Aircraft model**	Once you've written all the information from Step 3 and Step 4, **select the model** you which to consider in this calculation. You can choose the model in **cells B28** and **B32**, for stage 1 and 2 respectively.					
21							
22	**Write the Aircraft models and seat composition below**						
23		**Aircraft models**	**Seat Composition**				
24			Economy Class	Economy Confort Class	Business Class	First Class	Total Seats
25	Direct flight	A-330-300	178	40	45	0	263
26							0
27							0
28	**Select the model** for first stage	**A-330-300**					
29	Do not fill this stage	A-319	185	0	16	0	201
30		A-320	144	0	14	0	158
31							0
32	**Select the model** for second stage	**A-320**					

Figure 17 - Inputs related to the aircrafts considered in the replicated Finnair's calculator, in the excel layout.

	A	B	C	D	E	F	G
35	**STEP 6** **Input variable: Load Factor**	**Write the Load factor**, per stage, in **cells B41** and **B42**, using the information from Table 1 (after column U). **Check the route group considered, for each stage**, in **cells C41** and **C42**.					
36–37	Description	The occupancy of an airplane changes between flights. This affects the weight of the carbon footprint, attributed to each passenger.					
38							
39	**Write the Load Factor below**						
40		**Load factor**	Route Group considered				
41	Stage 1	81.5%	Central/South West Asia - Europe				
42	Stage 2	74.5%	Europe - Middle East				

Figure 18 - Inputs related to the occupation rate considered in the replicated Finnair's calculator, in the excel layout.

ICAO's replicated calculator follows the methodology appointed previously, but just as in the analysed calculator, the excel file allows to consider different leg flights, or stage flights. Figures 19 through to figure 22 characterise the Inputs used for the replication of ICAO's calculator. As in the Finnair's replicated calculator, in ICAO's replicated calculator it is also contemplated the aircraft models in the excel file, together with their respective number of seats.

	A	B
1	**STEP 1**	Open ICAO's Emissions Calculator, by clicking the cell below (cell **A2**). Replicate the trip you wish to analyse.
2	ICAO Emissions Calculator	
3		
4		
5	**STEP 2** **Input variable: Airport**	Write the **name of the airports** for each point (Departure and Destinations) in cells **B10 to B13**. If there is no Leg 2 (clear cell C12) or Leg 3 (clear cell C13), leave the respective cells empty.
6-7	Description	This step allows to estimate the distance travelled for each stage, based on the coordinates of each airport. The respective coordinates are used in the sheet named "Calculations".
8		
9		**Write the Airports names below**
10	Departure	Beijing Capital International Airport
11	Destination of Leg 1	Helsinki Vantaa Airport
12	Destination of Leg 2	Ben Gurion International Airport
13	Destination of Leg 3	

Figure 19-Inputs related to the airport's location used in the replicated ICAO's calculator, in the excel layout.

	A	B	C-G
18	**STEP 3** **Input variable: Aircraft model**	Using ICAO's Emissions Calculator, **write the aircraft numbers** (in cells **B27:B50**), according to each Leg. If needed, check **Figure 1**, in this sheet, for an example of the models displayed in ICAO's Calculator.	
19	**STEP 4**	To confirm what aircraft models are being referenced, click the link below (in cell C20), to open the "List of aircraft type designators".	
20		ICAO's Code	ICAO Code (click this cell for information)
21	**STEP 5**	Click one of the links, in the cells below (cells **C22** and **E22**). **Check the seat composition** of each aircraft model stated before (in Step 3), indicating the route group and/or airline. **Write the seat composition** for each model, according to the seat class.	
22		Use one of these **options** (on the right):	Seatguru / Seatmaestro
23-24	Description	Each aircraft model, has different fuel consumptions, and seat compositions. These steps allows to compare the carbon footprint, among different options.	

Figure 20 – Step description related to the Inputs considered in the replicated ICAO's calculator, in the excel layout.

	A	B	C	D	E	F	G
28	Write the Aircraft models and seat composition below						
29		Aircraft model	Seat Composition				
30	Aircrafts per Leg		Economy Class	Economy Confort Class	Business Class	First Class	**Total seats**
31	Leg 1	788	263	94		12	369
32							0
33							0
34							0
35							0
36							0
37							0
38							0
39	Leg 2	319	78	42		8	128
40		320	114	42			156
41							0
42							0
43							0
44							0
45							0
46							0
47	Leg 3						0
48							0
49							0
50							0
51							0
52							0
53							0
54							0

Figure 21 - Inputs related to the aircrafts considered in the replicated ICAO's calculator, in the excel layout.

	A	B	C	D	E	F	G
58	**STEP 6** **Input variable: Load Factor**	**Write the Load factor for each leg**, depending on the route group, using the information in table 1 (after column T, of this sheet). **Confirm the route group considered**, in **cells B64, B65, and B66**. If there is no Leg 2 or Leg 3, clear their respective cells.					
59–60	Description	The occupancy of an airplane changes between flights. This affects the weight of the carbon footprint, attributed to each passenger.					
61							
62	Write the Load Factor below						
63	Leg	Load Factor	Route Group				
64	1	81.5%	Central/South West Asia - Europe				
65	2	74.5%	Europe - Middle East				
66	3	82.6%	North America - South America				

Figure 22 - Inputs related to the occupation rate considered in the replicated ICAO's calculator, in the excel layout.