



## Case Study

# A comprehensive data analysis of e-bike mobility and greenhouse gas emissions in a higher education community: IPBike study of case

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## Abstract

Sustainable mobility is a goal for several countries. This kind of mobility depends not only on personal motivation but also on government actions. Encouraging people, particularly children and younger, to raise awareness of the importance and benefits of using sustainable transport, like bicycles, is crucial to developing a sustainable society. This work presents the IPBike project, a Portuguese project applied at the Polytechnic Institute of Bragança. This project aims to promote the use of sustainable transport in the academic community through a rental bike program. This paper presents the results of the over three years of the IPBike project, as well as the user's impressions and suggestions to improve the project. Moreover, a greenhouse gas emission reduction is estimated, comparing the displacement using bikes or only by cars. In general, the results achieved are promising to promote sustainable cities and plan the future since the bikes of the project are constantly rented and the user's positive feedback, which makes the IPBikes a popular community asset. Moreover, the results demonstrate a bike-sharing program's capacity to impact people's lives, improve their health, reduce travel expenses, and impact society and the environment. Besides, according to the estimates, the IPBikes provided a reduction of 7% per year in the greenhouse gases emitted by the users, which means a significant reduction all over the project implantation.

## Article Highlights

1. Encouraging the population to use bikes, especially the youngest is a way to create sustainable cities and plan the future.
2. By estimations, the use of bicycles instead of cars has a great impact on the reduction of emission of greenhouse gases.
3. Encouraging student biking benefits health now, environment, and mobility in the future.

**Keywords** Electric bicycle · Sustainable mobility · Greenhouse gas emission · Data analysis · Bike share system · University travel plans

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## 1 Introduction

In recent years the use of bikes as an urban transport has been gaining more followers, whether through electric bikes (e-bikes) or traditional bikes. Although in many places bikes are seen as archaic transport, a childhood toy or sports equipment [1], the usefulness of the bike goes far beyond that. Cycling practice contributes to sustainable mobility development and their practitioners' well-being and health.

In developed countries, the use of bikes in streets is more widespread; for example, among the European countries, the Netherlands is where citizens most use bikes for their daily mobility, with 36% of urban cyclists. In the subsequent positions of the same list is Denmark with 23%, Hungary with 22%, and Sweden with 17% of the population using bikes as their primary daily means of transport. However, this number is not a reality for all European countries. At the end of this list there is Malta with a percentage close to zero, and, Chipre and Portugal both have only 1% of the population using bikes as the means of transport [2].

The use of bikes in the urban environment is associated with cultural, social, geographic, and governmental aspects, mainly with the infrastructure that the city offers to its citizens. These aspects are more propagated in the cities of the developed countries, as presented in the Global Bicycle Cities Index 2022 (GBC22) [3], which considers 90 cities around the world and evaluates the most cyclist-friendly ones, pointing out the cities Utrecht (Netherlands), Munster (Germany), Antwerp (Belgium), Copenhagen (Denmark), and Amsterdam (Netherlands) as the top 5 list. On the other hand, developing nations find more challenging to devise strategies to increase the use of bikes, including but not limited to negligible cycling culture, a car-oriented culture, city infrastructure, and political initiatives [1, 4]. Thus, at the end of the cite score GBC22, are Moscow (Russia), Tbilisi (Georgia), Bangkok (Thailand), Medellin (Colombia), and Lagos (Nigeria) [3], all of them belonging to developing nations.

Bike-sharing programs are one of the possibilities to increase the number of cyclists and a way many countries have found to encourage sustainable personal transportation. In this case, there are bike-sharing programs in which it is possible to rent a bike for a short time [4], which is very useful for local citizens and tourists visiting the city. Furthermore, there are programs to rent a bike for a long time; in this case, the users pay monthly fees to stay with a bike for an extended period, up to their convenience. In both programs, electric bikes have been gaining more and more space in urban environments due to their practicality.

The cycling practice provides several personal, social, and environmental benefits, such as the prevention of a large number of severe and chronic diseases [5], alleviating of traffic congestion, transportation cost reduction, greenhouse gas emissions (GHG) reduction and air pollutants, and improving multimodal transport connections [6–9]. Moreover, a study conducted in Dublin, Ireland revealed that the implementation of a bike-sharing system had a positive impact on the urban economy. The introduction of this system resulted in significant time savings during journeys and enhanced connectivity, which, in turn, bolstered the productivity of local economic activities [10]. Furthermore, multiple research studies delve into the effects of bike-sharing programs on carbon emission reductions analyzing the policies and systems of carbon emissions trading markets, and their influence on the promotion of bike transportation [11–13]. Besides, according to [14], e-bikes are promising solutions to reduce the greenhouses gas impact of a region's passenger transportation system since an individual e-bike could provide an average reduction of 225 kg CO<sub>2</sub> per year.

As mentioned, Portugal is at the bottom of the European countries where citizens use the bike for their primary mobility. To promote bike use, the Portuguese government launched in 2017 the U-bike project [15]. This project is addressed to promote the use of bikes, particularly in academic communities, aiming at traveling between home-school through rented bikes. One strand of this project is the IPBike project [16], which consists of implementing the electric bike in the academic community of the Polytechnic Institute of Bragança (IPB), located in a small city in the Northern part of Portugal. The IPBike project is an important opportunity for a paradigm shift about the means of transport used in daily displacement in Bragança, particularly in the community of IPB. Thereby, this study presents the IPBike results over three years of implantation, possibly evaluating the data of the IPBike users, exploring their overall perceptions about the project, and evaluating the project development and future actions for its continuity. Moreover, an estimation of the greenhouses gases emission reduction is presented to measure the impact of the IPBike project on the environment.

Thereby, the main contributions of this work lie in the thorough analysis of the results achieved by the IPBike project, encompassing critical areas such as the acceptance of bicycles within the academic community, mobility patterns, and associated environmental impacts. These results hold significant relevance in guiding the future planning of the project and provide valuable insights to potential investors interested in expanding the project beyond the academic sphere.

This paper is organized as follows: after the introduction, Sect. 2 presents some benefits of bike use for human health and for city mobility. After that, Sect. 3 introduces the IPBike project. The project results and the user's impressions are described in Sect. 4, and a discussion about these topics is presented in Sect. 5. The last section, Sect. 6, concludes the paper and identifies future paths for improving the IPBike project.

## 2 Background

According to [5], the more tangible benefits of cycling are based on 3 dimensions of sustainable development, subdivided into three other categories: the environment (environment and climate; energy and resources; health), the economy (business; technology and design; time and space) and social affairs (social affairs; mobility, diversity of cultures). The presence of cycling infrastructure and services plays a crucial role in influencing individuals' decisions to commute using a bicycle [17]. Thus, one effective way to encourage cycling is by offering urban infrastructure such as bike paths, bike lanes, and bike routes in the cities. Besides, government actions such as tax reductions for bikes and bike-sharing programs are convenient when there is a wise increase in cyclists. As mentioned by [17], cyclists highly prioritize off-street bike paths and value neighborhood bike lanes that incorporate traffic-calming features. In turn, [18] investigates the environmental correlates and determinants of bike use for displacement in Barcelona-Spain. According to this study, the presence of more public bike stations and higher levels of urban green spaces can potentially lead to an increase in the use of bicycles by adults in urban environments. Similar results worldwide are also referred to in [4, 17, 19, 20].

### 2.1 The impacts of e-bike or cycling on health

The advantages of engaging in physical activities are already well-documented in the literature. In addition to yielding visible benefits like weight loss and muscle development, physical activity also offers imperceptible advantages. Moderate physical activity, for instance, reduces the risk of Alzheimer's disease by 29% and decreases cognitive decline by approximately 26% [5]. Studies have shown that physical activity is linked to a 17% lower likelihood of developing depression, as evidenced by a comprehensive meta-analysis [5]. According to the same source, cycling prevents 18110 premature deaths annually within the EU-28, translating to an economic value of EUR 52 billion per year in terms of public health. Cycling further promotes a healthier lifestyle by serving as a preventive measure against various severe and chronic diseases, such

as cardio-vascular diseases [21], diabetes (type 2) [22], cancer [23], osteoporosis [24].

Irrespective of whether a bike is electric or not, cycling serves as a physical activity that bestows numerous health benefits. An intriguing comparison of physical activity levels between e-bikers and traditional cyclists was conducted by [25]. The research highlights that e-bikes are favored by individuals who previously used private motorized vehicles and public transportation. Additionally, the emergence of the COVID-19 pandemic brought about significant shifts in the concept of urban mobility [26]. To minimize infection risks, people began to increase their walking and cycling activities while avoiding public transportation [27, 28]. Notably, bike-sharing programs gained heightened popularity during the pandemic [29]. Consequently, a pressing concern for the post-pandemic era involves sustaining the practice of cycling among these newfound enthusiasts.

Encouraging cycling could play a significant role in mitigating or even preventing another health concern, particularly in children and young individuals—the issue of overweight. This problem has become a significant health risk for this generation. An alarming trend of overweight cases has emerged among children and youth in the 21st century [30]. The prevalence of sedentary activities such as virtual gaming and virtual reality has led to reduced physical movement and energy expenditure, contributing to weight gain. Engaging in regular physical activity is pivotal in averting and managing childhood obesity, a condition linked to various health challenges during youth and an increased susceptibility to noncommunicable diseases [5].

Promoting walking and cycling to school serves as an effective strategy to enhance physical activity among young people and can potentially counteract excessive weight gain [31]. Moreover, the benefits of walking or cycling to school extend beyond weight management. According to [5], individuals who choose these modes of transportation exhibit a concentration level that is 8% higher, even 4 hours after arriving in the classroom, compared to those who are driven to school by car.

In Portugal, the government has taken steps towards fostering sustainable mobility by promoting bike usage among students, starting with those in higher education. To this end, the U-bike project provides both electric and conventional bikes for long-term rental to students, professors, and staff members [15], as presented in Sect. 3.

### 2.2 Bikes inside the cities and future mobility

Cities worldwide face various challenges such as burdened transportation systems, air pollution, traffic noise, and congestion. Addressing these issues and planning for future mobility is an urgent task. Sustainable smart and electric

mobility can play a vital role in overcoming these challenges [32]. Bike-sharing systems have emerged as green and sustainable transportation options that also encourage physical activity. Studies conducted in cities of different sizes and countries have reported promising results from the adoption of bike-sharing systems [4, 17, 33].

Transport policy initiatives are necessary to have rapid and long-term adhesion to sustainable means of transport. In the case of bikes, to establish strategies aimed at smart cities, the initiatives could be related to bike-sharing programs, paths, docking stations with recharge points for e-bikes, or mobile applications for bike-sharing programs as the real-time location of the bikes and their availability.

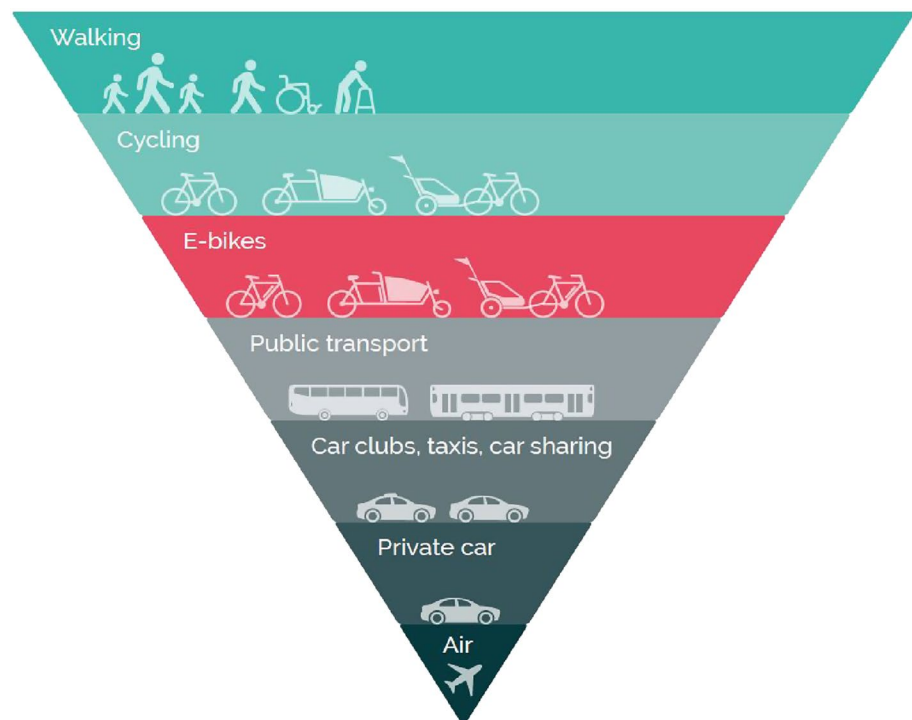
According to [1, 34], the rate of road occupation by cars (with an occupancy rate of 2 people per vehicle) is 6.4 times higher than the rate observed in bikes. Considering the environmental benefits and carbon emissions, [35] indicates by a study done in England that if e-bikes are used to replace car travel, they would be responsible for a reduction of car carbon dioxide (CO<sub>2</sub>) emissions by up to 50% (about 30 million tonnes per year). The study [36] affirms that walking or cycling could realistically substitute 41% of short car trips, saving nearly 5% of CO<sub>2</sub>eq (carbon dioxide equivalent) emissions from car travel.

Given all the problems pollution causes for human beings and the environment, actions are needed to contain the worsening of the current scenario. One of these actions could be the change in the form of human locomotion. Figure 1 shows the sustainable transport

hierarchy [35]. As evident, walking or cycling (traditional bicycles) are the most eco-friendly modes of transportation, with e-bikes coming next in line. Nevertheless, walking or cycling may not be feasible for medium and extended distances. Consequently, the e-bike emerges as the optimal choice when considering sustainable transportation options.

Interesting research is presented in [8], in which the author quantifies greenhouse gas emissions reduction from bike share systems in eight USA cities. The author's model considers factors such as trip distance, purpose, start time, accessibility of public transit, and historical transportation mode choices to estimate the modes of transportation that are replaced by bike share trips. The results point out that the annual GHG emission reductions contributed by the bike-sharing systems vary from 41 tons of CO<sub>2</sub>eq (Seattle) to 5417 tons of CO<sub>2</sub>eq (New York City), while the emission reductions per trip range from 283 to 581g CO<sub>2</sub>eq. The author discovered that there was a linear correlation between the total annual reduction in greenhouse gas emissions and factors such as the number of trips, bikes, and docks in bike share systems. Stations located in city centers made a significant contribution to the overall reduction due to their high trip volumes. On the other hand, stations situated further away had higher emission reductions per trip, likely because of longer trips and greater substitution of car trips.

**Fig. 1** E-bikes sustainable transport hierarchy [35]



### 3 The IPBike project

Sustainable mobility is an increasing goal for several countries; however, it is necessary to find attractive ways to promote it. In this sense, some actions have been developed by the Government of Portugal, such as the U-Bike project, coordinated by the Institute for Mobility and Transport (IMT) and financed by the Operational Program Sustainability and Efficiency in the Use of Resources (PO SEUR) [15, 37].

The U-Bike is a Portuguese national project that aims to promote sustainable mobility, focusing on bikes, particularly the electric ones, directing efforts on young people, especially high school students, which can be extended to the academic community, in general. The project started to be modeled in 2017, when 15 higher education institutions were selected to implement the project. The Polytechnic Institute of Bragança (IPB) was one of these institutions, which received the first bikes in March 2018, Fig. 2a presents the IPBike, and Fig. 2b is one of the docking stations in IPB.

The IPBikes are available to any member of the IPB academic community (professors, researchers, students, and other staff). To obtain an IPBike it is necessary to submit a request in the IPB system through personal credentials, available to every member of the academic community of the IPB. The request form asks for personal information such as the period in which the person wishes to use the IPBike and the distance they intend to travel daily with the bicycle, the type of transport used daily and the average distance covered in kilometers. Furthermore, the person must agree with the contractual

terms involving rules of use, insurance and maintenance plan, access conditions, and ranking rules for obtaining the IPBike. After submitting the form, if a bicycle is available, the person will receive an e-mail with the information to pay the deposit and the monthly payment. After that, the bike can be delivered to the user. If no bicycle is available, the person joins a waiting line and must wait for a notification email when a bicycle is free. Before getting an IPBike, the users must sign the contract and a term of responsibility, indicating that they are responsible for the IPBike during the contracted period.

Since the demand for IPBike is greater than the supply, some ranking rules are followed to allocate the bikes to users. Preference will therefore be given to users who commit to completing the greatest number of daily kilometers on the bicycle, to the detriment of kilometers of individual motorized transport and requesting the bicycle for a longer period of use (between 6 and 12 months). In addition, preference is also given to using bicycles when traveling for curricular internships or official service missions, to the detriment of individual motorized transport.

The IPBike project has financed support from U-Bike project of 241k euros, to buy 100 e-bikes and adapt the infrastructure of the IPB's parking for the coexistence of the bike and cars. During the last three years, each bike has been rented for 10€ euros per month with a cash deposit of 40€ per IPBike contract. Per month, the rent of all IPBikes generates a financial value of 1000€ euros approximated, which is the minimum value to maintain the project sustainable at IPB installation, considering that the main focus of IPBike project is to promote sustainable mobility rather than having a financed profit project. With this month's financed support, the IPBike project guarantees



(a) IPBike



(b) Docking station in IPB

Fig. 2 Bikes at IPB

a maintenance area to monitor the number of kilometers displaced by each bike and perform maintenance corrections or preventive maintenance.

IPB is located in Bragança, a small city in the inland Northern of Portugal. Beyond the IPBike project, the city of Bragança also has its own bike-sharing system. This system has 20 electric bikes available for the local population and tourists. Besides, the city offers a 6 km bike-path network with access to the city's main public spaces. One of these bike paths is the "Fervença bike path". This bike path has an extension of approximately 3.8 km, contours the IPB campus, and moves to the city centre. Figure 3 presents the map of Bragança, highlighting the location of the IPB and the city center location, as well as the bike path that goes around the IPB. As a small country city, Bragança Urban transportation is limited to a few buses operating on a restricted schedule. This situation leads to a heightened reliance on private cars and individual means of transportation. Due to these circumstances, promoting bicycle usage has become a highly advantageous option for the population.

It is essential to highlight that after the first year of the IPBike project, the number of user candidates is frequently higher than the number of IPBikes available, usually more than 50 users candidates are waiting to rent an IPBike,

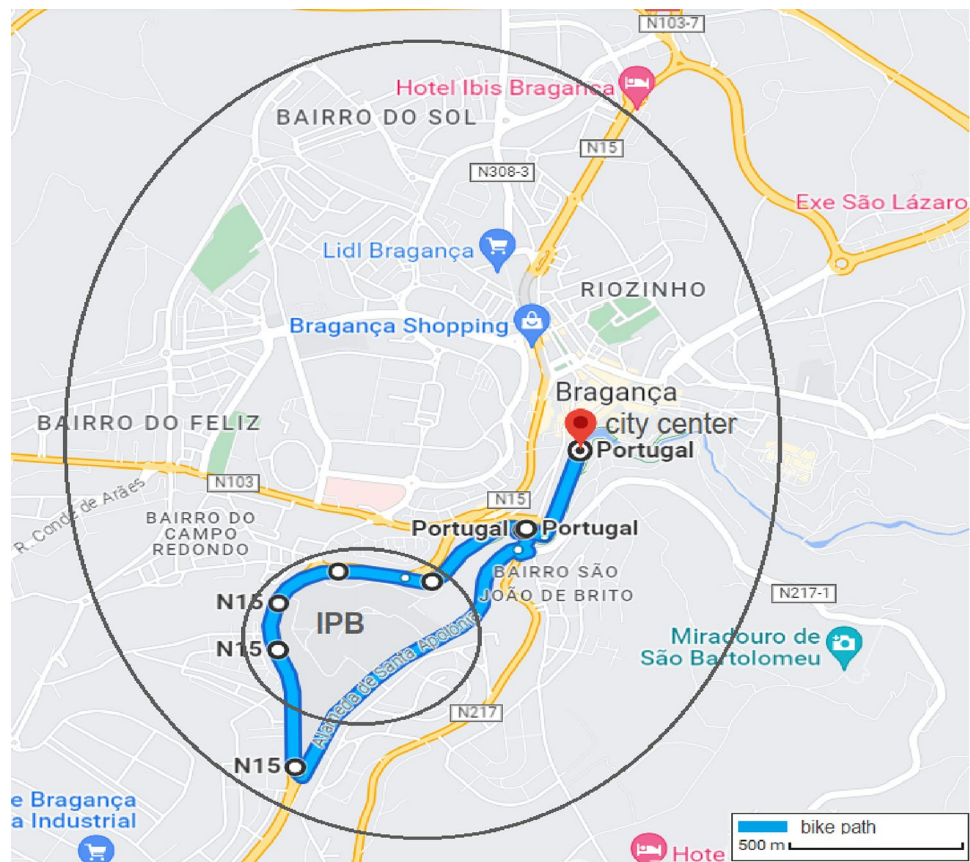
mainly in some summer months. This situation demonstrates that the Portuguese population is changing their traditional behavior of using their private cars as their daily transportation.

#### 4 IPBike project impact

In this paper, the results achieved over three years of IPBike project are presented and evaluated, aiming to investigate the hits and points to be improved for the project's continuity and presenting the users' feedback, indicating their motivations and difficulties as IPBike users. Moreover, a study of greenhouse gas emission (GHG) reduction is presented to evaluate the impact of the IPBike project on the environment.

Thereby, Fig. 4 is an overview of the data collection process to make it possible to analyze the project results. Initially, a set of questions was formulated and implemented on the *Google Forms Platform*. These questions aim to identify the profile of the users (students, professors, researchers, or staff), personal information such as gender and age, as well as details about the IPBike uses (frequency, time, kilometers traveled, positive and negative points observed during the IPbike utilization time).

Fig. 3 Map of Bragança



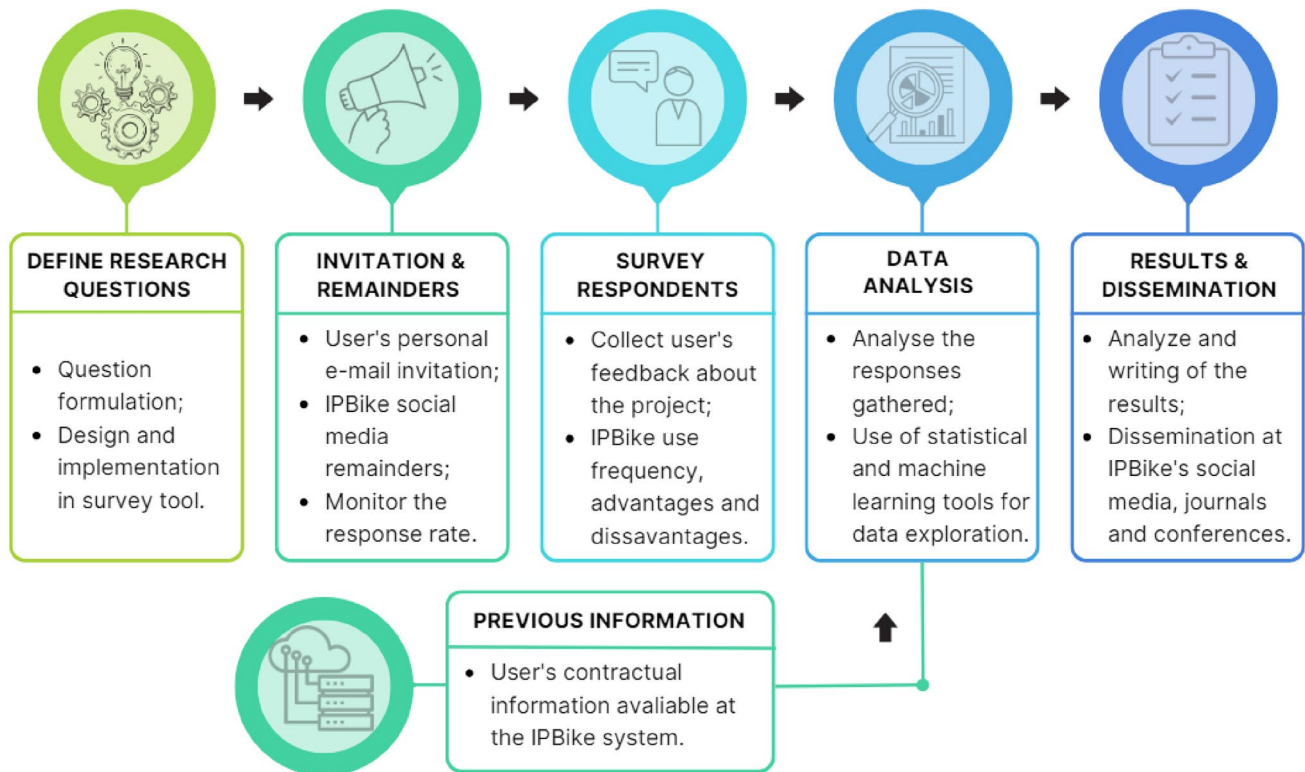


Fig. 4 Overview of the data collection process

The complete survey can be accessed at (<https://github.com/BeatrizFlamia/IPBIKE.git>). After that, the IPBike's past and current users were invited by e-mail to answer the survey. The response rate was periodically monitored and when necessary, a reminder email was sent to users who had not yet responded to the forms. The survey data were analyzed with the previous information in the contract, such as how many kilometers the user intends to travel with the IPBike daily and its main mode of transport at the time of the acquisition of IPBike. In this way, it is possible to analyze the results of the project and its impact on the academic community and its impact on the environment. As well as disseminate the results and plan future action to expand the project.

Thereby, this section is divided into three main parts; in the first one—the user's characterization, considers all IPBike users throughout the project, which is 303 people till February 2021; after that, the second part—IPBike user's perception, considers the opinions of 68 users who contributed, anonymously, answering a questionnaire. Finally, the last part presents a simulation of greenhouse gas emission to estimate the reduction of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide N<sub>2</sub>O on the environment.

#### 4.1 IPBike user's characterization

The IPBike project started in March-2018, with 100 electric bikes. Until February-2021, the IPBikes were rented by 303 people, among 8906 available in IPB community: 194 students (out of 8000), 75 professors or researchers (out of 709) and 34 IPB staff (out of 197). Among these users, 120 are female, and 183 are male, of different age ranges. In percentage terms, we have a participation of 2.42% of all students, 10.58% of professors and researchers, and 17.26% of staff; in this way it is possible to verify the participation per group. Thereby, even in smaller absolute numbers, the contribution of teachers, researchers, and staff is significantly notable in the project.

To rent an IPBike the users must characterize some personal behaviors associated with personal data and transports habits, such as which kind of transport they usually use (private cars, public transportation, or on foot); if private cars are mentioned, it is also required the information about the type of fuel and average vehicle consumption.

The following results were achieved by evaluating the information of the 303 users: 15 people use public transport, 171 make their main trips on foot, and 117 indicate use private cars. Among the people that answered private

cars, 34 chose gasoline as fuel, 81 chose diesel, 1 preferred to use liquefied petroleum gas (LPG), and 1 had an electric vehicle. In terms of consumption, it was evaluated the average of 7.89 (l/100 km) for cars powered by gasoline and 6.84 (l/100 km) for diesel cars.

The IPBike users also indicate how many kilometers they travel per day on the transports they use routinely. Considering all users, the total average is 15.12 km per day, being 20.06 km on average of kilometers displaced by car users, 14.33 km by public transport users, and 11.79 km on the walkers average.

As a daily goal to be displaced with IPBike, on average, the users indicate 14.78 km, and the contract is, on average, done for 7 months. However, it can be renewed whenever no major problems with compliance with the clauses are detected. Table 1 summarizes user-provided information based on the primary modes of transportation: number of users (Users), daily displacement average (km/day without IPBike), month average that the bike is required (Months required on contract) and the number of kilometers that the users are supposed to do, daily, with the IPBike (km/day with IPBike).

Although there is no strict control of the number of kilometers traveled per month by each user, the IPBikes have a system of counting traveled kilometers. Whenever necessary, the user is called upon to present the kilometers count. In addition, every time a bike is returned, it undergoes an inspection before it is available to the new user.

### 4.2 IPBike users' perceptions

In order to know the IPBike user's perception, a survey was performed to analyze the users' profile, named the IPBike use frequency, the user's impressions about the bikes, and the project development.

The survey was answered by 68 users (22% of the totality, which represents a confidence level of 90% with an error less than 9%): 36 students, 17 professors, 5 researchers, and 10 technical staff, in which 34 respondents are female and the other 34 are male. Most respondents are between 21 and 30 years old (47, 1%). Considering these 68 users, 23 answered they perform a displacement

smaller than or equal to 5 km per day, which correspond to 33, 82% of the data sample; 34 answered they perform a displacement between 5 to 10 km per day, which means 50% of the data; 3 users, 4, 41%, indicated a distance of 10 to 15 km, 7 users, 10, 29%, indicated that they usually use the IPBike to perform between 15 to 20 km and 1 user, that correspond to 1, 47% of the data, indicated displacement higher than 20 km every day using the IPBike, as it is possible to see in Fig. 5.

The IPBike's users were also questioned about how long they use the IPBike and how frequently they use this way of transportation during the week. Concerning the duration of IPBike contract, 8 users indicated less than 2 months (11, 76%), 26 between 2 and 6 months (38, 23%), 22 more than 6 and until 12 months (32, 35%), 9 more than 1 year (13, 23%) and 3 more than 2 years (4.41%).

Moreover, about the frequency of IPBike use, the answers are illustrated in Fig. 6, which indicates that more than 60% uses the IPBike at least five days per week.

Bragança is a small Portuguese city, and although it offers some infrastructure for bike users, it is still not ideal. It is also known that, about the IPBike project, there are aspects to be improved. For these, it is important to

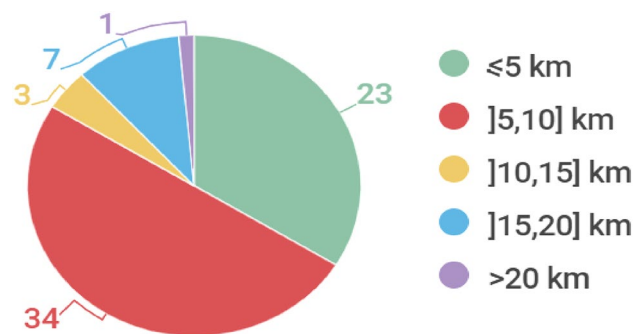


Fig. 5 IPBike user's daily displacement

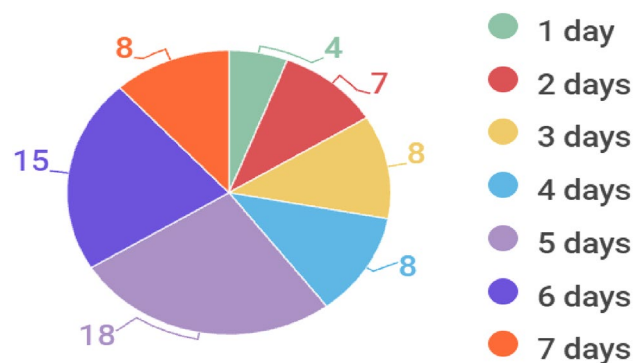


Fig. 6 IPBike frequency of use

Table 1 IPBike contractual information

Transport means	Users	km/day without IPBike	Months required on contract	km/day with IPBike
Private car	117	20.06	7.88	15.11
Public transport (bus)	15	14.33	7.73	14.73
On foot	171	11.79	6.62	14.57
Total average	-	15.12	7.16	14.78



understand why people require an IPBike. The result of this question is shown in Fig. 7.

It is known that cycling in urban environment involves several difficulties. Figure 8 presents the main difficulties found by the IPBike’s users.

It is important to mention that the results presented in Figs. 7 and 8 were provided by multiple choice questions, in which it is possible to select more than one option. In both figures, for each option available, it is shown the number of users, as well as the corresponding percentage of the ones who selected the option.

A free space was given for the users to express their criticisms and suggestions, providing feedback for the project improvement. In this case, many users mentioned maintenance as a critical point of the project that needs to be revised. The users also suggest implementing a predicted maintenance system to preserve IPBikes qualities, as well as a digital system to schedule maintenance procedures and give more support to the IPBike users.

In order to evaluate the user’s opinions about comfort, functionality, fees, maintenance service, and security, the

users classified each item according to the 5-level Likert scale [38] (from 1 (one) to 5 (five), in an ascendant order, where, 1 – “terrible”,..., 5 – “excellent”). The answers collected are presented in Fig. 9.

#### 4.2.1 Identification of IPBike user’s profile by cluster analysis

To better identify the IPBike user’s profile, a cluster analysis was done, considering the following data: age, time with IPBike, and kilometers displacement per day. The cluster techniques analyze the similarities and dissimilarities between the variables in question. In this study, we applied the widely used and popular k-means algorithm [39], which is known for its simplicity and effectiveness as a partitioning algorithm. At the beginning of this algorithm, a set of *k* points is selected, representatives of the classes or centroids [40]. In this sense, the k-means clustering algorithm was utilized to identify patterns and structures within the data, enabling its division into *k* groups or clusters. As a partitioning method, the k-means algorithm

Fig. 7 People motivations to require an IPBike

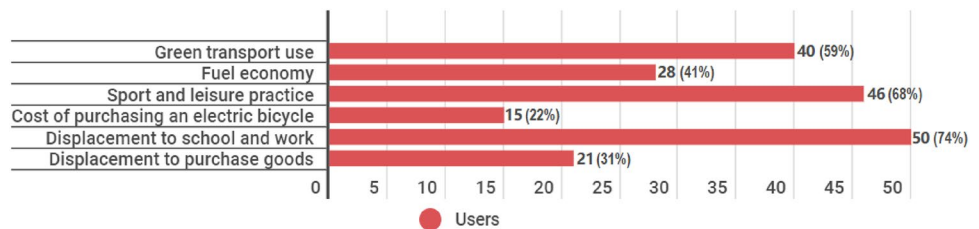


Fig. 8 People’s difficulties while IPBike users

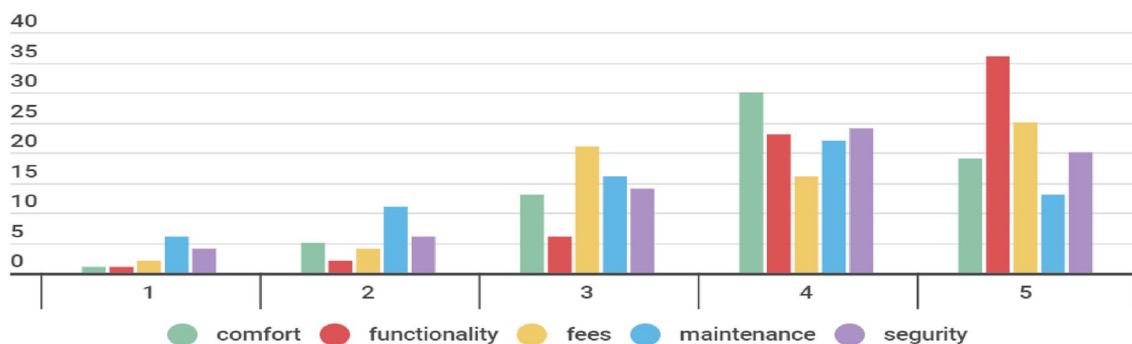
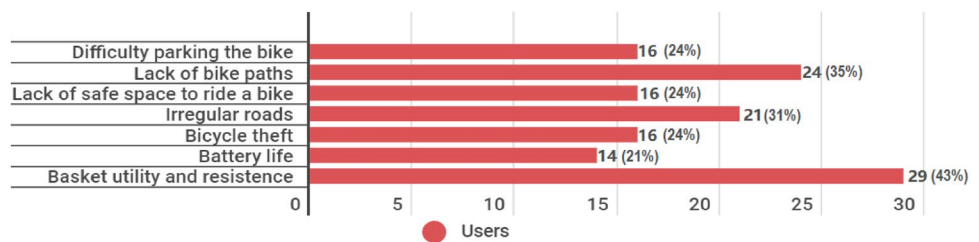


Fig. 9 IPBike evaluation according to comfort, functionality, fees, maintenance and security parameters

requires the pre-definition of the desired number of clusters  $k$  to be generated. This allows the algorithm to partition the data effectively. Therefore, the Silhouette method [41] was used to evaluate the number of clusters in which the data set will be divided. For the three considered variables, the Silhouette method indicated 3 as the optimum number of cluster divisions.

To generate the cluster, the information of the variables “Age—(A);” “Time with IPBike rented—(T)” and “Kilometers displacement per day—(D);” that were collected with the survey were discretized into 5 classes according to the options available for the users. All the classes and their correspondence with the variables are presented in Table 2. The class definition on the variable “Time with IPBike rented” is associated with the rent type (less than 2 months, one scholar semester, one scholar year, two scholar years, or more) as it is described in the IPBike project rules.

Besides, to evaluate the type of users, the cluster representation indicates if the data is provided by a student or a non-student user (professors, researchers, and technical staff). Thus, the generated cluster is shown in Fig. 10,

where the cluster division is represented by the 3 geometric forms and the circles, squares, and the plus signal. The division between student or not student is given by the colors, in which green, blue, and cyan represent students’ data and red and black, not student data. Moreover, each axis of the graph represents a mentioned class in Table 2.

Cluster 1 (in pink) and with centroid equal to  $C1 = (2.06, 2.16, 1.67)$  is composed of 25 students and 6 not students, with age in the classes A1, A2, and A3, being the majority in the class A2 ([21, 30]) years old. On the other hand, cluster 2 (in blue) and with centroid equal to  $C2 = (1.55, 2.44, 3.88)$  is exclusively composed of students (9 in total) with ages smaller than 31 years old (classes A1 and A2). This cluster contains the people that displace the longer distances per day with the IPBike (classes D4 and D5), mostly of the variable kilometers/day. Finally, cluster 3 (in yellow) and with centroid equal to  $C3 = (3.89, 3.14, 1.64)$  is almost entirely composed of not student people (26 non-student and 2 students), with ages equal to or superior to 31 years old (classes A3, A4, and A5). Note that some data is overlapping in Fig. 10.

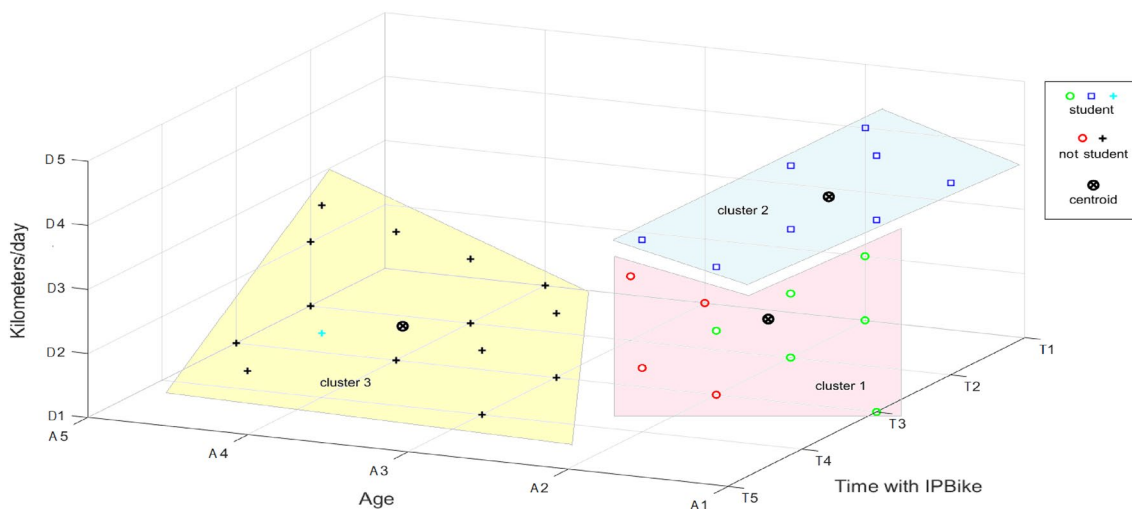
Concerning the time with the IPBike rented, it is not possible to have a clear division between the clusters; the data are very dispersed among the time with IPBike classes. However, the users are more concentrated in classes T2 ([2, 6] months) and T3 ([6, 12] months) of the variable “Time with IPBike”.

**Table 2** Variables categorization

Classes	Age (years)	Classes	Time with IPBike (months)	Classes	Kilometers/day
A1	≤ 20	T1	< 2	D1	≤ 5
A2	[21, 30]	T2	[2, 6]	D2	]5, 10]
A3	[31, 40]	T3	]6, 12]	D3	]10, 15]
A4	[41, 50]	T4	]12, 24]	D4	]15, 20]
A5	> 50	T5	> 24	D5	> 20

### 4.3 A simulation of greenhouse gas emission

Road transportation is one of the most critical emitters of greenhouse gases (GHG), such as carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) [42]. In order to understand the impact of the reduction of the greenhouse



**Fig. 10** IPBiker users cluster

gases emission provoked by the IPBike project, a simulation was done considering the information provided by the IPBike's users.

For the simulation, only IPBike users that have diesel or gasoline private cars as their primary transportation means were considered. Users of LPG cars were not considered because there is no significant number of this type of user in the IPBike project. In the case of public transportation, the emission was not considered because this transportation will continue to circulate in the city. However, it is important to highlight that bikes constitute an ally of public transport in the search for a minimization of the impact of the car in the city. In this case, it is essential to strengthen the complementarity between cycling and public transport, providing the possibility to park safely the bikes at public transport stops and being able to transport your bicycle on public transport vehicles, when necessary [1].

In this way, two groups were defined: users of diesel cars powered and users of gasoline cars. For each group, the following sums were evaluated: kilometers displaced with the indicated transport before the IPBike rent (Sum km/day without IPBike), months of all users that requested an IPBike (Sum months using IPBike), and kilometers per day intended to do with the IPBike (Sum km/day with IPBike). The amounts collected are described in Table 3. For this estimation, it was assumed that the daily quantity of kilometers indicated by all users had been fulfilled during 5 days per week during all months of the contract.

To accurately assess greenhouse gas emissions, a set of factors is necessary, such as environmental parameters and specific characteristics of the cars, among other information. Another possibility to estimate greenhouse gas emissions is using rates previously defined by the regulatory agencies. So, for this simulation, the second approach was used, considering the values of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) provided by the Portuguese Environmental Agency (PEA) [42] and presented in Table 4.

The PEA is the entity responsible for implementing environmental policies in Portugal. To obtain the value shown in Table 4, several national activity data and input variables were considered using COPERT5 [43]: environmental information (temperature, humidity), trip characteristics (trip

**Table 3** Estimated parameters based on IPBike users information

Transportation mean	Users	Sum km/day without IPBike	Sum months using IPBike	Sum km/day with IPBike
Diesel car	81	1517	677	1190
Gasoline car	34	741	242	571

**Table 4** Road transportation distance based implied emission factor for 2019, considering passengers cars [42]

Transportation mean	CO <sub>2</sub> g/km fossil	CH <sub>4</sub> mg/km	N <sub>2</sub> O mg/km
Diesel car	208.39	1.35	7.15
Gasoline car	206.77	30.30	4.46

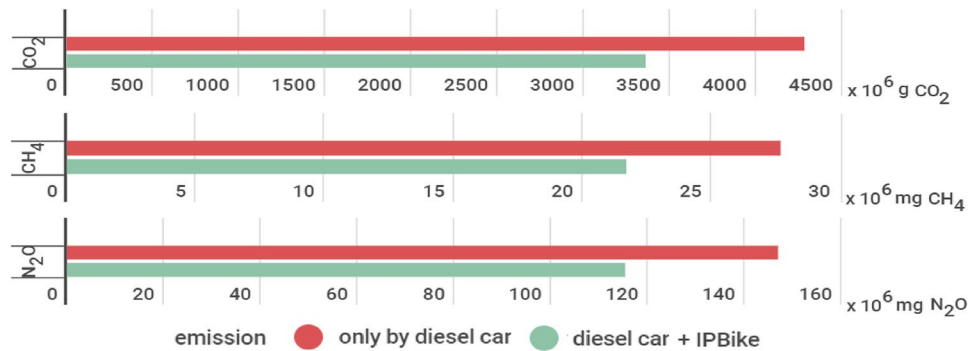
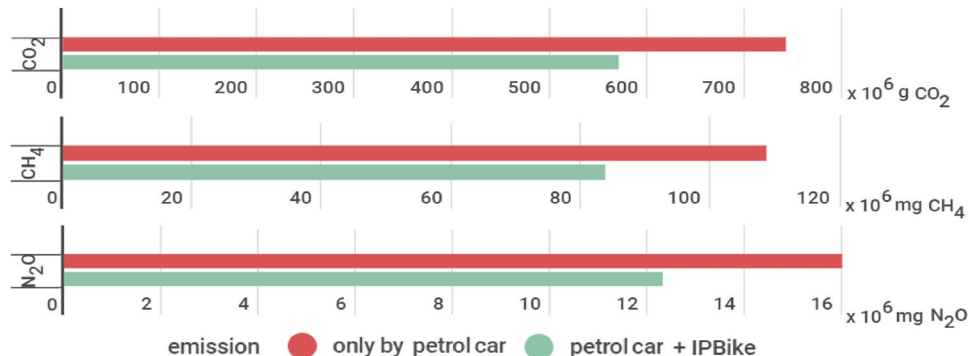
length, trip duration), fuel characteristics and specifications, energy consumption, vehicle fleet, distance traveled (mean activity—Km), circulation data (average speed, mileage % per driving mode). Estimated emissions from Road Transportation are based on Tier 2 method for CO<sub>2</sub> emissions, and Tier 3 for non-CO<sub>2</sub> emissions [42].

To estimate the gases emission, first, the quantity of each gas emitted was evaluated, considering that all km indicated by the users' displacement done by car, so for each group of fuel, the quantity of km/day without IPBike was multiplied by the sum of months using IPBike times 5 (days of the week), which in turn was multiplied by the rate of gas emitted per km displaced (Table 4). In this way, the value reached indicates the worst scenario in terms of gases emission without IPBikes in circulation.

After that, to estimate the gas emission of the transport means combined with the IPBike use, the difference between the number of km done with the transport means and the IPBike was evaluated. After that, the value found was multiplied by the sum of months using IPBike times 5 days per week. In the end, the values were multiplied by the rate of gases emitted per km displaced (Table 4).

Figures 11 and 12 illustrate the results of this simulation for cars powered by diesel and gasoline, respectively. The results of Fig. 11 consider the gas emission provoked by 81 people that use diesel cars, whereas the results of Fig. 12 represent the values acquired with the 34 people that use gasoline cars.

For both Figs. 11 and 12, the first bars (in red) represent the quantity of each gas that would be emitted by people only displaced by the main transport means indicated previously, resulting in  $4280.37 \times 10^6$ g CO<sub>2</sub>,  $27.73 \times 10^6$ mg CH<sub>4</sub> and  $146.86 \times 10^6$ mg N<sub>2</sub>O for the cars powered by diesel and  $741.57 \times 10^6$ g CO<sub>2</sub>,  $108.67 \times 10^6$ mg CH<sub>4</sub> and  $15.99 \times 10^6$ mg N<sub>2</sub>O for the cars powered by gasoline. On the other hand, the second bars (in green) of both figures indicate the gases emission values if the distance displaced by the people is done fulfilling the IPBike kilometers daily goal and the surplus is done by the other transport means, so the estimated results are:  $3357.70 \times 10^6$ g CO<sub>2</sub>,  $21.75 \times 10^6$ mg CH<sub>4</sub> and  $115.20 \times 10^6$ mg N<sub>2</sub>O for the cars powered by diesel and  $571.44 \times 10^6$ g CO<sub>2</sub>,  $83.74 \times 10^6$ mg CH<sub>4</sub> and  $12.32 \times 10^6$ mg N<sub>2</sub>O for the cars powered by gasoline.

**Fig. 11** Gases of diesel cars**Fig. 12** Gases of gasoline cars

Thus, it is possible to observe that the IPBike's users avoided the emission of  $922.66 \times 10^6 \text{g CO}_2$ ,  $5.98 \times 10^6 \text{mg CH}_4$  and  $31.66 \times 10^6 \text{mg N}_2\text{O}$  associated with diesel cars, that represents a reduction of 21.55%. And, for the users of gasoline cars, the quantity of gases avoided was  $170.13 \times 10^6 \text{g CO}_2$ ,  $24.93 \times 10^6 \text{mg CH}_4$  and  $3.67 \times 10^6 \text{mg N}_2\text{O}$ , which represents a reduction of 22.94%.

## 5 Discussion

Encouraging the population to use bikes, especially the youngest, through school projects is a way to create sustainable cities and plan the future. Besides, young people active tend to be more active and healthy adults. Moreover, there are many benefits of cycling to school, such as improvement of concentration, reduction in traffic congestion, lower greenhouse gases emission, reduced chauffeuring duties for parents, and personal skill development [5, 8, 10, 44].

According to the literature [45–47], Portugal presents a high index of overweight or obesity, with high prevalence in the younger age groups. Encouraging the use of bicycles can contribute to reducing these numbers. The U-bike project and IPBike, as a pilot project, focus on community-university students due to their ease of implementation, as this audience is generally over 18 years old and they do not depend on adult authorization for riding a bike. Over

the 3 years of project implementation, the results promise to be a first step towards expanding the project to younger age groups. However, when it comes to bike use by people under the age of 18, the challenges are still greater, requiring even more physical infrastructure and security for the successful implementation of a project like this, given the concerns of parents and challenges reported in [48, 49].

Another significant result achieved with IPBike is greenhouse gas emission reduction, a crucial point to consider regarding sustainable mobility. In three years of the project, the estimated reduction is around 20% (Figs. 11 and 12), which means a reduction of approximately 7% per year. These values are according to values presented on [36], which estimates a CO<sub>2</sub> reduction of around 5% when the bikes are used to replace cars in short trips. Moreover, using bikes for daily transportation represents a reduction in fuel costs for users and also a reduction in noise pollution.

The results of the IPBike project reinforce the ones described by the [4, 17–20, 50] demonstrating the capacity of a bike-sharing program has to impact on people's lives, improving their health and reducing travel expenses, and also the impact on the society and environment in a general way, reduction the air pollution, traffic noise, and congestion, among other. Therefore, people who adhere to sustainable mobility programs promote benefits for themselves and society as a whole. Thus, it is essential to encourage the creation of more projects such as IPBikes

and to provide infrastructure and security for the ever-increasing adherence of people to programs such as these.

The survey results make it possible to conclude that a diverse academic public, both gender of wide age groups, is using the IPBikes. Although the students request them, there is also significant participation from the other academy members. 50% of users indicated that they have been using the IPBike for more than 6 months. The vast majority of people who answered the questionnaire indicated that they use the IPBike at least 4 times per week, as can be seen in Fig. 6 with most users cycling a distance between 5 and 10 km a day (Fig. 5). This demonstrates a great acceptance of the project by different public and leads us to believe that using bikes as a means of sustainable mobility promotion is a strong trend towards the city of the future in the context of developing smart city technologies.

Through cluster analysis, a clear division can be observed between the profile of students, mostly concentrated in cluster 2, and the profile of non-student individuals, predominantly found in cluster 3. Cluster 1, on the other hand, could be regarded as an intermediary group comprising both students and non-students. When we analyze the duration of bicycle usage among students, we observe a high turnover. In terms of mobility patterns, analyzing the elements and the centroid's position (2.06, 2.16, 1.67), it can be said that cluster 1 is composed of young students and non-students up to 30 years old. Based on prior knowledge of the target audience, it is known that this cluster encompasses both students and young researchers from IPB. This audience tends to keep the bike for around 6 months to 2 years and covers up to 10 km daily with the IPBike. In cluster 2, with centroid (1.55, 2.44, 3.88), we have students who are younger than the members of the other clusters (mostly under 20 years old). This group typically commutes longer distances than the members of the other clusters, usually between 15 and 20 kilometers daily with the IPBike. Regarding the duration of bike ownership, they usually keep the IPBike for a shorter period, typically between 6 months to 1 year, corresponding to one or two academic semesters. Furthermore, it is known that students typically do not work, which means they have more time to displace longer distances compared to non-students who are employed. In cluster 3, which has the centroid (3.89, 3.14, 1.64), the majority of the members are from the academic community who are not students, meaning they are professors and staff. These individuals are typically around 40 years old and tend to keep the IPBike longer since they have a lasting connection with IPB. As for the distance traveled, on average, this group covers around 5 kilometers daily with the IPBike.

In general, the students who are the majority in bicycle rentals, are younger than non-students, and they travel

more kilometers per day with the IPBike. However, in most cases, students use the bicycle for around 6 months, corresponding to one academic semester. Due to prior knowledge of the project, it is known that students return the bike during the vacation period to avoid rental fees. But, they can't always rent a bicycle in the following semester due to the high demand and waiting list. On the other hand, the duration of bicycle usage among professors, researchers, and other staff tends to be longer, typically exceeding 6 months, since they have a more lasting link with the IPB and in most cases live permanently in Bragança. Nevertheless, a strong dedication to the project is evident in both situations, among students and non-students.

The inclination towards IPBikes by younger academic community members holds promise, as they are poised to be pivotal in molding the future of sustainable transportation [44]. Embracing sustainable transportation habits from an early age enhances the chances of nurturing a lasting appreciation for the importance of sustainable mobility among successive generations. As today's youth eventually become parents, they can lead by example and encourage their own children to use sustainable modes of transportation, such as riding bicycles to school.

During the COVID-19 pandemic and, consequently, with the restrictions on circulation and interruption of in-person classes, a large volume of IPBikes not rented, around 40% was noted. However, it was to be expected since most of the IPB's academic public comprises students from other Portuguese cities or other countries (more than 60) who have returned to their family houses. Nevertheless, with the return of in-person classes, the demand quickly surged, leading to a resurgence of the lines to have an IPBike.

To continue the IPBike project, it was important to understand the motivations and main difficulties of the users. As seen in Fig. 7, the 3 most voted options that motivated people to rent an IPBike were respectively: "Displacement to school and work", "Sport and leisure practice", followed by "Green transport use". These results demonstrate that the project's mission of promoting the use of sustainable transportation for displacement from home to work or school linked to the practice of sport has been fulfilled. Since bikes have mostly been rented by 21 and 30-year-old's, this may indicate a future shift in mobility. As young people today are concerned about sustainable mobility, they tend to continue to be in the future, generating a more sustainable society and better absorption of sustainable measures.

The main difficulties encountered are related to the infrastructure the city offers (lack of bike paths and irregular roads). Such complaints are similar to those reported on [17, 19, 20]. Although Bragança has some resources

for safe bike practice, it is still not ideal. Increasing the bike path grid, installing more bike docking stations, and strengthening city security should be the following steps to increase the number of bike users. In the meantime, the most voted difficulty according to IPBikers (Fig. 8) is related to the usefulness of the basket, which has low resistance, which restricts its use. It is important to mention that the IPBike's basket is removable if the user feels more comfortable since the primary function of the IPBike is for the displacement of school/work and to be used for sport and leisure.

Considering the IPBike user's opinions of comfort, functionality, fees, maintenance, and security as mentioned in Fig. 9, it is possible to analyze that all five items had mostly the positive highest scores. Functionally had the majority of votes on the higher score, proving that the IPBike is an efficient form of transport and is pleasing its users. Although comfort did not receive a maximum score from most users, this item had a good score for a shared bike with a low rental cost. Regarding the cost (fees), most users are satisfied with the IPBike fees. As already mentioned, the maintenance system needs revisions. The IPBike was generally considered safe, having the most votes on scores 4 and 5. Besides, it is important to highlight that the project offers protective equipment for users.

Overall, the IPBike initiative has shown encouraging outcomes. However, a significant challenge encountered in the project is the improper handling of the bicycles. Since the bikes are rented rather than owned, some users tend to be less cautious in their usage, resulting in avoidable maintenance costs. As a solution, the project must devise tactics to promote a sense of responsibility in using IPBikes, a responsibility shared by all users. This awareness should be ingrained in every interaction with the bike-sharing system, as only well-maintained bicycles can attract a larger user base and garner support for sustainable mobility in the future.

## 6 Conclusions and future work

For many people, especially those who live in bike-friendly places, using bikes for displacement is a widespread habit; however, for those who live in places where they are not so popular means of transport, leave the car in the garage and move whenever possible on foot or by bike is still a paradigm to be overcome. Particularly in Portugal, where just 1% of the population uses it as their preferred means of transport. Encouraging bike use as a means of transportation involves a series of issues, such as personal, governmental, and collaboration of other drivers in urban traffic.

Even in a small city, such as Bragança (population of approximately 35.000 inhabitants), with little cultural

tradition in the use of bikes, it is possible to create promising mechanisms to promote the use of bikes. Many IPBike users indicate their displacement on foot, but this situation is only possible in small cities. However, even in a small city, a bike can bring many benefits, such as traveling faster and more comfortably than walking. These reasons explain the high interest in renting a bike within the scope of the long-waiting-lines IPBike project.

This article discusses the various advantages of engaging in e-bike or cycling activities, with a specific focus on using bicycles for commuting to school. The paper introduces the IPBike project and presents the outcomes derived from its database. It also highlights the insights gathered from a survey conducted among IPBike users and their personal experiences. The implications drawn from this research hold significant importance in promoting and enhancing bicycle utilization, particularly within the city of Bragança; however, the scope could be extended to other locations as well. In a broader sense, the IPBike initiative is yielding remarkable benefits, evident through consistently high numbers of bike rentals and the frequent sight of IPBikes on the streets of Bragança. The data collected shows that the entire academic community adhered to the project. To increase the impact and avoid the waiting list, the IPBike project is considering acquiring more IPBikes with and without basket and with and without electrical support.

Promoting bicycle use among students yields immediate health benefits and long-term environmental advantages for the transportation and mobility sectors. Fostering bike usage within the academic community and advocating for bike commuting from home to school presents a forward-thinking urban preparation strategy. Given the importance of sustainable mobility in curbing pollution and traffic congestion, these initiatives contribute to city preparedness. Encouraging youth to adopt biking from an early age contributes to future sustainable cities by reducing car traffic, resulting in safer and cleaner streets.

The outcomes of this research and the IPBike project underscore the significance of initiatives like IPBike in promoting sustainable transportation, sports engagement, and healthy lifestyle habits. The IPBike project is pioneering bicycle use for schooling in Bragança and offers valuable insights applicable locally and across primary and secondary schools elsewhere. Moreover, leveraging the scientific community's influence, the aim is to propagate positive practices such as regular bike usage among the general population.

Through data analysis, it is clear that young people move more than middle-aged individuals. However, since bikes have been well-received by audiences of all ages and members of the academic community, it is important that proposals for expanding the project

to the general community consider a diverse range of audiences, from the youngest to the elderly.

Throughout this study, local limitations to widespread bicycle use in Bragança have been highlighted, including the lack of bike paths, safe cycling areas, issues with theft, and secure bike parking. These challenges can be addressed by presenting reports to public authorities, thereby enhancing city infrastructure to foster greater bicycle usage among students and the broader population.

Regarding the internal problems pointed out in the project, mainly the maintenance scheduling problems, it is expected to be solved soon and increase the number of bicycles available to the academic community. It should be noted that the high demand for IPBikes and their strong presence on the streets of Bragança aroused the interest of companies in investing in sustainable mobility in the city, with the creation of more bicycle-sharing programs aimed at the community in general. Thus, sharing information about the IPBike project will greatly benefit these entrepreneurs.

In scientific terms and for future research work, it is intended to assess the profile of IPBikers and non-academic members through another survey. It aims to study the project's impact on them in personal terms (health, economy, social). Furthermore, for those who have children, it is intended to know their opinions about the use of bikes to go to school by people under 18 years old, evaluating the viability of the project expansion to other younger age groups. Finally, given the project's positive outcomes, the project's plans involve collaborating with potential investors to extend similar initiatives beyond the academic community, encompassing individuals of all age groups, including members of the academic community and non-members.

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**Author Contributions** BFA and AIP Conceptualization, Methodology. BFA and KM Data curation, Writing-Original draft preparation. BFA and KM Visualization and Investigation. AIP Supervision. AIP Validation. AIP Writing-Reviewing and Editing.

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**Availability of data and materials** The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Conflict of interest** The authors have no relevant financial or non-financial interests to disclose.

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