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Students' home-university commuting patterns: A shift towards more sustainable modes of transport

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ABSTRACT

Students commuting to and from university campuses have important social, environmental and transportation impacts. Based on a questionnaire conducted with 686 students from the University of Minho, Portugal, this study analyses the transport modes used in their commuting trips, the potential to shift towards more sustainable modes and the respective CO_2 savings by considering two scenarios: an optimistic and a most likely scenario. Although 54% of students travel less than 5 km and 62% travel less than 20 min, 42% of them prefer to drive to university. Considering the students' travel distances and times, 55% of the trips could potentially be carried out by active modes of transport, while motorised trips could decrease from 70% to 45%. Depending on the scenario analysed, the modal shift can reduce the emissions of CO_2 from 8% up to 27%. The findings described in this study can help university campus managers and urban planners in adopting planning policies to make mobility more sustainable.

1. Introduction

In recent years, an increasing number of worldwide universities have begun to make inventories of greenhouse gas emissions (GHG) through the assessment of the carbon footprint to evaluate and improve the sustainability of their activities (Bertolin et al., 2019; Clabeaux et al., 2020; Mendoza-Flores et al., 2019; Varón-Hoyos et al., 2021). These footprints are indicators of the total direct and indirect GHG emissions produced by universities. Direct emissions come from sources controlled or owned by the universities, while indirect emissions are from the generation of electricity, steam and heating/cooling, as well as from sources not owned or directly controlled by the universities such as travel and commute (Clabeaux et al., 2020; Mendoza-Flores et al., 2019).

Recently, university students' modal choice patterns have been studied more intensively. Private car has been the preferred mode to commute to many universities around the world, such as Qatar University (Azzali and Sabour, 2018), Sydney University, Australia (Rissel et al., 2013), San Diego State University, USA (Appleyard et al., 2018); the University of Michigan-Flint, USA (Rybarczyk and Gallagher, 2014), the University of California, Los Angeles, USA (Zhou, 2016), the University of Alabama at Birmingham, USA (Sisiopiku, 2018), the University of Foggia, Italy (Cappelletti et al., 2021), the Autonomous University of Barcelona, Spain (Miralles-Guasch and Domene, 2010), the University of León, Spain (Pérez-Neira et al., 2020), and the University of A Coruña, Spain (Perez-Lopez et al., 2021), among many others. For this reason, many universities around the world have been classified as major traffic generators (Shannon et al., 2006; Romanowska et al., 2019).

The high use of private cars to commute to universities has a significant impact in terms of carbon footprint. For example, at San Diego State University (USA) and the Politecnico di Milano (Italy), about 40% of the total carbon emissions come from commuting by car to the campuses (Appleyard et al. 2018; Bertolin et al., 2019). In other universities, commuting by car represents >50% of the carbon footprint, such as at the cases of the Spanish universities of A Coruña (Perez-Lopez et al., 2021), Léon (Pérez-Neira et al., 2020), Technical University of Madrid (Sobrino and Arce, 2021), as well as in the case at the Chilean University of Talca (Vásquez et al., 2015).

Ensuring that the academic community makes sustainable transport choices is a challenge to achieve more sustainable university campuses (Romanowska et al., 2019). Many universities worldwide are adopting

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policies to discourage car trips to universities and encourage the use of public transport and active modes for their environmental and health benefits (Asadi-Shekari et al., 2014; Delmelle and Delmelle, 2012; Fernandes et al., 2019). Although student travel behaviour has been quite well studied, the environmental impacts of commuting to universities is a relatively recent and few analysed topic (Azzali and Sabour, 2018; Barros et al., 2018; Pérez-Neira et al., 2020). More particularly, the environmental benefits resulting from shifting from motorised transport to active modes have been underexplored in the literature (Neves and Brand, 2019).

In a previous paper, we examined the travel patterns of the entire community of the University of Minho and the barriers to not using active modes and public transport (Ribeiro et al., 2020a). This paper aims to assess whether the transport modes used by students are the most suitable considering their travel distances and travel times, to analyse the potential for a shift to more sustainable modes and the respective benefits of this shift in reducing CO_2. Based on a questionnaire conducted with 686 students, the study was carried out considering three main goals: i) analysing the travel distances and travel times of the students in their daily home-university trips; ii) evaluating the potential to shift towards more sustainable modes; and iii) evaluating the GHG savings in terms of CO_2 that may result from that switch. The approach described in this paper could help campus managers and urban planners in defining policies to restrict car trips and to promote the use of alternative sustainable modes of transport among students.

1.1. Literature review

Students are always the largest university community and, for that reason, their mobility often shapes the transport requirements of any city (Nguyen-Phuoc et al., 2018). Students are recognised for being a diverse population with considerable freedom and autonomy in their travel choice. As students are generally young, they are less likely to have a car and a driver's license and, as many live near campuses, they tend to travel by public transport and active modes (Lundberg and Weber, 2014; Danaf et al., 2014; Ma, 2015). They are also known for being more environmentally conscious and open-minded to new ideas, including in the transport domain (Gurrutxaga et al., 2017). However, the literature shows that many students prefer commuting by car.

Selecting a specific transport mode relies on various interconnected aspects: trip purpose and characteristics, built environment, factors related both to socio-demographics and public policies and incentives (Whalen et al., 2013; Ek et al., 2021). Studies in general that focus more directly on walking often highlight that this mode is more feasible for short distances (Fonseca et al., 2021a) and that compact and dense mixed urban areas, providing safe, appropriate and well-maintained sidewalks, are more conducive for walking (Boulange et al., 2018; Buehler et al., 2017; Fonseca et al., 2021b). Some of these findings are replicated in studies focused on the mobility of university students. . There is evidence that an increase in trip distance decreases the likelihood of students walking to universities and increases the probability of using motorised modes (Chillón et al., 2016; Delmelle and Delmelle, 2012; Moniruzzaman and Farber, 2018). For example, in Valencia, Spain, Chillón et al. (2016) found that students living near the university were more likely to active commute. In their study, the distance best discriminating walkers from passive commuters was identified as 2.6 km. In addition, infrastructural factors that make walking unpleasant, such as the absence of sidewalks, the lack of crosswalks and streets that are too busy have been reported for preventing students to walk even if they live near the campus (Kaplan, 2015). For example, at McMaster University, Canada, Whalen et al. (2013) found that modal choices are influenced by environmental factors such as street and sidewalk density. They found that street density increased the utility of cars and public transport, whereas sidewalk density decreases the utility of these motorised modes. In some cities, security is also a critical factor for the decision to walk. For example, better street lighting and more police presence were reported by the students of the University of Michigan-Flint (USA) to travel on foot to university (Rybarczyk and Gallagher, 2014). Unfavourable weather conditions have been also described as a barrier deterring students from walking (Azzali and Sabour, 2018; Kaplan, 2015; Stein and Silva, 2018). For example, Kaplan (2015) found that inclement weather was the main barrier preventing students living within a mile of Kent State University (USA) from walking to the university.

Regarding cycling, Pucher and Buehler (2017) argued that this is probably the most sustainable urban transport mode, feasible not only for short trips but also for medium trips. In general, the literature provides evidence that traffic safety is critical for cyclists. The provision of cycling infrastructure, such as protected cycle paths, and traffic calming measures, improve cycling safety and increase cycling levels (Buehler et al., 2017; Goel et al., 2021; Manaugh et al., 2017; Pucher and Buehler, 2017). The provision of secure parking facilities and bike-sharing systems also affect the likelihood of cycling (Fishman, 2016; Goel et al., 2021). Some of these findings are also replicated in studies focused on the mobility of university students. The lack of bicycle lanes and traffic safety have been described as major barriers preventing students from commuting by bicycle. For example, the studies carried out at the universities of Alabama, USA (Lundberg and Weber, 2014), Michigan-Flint, USA (Rybarczyk and Gallagher, 2014) and McGill, Canada (Manaugh et al., 2017) showed that the improvement of the bicycle infrastructure would increase bicycle commuting. Similarly, the lack of appropriate and safe bike lanes and bike stations was the main barrier preventing students and staff from cycling to the Eastern Mediterranean University, North Cyprus (Dehghanmongabadi and Hoşkara, 2018). Travel distance and travel time are also critical for cycling to universities. For example, Wang et al. (2015) found that proximity to bicycle infrastructure and the distance from campus were important factors in bicycling to The Ohio State University, USA. In the case of the Autonomous University of Barcelona, Spain, Miralles-Guasch and Domene (2010) showed that long travel distances were the second main barrier preventing students to cycle to the university (the first was not having a bicycle). In Valencia, Spain, Chillón et al. (2016) found that the distance best discriminating cyclists from passive commuters were identified as 5.1 km. Unfavourable weather conditions have also been listed as the main barrier deterring students from cycling (Kaplan, 2015; Rybarczyk and Gallagher, 2014; Stein and Silva, 2018). Considering unfavourable weather conditions, students tend to switch to cars, using particularly less the active modes (Delmelle and Delmelle, 2012). The fear of bicycle theft (Agarwal and North, 2012), not owning a bicycle (Miralles-Guasch and Domene, 2010; Rybarczyk and Gallagher, 2014), the lack of facilities such as showers on campus (Agarwal and North, 2012; Manaugh et al., 2017), and having too much to carry (Kaplan, 2015; Ribeiro et al., 2020a) are other reported reasons influencing the students' decision of commuting by bicycle to universities.

Public transport is considered a sustainable mode of transport that usually involves active travel when walking or cycling to and from stops, stations, homes and destinations. In general, the access to public transport and the quality of the service provided in terms of travel time, frequency, and fares influence the decision of using public transport (Litman, 2016; Ribeiro et al., 2020b). Many of these findings are also replicated in studies that focused on students. More specifically, long travel times (Danaf et al., 2014; Nguyen-Phuoc et al., 2018; Stein and Silva, 2018), low frequencies (Miralles-Guasch and Domene, 2010; García et al., 2016), unsuitable schedules (Sisiopiku, 2018), insufficient services (Gurrutxaga et al., 2017; Ribeiro et al., 2020b) and high fares (Pérez-Neira et al., 2020; Ribeiro et al., 2020b) are amongst the main barriers preventing students from travelling by public transport to universities.

Finally, socio-demographic characteristics (gender, age, income), as well as public policies and incentives are important factors that shape individual mobility, in general and students' mobility in particular. For example, the study conducted by Nayum and Nordfjærn (2021) at the

Norwegian University of Science and Technology in Trondheim, Norway, shows that male students are usually less likely to use public transport than female students (Nayum and Nordfjærn, 2021) because they attributed more negative social status to public transport . In turn, findings from previous studies indicated that female students usually cycle less to universities than their male counterparts (Delmelle and Delmelle, 2012; Kaplan, 2015; Zhou, 2016) because they are more constrained by traffic safety (Delmelle and Delmelle, 2012). Students from families with higher incomes are less likely to use active modes (Moniruzzaman and Farber, 2018) and are more prone to pay for parking (Dell'Olio et al., 2018). Owning a car/motorbike has been described as a major reason preventing students from not commuting by active modes (Nguyen-Phuoc et al., 2018; Stein and Silva, 2018), while students not owning a bicycle are less like to cycle to universities (Rybarczyk and Gallagher, 2014).

The availability of car-parking facilities on campus and the respective prices also influence travel behaviours. For example, Perez-Lopez et al. (2021) demonstrated that the presence, availability and proximity of car-parking facilities directly influence the choice of the car as a mode of transport to the University of A Coruña, Spain. In turn, low-cost parking, paid upfront through annual parking passes, encourages students to drive to universities (Appleyard et al., 2018; Delmelle and Delmelle, 2012; Dell'Olio et al., 2018) and is a main explanatory factor for crowded parking lots on campus (Barata et al., 2011). In sum, this review shows that student motivations for using various commuting modes to and from university campuses are driven by multiple, resulting in highly complex travel behaviours.

2. Material and methodology

2.1. Case study

Comprising approximately 19,000 students, the University of Minho has the fourth largest student community in Portugal. Located in

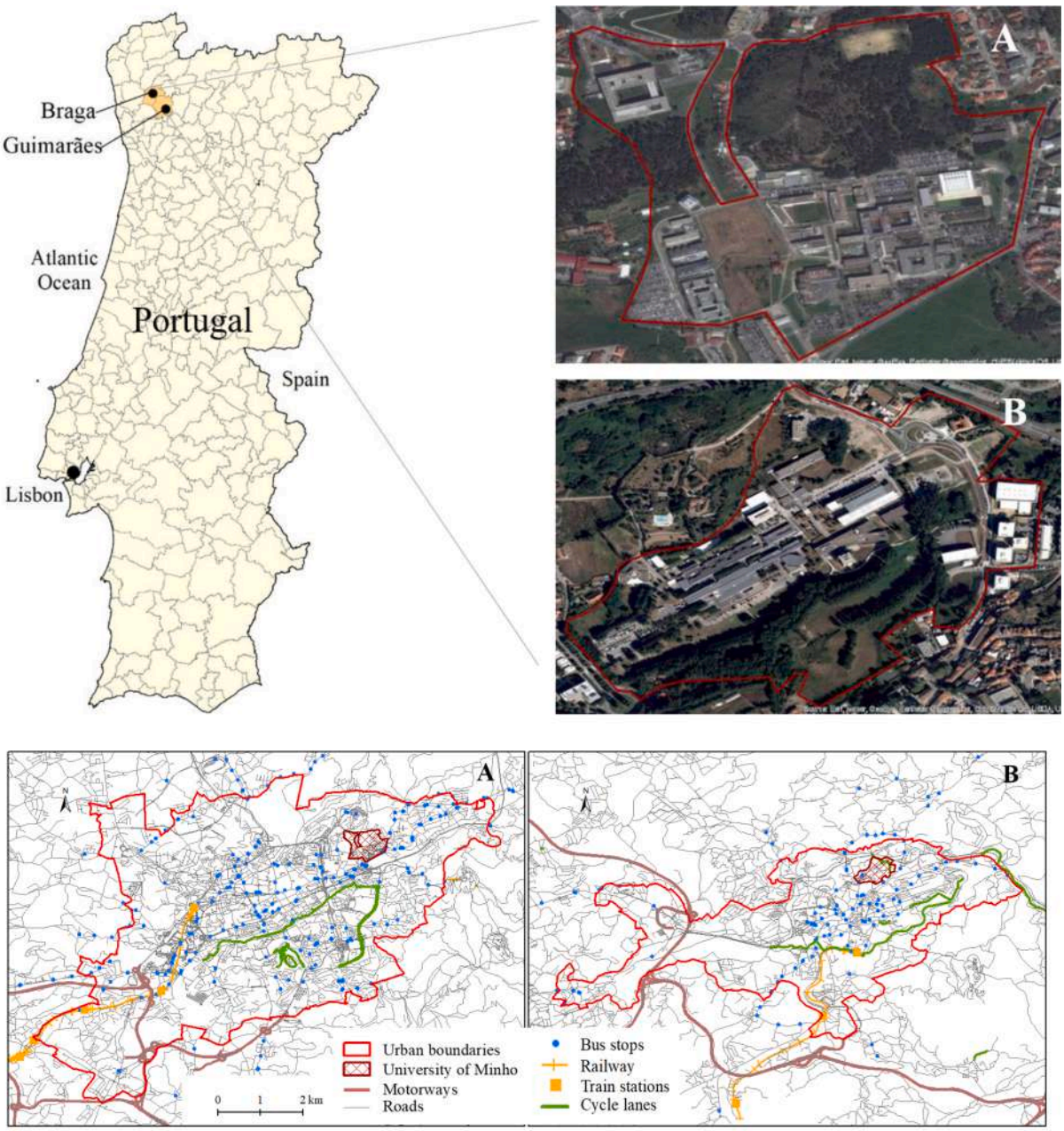

Fig. 1. Location and transport infrastructure at the Gualtar (A) and Azurém (B) campuses.

Northern Portugal, the University of Minho has two campuses, one in Braga (Gualtar Campus) and the other in Guimarães (Azurém Campus). Braga and Guimarães are two medium-sized Portuguese cities. The respective municipalities have a population of about 350,000 inhabitants (SP, 2021). Both campuses are about 3 km from the respective city centres, they have close access to primary distributors and are around 5 km from train stations (Fig. 1). Regarding bus access, four lines serve the Gualtar Campus, and one line serves the Azurém Campus. In Azurém, there is one bus stop inside the campus, while in Gualtar there are various bus stops around the campus. Both cities only have a few cycling lanes, which are not integrated into a network and do not connect the campuses to key destinations, such as the train station and the city centres (Fig. 1). In terms of parking, the two campuses provide 29 car parking and 9 bicycle parking areas. Students are allowed to buy car parking passes at a fixed price of 22.50€ per year.

2.2. Travel data

Students travel data was collected using an online questionnaire performed on SurveyMonkey (https://pt.surveymonkey.com). The questionnaire was previously structured and contained 36 closed-ended questions divided into four main parts. The first part included personal information related to gender, age, and type of student. The second was to collect data about the main mode of transport used by the students for commuting to the university. Students were asked to specify their residential locations (home address) so that home-university travel distances and travel times could be accurately calculated for each mode selected. The third part was focused on the reasons for using the selected modes and the willingness to change to other modes. The fourth part was related to the barriers preventing the use of public transport and active modes. These last two aspects were already analysed in a previous paper (Ribeiro et al., 2020a). The target population was approached through databases from the University. The questionnaire required about 15 min to complete, was administered in Portuguese and was concluded in April 2015.

The second step of the work consisted of calculating the travel distances and times of the commuting trips. The Google Maps journey planner was the tool selected to determine travel distances and travel times, due to its accuracy for measuring journeys (McBain and Caulfield, 2018). The process was done individually by entering the address and the mode of transport reported by each student into the journey planner. For Braga, Google Maps provides routing options for car, bus and pedestrian trips, but bus routing is not available for Guimarães. Bicycle routing is not available for both cities. The shortest home-university route provided by Google Maps was the criteria adopted to calculate travel distances and times.

2.3. Target travel distances and travel times

Acceptable travel distances and travel times for different services have been a matter of debate in the field of transport. The literature establishes the different distance and time thresholds for the various modes of transport for general urban trips (Dekoster and Schollaert, 2000; Rybarczyk and Gallagher, 2014; Sagaris et al., 2017), as well as for students commuting (Shannon et al., 2006; Zhan et al., 2016). In this paper, the students' mobility pattern was analysed by considering the following four travel distance and travel time classes: the walkable class, the bicycle class, the public transport class and the multimodal class (Fig. 2).

The walkable class comprises a home-university travel distance and travel time of up to 0.8 km and 10-minutes respectively. The literature shows that, on average, walking for 10 min at a speed of 5 km/h is a widely accepted utilitarian walking distance (Vale, 2013; Kang et al., 2017). Furthermore, some studies focused on students' mobility also show that the competitive distance of walking is<1 km (Shannon et al. 2006; Zhan et al., 2016).

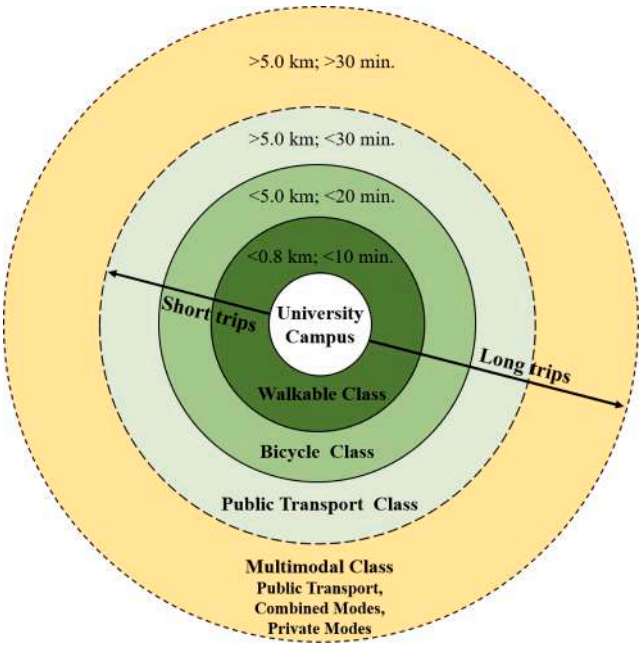

Fig. 2. Travel distance and travel time classes adopted in the study.

The bicycle class comprises a home-university cycling distance and time of up to 5 km and 20-minutes, considering a widely recognised cycling speed of 15 km/h (Goel et al., 2021; Sagaris and Arora, 2016). Some studies show that students usually cycle up to 5 km to university (Chillón et al., 2016; Pogačar et al., 2020) and that the distance between 4 km and 7 km is the maximum cycling travel distance for students (Zhan et al., 2016). Within these distances, bicycles are faster than walking and other motorised modes (Dekoster and Schollaert, 2000; Pérez-Neira, et al., 2020).

In this paper, motorised modes are considered more suitable for travelling distances longer than 5 km and for connecting lower density areas to urban centres (Sagaris and Arora, 2016). Accordingly, the public transport class is defined for trips longer than 5 km and shorter than 30 min. For Kelobonye et al. (2019), travel times of 30 min to universities by public transport are reasonable as these educational institutions are fewer in number and have sub-regional catchments. Moreover, the study of Coutts et al. (2018) also showed that travel times>30 min discourage students from commuting by public transport to universities.

Finally, the multimodal class is proposed for the longest home-university trips (>5 km; > 30 min). This class includes public transport, private motorised modes and all possible combinations between motorised and active modes.

2.4. CO_2 emissions from commuting to the university

The third aim of the paper was to estimate CO_2 emissions resulting from commuting to university and the potential reduction that can be obtained namely by replacing car trips with more sustainable modes. In this study, CO_2 emissions were calculated by using the DEFRA methodology (DEFRA, 2016). This methodology has been used by several authors to calculate CO_2 and air pollutants emitted by vehicles (Namdeo et al., 2019; Tiwari and Kumar, 2020; Wyatt et al., 2014). Emissions resulting from home-university commuting were estimated according to the following variables:

- Home-university travel distances. The main indicator used to calculate CO_2 emissions was the total passenger-kilometers (pkm) considering motorised modes. Data about the modes used came from

the questionnaire, while travel distances and times were retrieved from the Google Maps journey planner.

- Motorised modes of transport used for commuting. The two motorised modes considered in this study were cars and buses. As specified in Section 3, motorcycles and trains are little used by the students to commute to the university.
- The characteristics of vehicles in terms of the type of fuel (petrol, diesel), fuel consumption, and vehicle class (Euro Class). A representative vehicle type was adopted to reflect the local condition more accurately and the characteristics of motorised vehicles. This vehicle class data was taken from the Portuguese Insurance and Occupational Pensions Authority (data from 2016) and considering the North Region (NUTS 2), where the University of Minho is located and most of the students were living.
- DEFRA emission factors were defined according to the average speed and the type of roads. In this study, motorways and similarly high-speed roads in urban areas (with a population of 10,000 or more) were not selected for estimating the emissions. The corresponding average traffic speed considered was the legal speed limit for urban roads in Portugal (50 km/h).
- An average full time of 160 days per annum. According to the 2016 school calendar, there were 160 days with teaching activities. All periods without classes (weekends, bank holidays, recess and examination periods) were not included. Similar periods have been adopted by other authors in the assessment of university carbon footprints (Mendoza-Flores et al., 2019).

The emissions were estimated by considering an optimistic (based on the distance and travel time for model shifting evaluation) and a most likely (based on the stated choice of students) scenario. The optimistic scenario shows the impact that the total modal shift proposed in this study will have on the reduction of CO_2 emissions. The most likely scenario shows the impact according to the willingness to shift to more sustainable modes that was expressed by the students in the questionnaire (22%). For each scenario, the share of car and bus trips and respective travel distances and times was extrapolated to the entire student community to understand the overall reduction impact in potential CO_2 emissions that may result from shifting from motorised modes towards more sustainable modes of transport.

Finally, the average emissions of CO_2 per passenger kilometre (g CO_2/pass-km) for cars (137 g CO_2/pass-km) were similar to those obtained in other studies. For example, for private cars in Madrid, Sobrino and Arce (2021) used an average value of 136 g CO_2. The average emissions of CO_2 per passenger kilometre (g CO_2/pass-km) for buses (39 g CO_2/pass-km) were also similar to those obtained by Walsh et al. (2008) for buses in Dublin (18 g CO_2) since the bus occupancy rate in Braga and Guimarães is about half of that of Dublin. This indicates that although calibrated to the UK, the emissions factors toolkit of DEFRA can be used in countries like Portugal to calculate the vehicle emissions factors for CO_2.

3. Results

3.1. Sample structure

A total of 1073 students answered the questionnaire but, from these, only 686 fully answered the modes used for commuting to the university, specifying their home addresses. Of these, 67% were studying at the Gualtar Campus, while 33% were at the Azurém Campus. In our sample, 79% of the students were aged<24 years old, 62% were female, and 96% were undergraduate students (Table 1). The obtained sample corresponded to 5.15% of the entire student community at the time of the questionnaire.

Table 1
Main characteristics of the sample.

Variables		Students (N = 686)
Gender	Male	37.6%
	Female	62.4%
Age	< 24	78.7%
	≥ 25	21.3%
Type of student	Undergraduate	95.9%
	Graduate	4.1%

Source: Questionnaire conducted with students at the University of Minho.

3.2. Transport modes used, travel distances and times

Fig. 3 shows the transport modes used by the students for commuting to the university. Car trips represented 42% of the modal share, trips on foot 28% and bus trips 28%. There were slightly more students driving and walking to the Azurém Campus, while more students were riding a bus to the Gualtar Campus. The remaining modes (bicycle, motorcycle and train) were used by a relatively low proportion of students (2%) for commuting to the university.

The selected modes of transport differ among gender. Considering the most used modes, the percentage of commuting by car was much higher among male students (53%) than female students (36%). In turn, the percentage travelling by bus was higher among females (32%) than male students (22%). The walking trips were more representative among females (29%) than male students (21%).

The students' residential places are shown in Fig. 4. In the case of people studying at Gualtar, 62% were living in Braga, but only 29% of the people studying at Azurém were living in Guimarães. The remaining were mostly living in Braga (34%) and neighbour municipalities (32%). This distribution suggests that the students of Azurém tend to make longer trips than those of Gualtar. Some students travelled significant distances (>50 km) to commute to the university.

The home-university travel distances and times for the main modes of transport used by the students (car, bus and on foot) are shown in Tables 2 and 3, respectively. Regarding travel distances, results indicated that many car and bus trips were short trips within the cycling (<5 km) and walking (<0.8 km) classes. This is particularly evident in the case of Gualtar, where 38% of the car trips and 43% of the bus trips were shorter than 5 km. Car trips to Azurém were in general much longer: 51% of the students drove for ≥ 20 km. This could be explained by the fact that>50% of these students were not living in Guimarães. Walking was mostly preferred for very short urban trips: around 50% of the students walk<0.8 km to the university. The percentage of students walking decreases with the distance, but 11% walk > 1.6 km to reach the Gualtar Campus, which could be explained by the greater size of Braga in comparison to Guimarães.

Concerning travel times (Table 3), findings showed correlations with travel distances. Therefore, car trips to Gualtar (47% are < 15 min) were much more prevalent than short car trips to Azurém (21% are < 15 min).

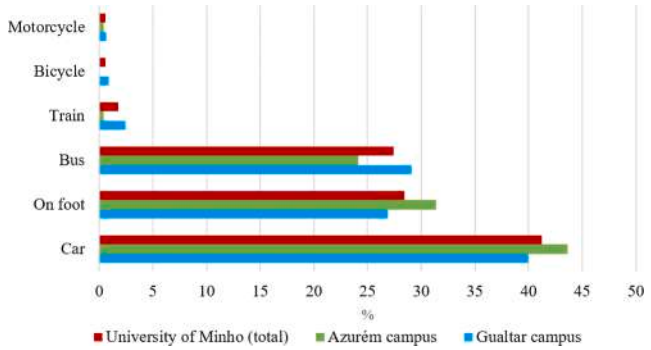

Fig. 3. Transport modes used by the students for commuting to the university.

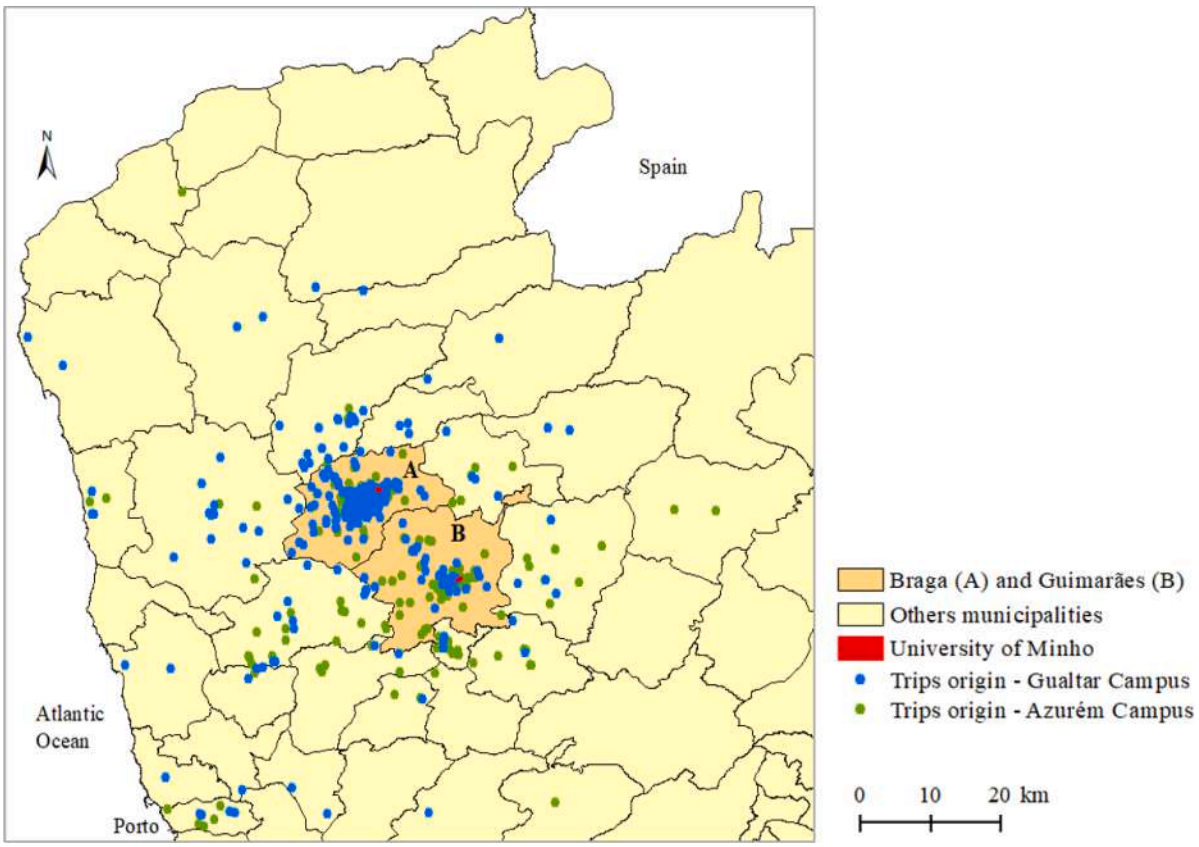

Fig. 4. Residential places of the people studying at the University of Minho.

Table 2
Home-university travel distances.

Distance classes (km)	Car		Bus		Distance classes (km)	Walking	
	Gualtar Campus (N = 182)	Azurém Campus (N = 105)	Gualtar Campus (N = 133)	Azurém Campus (N = 57)		Gualtar Campus (N = 117)	Azurém Campus (N = 72)
≤1	2.7%	0.0%	0.0%	–	≤0.80	46.2%	56.9%
>1 - ≤ 5	35.3%	14.3%	42.8%	–	>0.80 - ≤ 1.60	38.4%	37.5%
>5 - ≤ 10	10.4%	8.6%	21.8%	–	>1.60 - ≤2.40	5.1%	2.8%
>10 - ≤ 15	15.9%	11.4%	7.5%	–	>2.40	6.0%	2.8%
>15 - ≤ 20	6.1%	14.3%	5.3%	–	Unknown	4.3%	0.0%
>20 - ≤ 25	2.2%	20.0%	3.8%	–			
>25 - ≤ 30	7.1%	11.4%	10.5%	–			
>30	19.8%	20.0%	8.3%	–			
Unknown	0.5%	0.0%	0.0%	–			

Source: Questionnaire conducted with students at the University of Minho; Google Maps.

In turn, car trips > 25 min were much more prevalent among students from Azurém (57%), confirming that these students make longer trips than those from Gualtar. Regarding bus trips to Gualtar, 45% were > 25 min. The pedestrian trips were the shortest, more than half of the students walk<10 min to reach the university.

Table 4 and Fig. 5 summarise some additional data about the students' commuting trips. Car trips represented about 65% of the total distance travelled with the main modes of transport. On average, the home-university commuting distance was 12.4 km. Also, on average, walking trips had a duration of 12 min to cover a distance of 1.0 km, bus trips had an average duration of 33 min to cover a distance of 15 km and car trips had a duration of 23 min to travel 18 km.

3.3. Potential to shift towards more sustainable modes of transport

Considering the aforementioned daily home-university travel distances and travel times, many motorised trips could potentially be replaced by more sustainable and healthier modes of transport. Based on the four classes presented in the Methodology, the potential shift towards more sustainable modes of transport is presented in Table 5.

For many students moving on foot, bicycles could be an alternative mode to keep commuting actively but in a faster way. The analysis showed that about 43% of the walking trips (≥0.8 km/10 min) are within the bicycle class. Thus, these students could reduce their commuting times by shifting to bicycles. The analysis also indicated that many bus trips (<5 km/20 min) are within the bicycle class. For about 28% of these bus trips, the bicycle could be a healthier and more sustainable mode of transport, without affecting travel times. However, the

Table 3
Home-university travel time.

Time classes (minutes)	Car		Bus		Walking	
	Gualtar Campus	Azurém Campus	Gualtar Campus	Azurém Campus	Gualtar Campus	Azurém Campus
	(N = 182)	(N = 105)	(N = 133)	(N = 57)	(N = 117)	(N = 72)
≤5	0.0%	0.0%	0.0%	–	25.6%	6.9%
>5-≤ 10	23.1%	6.7%	6.0%	–	23.9%	61.1%
>10-≤ 15	23.7%	14.3%	14.3%	–	32.5%	23.6%
>15-≤ 20	10.4%	8.6%	25.6%	–	4.3%	5.6%
>20-≤ 25	11.0%	13.3%	3.8%	–	2.6%	1.4%
>25-≤ 30	7.2%	21.9%	7.5%	–	3.4%	1.4%
>30-≤ 35	4.9%	19.0%	3.0%	–	1.7%	0.0%
>35	19.2%	16.2%	34.6%	–	1.7%	0.0%
Unknown	0.5%	0.0%	5.2%	–	4.3%	0.0%

Source: Questionnaire conducted with students at the University of Minho; Google Maps.

Table 4
Main data about the students' home-university commuting*.

Modes of transport	Total passenger-kilometres (pkm)	Total passenger-minutes (pmin)	Average distance per student (km/day)	Average time per student (min/day)	Average distance (km) per student (annual)*	Average speed (km/h)
Walking	184	2165	1.00	11.77	160.41	5.67
Bus	2633	5589	14.71	32.49	2353.60	24.22
Car	5217	6696	18.24	23.41	2918.35	38.27
Total	8034	14450	12.38	22.40	1980.80	25.34

* Considering 160 attendance days per year, one way.

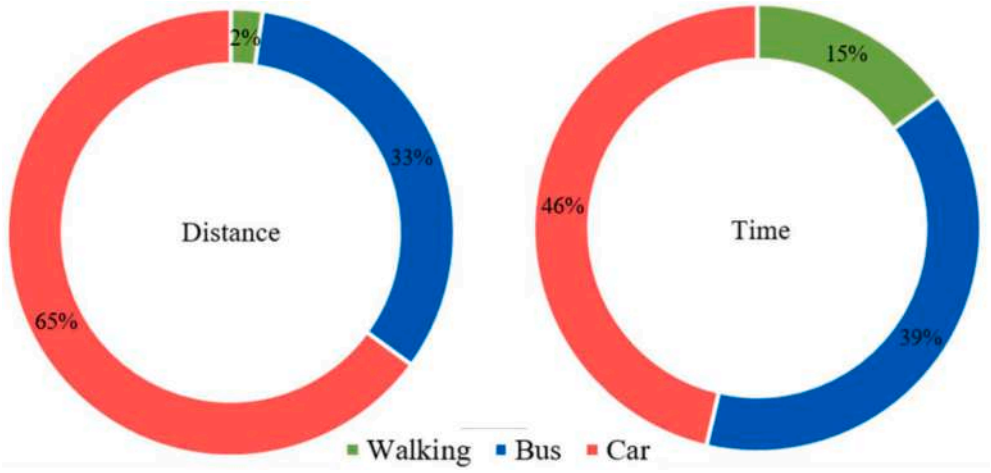

Fig. 5. Total passenger-kilometres and total passenger-minutes.

Table 5
Transport modes used and potential shift towards more sustainable modes.

Modes of transport	Modes currently used		Potential shift								Unknown	
			Walking		Bicycle		Bus		Car			
	#	%	#	%	#	%	#	%	#	%	#	%
Car	287	41.8%	3	1.1%	81	28.2%	121	42.2%	81*	28.2%	1	0.3%
Bus	190	27.7%	0	0.0%	54	28.4%	43*	22.7%	75	39.4%	18	9.5%
Bicycle	4	0.6%	0	0.0%	4*	100.0%	0	0.0%	0	0.0%	0	0.0%
Walking	189	27.6%	89*	47.1%	81	42.9%	14	7.4%	0	0.0%	5	2.6%
Motorcycle	4	0.6%	0	0.0%	3	75.0%	1	25.0%	0	0.0%	0	0.0%
Train	12	1.7%	0	0.0%	0	0.0%	0	0.0%	1	8.3%	11	91.7%
Total	686	100%	92	100%	223	100%	179	100%	157	100%	35	100%

*Keep the mode.

modal shift with the greatest potential involves car trips. More specifically, 28% of the car trips are within the bicycle class (<5 km/20 min), 42% were within the public transport class (>5km/<30 min) and 1% within the walking class (<0.8 km/<10 min). This means that many of these short car trips can be potentially replaced by more sustainable and healthier modes of transport. Nonetheless, a significant part of the bus

trips (39%) could also be faster if students shifted to cars. This potential shift that mostly involves long bus trips should be discouraged to avoid a switch to a less sustainable mode. Providing more direct bus lines between the campuses/centres of Braga and Guimarães and the respective surrounding municipal areas will reduce travel and transfer times and make buses more competitive when compared to cars.

Considering the described target modes, there is a potential to switch 205 daily car trips to bus, bicycle and walking trips, representing a reduction of 71% in the car trips. In terms of modal share, car trips can decrease from 42% to 14% (Fig. 6), while bus trips can increase from 28% to 31%. The bicycle could potentially become the most relevant mode of transport. According to the students' travel distances and times, about 39% of their trips could be made by bicycle. Finally, the modal share of the walking trips decreases from 28% to 16%, but 94% of this shift was replaced by the bicycle. Thus, motorised trips could decrease from 70% to 45%, while there is a potential to increase the active modes from 28% to 55%. The environmental benefits of this potential shift are analysed in the following subsection.

3.4. CO_2 travel emissions

In this study, it was considered that walking and cycling (assuming only the use of regular human-powered bicycles) do not have a direct impact in terms of CO_2 emissions. Thus, emissions were estimated for car and bus trips according to the DEFRA methodology described above. As shown in Table 6, annually the 477 motorised trips made by the students for commuting to the university generate about 265 tons of CO_2. Car trips were responsible for around 86% of these emissions.

The CO_2 savings resulting from the proposed modal shift are also presented in Table 6. In our sample (n = 686) and an optimistic scenario (full shift), switching from car to bus could result in an annual saving of 57 tons of CO_2, while switching from car to active modes would save 13 tons of CO_2 annually. The overall benefit of this modal shift is a reduction of 27% in the CO_2 generated by the students' daily home-university trips. This also means that long commuting contributes the most to CO_2 emissions. Given the reported willingness to switch to more sustainable modes (22% of the students are willing to shift mode), the savings are likely to be lower. In this most likely scenario, replacing car trips with active modes will only decrease the annual emissions of CO_2 by 4 tons, while replacing cars with bus trips will result in an annual saving of 16 tons of CO_2.

The extrapolation of the modal share of our sample to all students gives a different overview of the potential CO_2 savings (Table 7). The motorised trips of all students (N = 19077) produce about 7,357 tons of CO_2 annually. In an optimistic scenario, a full shift towards more sustainable modes will represent an annual saving of 1963 tons of CO_2, while in the case of the most likely scenario (N = 4116), the modal shift will represent an annual saving of 597 tons of CO_2.

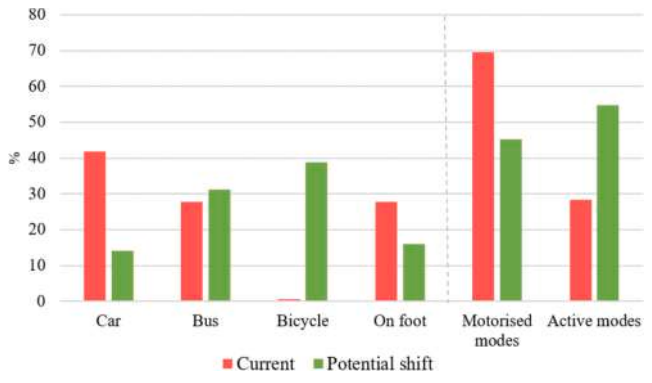

Fig. 6. Transport modes used and potential shift towards more sustainable modes.

Table 6
Annual emissions of CO_2 from motorised commuting to the university and potential savings from shifting towards more sustainable modes.

Modes of transport	Estimated annual emissions	Estimated annual savings			
		Optimistic scenario (N = 686)		Most likely scenario (N = 148)	
		Walking and cycling	Bus	Walking and cycling	Bus
Car	228.78 ton	− 11.27 ton	− 57.10 ton	−3.89 ton	−16.05 ton
Bus	35.77 ton	− 2.16 ton	–	−0.37 ton	–
Total	264.65 ton	− 13.43 ton	– 57.10 ton	−4.26 ton	−16.05 ton

Table 7
Extrapolated annual emissions of CO_2 from motorised commuting to the university and potential savings from shifting towards more sustainable modes.

Modes of transport	Estimated annual emissions	Estimated annual savings			
		Optimistic scenario (N = 19077)		Most likely scenario (N = 4116)	
		Walking and cycling	Bus	Walking and cycling	Bus
Car	6 361.88 ton	− 313.41 ton	– 1 588.02 ton	−168.28 ton	−414.55 ton
Bus	994.67 ton	− 61.12 ton	–	−14.01 ton	–
Total	7 356.55 ton	− 374.53 ton	– 1 588.02 ton	−182.30 ton	−414.55 ton

4. Discussion

Based on travel data retrieved from a questionnaire, this study evaluates if the transport modes used by the students of the University of Minho are the most sustainable considering their travel distances and times and analyses the potential to shift towards more sustainable modes and the benefits of such shift in terms of CO_2 savings. Results indicated that about 54% of the distances travelled by the students were < 5 km and 61% were < 20 min. Physical proximity has been mentioned as a factor that increases the probability of commuting by active modes to university (Delmelle and Delmelle, 2012; Zhan et al., 2016; Pérez-Neira et al., 2020). Nonetheless, in our sample, 42% of the students commuted by private motorised modes. As highlighted in the Introduction, the car has been the preferred mode of transport for many students around the world. In a previous study, we found that convenience, the need for performing other activities before/after classes, and the poor public transport service were among the main reasons for commuting by car to the University of Minho (Ribeiro et al., 2020a).

Based on the methodology proposed in the current study, a significant part of the motorised trips could potentially be replaced by more sustainable and healthier modes. Bicycles could potentially replace 28% of the car trips, 28% of the bus trips and 43% of the walking trips and, therefore, ensure 39% of all the students' trips (Fig. 6). This modal shift is close to that identified by Bodor and Küster (2017) in the context of the EU Cycling Strategy. They argued that 42% of all motorised trips in the EU urban areas could be made by bicycle because they are short enough, they are not part of complex trip chains and do not involve transporting heavy goods.

Considering this target mode share, university administrators and city planners should be focused on improving the use of bicycles and discouraging students from driving to university. As shown in Fig. 1,

Braga and Guimarães only have a few cycling lanes, which do not form a useful network and do not link the campuses to critical destinations, such as transport hubs and city centres. The literature shows that providing cycling facilities is one of the most effective ways to increase the number of cyclists (Lundberg and Weber, 2014; Motoaki and Daziano, 2015). Thus, city planners should focus on providing cycling facilities, such as lanes segregated from traffic, bicycle parking, and bike-sharing solutions to offer a safe, convenient and comfortable bicycle connection between the campuses and key urban areas. Campus administrators should also focus on providing suitable bicycle facilities, including bicycle parking, bike-sharing, dressing rooms and showers. Except for bicycle parking, these facilities are missing on both campuses. The reposition of free bike-sharing initiatives launched by the University of Minho, such as the *Bute* and *U-bike* projects, could also help to raise the cycling share among students.

To increase the number of students travelling on foot, an overall improvement of the pedestrian conditions around the campuses is required. This includes pedestrian facilities and sidewalks providing comfortable, safe and convenient conditions for walking and good connections to public transport stops. As shown in previous studies, the provision of suitable pedestrian facilities is an effective way to encourage people to walk to universities (Lundberg and Weber, 2014; Azzali and Sabour, 2018; Göçer and Göçer, 2018).

Increasing the bus occupancy rate, which is relatively low in both cities (around 25%), and the overall number of students travelling by bus also depends on policies to improve the service provided. This is particularly important for Guimarães. The city has a lower bus stop density (4.7 stops/km2) than Braga (6.3 stops/km2) and the Azurém Campus is only served by one bus line. Long travel times, long route extensions, no stops closer to the residence, the need to catch more than one bus are amongst the barriers preventing the use of public transport among the community of the University of Minho (Ribeiro et al., 2020a). In fact, there is evidence that the lack of reliable public transport services is one of the main reasons leading students to travel by car to universities (Aoun et al., 2013; Hickman et al., 2018; Sisiopiku, 2018). As confirmed in previous studies (Shannon et al., 2006; Zhou, 2014), a fare policy reform, through discounts and subsidised passes, may also boost the public transport ridership among students. Improving the bus connections between the campuses and the train stations, creating bicycle lanes linking the campuses to the stations and providing bicycle share solutions at these stations could encourage students to use public transport in combination with active modes of transport.

University administrators should also focus on discouraging car trips. As can be found in previous studies (Shannon et al., 2006; Barata et al., 2011), the low parking price at the University of Minho (22.5€/year in average for students) could be the main reason to commute by car. Preventing the students living near the campus from parking on the campus and raising the parking fees have been described as efficient policies to reduce car trips to universities (Toor and Havlick, 2004; Aoun et al., 2013; Dell'Olio et al., 2018). Institutional policies developed to promote car sharing and carpooling can also contribute to reducing individual car trips (Gurrutxaga et al., 2017).

In Minho, the home-university trips of the 686 students produced around 519 tons of CO_2 per year. Nonetheless, extrapolations to the whole student community showed that commuting could produce 7357 tons of CO_2 annually. Considering the target modes defined, shifting from motorised towards more sustainable modes could result in substantial CO_2 savings that range from 8% in the most likely scenario up to 27% in the optimistic scenario. Nonetheless, most of the current CO_2 emissions were associated with long motorised trips (>5 km and > 30 min). Changes in the modal behaviour of the students living far from the campuses are recognisably more difficult (Pérez-Neira, et al., 2020) due to time constraints, excessive distance for using active modes, and a lack of efficient public transport services, among other reasons. Improving the coverage and the quality of the public transport connections between the cities and the surrounding municipalities and car-sharing is vital to discourage long individual car trips.

The described results have some limitations that must be mentioned. The modal share targets based on using travel distances and times are somewhat simplistic (Whalen et al., 2013), but they could be helpful for sustainability planning, namely to examine excessive dependence on private cars and to operationalize the sustainability pyramid, which establishes walking, cycling, and public transport as a top priority for investment (Sagaris et al., 2017). Although travel distances and travel times have a great influence on the student's travel mode choice (Shannon et al., 2006; Rybarczyk and Gallagher, 2014; Zhan et al., 2016; Fontalvo et al., 2018), other important factors, such as comfort, safety, weather, were not included in the analysis. Therefore, different students may choose different modes for travelling the same distance. For example, we found that there were more male students driving and more females walking and travelling by bus. Although there are some studies indicating that female students are more likely to use active modes (Moniruzzaman and Farber, 2018; Nguyen-Phuoc et al., 2018) and public transport (Nayum and Nordfjærn, 2021), previous studies also showed the opposite, e.g., student car users are more likely to be females (Davinson et al., 2015; Delmelle and Delmelle, 2012; Zhou, 2014). More importantly, male students have been found more likely to switch from cars to other modes of transport (Delmelle and Delmelle, 2012). Thus, launching information and awareness campaigns especially addressed for male students about the benefits of walking, cycling and using public transport might also be part of a successful policy to reduce car use.

Secondly, the analysis used for estimating the CO_2 emissions from commuting to the university was based on home-university commuting during 160 school days/year. This is an average frequency which overlooks the fact that students could make more trips per day, such as to have lunch, as well as during examinations, but also omits the fact that students may not necessarily travel to the campus every school day, as students do not have compulsory attendance for all activities. Further, students do not have the same travel behaviour during the year. As shown in previous studies (Miralles-Guasch and Domene, 2010; Agarwal and North, 2012), students are more likely to drive than walk and cycle during the winter due to the bad weather (rain, low temperatures). The modes used may also differ during the week, depending on individual circumstances, such as being dropped-off by a family member or by a colleague. Furthermore, when estimating the CO_2 emissions factors, the time spent in traffic jams or looking for parking was not considered. For that reason, the emissions calculated could be underestimated.

Thirdly, the optimistic scenario defined for estimating CO_2 savings assumes an entire switch to the target modes. This scenario is unlikely to happen, because students may not switch for many reasons: not knowing how to ride a bicycle, mobility impairments, safety concerns, convenience, etc. In this case, the intention was to show the overall CO_2 savings that may result from a full shift towards more sustainable modes.

Fourthly, the questionnaire was performed before the COVID-19 crisis, which abruptly changed our travel behaviours and wiped out some of the described findings. Recent studies reported a strong reduction of trips to universities due to remote classes, a high decrease in the use of public transport and a rise in private transport and active modes (Beria et al., 2021; Perez-Lopez et al., 2021). In our case study, active travel is convenient, because many trips are at distances < 5 km and < 30 min. However, bringing back the students to public transport could be more difficult and may require specific actions, such as campaigns and discounted fares. It is particularly important to show that when measures recommended by the health authorities are implemented, public transport can be COVID-safe.

5. Conclusions

Universities are privileged spaces for creating and promoting sustainable behaviours, but they can also be significant generators of transport-related GHG emissions. This paper analysed the home-university commuting patterns of 686 students at the University of

Minho, Portugal. Results indicated a strongly car-dependent mobility: 42% commuted by car and from these car trips, 29% were within walking and cycling distances up to 0.8 km and 5 km, respectively. Considering the overall short travel distances and travel times, many of these car trips can potentially be replaced by more sustainable and healthy modes of transport (active modes and bus), decreasing car trips from 42% to 14%. In the environmental domain, car trips were responsible for 86% of the CO_2 emitted and depending on the scenario analysed, a shift towards more sustainable modes can reduce the emissions of CO_2 from 8% up to 27%.

The findings obtained can be applied to better design policies to move car trips towards more sustainable modes. Within the university policy scope, car trips could be discouraged by: i) changing the parking policies, namely by raising parking fees and restricting car access; ii) providing facilities for walking and particularly for cycling, such as bike parking, showers, and changing facilities; iii) promoting cycling initiatives, incentives and campaigns such as the *Bute* and *U-bike* projects. Within the city policy scope, there are various policies that may convince students to replace cars with more sustainable modes. These include: i) improvement of the public transport service provided, including in the outskirts and less compact urban areas; ii) incentives, such as subsidised public transport passes, for students; iii) planning and providing a network of cycling lanes, connecting the campuses to key urban destinations; iv) providing bike sharing stations in the campuses and key destinations, including in public transport stations, city centres and main residential areas; and v) improving the pedestrian infrastructure around the campuses. Meanwhile, the recent crisis caused by the COVID-19 pandemic abruptly changed our travel behaviours. It is not yet entirely known how travel habits may change after the pandemic passes. People are apparently more reluctant to use crowded modes of transport but are willing to switch to active modes to travel to universities (Caulfield et al., 2021). This could be an interesting avenue for further research in the future.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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