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# Active travel in the university setting: Assessing the effects of social behavior, socioeconomics, and spatial location

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**Abstract:** University campuses are pooling efforts to promote active mobility to reduce their negative impacts on the urban environment, which is significantly influenced by the overreliance on motorized modes of transport. Providing sufficient and safe accessibility conditions for active travel has been highlighted as a crucial strategy for transforming campuses into more livable and sustainable areas in cities. To further explore the likelihood of active mobility uptake at university campuses, this study explored university students' mobility patterns over time, examining the role of social behavior, socioeconomics, and spatial location factors. The Faculty of Engineering at the University of Porto, Greater Oporto, Portugal, provided the empirical focus for this research. The data analyzed were acquired through surveys of representative samples and spatial analysis over the academic years of 2012, 2017, and 2023. The statistical analysis explained the tendencies and multifactorial influences on travel behavior among university students. Results indicated that travel distance is associated with housing options and travel costs, whereas access to a metro station was associated with walking or cycling. Hence, this study contributed to a deeper understanding of active travel behavior. It provided insights to guide planning practitioners and decision makers in creating integrated transport policy packages that address the barriers and needs of the university community and the surrounding neighborhoods.

**Keywords:** Travel behavior, active travel, accessibility, survey, university students

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## 1 Introduction

Over the last decades, cities have experienced rapid urban and demographic growth accompanied by an increasing dispersion of population and activities over territories. Such dispersion affects the distribution of services and infrastructure, ultimately influencing land and energy consumption and perpetuating dependence on motorized modes of transport, especially private vehicles (Banister, 2011). In response, advancing sustainable mobility has become a central theme among international organizations, scientific research and the political realm.


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Promoting active travel in cities brings numerous benefits that encompass the livelihood of urban areas, quality of public spaces, public health, and environmental protection. The use of alternative mobility options is closely related to urban proximity (Kinigadner et al., 2020; Moreno et al., 2021; Pajares et al., 2021) and increased accessibility to services, supported by a diverse range of land-use activities and travel demand measurements in favor of sustainable modes.

In such a debate, increasing attention has been drawn to university campuses and the student population (Zhou, 2014, 2016) because this group is flexible and receptive to changes, which is pivotal in community-scale behavioral change (Balsas, 2003). Moreover, university campuses highly impact mobility patterns at the city scale since they generate an elevated number of trips, especially during peak hours. Previous research shows that university students can change attitudes towards alternative and sustainable patterns, notably when adequately supported (Lundberg & Weber, 2014). Hence, active commuting in universities has slowly but steadily become a priority, as pushed by the sustainable mobility agenda.

Nevertheless, it remains unclear whether the uptake of active modes of transport among university students in the context of a car-oriented city is positively affected over time by factors encompassing social behavior, socioeconomic and spatial location, the so-called "3Ss" (Soria-Lara et al., 2017). Such an approach allows a deep understanding of car dependency from an integrated perspective and the identification of factors positively associated with sustainable mobility at university campuses. According to Soria-Lara et al. (2017), spatial location factors are linked to the spatial characteristics of metropolitan regions, including campus location, public transport availability, and urban density. Socioeconomic factors, on the other hand, encompass the characteristics of the student population, such as income levels and age. Finally, the social behavior factors consist of a collective perspective on the student lifestyle, including the time this group spends at the University and how many days per week they travel to campus (Soria-Lara et al., 2017).

Numerous studies have highlighted the determinant factors that may affect active and sustainable travel behavior (Chillón et al., 2016; Ribeiro & Fonseca, 2022; Sun et al., 2014), but few have compared them over time. Studies over time have the advantage of identifying trends and determining the effects of packages of mobility measures and plans, allowing a deeper understanding of the relationship between distinct factors and how their dynamics may be a determinant tool to support planning practice. According to Anable (2005), to build policy measures with effective results, attention should be drawn to the limitations and needs of specific groups, suggesting that segmentation should tackle different attitudes and travel behaviors (Anable, 2005; Beirão & Cabral, 2008; Marquet & Miralles-Guasch, 2014).

Hence, this paper delves into the commuting patterns of university students, exploring the main modal choice determinants and identifying whether commuting has become more environmentally friendly over time. This study aims to provide empirical evidence and insights to help practitioners develop sustainable policies, programs, and actions that more effectively address the mobility needs of university students and the broader community.

Therefore, this study explores changes in modal choice encompassing active commuting, perceptions, and barriers to understand the explanatory factors that influence modal choice over time. Henceforth, this research addresses the following question: To what extent do factors associated with spatial location, socioeconomics and social behavior influence active commuting to the University?

This manuscript is organized as follows. After this introduction, the second section presents a literature review that explores mobility patterns in university settings, focusing on the "3Ss" approach and travel demand management practices. The third section

describes the case study, the data-gathering process, and the quantitative methodology applied in this research to shed light on the abovementioned research question. The fourth section discusses this research's main findings and implications for planning practice. Finally, the last section of this paper summarizes the main conclusions, research limitations, and potential future research pathways.

## 2 Active mobility on university campuses

Higher education institutions are widely acknowledged as catalysts for awareness creation, strengthening, and reshaping sustainable mobility. Research on college students' travel behavior is particularly relevant because such a target group has a high potential for changing behavior and attitudes, standing as forerunners of society (Marquet & Miralles-Guasch, 2014). Furthermore, mobility habits built during University will likely endure and be pivotal in future mobility patterns (Zhou, 2012, 2016).

During the last decades, studies focused on the role of the university community in advancing sustainable mobility have been increasing (Bonham & Koth, 2010; Crotti et al., 2022; Stein & Rodrigues da Silva, 2018). Indeed, universities are not only major traffic generators but also privileged places to communicate the values of sustainable travel behavior (Zhan et al., 2016). In this context, travel demand management (TDM) measures are of general population interest (Balsas, 2003), not only because universities have broader importance and affect the community they belong to but also because the same measures aimed at improving student mobility are beneficial to the broader community (Crotti et al., 2022).

University campuses can take advantage of complementary strategies to promote sustainable mobility patterns, considering the role of walking, cycling, and e-scooters as safe and feasible modes of transport. Whereas pedestrian facilities mainly encompass sidewalk networks and walking dedicated zones, bicycle users are affected by road network directness, quality of cycling infrastructure, bicycle parking, maintenance, comfort, convenience, and safety (Balsas, 2003; Cunha et al., 2024; Wilson et al., 2018). According to previous research, university students constitute one of the most significant proportions of the market e-scooter share and, therefore, represent a crucial target group for advancing political strategies tailored to their barriers and needs (Nikiforiadis et al., 2023).

To further explore the current empirical evidence encompassing active travel in university settings, this literature review focuses on the factors associated with the 3Ss framework, considering differences between walking, cycling, and e-scooter usage.

### 2.1 Social behavior

Factors encompassing attitudes, individual limitations, and cultural norms are discussed as fundamental to understanding satisfaction towards different modes of transport. Attitudes towards active modes are relatively positive among university students, who consider active commuting relaxing, flexible and fast (De Angelis et al., 2021). Likewise, a previous study reported a positive relationship between active modes uptake and travel satisfaction (Nematchoua et al., 2020). Embodied, emotional and affective mobility practices have also been highlighted as critical in students' experiences and identities. In this case, walking for commuting helped students to integrate themselves into the community and overcome loneliness (Wilkinson & Badwan, 2021).

Students who have swapped motorized modes to cycling or walking were twice as satisfied because of the underlying benefits, including physical and mental health, social interaction, self-reliance and environmental belonging (Schneider & Willman, 2019). The use of e-scooters for utilitarian trips has grown significantly within the last five years, especially after the COVID-19 outbreak (Chahine et al., 2024; Sorkou et al., 2022). University students reliant on e-scooters perceive this mode of transport positively, considering issues of convenience, cost, safety, parking, and usefulness (Buehler et al., 2021; Nikiforiadis et al., 2023).

Previous studies indicate that significant differences in perception exist between bike users and non-users, especially concerning individual and group awareness of road safety (Bonham & Koth, 2010; Mateo-Babiano et al., 2020; Pazhuhan et al., 2022). Accordingly, students reliant on public transport options to travel long distances reported negative travel satisfaction compared with car users (De Angelis et al., 2021). On the other hand, cyclists and scooter users are likely to perceive their travel experience as efficient and funny (Buehler et al., 2021).

Promoting active travel can create and foster awareness about the individual impacts on urban mobility (Thigpen, 2019). In particular, previous studies demonstrated that cultural norms play a pivotal role, especially in active travel on university campuses (Ibrahim et al., 2022). According to previous studies, a higher volume of cyclists leads to increased visibility and attractiveness of this mode of transport (Rybarczyk & Gallagher, 2014; Wang et al., 2015).

Although previous studies indicate that the car-oriented paradigm negatively affects the uptake of active modes of transport (Cunha et al., 2023), there is still a lack of studies examining the social behavior explanatory factors that shape modal choices in the university setting. Moreover, few studies have examined such factors within car-dependent cities with low bicycle usage (Maas et al., 2020; Rahman et al., 2018) and walkability levels (King et al., 2020), and higher political and social resistance towards active modes of transport (Bicalho et al., 2019; Cunha et al., 2024; Silva et al., 2019).

### 2.2 Socioeconomics

Distinct socioeconomic factors affect active travel among the student population. According to previous research, active and sustainable commuting is influenced by income, travel costs (Wang et al., 2015; Whalen et al., 2013), and car ownership (Henning et al., 2020; Ribeiro et al., 2020; Ribeiro & Fonseca, 2022; Soria-Lara et al., 2017). Scholars argue that the income level explains vehicle ownership and the number of car trips and miles travelled (Etminani-Ghasrodashti et al., 2018).

Bicycle ownership and cycling skills are positively associated with active commuting (De Wet et al., 2021). To make cycling attractive among students, campus-based public bike-sharing programs emerged in recent years to facilitate access to the bicycle itself and promote cycling among university students, changing travel behavior and attitudes (Kutela & Teng, 2019; Pazhuhan et al., 2022). Moreover, financial incentives have been shown to promote active commuting significantly (Martin et al., 2012).

Scholars found that TDM strategies focused on increasing automobile costs and paid parking will likely promote a shift towards active modes among university members (Rybarczyk & Gallagher, 2014). Conversely, regarding the changes associated with life transition during university years, a study indicated that economic factors related to early adulthood, such as housing relocation and full-time employment, decreased active travel participation in later life stages (Bopp et al., 2019).

From a gendered perspective, studies have uncovered that men are more likely to use active modes than women (Sims et al., 2018). Likewise, the use of e-scooters is more common among males under 40 years old, who are less sensitive to safety and security issues (Buehler et al., 2021; Huo et al., 2021; Moosavi et al., 2022). Women more frequently combined bicycle-sharing systems with public transport, motivated by fitness improvements and the positive influence of their social circle (Teixeira & Cunha, 2023).

The size of household composition also plays a critical role in mobility behavior and modal choice (Tolley, 1996). Previous studies disclosed that having children is highly associated with trip chaining and using private motorized modes of transport (Akar et al., 2013; Delmelle & Delmelle, 2012).

### 2.3 Spatial location

Active commuting is directly associated with travel distance, time (Zhang & Xiaowei, 2024) and the quality of the infrastructure (van Nijen et al., 2024). Previous studies indicate that campuses located within urban areas have a higher share of students travelling by foot, bicycle and e-scooters than on campuses situated in the outskirts and rural zones (Buehler et al., 2021; Lundberg & Weber, 2014; Tormo-Lancero et al., 2022). Considering the threshold distance, scholars suggest that active mobility decreases with longer distances, highlighting the average thresholds of 2.6 km for walking and 5.1 km for cycling (Chillón et al., 2016).

Accordingly, shorter commute distances to the University are positively associated with the likelihood of using active modes (Henning et al., 2020; Sims et al., 2018) and positive travel satisfaction (Schneider & Willman, 2019). The proximity to campus and the presence of bicycles (Havet & Bouzouina, 2024) and e-scooters infrastructure encourage riding for commuting purposes (Nikiforiadis et al., 2023; Wang et al., 2015). Likewise, good weather conditions, suitable topography, and street greenery will likely affect active commuting (Bai et al., 2022; Ibrahim et al., 2022), especially for women and public transport pass holders (Nahal & Mitra, 2018).

Individual and shared e-scooters are more common in city centers, often covering gaps in public transport networks (Huo et al., 2021). In particular, shared e-scooters are a preferred option for students travelling for up to 30 minutes (Nikiforiadis et al., 2023).

Regarding the role of neighborhood configuration, a study demonstrated that bicycle users are more likely to live in zones with good-quality infrastructure. In contrast, people from medium-density and suburban single-family neighborhoods are less likely to rely on active transport (Park & Akar, 2019), whereas students living in cyclable and walkable zones are more likely to rely on active modes of transport (Rybarczyk & Gallagher, 2014).

According to a previous study, e-scooter ridership positively correlates with population and employment density, land use mixed entropy and bus stop density (Huo et al., 2021). Moreover, pedestrianized zones have also been identified as effective in reinforcing walking and the attractiveness of shared e-scooters (Sorkou et al., 2022). Nevertheless, a crucial quest for city planners and policymakers is reducing the potential conflicts between different modes of transport in shared streets (Gössling, 2020), and in this case, road safety and speed limits are critical issues in the discussion agenda.

Table 1 below summarizes the main factors affecting walking, cycling, and e-scooter usage, considering social behavior, socioeconomics, and spatial location dimensions.

**Table 1.** Summary of factors affecting active commuting across the 3Ss dimensions

| 3Ss | Factors | 🚶 | 🚲 | 🛴 | References |
|---|---|---|---|---|---|
| Social Behavior | Individual attitudes | * | * | | (De Angelis et al., 2021) |
| | Travel Satisfaction | * | * | * | (Nematchoua et al., 2020; Schneider & Willman, 2019) |
| | Convenience | | | * | (Buehler et al., 2021) |
| | Social Interaction | * | * | | (Wilkinson & Badwan, 2021) |
| | Health | * | * | | (Bopp et al., 2019; Teixeira & Cunha, 2023) |
| | Cultural norms | * | * | | (Ibrahim et al., 2022; Rybarczyk & Gallagher, 2014; Thigpen, 2019; C. H. Wang et al., 2015) |
| | Safety | * | * | * | (Bonham & Koth, 2010; Mateo-Babiano et al., 2020; Pazhuhan et al., 2022) |
| | Usefulness | | | * | (Nikiforiadis et al., 2023) |
| | Cycling skills | | * | | (Thigpen, 2019) |
| Socioeconomics | Cost | | * | * | (C. H. Wang et al., 2015; Whalen et al., 2013) |
| | Gender imbalance | | * | * | (Buehler et al., 2021; Huo et al., 2021; Moosavi et al., 2022; Sims et al., 2018; Teixeira & Cunha, 2022) |
| | Having children | | * | | (Akar et al., 2013; Delmelle & Delmelle, 2012) |
| | Car ownership | * | * | | Henning et al., 2020; P. Ribeiro et al., 2020; P. J. G. Ribeiro & Fonseca, 2022; Soria-Lara et al., 2017) |
| | Bicycle ownership | | * | | (De Wet et al., 2021) |
| | Shared schemes | | * | * | (Kutela & Teng, 2019; Pazhuhan et al., 2022) |
| | Employment | * | * | | (Bopp et al., 2019) |
| | Financial incentives | * | * | | (Martin et al., 2012; Rybarczyk & Gallagher, 2014) |
| Spatial location | Travel distance | * | * | * | (Chillón et al., 2016; De Angelis et al., 2021; Henning et al., 2020; Sims et al., 2018) |
| | Urban areas | * | * | * | (Buehler et al., 2021; Lundberg & Weber, 2014; Tormo-Lancero et al., 2022) |
| | Infrastructure | * | * | * | (Park & Akar, 2019; Rybarczyk & Gallagher, 2014; Sorkou et al., 2022) |
| | Topography | | * | | (Ibrahim et al., 2022) |
| | Street greenery | * | * | | (Bai et al., 2022) |
| | Weather conditions | | * | | (Ibrahim et al., 2022) |
| | Land use mix | | | * | (Huo et al., 2021) |
| | High-density zones | * | * | * | (Huo et al., 2021; Park & Akar, 2019) |

# 3 Methodology

## 3.1 Study area

The Faculty of Engineering of the University of Porto, Greater Oporto, Portugal, provided the empirical focus for this research as this university campus is a vital transport activity generator in the Oporto Metropolitan Region (Figure 1). The selected faculty has a population of nearly 5000 students and is located on the largest campus in the metropolitan region, comprising many higher education and research institutions.

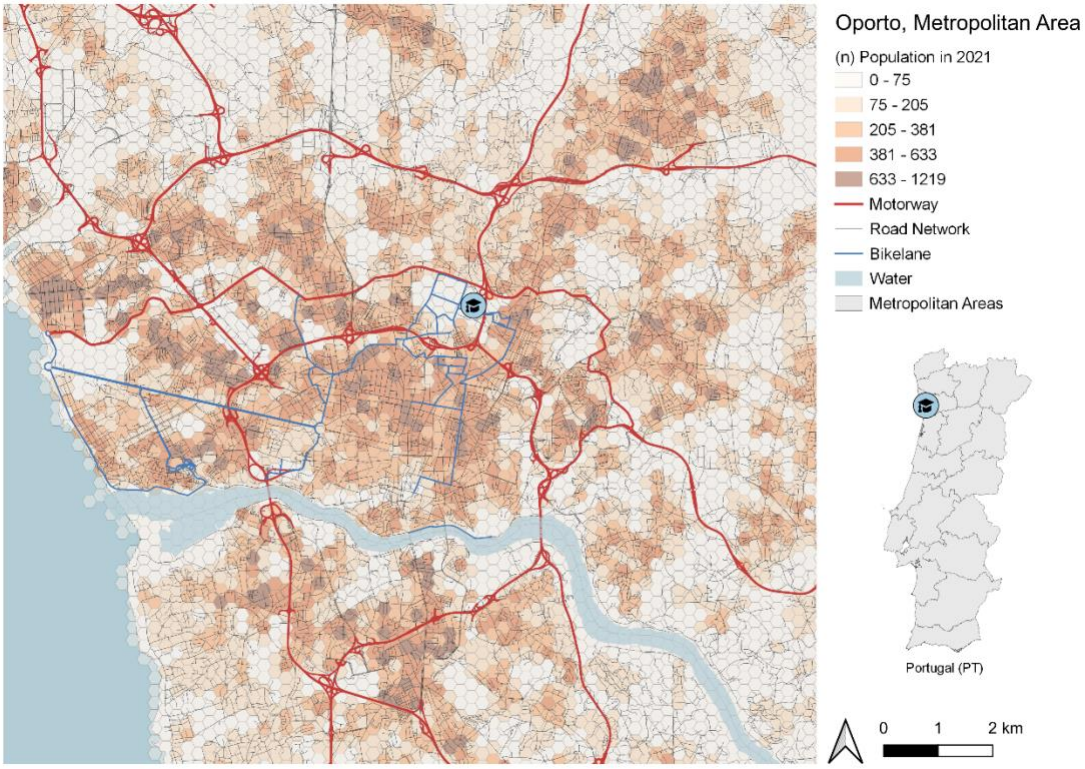


**Figure 1.** University campus location in the metropolitan area of Oporto
*Sources: OpenStreetMap, 2021 Census*

The urban fabric of the case study is monofunctional despite some attempts to revise the municipality master plan. Therefore, the site is poorly consolidated in the urban fabric and bounded by a hurdle ring road, which constrains the movement of people towards the facilities installed in the surrounding area.

The existing road network and pedestrian infrastructure present significant articulation problems between the main connecting roads and the elements of the road macrostructure, whereas the cycling network is virtually absent. Moreover, over the last few years, this area has been a target for constructing new extensive private facilities for overpriced student accommodations.

As illustrated in Figure 2, the campus area has a low population density and lacks land-use diversity. Concerning essential services, food, health and education services, and students' accommodations stand out, whereas cultural facilities are absent. Regarding the transport systems, the campus is surrounded by motorways and served by a segregated

cycling infrastructure. Although students are served by public transport stations across the campus, few bicycle repair services and pedestrian amenities were provided.

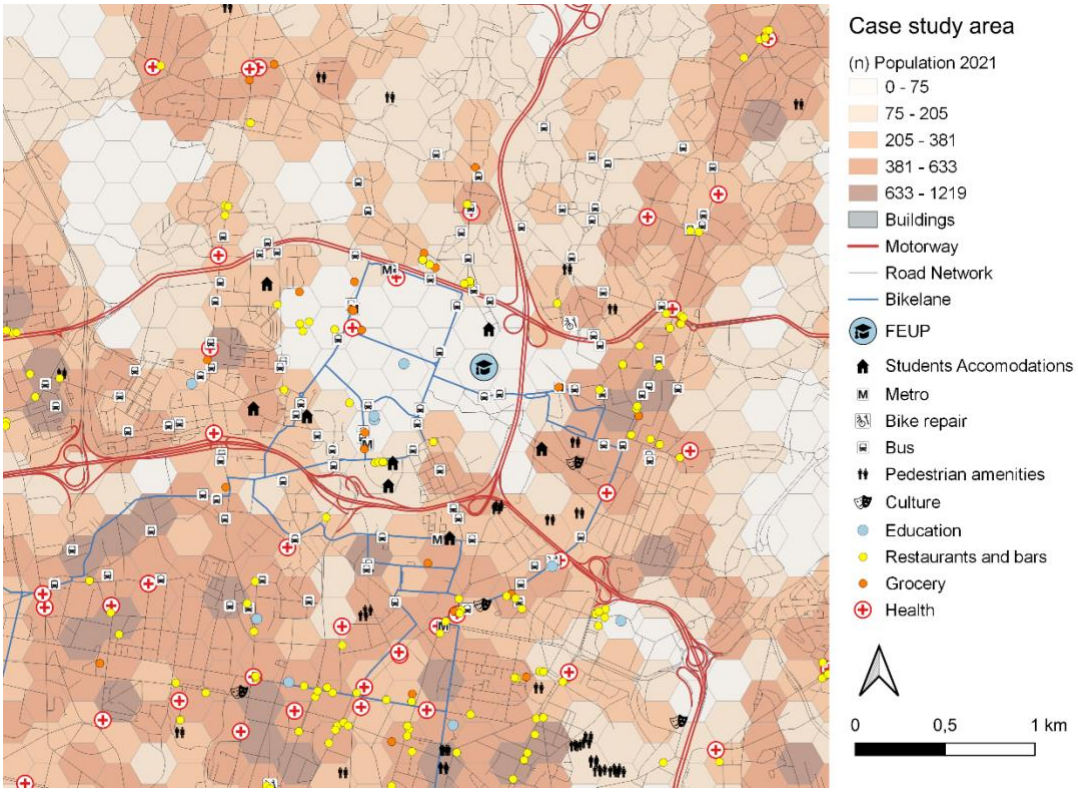


**Figure 2.** Case study characterization and spatial distribution of services
*Sources: OpenStreetMap, 2021 Census*

### 3.2 Data gathering: Survey

This paper examines the mobility patterns of university students over time. We aimed to characterize commuting patterns and identify the main factors influencing active commuting. We adopted a mixed-method approach, conducting a systematic cross-section analysis using data acquired through surveys of representative samples and spatial analysis over the academic years 2012, 2017, and 2023. We also used data from the National Portuguese Census (INE, 2021 and 2011) and documents from the local transportation system operators and Oporto University.

The selected faculty has a population of nearly 5000 students. This research conducted a set of procedures throughout the three years to select respondents, using a stratified sampling method, with participants randomly selected based on the list of students enrolled at FEUP. The data collection process was conducted in the classroom during the first weeks of the second period of each year. Over the years, two researchers administered the same survey (Cadima et al., 2020), providing information and support to the participants. The final sample was estimated based on Krejici and Morgan's recommendations (Almeida & Freire, 2007), which states that for a population of 5000 individuals and a probability of error of less than 5%, a representative sample should include at least 357 subjects (Cadima et al., 2020).

Hence, the total sample included 352 university students in 2012, 424 in 2017, and 545 in 2023. We combined and aggregated information from both studies (statistical and spatial analyses) through each student's home address.

The applied personal survey included questions regarding commuting travel behavior on social factors (social background and attitudes towards travel), travel factors (modal choice, travel time, frequency and monthly costs), and urban environmental factors (residential location zip code and accessibility levels to transport systems), as well as the main barriers and motivations affecting transport decision in a student population.

This study also examined two other variables, namely travel mode choice and distance, combined with a spatial analysis based on OpenStreetMap (OSM). The discussion revolves around the changing commuting patterns, with particular attention to cycling and walking, as the number of e-scooters was insignificant over the assessed years. Hence, in this analysis, active commuting aggregates data for walking, cycling and e-scooters.

### 3.3 Data analysis

This study conducted inferential statistical analysis using SPSS software. The initial assessment focused on descriptive statistics, namely the Chi-square ($\chi 2$), T-test or the Mann-Whitney test, to explore differences between active and motorized commuters (public transport and private vehicles). Analyses were conducted separately, considering significance was accepted as $p<.001$ or $p<.05$. To explore differences in university mobility patterns between the active and motorized commuters, this study ran binary logit models for each academic year (i.e., 2012, 2017 and 2023), by applying the following logistic regression equation (Field, 2013; Kelarestaghi et al., 2019; Small et al., 2007; Washington et al., 2011):

$$P_i = \frac{\exp[\beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} \ldots + \beta_k X_{k,i}]}{1 + exp\,[\beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} \ldots + \beta_k X_{k,i}]} \qquad (1)$$

On which, $P$ represents the probability that $i$ is chosen, $k$ is the set of independent variables, i represents the alternative, with $i$=1 for active modes, and $i$=0 for other modes. , $\boldsymbol{\beta_0}$ is the model constant, and $\boldsymbol{\beta_1}, \boldsymbol{\beta_2}, \ldots, \boldsymbol{\beta_k}$ are the regression coefficients corresponding to the predictor variables ($\boldsymbol{X_{1,i}}, \boldsymbol{X_{2,i}}, \ldots, \boldsymbol{X_{k,i}}$). A total of 19 variables were initially included in the full model (Table 2).

Finally, we applied a backward elimination stepwise regression to exclude the variables with the least explanatory influence. Table 2 summarizes all variables that were included and excluded from the model. The regression model was statistically significant according to the statistical tests performed, proving to meet the requirements: $\chi 2$ (8) =223,804, $p < .001$, $R2 = .53$ (Cox and Snell), $R2 = .78$ (Nagelkerke).

**Table 2.** Variables included in the logit model

| Variables | 2012 | 2017 | 2023 | (N) | Abbr. | Model |
|---|---|---|---|---|---|---|
| ***Dependent variable*** | | | | | | |
| ***Modal choice (binary)*** | | | | | | |
| *Active modes (1)* | *67* | 123 | 145 | 335 | Act | |
| *Other modes (0)* | *285* | 301 | 400 | 986 | PT+Car | |
| ***Predictor variables*** | | | | | | |
| ***Spatial location (binary: 0 – no; 1 – yes)*** | | | | | | |
| *I have access to sidewalks* | *171* | *209* | *263* | 643 | Acc_w | *Yes (χ2)* |
| *I have access to the metro* | *98* | *293* | *135* | 525 | Acc_m | *Yes (χ2)* |
| *I have access to the motorway* | *118* | *142* | *167* | 427 | Acc_c | *Yes (χ2)* |
| *I live 1 km from the campus* | *19* | *32* | *40* | 91 | < 1km | No (MW) |
| *I live between 1 and 2 km from the campus* | *46* | *84* | *55* | 185 | 1km – 4km | |
| *I live between 2 and 4 km from the campus* | *43* | *47* | *32* | 122 | 1km – 4km | |
| *I live between 4 and 8 km from the campus* | *232* | *244* | *293* | 769 | 4km – 8km | |
| *I live more than 8 km from the campus* | *7* | *11* | *87* | 105 | > 8km | |
| *Sidewalks decay or do not exist* | *64* | *93* | *111* | 268 | No_w | *Yes (χ2)* |
| *I have direct access to bus stops* | *77* | *128* | *160* | 365 | Acc_bus | |
| ***Socioeconomics (binary: 0 – no; 1- yes)*** | | | | | | |
| *Female* | *109* | *144* | *170* | 423 | F | *Yes (χ2)* |
| *Male* | *239* | *274* | *337* | 850 | M | |
| *I am renting or living in university accommodation* | *92* | *157* | *158* | 407 | H_RU | *Yes (χ2)* |
| *I live with my family* | *256* | *261* | *349* | 866 | H_Fam | |
| *I have a car available for use* | *135* | *124* | *155* | 414 | Car_SA | *Yes (χ2)* |
| ***Social Behavior (binary: 0 – no; 1 – yes)*** | | | | | | |
| *I use this mode of transport because it is fast* | *138* | *142* | *138* | 418 | Speed | *Yes (χ2)* |
| *I use this mode of transport because of its cost* | *131* | *144* | *188* | 463 | Cost | *Yes (χ2)* |
| *I use this mode because I do not have other options* | *72* | *102* | *154* | 328 | No_Opt | *Yes (χ2)* |
| *I use this mode of transport because it is comfortable* | *115* | *277* | *210* | 602 | Comf | *Yes (χ2)* |

To support the statistical analysis, this study conducted a GIS-based accessibility analysis relying on the network analysis calibrated for pedestrians (1 and 3 km) and cyclists (5 and 8 km) as a travel distance threshold to access the university campus. We used a hexagonal grid (Cunha & Silva, 2023; Pereira, 2019), also known as the H3 geospatial index system, at resolution 9 to overcome data incongruities between the different study years. With the spatial analysis, we computed the number of motorized students living within the cyclable and walkable zones to further discuss travel demand measures and policies.

# 4 Results and discussion

## 4.1 Descriptive statistics

The results of the descriptive statistics show that the demographic characteristics did not substantially change over the assessed years. As described in Table 3, the sample is predominantly comprised of undergraduate students compared with master's students, with more than half of the sample represented by males. The average age of the sample is approximately 21 years, representing young adults at the start of their professional and academic lives. This study indicates increased active commuting and a slight decrease in private vehicle access and driving licenses during the years analyzed.

**Table 3.** Sample characteristics for 2012, 2017, and 2023

| | **2012** | **2017** | **2023** |
|---|---|---|---|
| undergraduate students | 75.9% | 74.3% | 64.6% |
| master's students | 24.1% | 25.7% | 35.4% |
| male | 69.0% | 66.0% | 65.3% |
| female | 31.0% | 34.0% | 34.7% |
| age (σ) mean | 20,9 | 20,7 | 22,0 |
| Active travel | 19% | 27,4% | 25,3% |
| no car ownership | 61.4% | 70.8% | 66.4% |
| no driving license | 21.6% | 27.6% | 28.0% |

The results of the surveys indicate that the vast majority of active travelers are pedestrians, representing around 98% in 2012, 99% in 2017 and 96% in 2023. Compared to 2012, this study identified an increase in cyclists (1%) and e-scooter users (3%) in 2023. Although many European cities have been experiencing technical improvements in the electric mobility sector (Efe et al., 2018), there is no evidence that the same phenomenon is occurring in Oporto, acknowledged as a starter cycling city (Lopes et al., 2021; Silva et al., 2019). This city has a residual infrastructure and bicycle modal share, with a general political skepticism towards active modes, which hinders the allocation of funds and investments towards cycling and alternative mobilities (Bicalho et al., 2019).

### 4.1.1 Spatial location

Concerning the spatial distribution of population and active commuters, the results indicate increased population density near the campus (Figure 3). In addition, the spatial analysis suggests that most active commuters live close to the University within a distance of 3 km, which can be covered by walking or cycling trips (Figure 4). These results align with previous thresholds discussed in the literature (Lundberg & Weber, 2014; Rybarczyk & Gallagher, 2014).

Through the intersection of respondents and distance buffers, this study suggests that active commuters have opted to live closer to campus through the years. In 2012, a share of 12.5% of the sample was located within a 1 km walking distance. This number steadily increased, reaching 14% in 2017 and 25% in 2023. Most students lived within the 3 km walking distance buffer, covering almost 98% in 2012, 96% in 2017 and 97% in 2023. Regarding cycling, an outstanding share of around 98% is located within a 5 km bike ride

in 2023. Finally, although the entire sample was within the 8km cycling buffer from 2012 to 2017, in 2023, this number decreased to 99%.

Throughout the years, accessibility conditions for active commuters improved, with approximately 51,9% of the students having access to sidewalks in 2023, compared to 49,1% in 2012. Yet, the results indicate a rise in travel time and distance required for walking and cycling to reach the University. In 2023, the time spent was nearly twice that in 2017 (Table 4). This result suggests that some students have moved away from campus to pursue other accommodation options over time. Regarding the accessibility conditions for reaching facilities, there was a noted increase in the accessibility to sidewalks and a decrease in the accessibility levels to bus stops and the motorway. Accessibility conditions to the cycling network were not considered in this assessment because, to date, the city has not implemented a cycling plan with a cohesive network throughout the territory. This study disclosed an increase in the overall average range over the years regarding travel distance and time.

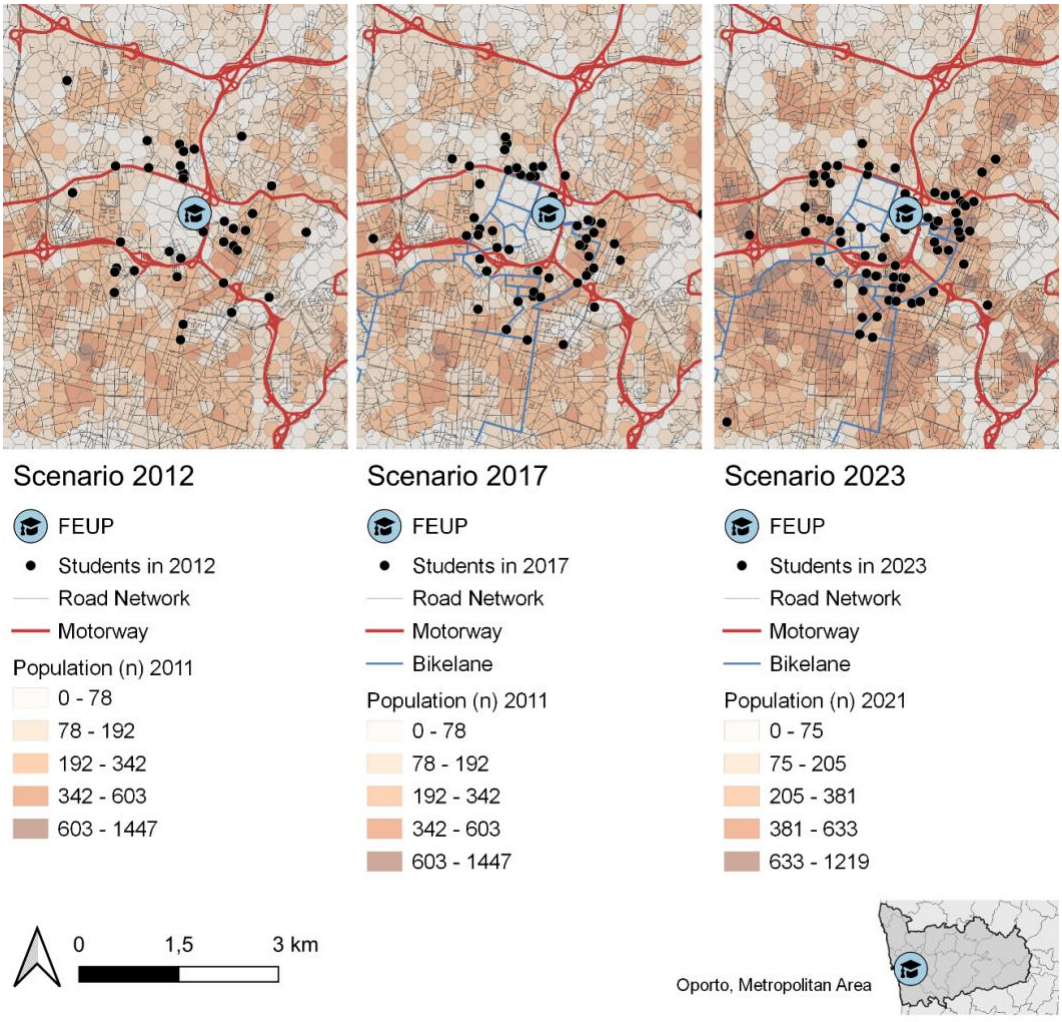


**Figure 3.** Spatial distribution of students (active commuters' locations) and population density over the years 2012, 2017, and 2023

**Table 4.** Spatial location factors variation through 2012, 2017, and 2023

| | **Spatial Location** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Travel Distance** | | | **Travel Time** | | | **Accessibility** | | | |
| | *mean* | *σ* | *Range (km)* | *mean* | *σ* | *Range (min)* | *Acc_w* | *Acc_b* | *Acc_m* | *Acc_c* |
| **2012** | 1,4 | 65 | .75-4.2 | 14 | 67 | 3-40 | 63 | 33 | 49 | 43 |
| **2017** | 1,5 | 119 | .45-5.3 | 13 | 123 | 2-30 | 57 | 24 | 52 | 33 |
| **2023** | 1,7 | 151 | 0.25-6.4 | 14 | 193 | 2-60 | 66 | 27 | 41 | 41 |

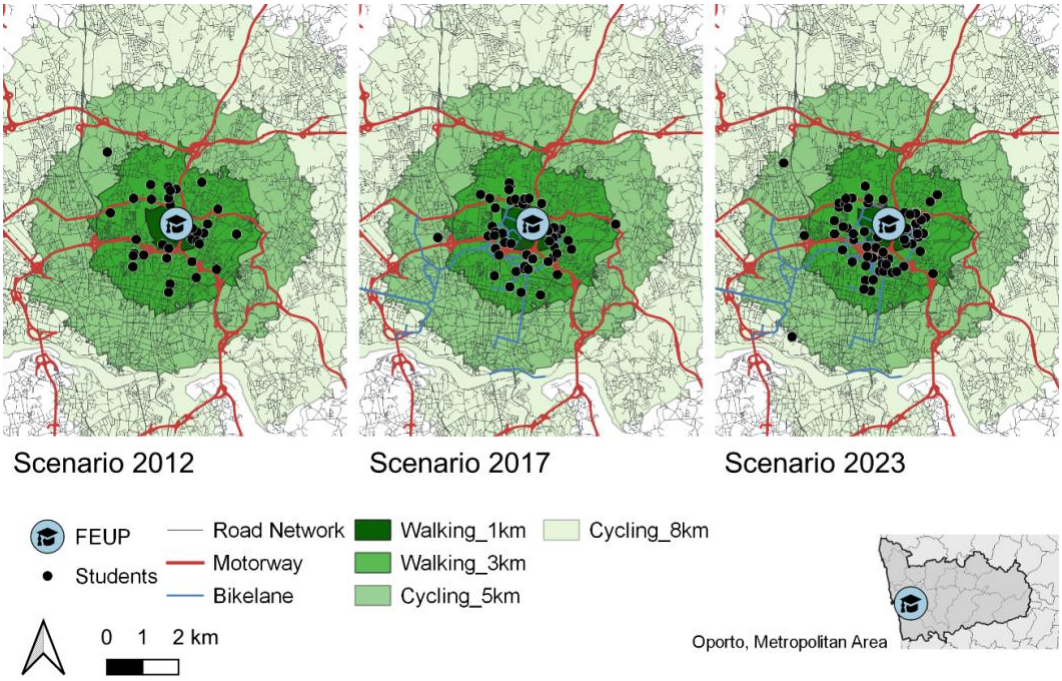


**Figure 4.** Accessibility analysis of students (active commuters' locations) over the assessed years

### 4.1.2 Socioeconomics

Over the years, the assessment of variation in socioeconomic factors disclosed gender disparities regarding modal split and travel costs (Table 5). As already identified in previous research (Teixeira & Cunha, 2023), in general terms, females rely more on public transport, whereas male students are more likely to drive to the University.

Nevertheless, these trends have been changing over the years, with a gradual decrease in private car use and an increasing use of public transport and active modes. This phenomenon might be associated with urban transformations that have taken place on campus over the last decade, including the construction of new university residences and commercial centers and improvements to the public transport system, especially metro stations (Cadima et al., 2020).

Regarding travel costs, active modes of transport (i.e., walking and cycling) remain the most affordable option for university students. The number of students living near the campus (i.e., renting or student accommodation) increased over the years, reaching a viewpoint in 2017 with a share of 37.6%, declining to 31.1% in 2023.

**Table 5.** Socioeconomic factors variation through 2012, 2017, and 2023

| | **Socioeconomics** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Gender (%)** | | **Living (%)** | | | **Travel cost (€)** | | |
| | *women* | *men* | *H_Fam* | *H_RU* | *Car_SA* | *mean* | *σ* | *Max* |
| **2012** | 17,4 | 19,8 | 22.4 | 76.1 | 13 | 3 | 63 | 40 |
| **2017** | 32,6 | 27,1 | 12.4 | 87.6 | 22 | 2 | 123 | 50 |
| **2023** | 23,9 | 25,5 | 24.3 | 75.1 | 16 | 4 | 192 | 35 |

#### 4.1.3 Social behavior

This research investigated how various social behavior factors are associated with modal choices over the years (Table 6). Results disclosed that cost and comfort are critical factors in commuting preferences for those reliant on active modes of transport. Nevertheless, active commuters indicated a perceived lack of safety and security. Despite these challenges, active commuters are inclined to view their commuting experience as fast, comfortable, and adaptable to the flexible time schedules at the University.

**Table 6.** Social behavior factors variation through 2012, 2017, and 2023

| | **Social behavior** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Within mode choice (%)** | | | | | | |
| | *Cost* | *Comf* | *Fast* | *No_Opt* | *Time* | *Safe* | *No_Sev* |
| **2012** | 28.6 | 17.2 | 22.0 | 9.7 | 10.8 | 83.6 | 3.0 |
| **2017** | 26.2 | 29.5 | 35.7 | 25.2 | 14.3 | 87.8 | 3.3 |
| **2023** | 25.1 | 27.8 | 15.6 | 18.4 | 8.0 | 87.6 | 6.2 |

### 4.2 Logit model

This study employed a logistic model to explore the impact of several factors on modal choice and measure their relative importance to complement the descriptive analysis of the factors and main characteristics of students' modal choice and preferences.

Table 7 summarizes the results of the binary logit model for active travelers. The model estimates that the dependent variable is binary whenever they rely on active modes (1) or not (0) to commute to the University daily. The regression model was statistically significant according to the statistical tests (Table 7). As explanatory initial variables, we considered the following:

(i) Spatial location: access to sidewalks, access to the metro, access to a direct bus route, access to motorway, sidewalks are decayed or do not exist, distance;
(ii) Socioeconomic: gender, car available for use, age, housing options;
(iii) Social behavior: comfort, speed, cost, pollution, and no other option available.

The remaining variables in the final model are all significant, at least at the significance level of ($p<.1$), supporting an in-depth analysis of the results by year. The method eliminates the indicators with the weakest values; therefore, the strongest variables may differ each year. Eight predictors were retained in 2012, nine in 2017 and eleven in 2023. As the active commuters represent the reference category, a positive coefficient is associated with active travel and predictors with a higher likelihood ratio, suggesting a more significant effect.

**Table 7.** Logit model

| | 2012 | | | 2017 | | | 2023 | | |
|---|---|---|---|---|---|---|---|---|---|
| **Variables** | B | Wald | Sig. | B | Wald | Sig. | B | Wald | Sig. |
| *Constant* | -2.576 | 13.9 | *** | -1.215 | 7.2 | ** | -0.089 | 0.1 | |
| *Gender* | n.a | n.a | | n.a | n.a | | -0.822 | 4.3 | * |
| *Rent* | n.a | n.a | | 1.321 | 5.2 | * | 1.325 | 12.7 | *** |
| *Acc_w* | 1.522 | 6.2 | ** | n.a | n.a | | n.a | n.a | |
| *1km* | | 56.3 | *** | | 54.7 | *** | | 81.1 | *** |
| *1km – 2km* | 2.860 | 4.3 | * | 2.884 | 7.0 | ** | 3.466 | 18.7 | *** |
| *2km – 4km* | 1.631 | 2.9 | ‘ | 1.593 | 3.3 | ‘ | 2.139 | 20.7 | *** |
| *4km – 8km* | -1.374 | 1.9 | | -0.862 | 0.9 | | -0.016 | 0.0 | |
| *> 8km* | -5.187 | 14.5 | *** | -4.430 | 16.3 | *** | -2.675 | 27.5 | *** |
| *No_w* | 1.691 | 6.7 | ** | 2.864 | 24.3 | *** | 0.623 | 2.8 | ‘ |
| *Acc_bus* | n.a | n.a | | -1.826 | 13.9 | *** | -0.684 | 3.3 | ‘ |
| *Cost* | 1.253 | 4.9 | * | n.a | n.a | | | | |
| *Speed* | n.a | n.a | | n.a | n.a | | -1.056 | 6.3 | ** |
| *No_opt* | n.a | n.a | | -1.040 | 3.5 | ‘ | -0.696 | 2.9 | ‘ |

| | | | | | |
|---|---|---|---|---|---|
| Hosmer and Lemes H0 not rejected | | | Cox & Snell R Square | Nagelkerke R Square | |
| Classification | 2012 | 81% | 0,498 | 0,801 | ‘ 0.1 |
| | 2017 | 71% | 0,572 | 0,818 | *0.05 |
| | 2023 | 75% | 0,482 | | **0.01 |
| n.a not applicable | | | | | ***0.001 |

Regarding spatial location factors, as expected and according to the literature, distance emerges as a crucial explanatory factor (Whalen et al., 2013; Zhou, 2012), being statistically significant for distances of less than (p>.001) in 2012, between 1km and 2km (p<.05) in 2017 and (p<.001) in 2023. This research identified that housing issues significantly influenced modal choice, with active commuters more likely to be renting or living in university accommodation and less likely to live with their families in 2017 and 2023.

Concerning accessibility, we found that in 2012, students were more likely to state they had access to a broad, comfortable, and good pedestrian infrastructure in their home location. Nevertheless, students were more likely to report negative perceptions towards crossings and degraded pavement in all three years due to the lack of safe infrastructure near the faculty building. On the other hand, the cost or affordability is the likely reason behind active mode choice. This result aligns with similar findings in other studies (Wang et al., 2015). Active commuters were less likely to have access to direct buses in 2017 (p<.001) and 2023 (p<.1).

Outstandingly, an increase in the distance between home and University was observed, with a higher probability of students living within 1 km to 4 km distance. In this case, the quality of sidewalks significantly influences the modal choice. Indeed, although sidewalks and motorways serve the campus zone well, the connection with the inner city remains problematic. The campus is on the outskirts, surrounded by several motorways (see Figure 1), representing a critical barrier for active commuters (Lundberg & Weber, 2014; Tormo-Lancero et al., 2022). This challenge is not limited to individuals who prefer walking or cycling; it also extends to those who opt for car travel or other modes of transport, encountering daily congestion. Considering the context of car-

dependent and motorized societies, this study uncovered that active commuters are likely to endure the burdens created by motorized modes, such as pollution.

Regarding socioeconomic factors, this study revealed that over time, gender differences have become more pronounced, and the effect of accommodation and cost have become increasingly significant in modal choice. For instance, in 2012, gender issues and housing had no significant influence on the use of active commuting modes to the University. Nevertheless, these indicators became a strong predictor over the years. Accordingly, in 2023, gender disparities were identified, with active commuters more likely to be men. These results align with previous research findings (Wang & Akar, 2019). Like the prior year, active commuters are probably renting a house near the campus.

Lastly, this study identified differences in social behavior factors. In 2012, a significant share of students argued that the reason for travelling by active mode to the University was due to the cost, which reflects the economic crisis that Portugal was undergoing (Cadima et al., 2020). In 2023, however, the motivations were likely related to the speed and congestion. This study revealed that in 2017 and 2023, some students opted for active modes ($p<.1$) because they did not have other options or low access to private vehicles and public transport.

## 5 Conclusions

This study sought to examine the main determinants encompassing active commuting and modal choice among university students at a university campus situated in a car-dependent context. The presented research framework explored factors encompassing social behavior, socioeconomics, and spatial location dimensions over time. The Faculty of Engineering of the University of Porto, in Greater Oporto, Portugal, provided the empirical focus for this research through data acquired through surveys of representative samples and spatial analysis over the academic years of 2012, 2017 and 2023.

The descriptive analysis suggests an increasing uptake of active commuting among young adults throughout the assessed years. The spatial examination of the sample location distribution over the years revealed a growing concentration of students near the campus and towards the downtown area, with nearly all active commuters residing within a distance of up to 4 km from the University. Likewise, this study suggests that accessibility conditions have improved, with 51.9% of the students having access to good-quality sidewalks in 2023.

Although there has been an increase in the number of students living in the campus area over the years, a significant proportion has also moved away to more remote locations, resulting in a rise in travel time and distance required for walking and cycling to the University. We argue that this phenomenon is due to the increasing housing cost and the lack of policies geared towards the limitations of low-income students.

Regarding housing conditions, the scenario analysis indicates that in 2012, only 12.5% of respondents lived within 1 km of the University, suggesting a potential shortage of housing options in this vicinity. In 2023, this number steadily increased to 25%. Nevertheless, to improve university campuses' attractiveness and livability, the local municipality could define new policies to tackle the students' barriers, especially those in deprived socioeconomic situations, and facilitate access to affordable housing.

Whereas results indicate positive perceptions towards the accessibility conditions to the campus, the conditions for cycling did not improve during the assessed years. Likewise, walking in such an area is still perceived as unsafe for most of the respondents. Active travelers suffer the burdens of pollution exposure, perceiving the urban environment as unsafe. Indeed, the campus is located close to the principal city

motorway, representing a physical, geographical, and human barrier segregating the campus and the city. As a solution, planning practitioners could rethink this zone, providing safe and accessible infrastructure and facilities to support active travelers.

Concerning the socioeconomic aspects, this study indicates gender imbalances in active commuting and travel cost discrepancies. Although walking and cycling remain the most affordable options, females rely more on public transport and males on private vehicles. Finally, the social behavior analysis suggests comfort as a significant factor affecting modal choice.

This study employed a binary logit model to explore the impact of such dimensions on modal choice and assess the relative importance of the selected factors. The initial variables encompass spatial location, socioeconomic factors, and social behavior considerations. Notably, spatial factors revealed that distance is crucial for active commuters residing near the University. This group faces challenges related to burdens created by the motorized modes and has limited access to high-quality pedestrian and cycle infrastructure. Socioeconomic factors highlight the significance of housing conditions, often due to the high cost of renting or living in private student accommodations. Regarding social behavior, cost is a pivotal factor influencing active commuting, aligning with previous research (Buehler et al., 2021), while pollution concerns negatively affect active commuters' satisfaction. Overall, the study provides a comprehensive analysis of the multifaceted factors influencing active commuting behavior among university students.

The results of this study have some crucial implications for policymakers and planning practitioners, primarily situated in car-dependent and starter-cycling city contexts. For instance, to improve accessibility conditions in low-density areas, urban planners could set new strategies to redistribute road space in favor of active modes. In this sense, providing a segregated, safe infrastructure protected from the externalities caused by motorized vehicles is a paramount strategy.

To reduce the gender gap in active travel, cities and university campuses could propose mobility management packages to improve accessibility, road safety, secured parking and commuting comfort. Moreover, as females are likely to pursue multi-propose trips, Universities could be flexible in terms of timeframe and offer facilities to promote the uptake of active modes, such as bike repair services, showers and cloakrooms. Finally, to improve housing affordability in campus areas, municipalities could set up social-aid strategies to facilitate access to housing options for socioeconomically disadvantaged students.

Although this research brings some critical evidence about the factors influencing active mobility in the university context, we highlight some caveats to be addressed in future research. For instance, one of the limitations of this study concerns the quality of the sample responses, which affected the final model. This city represents a starter-cycling city typology (Lopes et al., 2021; Silva et al., 2019) with residual bicycle infrastructure and cycling levels. Consequently, most of our respondents who claimed to be active travelers are pedestrians. This discrepancy hindered a more in-depth analysis of the preferences and barriers cyclists and e-scooter users faced. Accordingly, to ensure the representativeness of our logit model analysis, we aggregated pedestrians, cyclists and e-scooter users in the final sample.

To address these caveats, future models could explore the determinant factors across each active mode of transport to shed light on the travel experiences and barriers for pedestrians, bicycle, and e-scooter users separately. In terms of an equity-oriented research agenda, another research pathway could examine the enablers of active commuting within campuses located in low-density and rural areas to fully grasp the barriers and needs of the students from deprived zones.

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## Author contribution

The authors confirm their contribution to the paper as follows. I. Cunha: Conceptualization, methodology, formal analysis, visualization, investigation, writing—original draft preparation, writing—review & editing. C. Cadima: Conceptualization, methodology, formal analysis, investigation, writing—original draft preparation, and writing—review. All authors reviewed the results and approved the final version of the manuscript.

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