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Bicycle commuting beyond short distances: built environment, socio-demographic factors and type of bicycle influencing the choice to cycle to three university campuses.

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Abstract

Promoting cycling as commuting mode has gained interest due to the increasing consensus among policymakers, supported by scientific evidence on the benefits of cycling. While the convenience of cycling as main commuting mode tends to decrease as commuting distances increase, emerging travel modes such as e-bikes and speedpedelecs, and the promotion and development of cycle highways could overcome distance as barrier to commute by bicycle. This paper uses the commuting data (n= 6,425) of a mid-size university in Belgium to identify the commuter characteristics and built environment determinants that are associated with a higher prevalence of battery-assisted and long-distance regular cycling through a multinomial logistic regression analysis. The case offers a wide range of workplaces and residential locations in terms of density as well as other built environment factors. The paper discusses the potential of long-distance bicycle commuting to shift individuals from motorized commuting towards more active modes. The results suggest that e-bikes and speedpedelecs offer broader geographical reach and appeal to a more diverse demographic. The development of a comprehensive network of cycle highways, emphasizing safety and separation, holds promise for promoting these types of bicycles. Additionally, mixed-use dense (peri-)urban neighbourhoods can stimulate cycling commuting also beyond short distances.

1 Introduction

The shift from motorized travel to more active travel has gained considerable attention over the past few decades. Policymakers and governments see active travel as a means to reach climate goals (reduction of emissions), to enhance physical activity among the population, and to create more liveable environments through the redesign of public spaces. The potential of active travel to cope with these challenges (Götschi et al., 2017) has led to a growing number of studies within various disciplines on how the built environment can influence active travel behavior (e.g. Aldred, 2019). Many authors have described how safe, comfortable, user-friendly, and well-connected walking and cycling infrastructures are essential for promoting active travel to enhance public health (e.g. De Nazelle et al., 2011; Fraser & Lock, 2011). Specifically, facilitating cycling for commuting purposes is an opportunity for employees to integrate physical activity into their daily routines (Sahlqvist et al., 2012) thus enhancing their general physical performance (De Geus et al., 2009).

Because of the spatial distribution of residential and work locations, commuting distances are often longer than other functional trips (e.g., Ewing & Cervero, 2010). Within the available empirical knowledge on the relationship between the built environment and active travel behavior, longer distances are often identified as barriers to walking and cycling (e.g., Heinen et al., 2013; Pucher & Buehler, 2017; Vandenbulcke et al., 2011). Heinen (2011) states that when distances increase, the choice of cycling as the main transport mode decreases disproportionally. Hansen and Nielsen (2014), however, pointed out that facilitating cycling over longer distances might be essential to achieve higher levels of cycling in general. Therefore, local governments, as well as planning and transport authorities, have been making efforts to facilitate long-distance cycling by facilitating access to battery-assisted bicycles, because these could facilitate cycling beyond short distances (e.g. Banerjee et al., 2022; van der Salm et al., 2022). Battery-assisted bicycles are the fastest growing segment of the transport market. However, to the best of our knowledge, only a few studies have examined the influence of sociodemographic and environmental factors on battery-assisted bicycle use and travel behavior through quantitative estimates (Bourne et al., 2020; Casier & Witlox, 2022). Moreover, Rérat (2021) stated that a systematic comparison with conventional cycling is lacking in the available literature on battery-assisted cycling. There is a wide variety of electric bicycles available but within the European Union they can be classified as 'regular' e-bikes, with battery assistance up to 25 km/h and speedpedelecs that offer pedal assistance up to 45 km/h (Casier & Witlox, 2022; Fishman & Cherry, 2016).

In addition to the growing popularity of electric bicycles, a cycling infrastructure has been developed to facilitate cycling over longer distances. Across Europe, cycle highways are being installed (G. Liu et al., 2019) providing safe, comfortable, and direct cycle infrastructure between major destinations and connecting the hinterland with urban centers. These highways are intended to aid long-distance cycling (Banerjee et al., 2022). While some studies have confirmed that cyclists on these types of infrastructure travel longer distances (Hallberg et al., 2021; G. Liu et al., 2019), there is still very little scientific understanding of the interaction between cycle highways, built environment features, socio-demographic characteristics, and the choice of an e-bike or speedpedelec to commute longer distances by bicycle. However, as Rérat (2021) points out, e-bikes and speed pedelecs expand cycling beyond urban areas to more suburban and rural areas. Cycle highways can enhance cycling for utilitarian purposes in environments that are generally less bikeable than urban environments. Moreover, Marincek (2023) concluded, based on survey data from e-bike users in Lausanne, that e-bikers' perceived safety differs based on the level of separated bicycle infrastructure available to them.

Finally, Jenkins et al. (2022) pointed out in their scoping review, that battery-assisted bicycles can contribute to a modal shift from motorized commuting modes towards more active commuting because these types of bicycles overcome barriers such as distance and time. However, infrastructure and policies supporting both e-bikes and speedpedelecs are required to realize this shift.

This study examines how different variables, including socio-demographics and built environment characteristics, influence the choice of a particular type of bicycle (regular, e-bike, or speedpedelec) for longer commuting distances. Our aim is to provide insights into factors that could influence a modal shift from motorized transport towards cycling commuting beyond short distances through an explorative analysis of the commuting data of a mid-sized university in Flanders, the Northern region of Belgium.

This study identifies similarities and differences between conventional and battery-assisted bicycle use and provides recommendations to enhance cycling for commuting purposes. First, socio-demographic and built environment characteristics that could influence long-distance cycling are derived from the existing literature. Next, we introduce our case study, followed by our research design and analysis of commuting data. Through a multinomial logistic regression analysis, infrastructure and socio-demographics that influence the choice of a specific bicycle type for long-distance commuting are identified. The study concludes by proposing strategies and recommendations to promote and facilitate cycling for longer commuting trips.

2 Factors affecting (long-distance) cycling commuting

2.1 *Built environment characteristics*

As stated by Heinen et al. (2011), attitudes towards bicycle commuting vary between short- and long-distance commuters. It can be expected that bicycle infrastructure and the built environment also have different weights for long versus short travel distances, but empirical data are lacking. The influence of the built environment on travel behavior has been described by Cervero & Kockelman (1997) using the '3Ds' framework: Density, Diversity and Design. This '3Ds' model has since become the most frequently used framework for examining how the built environment influences travel behavior (J. Liu et al., 2021) and will be used to structure this brief literature overview. Eventually, the '3Ds' model has been further expanded to '7Ds' '(Ewing & Cervero, 2010) adding distance to transit, destination accessibility, demand management and demographics to the framework. Because not part of the built environment, a separate section on demographics influencing active travel behavior is added.

Density is described in terms of the population density or compactness of the environment (e.g., Cervero and Duncan, 2003, Frank et al., 2006). *Design* refers to the design and layout of the transport network within active travel studies and to the design of station environments in transit-oriented development literature (Ogra & Ndebele, 2013). There is a wide consensus that well-connected, comfortable, and safe cycling infrastructure enhances cycling (Heinen et al., 2010; Manaugh et al., 2017; Pucher & Buehler, 2017). Recent studies (e.g. Liu et al., 2019) have confirmed that users of cycle highways are more likely to cycle longer distances. However, the impact of the availability of a cycle highway on the choice to cycle longer distances has not yet been examined. The third D, *Diversity* is approached in the literature as the extent to which the environment offers various functions. Heinen (2010) concluded in her review study that "mixed land use" has a positive effect on the share of bicycle trips in general, but whether this effect is the same for short and longer trips remains to be answered.

Destination accessibility and *Distance to transit* mainly affected the choice to use public transport. Although destination accessibility has a clear impact on modal choice (Ewing & Cervero, 2010), most studies on commuting focus on the accessibility of transit stops rather than on the accessibility of the workplace itself.

Demand management includes the cost and availability of facilities at work, such as parking availability (Ewing & Cervero, 2010). When commuting longer distances by bikes, facilities such as showers (Hansen & Nielsen, 2014; Larsen, 2018) and lockers (Larsen, 2018) play a more important role because of the higher level of physical effort (Banerjee et al., 2022), and the more expensive bikes used. While studies (e.g. Heinen & Buehler, 2019; Wilson et al., 2018) suggest that secure bicycle parking affects mode choice, there is still very little scientific understanding of their impact on long-distance cycling.

2.2 Commuter characteristics

As argued by Heinen (2010), the influence of socioeconomic and demographic characteristics on cycling commuting strongly depends on the context (e.g., in terms of general cycling levels), leading to conflicting findings in the literature.

Ton (2019) argues that there is no significant relationship between age, gender, and cycling in the Netherlands, while Witlox and Tindemans (2004) have shown that within the active population in the urban region of Ghent (Belgium), women commute more often by bicycle to work. According to Vandenbulcke et al. (2011), in Flanders, younger people (under 45 years old) are associated with higher rates of cycling commuting. In contrast, Hansen and Nielsen (2014) state that the age group of 45-60 years is most likely to commute by bicycle to work in Denmark. Additionally, a higher level of education is associated with higher rates of bicycle use (Hansen & Nielsen, 2014; Ton et al., 2019). Furthermore, there are a number of other explanatory determinants in the travel behavior literature, including car ownership, family composition, ethnicity, and income (e.g. Heinen et al., 2010).

The characteristics of commuters for long-distance cycling have been less researched. Nordengen et al. (2019) conducted a study in three Norwegian counties and suggested that longer commuting distances are negatively correlated with women's choice of cycling. Manaugh (2017) examined the barriers to cycling within a university setting in the US and concludes that women find commuting distances of 7.5 kilometer or higher more discouraging than men. A recent review on long-distance cycling (Banerjee et al., 2022) found no empirical evidence to support a relationship between age and longer cycling distances. A Danish study (Hansen & Nielsen, 2014) stated that long-distance cyclists have higher incomes, more mobility options, and a higher education level than short-distance bicycle commuters, suggesting that long-distance cyclists are less likely to be women.

2.3 Type of bicycle

As stated earlier, battery-assisted bicycles can facilitate cycling over long distances. Studies (e.g. Nordengen et al., 2019; Sun et al., 2020) have found that e-bikes increase the average distance cycled compared to regular bicycles. Despite the growing body of research on battery-assisted bicycles, few studies have explored the use of electric bicycles from a travel behavior perspective (Fishman & Cherry, 2016). Moreover, empirical evidence on the influence of the built environment on battery-assisted bicycle use is lacking. Nematchoua et al. (2020) conducted a survey of staff and students at the University of Liège to evaluate the potential of electric and regular bicycle use for commuting. Their findings suggest that securing parking facilities at work is more important for electric than regular bicycle commuters. Moreover, the lack of shower facilities is a barrier to PhD students using an electric bicycle for their commute. These findings align with those of Casier and Witlox (2022), who conducted an online choice-based experiment to analyze trip preferences among e-bike commuters. Their study suggests that the factors affecting the likelihood of commuting by battery-assisted bicycles are similar to those for regular cyclists, such as the availability of cycle infrastructure, secure bicycle parking, and showers. But as stated previously, Rérat (2021) points out that a systematic comparison of regular cycling and battery assisted cycling is lacking within the available literature, but based on a large-scale survey in Switzerland, the study (Rérat, 2021) suggests that e-bikes can expand cycling commuting towards suburban and rural areas.

A recent study on speedpedelec use in the Netherlands (van der Salm et al., 2022) further confirms that with trips ranging from 10 to 40 km, speedpedelecs could facilitate the shift from car use to cycling. The study points out that current cycling infrastructure, apart from the cycling highways in the Netherlands, do not sufficiently support the use of speedpedelecs. Furthermore, the study revealed that speedpedelec users are more likely to be highly educated men.

This section provides a brief summary of the literature related to the determinants that could facilitate bicycle commuting over longer distances. It is well established that the identified built environment factors and socio-demographic characteristics influence cycling commuting. However, the influence of these characteristics on long-distance bicycle commuting remains unclear, particularly in relation to battery-assisted bicycle use.

3 Case study: University of Antwerp, Belgium

Many researchers have studied travel behavior within a university setting (e.g. Crist et al., 2021; Engelen et al., 2019; Manaugh et al., 2017; Nematchoua et al., 2020) because universities typically have a significant number of commuters and often possess valuable transport data for their employees. Studying travel behavior can enhance our understanding of the factors that influence mode choice and the impact of transport infrastructure on daily commuting patterns. More specifically, universities are large employment centers that attract employees from a wide region and are at the forefront of sustainability initiatives, including the promotion of sustainable commuting modes. As pointed out by Heinen (2010), bicycle commuting is also highly related to contextual factors such as climate, topography, and general cycling culture. Thus, the findings from our research not only contribute to academic knowledge on long-distance cycling commuting, but also aim to formulate context-specific recommendations.

3.1 Context

The University of Antwerp (UAntwerp) has four campuses distributed in and around the city of Antwerp, a medium-sized city centrally located in the northern region of Belgium (Flanders). The University has over 80 buildings spread over four campuses, each with a distinct geographical setting, as shown in Figure 1. The main city campus (CST) is located within the historical and dense center of the city with an intercity (IC) train station less than 1 km away, and several buses, trams, and (pre)metro (BMT) stops in the neighborhood. By far, this is the most accessible campus in terms of public transport. The two campuses, Middelheim (CM) and Groenenborger (CG), are located next to each other within the 20th century belt of the city. This expansion belt is characterized by a very space-consuming but low-density urban pattern. Since both the CM and CG campuses share the same geographical context, the data for both campuses will be grouped within the analysis and referred to as the CMG. Campus Drie Eiken (CDE) is the most peripheral campus and is situated 5.9 km from an IC station. Located at a distance of 2.5 km from the nearest highway access, and given the high ratio of parking facilities per employee, this is the most car-oriented campus.

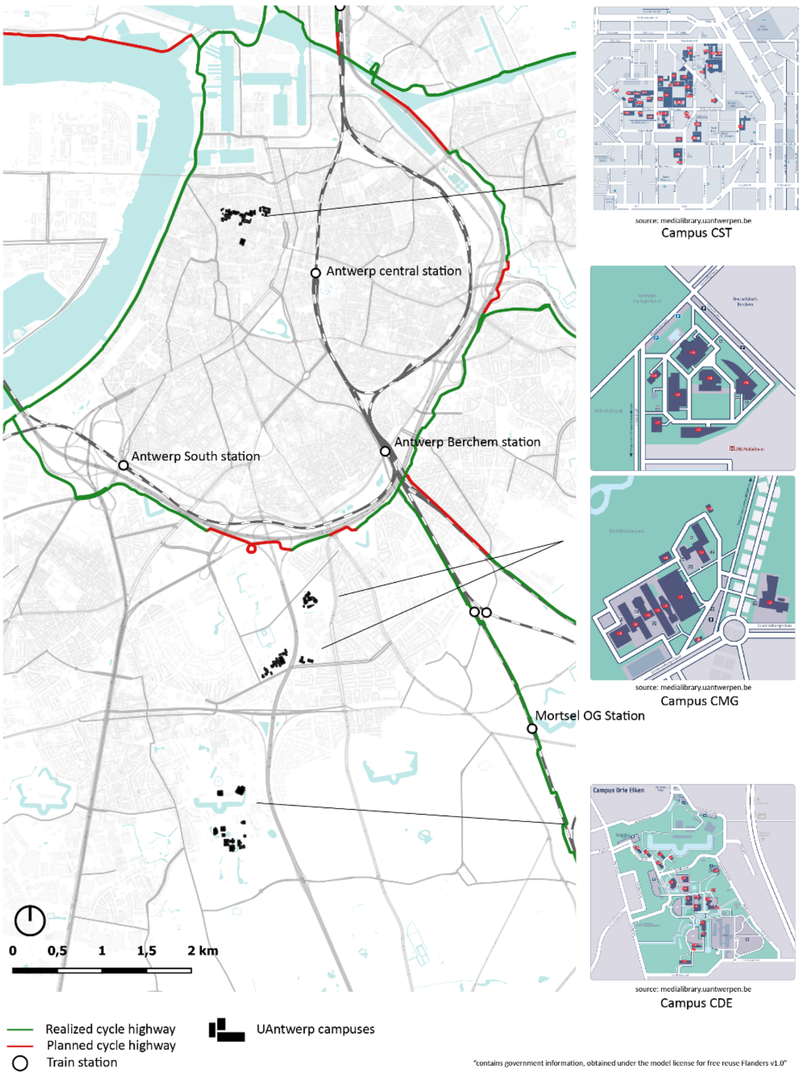

Figure 1. Location and accessibility of the UAntwerp campuses

UAntwerp provides numerous bicycle facilities on each campus, such as showers, lockers, charging points for e-bikes, bicycle repair kits, and secure bicycle parking facilities that are accessible only to staff members. Table 1 provides an overview of the different bicycle and parking facilities on each campus.

Table 1. Bicycle and parking facilities per campus

Campus	CST	CMG	CDE
Employers per campus (n)	1787	961	1581
Car parking (n)	343	408	1065
Car parking per employee	0.2	0.4	0.7
Bicycle parking (n)	1048	638	1781
Bicycle parking per employee	0.6	0.7	1.1
Showers	6	7	19
Lockers	0	52	0
Docking stations e-bike	5	1	1
Bicycle repair boxes	7	5	10
Bicycle repair point	x	n.a.	n.a.

Flanders is developing an extensive network of cycle highways and aim to provide 2,700 km of comfortable, direct, and high-quality cycle infrastructure across the region. This network is managed by the five Flemish provinces and supported by the "Flemish Bicycle Fund”(Subsidies Voor Fietsvoorzieningen Op Het Bovenlokaal Functioneel Fietsroutenetwerk (Fietsfonds), n.d.). Figure 2 shows the realized and planned cycle highway networks in Flanders.

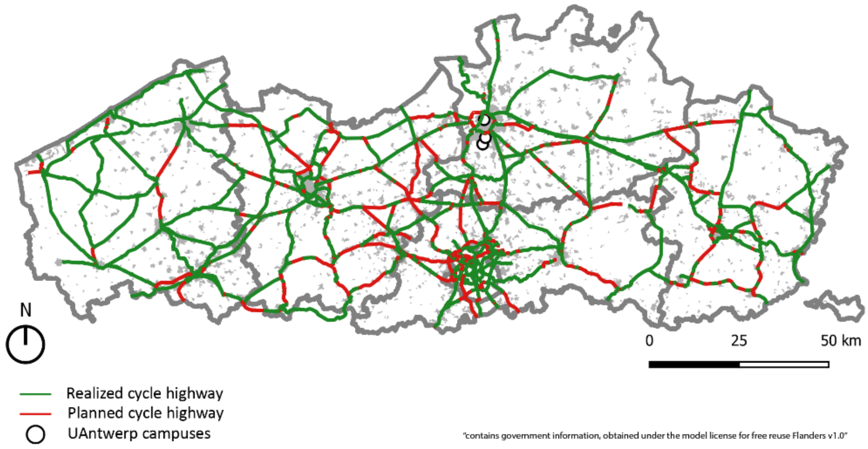

Figure 2. Realized and planned network of cycle highways in Flanders

The high rate of urban sprawl in Flanders (European Environment Agency, 2016) has led to a higher share of long commuting trips compared with other European countries (Eurostat, 2020). However, many employers try to influence employee travel behavior by implementing mobility management measures (Vanoutrive et al., 2010). Through a bicycle allowance, promotion events for active travel, and the provision of cycling facilities (e.g., showers), employers try to convince their employees to commute more sustainably. Despite these efforts, cars remain the dominant mode of commuting in Flanders, with a share of 67% (IMOB, 2020). Only 17.5% of all commuting trips is done by bicycle, of which 4.6% use an e-bike. Public transport is used by 10.9% of Flemish commuters. However, 57% of the working population live within 15km of the workplace and 68% within 20km. Besides, in Belgium, a car-friendly fiscal policy promotes the provision of company cars, in particular in the private sector, which results in high rates of car ownership with an average of 1.06 cars per household in Belgium and even 1.14 cars per household in the region of Flanders (Statbel, 2022). Company cars are an important predictor of car use (Saeidizand et al., 2022), however, at the University of Antwerp (as in the entire education sector), company cars are virtually nonexistent. The city of Antwerp has also conducted various studies to measure travel behavior. A survey conducted among employees working in Antwerp (Slim naar Antwerpen, 2021) revealed that in 2020, 45% of them commuted by car for distances less than 7.5 km.

4 Data

In Belgium, every employer with at least 100 employees is obliged by law to conduct a home-to-work-travel (HTWT) survey to provide information on their employees’ commuting behavior. This survey provides a global picture of commuting behavior but shows some shortcomings, such as incomplete data on commuting distances (Vanoutrive et al., 2010) and the type of bicycle used. At the University of Antwerp, the Environmental Department was responsible for data collection in the context of the HTWT survey. They conduct a compulsory online survey that is sent to every member of the staff and is updated in the case of a change in status, function, relocation, or after a long absence. This survey probes for the primary mode choice in terms of access, main and egress mode and the destination (one of the campuses) and makes a distinction between ‘regular bike,’ ‘e-bike’ and ‘speedpedelec. ’ The database contains the following socio-demographic characteristics of employees: gender, age, educational level, and employment status, and provides the home address of each employee (city, street, and number).

To define what influences long distance bicycle commuting to the University of Antwerp, we first cleaned the original database (n=6,425) (removing outliers and deleting double lines) and eventually obtained a final dataset of 4,322 unique observations. Through geocoding the home addresses of all employees (using QGIS 3.16.5), the commuting distance for each commuting trip was calculated using the openrouteservice plugin for QGIS. Based on the literature review and available data from our case study, we identified four built environment characteristics that were added to the dataset in QGIS (see Table 2). The 'distance to the nearest cycle highway' was calculated from the place of residence of each employee to examine the influence of the proximity of a supra-local bicycle infrastructure on the choice to commute over longer distances by bicycle. 'Land-use mix' at the place of residence is derived from the study by Verachtert (2016), which provides data on the level of facilities per hectare on a scale from 0 to 1. Although population density or building density emerged from the literature as possible predictors for bicycle use, it was not included because this variable is strongly correlated with land-use mix. However, the detailed geographic information of the employees allows us to determine the 'building typology' of the employee's home by analyzing the address points in QGIS and categorizing it as: rowhouse, semi-detached or detached housing. On the one hand, this allows us to make statements about the type of living environment, and on the other hand, it gives an indication of bicycle parking possibilities at home. The destination was included as a categorical variable. Finally, age, gender, and highest educational level were included as sociodemographic variables, resulting in a final dataset containing eight independent variables (see Table 2) and one dependent variable, commuting mode choice.

Table 2. Overview of retained predicator variables

Variable	Type of variable	Source
Built Environment variables		
Distance to Cycle Highway (km)	Continuous	own calculation through openroute services
Building typology (Rowhouse - Semi-detached - Detached)	Categorical	own calculation through GRB
Land-use mix	Continuous	(Verachtert et al., 2016)
Campus (CST-CMG-CDE)	Categorical	Database UAntwerp
Socio-demographic variables		
Educational level (High School - Bachelor - Master - PhD)	Categorical	Database UAntwerp
Age	Continuous	Database UAntwerp
Gender (Men - Women)	Categorical	Database UAntwerp
Trip Characteristics		
Commuting distance (km)	Continuous	own calculation through openroute services

4.1 *Explorative data analysis*

How long is long?

Within the literature there is no clear consensus on the definition of 'long' in long-distance cycling commuting. The willingness to cycle over longer distances varies from person to person (Heinen et al., 2010). Moreover, cycling commuting trips for distances longer than 5 km tend to be higher in regions with higher general cycling levels than in those with lower cycling levels (Banerjee et al., 2022). Within the Belgian context, Vandenbulcke et al. (2011) defined an acceptable cycling distance of < 5 km. Lopez et al. (2017) identified three distance ranges for e-bikers: short-range (<5 km), mid-range (between 5 and 13 km), and long-range (>13 km). Within this study we use 5.8 km (i.e., the median bicycle commuting distance from our case study) as cut-off to differentiate between long and short bicycle trips. The choice for this cut-off is further supported by a visual analysis of the cycling data used in the analysis (Figure 3), where trip lengths above 5.8 km showcase much greater variation in the frequency of cycling usage, as compared to the <5.8 km category, where cycling usage is high.

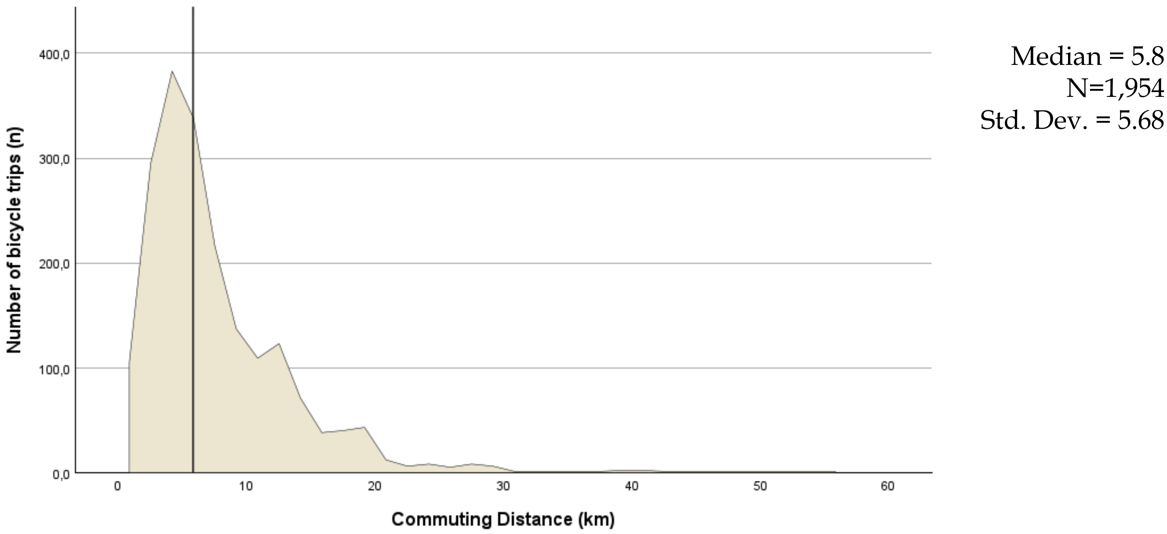

Figure 3. Distribution of cycling usage in relation to commuting distance towards the University of Antwerp (vertical line = 5.8km)

Commuters

Apart from the geographical differences between the various university campuses, we also observe differences in the socio-demographics of the employees. These differences can be explained by the distribution of programmes and services across various campuses. Figure 4 provides an overview of the distribution of employees across the campuses according to gender, age, and educational level.

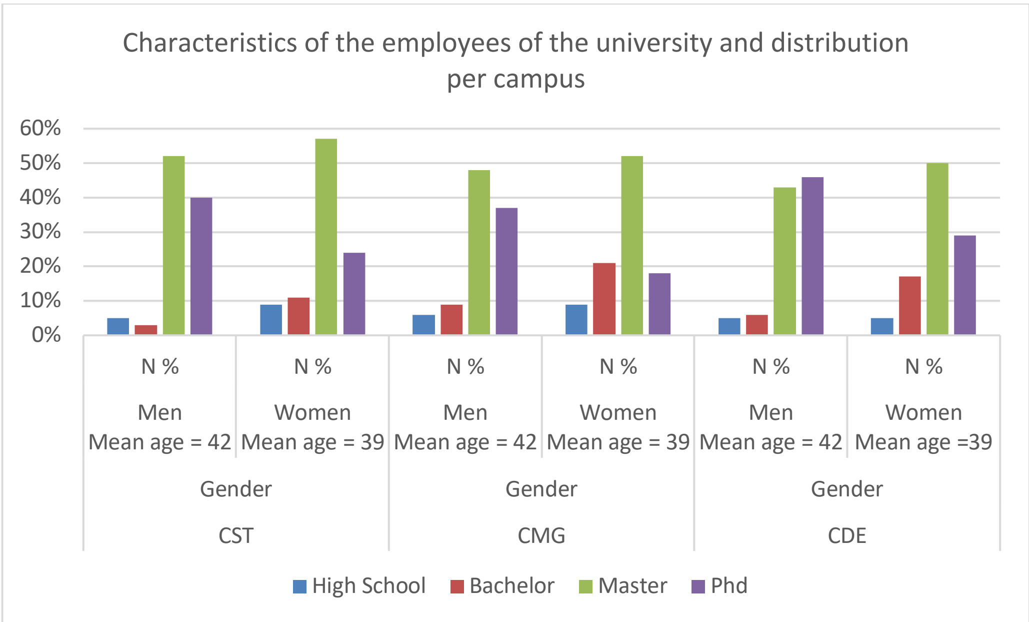

Figure 4. Characteristics of the employees of the university and distribution per campus

The employees of the University of Antwerp are highly educated. Where in Flanders (Statbel, 2022) 48.4% of the working population holds a degree in higher education (bachelor and master included), at the university, almost 94% of the employees have a higher education degree (of which

10.6% a bachelor and 83.1% a master degree). In general, UAntwerp employees are fairly young: 68.2% of employees are younger than 44 years, compared to 56% in Flanders (Statbel, 2022). Regarding gender, 53% of the working population in Flanders are men (Statbel, 2022) while this figure ranges from 43% to 47% for the campuses under study.

Modal split

As shown in Table 3, the modal split for commuting to the University of Antwerp is more sustainable than the Flemish Region and the City of Antwerp. The location of the workplaces and the profile of the employees could explain this difference.

Table 3. 3 modal split for commuting trips to UAntwerp, City Campus (CST), Campus Middelheim Groenenborg (CMG), Campus Drie Eiken (CDE) - Flanders – City of Antwerp

Modal Split		Commuting to the University (Database UAntwerp, 2019)				Commuting in Flanders (Janssens et al., 2020)	Commuting to Antwerp (Slim naar Antwerpen, 2021)
		TOTAL	CST	CMG	CDE		
Car		**25.3%**	**13.0%**	**26.0%**	**39.0%**	**67.5%**	**43.0%**
Bike		**45.2%**	**42.0%**	**50.0%**	**47.0%**	**17.5%**	**31.6%**
	regular bike	39.8%	37.0%	44.0%	41.0%	12.9%	No data available
	battery assisted bike	5.4%	5.0%	6.0%	6.0%	4.6%	
Walk		**3.1%**	**6.0%**	**2.0%**	**1.0%**	**2.5%**	**2.9%**
Public Transport		**24.8%**	**37.0%**	**20.0%**	**12.0%**	**10.9%**	**16.9%**
	BMT	7.6%	10.0%	7.0%	4.0%	3.3%	No data available
	Train	17.2%	27.0%	13.0%	8.0%	7.6%	
Other		**1.5%**	**2.0%**	**1.0%**	**1.0%**	**1.7%**	**5.3%**
Total		100%	100%	100%	100%	100%	100%

When looking at the modal split for commuting to different campuses, we can see some significant differences. As shown in Table 3, the use of public transport can be explained by the accessibility of the destination. Employees who commute to the more centrally located CST campus use the train almost twice and three times as often as employees of the CMG and CDE campuses, respectively. The proximity of Antwerp Central Station (just under a kilometer) for CST and Antwerp Berchem Station for CMG (at approximately 2 km) can partly explain these figures. Limited car parking facilities (0.16 places per employee) and difficult car accessibility explain the low share of car use despite the long commuting distances (which are mainly covered by trains, as shown in Table 4), and the use of BMT is also significantly higher for campuses within or closer to the city center (CST and CMG). Although all campuses are served by a bus stop less than 500m away, the degree of accessibility for CST is much higher, with several frequent bus, tram, and pre-metro lines in various directions. Whereas the CMG is only served by two bus lines, it provides a direct connection to the Antwerp Berchem transport hub. The campus CDE is only served by one bus connection, and there is no direct connection to the important transport hub of the Antwerp Berchem rail station. The accessibility by car and parking facilities makes CDE the most car-oriented campus (39% mode share). The availability of free car parking spaces (0.67 parking spaces per employee) and easy car accessibility could explain this finding. The longer commuting distances to CDE, in combination with poor accessibility by public transport, can also explain the high levels of car use. However, this campus is also characterized by the second highest level of bicycle use (41%), suggesting that bicycle commuting is mainly an alternative for public transport rather than for car use. CMG, on the other hand, is a bicycle champion with 44% bicycle trips. Finally, we note that the walkable environment (historical center of Antwerp) in combination with a high population and building density (many potential employees) of CST can explain the high share of walking.

Table 4. Descriptive statistics for main mode choice and commuting distance

Main Mode choice	Mean (km)	Standard Deviation	Min (km)	Max (km)	Modal Split
Car	24.21	17.33	0.99	75.85	25%
Bike	6.51	4.08	0.24	19.62	40%
e-Bike (25km/h)	12.87	7.22	0.98	41.31	4%
Speedpedelec (45km/h)	24.95	11.34	2.68	55.37	1%
Foot	1.43	0.92	0.03	4.41	3%
BMT	8.61	5.37	0.13	25.96	8%
Train	48.01	22.67	0.06	111.38	17%
Other	12.73	13.34	0.26	56.75	2%

5 Research design

Based on prior studies discussed in previous paragraphs, this study starts with the assumption that commuting mode choice (see Figure 5) is affected by three (groups of) variables: distance, built environment, and personal characteristics. Other factors, such as climate, (cycling) culture, topography, and travel motive, also affect the choice of travel mode, as identified by Götschi et al. (2017) in their comprehensive framework for active travel behavior. Since this study uses commuting data from one university, we abstract these factors as they apply to every employee.

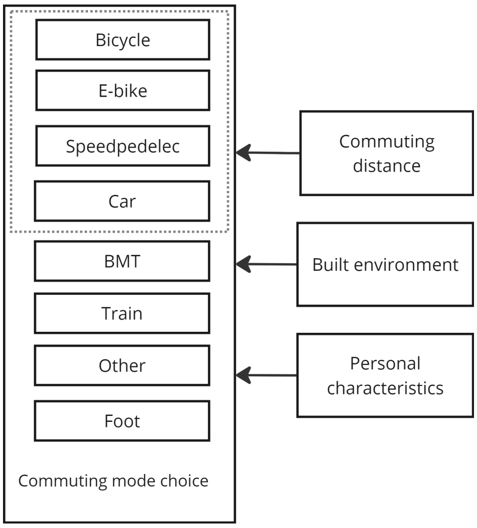

Figure 5. conceptual framework for commuting mode choice

In this study, we focus on bicycle commuting and how these variables affect the choice of a specific type of bicycle in relation to longer commuting distances. Based on the literature review (see section "Factors affecting (long distance) bicycle commuting"), we identified the characteristics of the built environment and socio-demographic characteristics that influence cycling commuting in general. However, the influence and interaction of these characteristics on long-distance bicycle commuting remains unclear, particularly in relation to e-bike and speedpedelec use. This study addresses this research gap by posing the following research question: How do the built environment and socio-demographic factors influence the choice to commute (longer distances) by a regular bike, an e-bike, or a speedpedelec? Therefore, the following assumptions were made in this study:

(H1) When commuting distance increases, the odds of choosing a conventional bicycle decreases disproportionally (Vandenbulcke et al., 2011). We assume that distance also influences the choice of e-bike and speedpedelec.

(H2) As cyclists travel longer distances on cycle highways (G. Liu et al., 2019) we assume that the proximity of a cycle highway positively influences their choice to commute longer distances by bicycle. Because e-bikes and speedpedelecs are generally characterized by longer commuting distances, we expect that cycle highways will affect the choice of an e-bike or speedpedelec even more.

(H3) Because e-bikes and speedpedelecs expand the practice of cycling (Rérat, 2021), we assume that e-bike and speedpedelec users differ from conventional cyclists in terms of socio-demographics and their residential environment. Method

Traditionally, commuting mode choice has been described in a discrete choice framework (Ben-Akiva & Lerman, 1985). The multinomial logit (MNL) model is a widely used method for modelling commuting mode choice within this framework (Ortúzar & Willumsen, 2011) and is commonly accepted and implemented in transport and urban planning research (e.g. Manaugh et al., 2017). The MNL model estimates the probability that an individual will choose a specific mode over all other available modes, which is valuable for understanding the likelihood of making different choices. The coefficients estimated in the MNL model represent how changes in the independent variables affect the relative attractiveness of each mode. Moreover, MNL models can accommodate both categorical and continuous independent variables. This flexibility allows for the inclusion of a wide range of predictor variables, such as sociodemographic and built environment-related factors. Hence, we can use this type of model to test the research question (i.e., how the built environment and socio-demographic factors influence the choice to commute (longer distances) by a regular bike, e-bike, or speedpedelec).

As we aim to provide insights into the factors that could influence a modal shift from individual motorized transport towards more active commuting modes, we first built an MNL model (see Figure 6 – MNL model 1) for commuting trips by car, bicycle, e-bike, and speedpedelec for all commuting distances. This baseline model was used to test the statistical significance of our identified set of independent variables and assess the impact of commuting distance on commuting mode choice (H1).

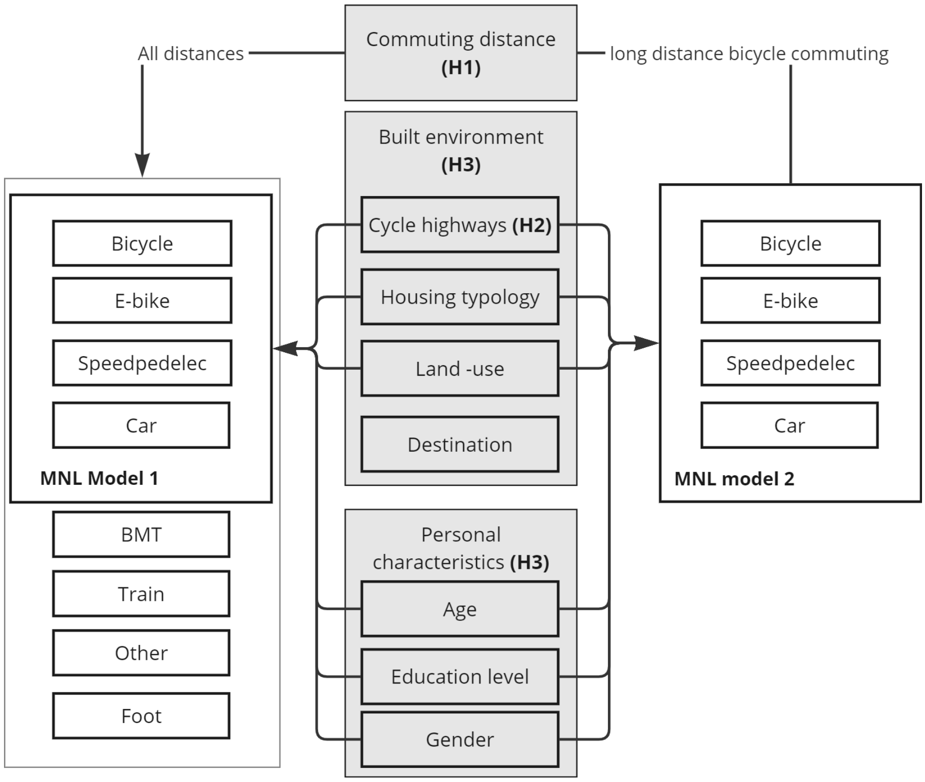

Figure 6. Research Design to test assumptions (H1, H2, H3) through MNL model 1 & 2

Next, a second MNL model, the long-distance bicycle commuting model, was built to test hypotheses H2 and H3 (see Figure. 6, MNL model 2) and to estimate the probability of choosing a bike, e-bike, or speedpedelec over a private car when commuting longer distances (>5.8 km). The predictor variables for this model were age and sex (ref. =women), educational level (Ref. =PhD), distance to cycle highway, and building typology (Ref. =detached houses), land use mix, and destination (ref. =CDE). This model excludes commuting distance as a predictor variable because the effect of this variable is tested within the first model, and is used as an exclusion criterion to select only cyclists with longer distances in the second model.

All statistical analyses were performed using the SPSS software (version 29). The 0.05 tolerance rate was used to identify significant effects ($p < 0.05$). The assumptions underlying the MNL analysis were examined and no violations were detected. Both MNL models fit the data well (chi-squared <0.05).

6 Results

The statistically significant results of the MNL model are presented in Table 5. Model 1 explains 58.3% (Nagelkerke R^2) whereas Model 2 explains 36.1% (Nagelkerke R^2) of the variability in the dependent outcome.

The results of the baseline model (Model 1) are in line with the general assumption that when commuting distance increases, the odds (OR=0.822; p<0.001) to opt for a conventional bike decreases disproportionally. In addition, the choice of an e-bike decreases (OR=0.939; p<0.001) when the commuting distance increases yet this effect is smaller. However, the model does not show a significant effect of commuting distance on the choice for speedpedelec compared to the choice to commute by car.

Table 5. Significant results of MNL model 1 & 2 - the reference category is car (n.s. = not significant – n.a. = not applicable)

		Bike						e-Bike						Speedpedelec					
		Model1[a]			Model 2[a]			Model1[a]			Model 2[a]			Model 1[a]			Model 2[a]		
		B	Sig.	Exp (B)	B	Sig.	Exp (B)	B	Sig.	Exp (B)	B	Sig.	Exp (B)	B	Sig.	Exp (B)	B	Sig.	Exp (B)
Built-environment variables	Land-use mix	2.16	**<0.001**	8.70	5.54	**<0.001**	253.65		n.s.			n.s.			n.s.			n.s.	
	Building typology (ref= Detached house)																		
	Rowhouse	0.40	**0.046**	1.49	0.52	**0.005**	1.69		n.s.			n.s.			n.s.			n.s.	
	Semi-detached house		n.s.			n.s.			n.s.			n.s.		-1.43	**0.025**	0.24	-1.40	**0.027**	0.25
	Distance to cycle highway		n.s.		-0.14	**0.009**	0.87	-0.18	**0.021**	0.83	-0.25	**0.002**	0.78		n.s.			n.s.	
	Destination (ref=CDE)																		
	CST	1.01	**<0.001**	2.74	1.03	**<0.001**	2.81	1.04	**<0.001**	2.84	1.21	**<0.001**	3.36		n.s.			n.s.	
	CMG		n.s.		0.39	**0.007**	1.47	0.42	**0.044**	1.53	0.57	**0.010**	1.78		n.s.			n.s.	
Socio-demographic variables	Highest educational level (ref=PhD)																		
	Highschool	-0.83	**<0.001**	0.44	-0.65	**0.011**	0.52		n.s.			n.s.			n.s.		0.56	n.s.	
	Bachelor		n.s.			n.s.			n.s.		0.73	**0.004**	2.08		n.s.		-0.19	n.s.	
	Master		n.s.		0.40	**0.004**	1.49		n.s.			n.s.			n.s.		-0.74	n.s.	
	Age	-0.06	**<0.001**	0.95	-0.04	**<0.001**	0.96		n.s.			n.s.		-0.03	**0.047**	0.97	-0.03	**0.024**	0.97
	Gender (ref = Women)																		
	Men	0.69	**<0.001**	2.00	0.61	**<0.001**	1.83	-0.42	**0.025**	0.66	-0.41	**0.035**	0.67	1.08	**0.002**	2.95	1.04	**0.003**	2.83
	Commuting distance	-0.20	**<0.001**	0.82	n.a.			-0.06	**<0.001**	0.94	n.a.				n.s.		n.a.		

	Bike Model1		Bike Model 2		e-Bike Model 1		e-Bike Model 2		Speedpedelec Model 1		Speedpedelec Model 2	
Population (N)	**3048**		**2087**		**3048**		**2087**		**3048**		**2087**	
Subpopulation	1720	cyclists	787	cyclists	194	e-bikes	167	e-bikes	40	speedpedelec	39	speedpedelec
Nagelkerke R-Square	**0.583**		**0.361**		**0.583**		**0.361**		**0.583**		**0.361**	

a. The reference category is: car.

Additionally, as Table 6 indicates, a Games-Howell post hoc test (p=0.888) confirms that there is no statistically significant difference between the mean distance cycled with speedpedelec and the mean distance commuted by car.

Table 6. Welch-Anova and Games Howell test for commuting distance and mode choice

Mode Choice	(N)	Descriptives Mean	St. Dev.	Anova Welch W	Df1	Df2	Sig.	Games Howell Mean Dif. (I-J)	Sig.
Commuting Distance	2087	18.07	14.64	269.64	3	154.59	**<0.001**		
car (I)	1094	24.21	17.33						
bike (J)	787	9.97	3.47					14.240	**<0.001**
e-bike (J)	167	14.34	6.69					9.871	**<0.001**
speedpedelec (J)	39	25.52	10.89					-1.315	0.888

What stands out in the long-distance cycling MNL model (Model 2) compared with Model 1 is the significant effect of the proximity of a cycle highway (OR=0.870; p=0.009) on the choice of a regular bicycle when commuting longer distances. However, no significant effect of this predictor variable on the choice for speedpedelec was found. In the following sections, more elaborate results of the second MNL model are discussed.

6.1 Long distance bicycle commuting and the built environment

The choice of a regular bicycle to commute longer distances was affected by the proximity of a cycle highway (OR=0.870; p=0.009), building typology (Rowhouse; OR=1.685; p=0.005), and mixed land-use (OR=253.6; p<0.001) environments. The proximity of a cycle highway (OR=0.833; p=0.021) also influenced the choice of an e-bike when commuting more than 5.8 km but land-use mix and building typology had no significant effect. Employees living in semi-detached houses (OR=0.246; p=0.027) are less likely to opt for speedpedelec than those living in detached houses. Commuting to CST and CMG had a positive effect on the choice of a regular bicycle (CST; OR=2.810; p<0.001; CMG; OR=1.47; p=0.007) and an e-bike (CST; OR=3.365; p<0.001; CMG; OR=1.776; 0.01) compared with the more remote campus CDE. However, destination has no significant effect on the choice of an e-bike.

Moreover, the results in Table 7 indicate that speedpedelec users W(2, 87.34)=3.34; p=0.04; Games-Howell post hoc test (p=0.04) live further from a cycle highway and do not reside in mixed-land use environments W(2, 88.92)=57.81; p<0.001; Games Howell post hoc test (p<0.001).

Table 7. Descriptive statistics, Anova Welch and Games Howell for Distance to cycle Highway, Land-use mix and bicycle type

Mode Choice	(N)	Descriptives Mean	St. Dev.	Anova Welch W	Df 1	Df2	Sig.	Games Howell Mean Dif. (I-J)	Sig.
Distance to Cycle Highway				3.34	2	87.34	**0.04**		
bike (I)	787	1.14	0.83						
e-bike (J)	167	1.13	0.97					0.01	1.00
speedpedelec (J)	39	2.06	2.22					-0.92	**0.04**
Land-use Mix				57.81	2	88.92	**<0.001**		
bike (I)	787	0.77	0.12						
e-bike (J)	167	0.67	0.15					0.10	**<0.001**
speedpedelec (J)	39	0.53	0.18					0.24	**<0.001**

6.2 *The long-distance cyclist*

Conventional long-distance cyclists tended to be younger (OR=0.959; p<0.001), male (OR=1.835; p<0.001), and often held a master's degree (OR=1.485; p=0.004). Employees holding a bachelors degree (OR=2.076; p=0.004) on the other hand are more likely to opt for an e-bike when commuting longer distances. Moreover, women (OR=0.666, p=0.035) were more likely to use an e-bike for long-distance cycling commute. Age, on the contrary, had no significant effect on the choice of an e-bike. Speedpedelec users were slightly younger (OR=0.966; p=0.024) than car users and were highly educated (PhD). Men (OR=2.834; p=0.003) were more likely to use speedpedelec for their commute.

7 Discussion

7.1 *Commuting distance*

The impact of commuting distance on commuting mode choice cannot be understood. Our results align with previous research (e.g. Heinen et al., 2010), showing a clear inverse relationship between distance and the popularity of cycling, with regular bicycles being the most affected by longer distances. Notably, our study reveals that speedpedelecs remain an exception, showing no decline in popularity with increasing commuting distance. This confirms that speedpedelecs have the potential to replace (longer) car commuting trips, thus promoting more active transportation (Jenkins et al., 2022).

7.2 *Built environment and bicycle commuting*

The proximity of a cycle highway affects the choice of an e-bike regardless of the commuting distance, and has a positive effect on the choice to use a regular bike for long-distance commuting trips. As perceived safety among e-bikers is strongly related to the quality of cycle infrastructure (Marincek, 2023) and the level of separation from motorized traffic, this may explain the effect of the proximity of a cycle highway on the choice to commute by e-bike. Our study did not find any effect on the choice to use speedpedelec. However, a note of caution is due here, since our study does not consider the use of a cycle highway, and the number of speedpedelec users in our study remains limited. As other studies (e.g. Liu et al., 2019) have reported longer cycling distances among the users of cycle highways, we may assume that these infrastructures do play a role in route choice and even in mode choice when cycling over longer distances. Additional research on the impact of cycle highways on route choice through surveys or GPS data is needed to enhance our understanding of the impact of these infrastructures on (long-distance) cycling commuting. Nevertheless, our study confirms the assumption that having a cycle highway within the proximity of the place of residence facilitates long-distance regular bicycle and e-bike commutes.

The strong correlation between land use mix and regular (long distance) bicycle commuting confirms that urban areas with diverse land use patterns are more conducive to bicycle commuting (e.g. Heinen et al., 2010) even for longer distances. We did not find this relationship between e-bike users and speedpedelec. This finding confirms our assumption that these types of bicycles expand cycling towards more suburban and rural areas, which is in line with previous findings from Rérat (2021) and is also reflected in the estimates for building typology. Living in a row house has a significant positive effect on the choice of a regular bike, whereas speedpedelec users tend to live in detached houses.

Destination accessibility is a significant predictor for sustainable commuting mode choice: a well-accessible workplace such as the CST campus, located in the city center, has a positive effect on both commuting by public transport as well as commuting by a regular bicycle and an e-bike. For the choice to use speedpedelec, we did not find a relationship with the destination. However, the influence of cycling facilities at the workplace on commuting behavior cannot be derived from our study because the destination is included as a categorical variable due to statistical significance. Further qualitative research through focus groups could shed light on how these types of facilities influence the choice of a regular bike, e-bike, or speedpedelec, and how these facilities can contribute to higher cycling rates.

7.3 Bicycle commuter characteristics

Witlox and Tindemans (2004) suggested that in the urban region of Ghent (Belgium), cycle commuters are more likely to be women. This differs from the findings of our data, where men, especially those living in dense and mixed-land use areas, are more likely to commute by regular bicycle regardless of the distance cycled. Our study confirms the results of the few identified empirical studies on long-distance cyclists (Hansen & Nielsen, 2014; Manaugh et al., 2017; Nordengen et al., 2019) that these are more likely to be men. However, cyclists commuting longer distances by e-bikes are more likely to be older and female. In contrast, Speedpedelec users are more likely to be men, confirming the results of van der Salm et al. (2022). Furthermore, our findings are in line with previous research carried out by Vandenbulcke et al. (2011), who concluded that younger people tend to commute more often by regular bike. Moreover, our study adds to the existing literature that age has no effect on the choice to commute by an e-bike regardless of the distance cycled and reveals that e-bikes and speedpedelecs broaden participation in cycling across various socio-demographic profiles in combination with certain built environment characteristics.

8 Conclusion

In this study, we explored the complex relationship between bicycle commuting mode choices, commuting distance, the built environment, and various bicycle commuter characteristics. Our findings contribute to the growing body of research on active transport modes and provide insights into the dynamics of cycling behaviors in relation to emerging types of bicycles, particularly in Antwerp, Belgium.

Facilitating long-distance bicycle commuting can enhance the shift from individual motorized transport towards more active commuting. Promoting the use of e-bikes and speedpedelecs can play a crucial role in facilitating this shift, as these types of bicycles expand the practice of cycling in terms of space (suburban and rural areas) and users (age, gender, and level of education). Therefore, further development of a network of cycle highways, well-integrated in the local cycling network, is a promising strategy, as perceived safety and separation from motorized traffic are key factors for e-bikers. Nevertheless, the absence of an effect on speedpedelec usage requires further research, as it may suggest the need for a tailored infrastructure for this specific bicycle type. Notably, the subpopulation of speedpedelec commuters was relatively small, which may affect the significance levels for this group.

However, as speedpedelecs and e-bikes may offer an alternative to cars for residents of suburban and even rural neighborhoods, we risk maintaining and even reinforcing urban sprawl, and investments to make cycling more attractive for suburban commuters may benefit more affluent households. Moreover, our findings emphasize the critical role of diverse land-use patterns in encouraging regular bicycle commuting, even over longer distances. Urban planners and policy makers should therefore focus on creating compact, mixed-use neighborhoods, integrating residential, commercial, recreational spaces, and workplaces to encourage bicycle use.

Destination accessibility significantly influences commuter mode choice. Highly accessible workplaces, such as the CST campus located in a dense urban city center, have a positive effect on cycling, both for regular bicycles and e-bikes, and on the use of public transport. When commuting distances are substantial, bicycles and even battery-assisted ones are less convenient because of the longer travel times and required effort. High-quality public transport that connects both the origin and destination remains useful. A thoroughly implemented location policy for major employers (and other large trip generators) is therefore crucial for establishing a transition away from individual car use.

In conclusion, our study provides valuable insights into the multifaceted nature of commuting behaviors, offering a comprehensive understanding of how commuting distance, built environment, and commuter characteristics influence the choice of a regular bike, e-bike, or speedpedelec. These findings can inform urban planning and policy decisions, ultimately fostering more sustainable, efficient, and active transportation systems in urban and suburban areas. However, further research is needed to delve deeper into the specific nuances of e-bike and speedpedelec usage, and the impact of cycle highways on route and mode choices for long-distance bicycle commuters.

Contributor Statement

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Conflict of interest

There is no conflict of interest.

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