Cities 153 (2024) 105298

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities

Shared micro-mobility and transport equity: A case study of three European countries

Xiaodong Guan [a,*], Dea van Lierop [a], Zihao An [b,c,d,e], Eva Heinen [b,f,g], Dick Ettema [a]

[a] Faculty of Geosciences, Utrecht University, Utrecht, the Netherlands
[b] Institute for Transport Studies, University of Leeds, Leeds, United Kingdom
[c] Department of Land Economy, University of Cambridge, Cambridge, United Kingdom
[d] Cambridge Centre for Smart Infrastructure and Construction, University of Cambridge, Cambridge, United Kingdom
[e] Cambridge Centre for Environment, Energy and Natural Resource Governance, University of Cambridge, Cambridge, United Kingdom
[f] Department of Transport Planning, Faculty of Spatial Planning, Technische Universität Dortmund, Dortmund, Germany
[g] Department of Architecture and Technology, Norwegian University of Science and Technology, Trondheim, Norway

ARTICLE INFO

Keywords:
Shared micro-mobility
Transport equity
Transport poverty
Mobility
European cities

ABSTRACT

Shared micro-mobility services (e.g., shared bikes/e-bikes/e-scooters) have the potential to facilitate transport equity by offering available travel modes for transport disadvantaged groups. The achievement of this goal requires disadvantaged people to be able to use and benefit from shared micro-mobility equally compared with others. However, while many studies have explored the equity impact of shared micro-mobility from the perspective of its spatially and socially unequal usage, how its use can help alleviate transport poverty remains unclear. This study provides a more comprehensive picture of the role that shared micro-mobility services play on transport equity by investigating the influential factors of shared micro-mobility use and its impact on perceived transport poverty between different income groups. We developed regression models using data from an online survey conducted in 2022 in three European cities (Malmö, Manchester, and Utrecht). The results suggest that some transport disadvantaged groups (the elderly, females, car non-owners, and suburban residents) used shared micro-mobility less than others in our sample. Shared micro-mobility use shows little potential in promoting the users' accessibility and travel affordability. Nonetheless, shared e-scooters/e-mopeds have a great potential in facilitating transport equity by favoring low-income users' mobility equally or more greatly compared with that of high-income users.

1. Introduction

Due to the technology innovation of GPS (global positioning system) location tracking and digitalized payment systems, many cities around the world have recently witnessed an increasing development of shared micro-mobility services (e.g., shared bikes, e-bikes, e-scooters, and e-mopeds). These new mobility services are intended to facilitate a more efficient and sustainable urban transport system by introducing new transport options and by becoming available as a 'first' or 'last mile' solution in connection with public transport (Hirsch et al., 2019; Ricci, 2015). Accordingly, many studies have explored the usage of shared micro-mobility services (Fishman, 2016; Sun et al., 2021), their impacts on people's travel mode choice (Nikiforiadis et al., 2021; Sanders et al., 2022), and the result on activity generation (Bai et al., 2021). At the same time, what also received great attention is the impact of shared micro-mobility on transport equity, which refers to "the fair and appropriate distribution of transport benefits and costs among individuals or population groups (Pereira et al., 2017)." As suggested by Lucas et al. (2016), some individuals suffer from transport poverty because of the following issues: transport (in)affordability (i.e., excessive amount of time or money spend on travelling), mobility poverty (i.e., lack of available transport options), accessibility poverty (i.e., low access to destinations for daily activity needs), and exposure to externalities (e.g., unsafe/unhealthy travel condition). While some researchers have suggested that shared micro-mobility services could facilitate transport equity by increasing transport disadvantaged groups' mobility options (Dill & McNeil, 2021), others have suggested that their development may aggravate transport inequality because of the unequal

* Corresponding author.
E-mail addresses: x.guan@uu.nl (X. Guan), d.s.vanlierop@uu.nl (D. van Lierop), za338@cam.ac.uk (Z. An), eva.heinen@ivt.baug.ethz.ch (E. Heinen), d.f.ettema@uu.nl (D. Ettema).

https://doi.org/10.1016/j.cities.2024.105298
Received 23 October 2023; Received in revised form 6 July 2024; Accepted 11 July 2024
Available online 27 July 2024

distribution of these services as well as barriers associated with using these services related to physical ability and tech savviness (e.g., Groth, 2019).

The impact of shared micro-mobility on transport equity depends on how it influences the mobility levels of different population groups. In other words, to increase transport equity in a region, shared micro-mobility services must benefit disadvantaged groups and alleviate their transport poverty equally (or more greatly) compared to groups that do not experience transport poverty. Previous studies tend to investigate the role of shared micro-mobility in transport equity from the perspective of people's unequal use of (or access to) these services only (Böcker et al., 2020; Chen et al., 2020a; Dill & McNeil, 2021; Laa & Leth, 2020; Mooney et al., 2019; Reck & Axhausen, 2021; Ricci, 2015). However, whether the adoption of these services can help reduce the users' transport poverty and how such benefit varies across population groups were largely neglected. This results in an incomplete understanding of the equity implications of shared micro-mobility.

For this reason, we argue that research on shared micro-mobility and transport equity needs to consider two aspects simultaneously: the equity of shared micro-mobility use (i.e., by whom it is used) and the impact of its use on transport poverty. However, so far limited research has paid attention to the latter aspect (Abouelela et al., 2024; Chen et al., 2022; Qian & Niemeier, 2019). Moreover, more studies are needed to compare the equity impacts of different kinds of shared micro-mobility services and their potential context difference. Shared electric micro-vehicles (e.g., shared e-bikes/e-mopeds) may benefit the users' mobility and accessibility more greatly than conventional bikeshare because of the higher levels of travel speed and less physical effort needed in use. Dock-based shared micro-mobility services may play a limited role in improving accessibility because they require additional travel time a user should walk to and from the station. Relatively, dockless services can provide more flexible transport options for daily travel by freeing the users' route and destination choices from around the docked stations. However, the achievement of such accessibility benefit requires a sufficient supply of vehicles around the city to guarantee that it's easy for the users to access them at any time. Also, the high dependency on smart phone applications for dockless services might exaggerate the transport inequality between groups with digital barriers and the rest population. Besides, the role that shared micro-mobility plays in daily travel may largely depend on the transport infrastructure, spatial distribution of facilities, and mobility culture, thus varies across different spatial contexts.

To fill these research gaps, this paper aims to contribute to an improved understanding on the role of shared micro-mobility in transport equity by investigating the equity of shared micro-mobility use and on the other hand, its impact on individual's perceived transport poverty, measured by the perceived mobility level, accessibility level, travel costs (monetary, time and emotional) and exposure to externalities (Lucas et al., 2016). A comparative study is conducted using an online questionnaire survey data from cities in three European countries (Netherlands, Sweden, and United Kingdom). In addition, our study involves all the different kinds of shared micro-mobility services (including shared bike, shared e-bike, shared e-scooter, shared e-moped, and shared e-cargo bike) implemented in each city simultaneously to clarify their potential different roles in alleviating transport inequity.

2. Literature review

2.1. Research on shared micro-mobilities

The rapid development of shared micro-mobility services around the world has gained extensive research attention in the last decade. Relevant studies started from understand the effect of docked bikeshare systems (Fishman, 2016) and, more recently, research on dockless shared e-bikes and e-scooters emerged. Research on the use of shared e-mopeds remains scarce. Numerous studies have investigated the determinants of shared micro-mobility use, which could be roughly divided into three categories: First, personal attributes, including socio-demographic characteristics like age (Reck & Axhausen, 2021), gender (Reilly et al., 2020), income level (Frias-Martinez et al., 2021), health conditions (Barbour et al., 2019), and car ownership (Fishman, 2016), as well as psychological factors such as travel mode preferences (Chen et al., 2020b), perceived convenience of using shared micro-mobility (Guo & Zhang, 2021), environmental and health consciousness (Kim et al., 2017; Mitra & Hess, 2021), and subjective norms (Si et al., 2020). Second, environmental features. Shared micro-mobilities were found to be used more frequently in areas with high population density, better access to transit, and well-equipped cycling infrastructures (Bai & Jiao, 2020; Shen et al., 2018; Sun et al., 2021; Zhang et al., 2017). Meanwhile, the natural environment, such as air quality (Campbell et al., 2016) and weather conditions (Caulfield et al., 2017; Hosseinzadeh et al., 2021), also influences the decision to use shared micro-mobility services. Third, several studies have also focused on level of service, such as the access to shared micro-mobility services (Reck & Axhausen, 2021; Sanders et al., 2020), available fleet size (Shen et al., 2018), the lengthy of sign-up process (Fishman et al., 2012), and the price of usage (Reck et al., 2021) of shared micro-mobility services.

Many other scholars analyzed the users' travel patterns with shared micro-mobilities. In general, both shared bikes and e-bikes were observed to be used mostly during morning and evening peak hours on weekdays, and during the day on weekends (Fishman et al., 2015; McKenzie, 2019; Nickkar et al., 2019; Shen et al., 2018). This suggests that shared bikes/e-bikes are used mostly for commuting trips on weekdays and for other purposes (e.g., recreation) on weekends (Fishman et al., 2015; Sun et al., 2021). Findings on the temporal distribution of shared e-scooter trips are inconsistent. Specifically, while some studies reported evidence on commuting peaks (e.g., McKenzie, 2019), others found only afternoon peaks (Bai & Jiao, 2020; Reck et al., 2021). In accordance with the latter finding, most studies concluded that shared e-scooters are predominantly used for shopping or recreation, rather than commuting purposes (Bai et al., 2021; McKenzie, 2019). In terms of travel duration, it was found that most trips by shared bikes are under 30 min and within 2 km (Chen et al., 2020a). Trips by shared e-bikes are relatively longer, with the mean trip distance between 2 and 4.5 km (Campbell et al., 2016; McKenzie, 2019), while shared e-scooter trips tend to be shorter, with a median distance of 1.3 km in Louisville, USA as an example (Reck et al., 2021).

The transport and environmental impacts of shared micro-mobility services have also been investigated. The majority of research found that shared bikes (Barbour et al., 2019; Chen et al., 2020a; Fishman, 2016) and e-bikes (de Haas et al., 2022; Fukushige et al., 2021) substituted trips which were previously made by walking, cycling, and public transport, rather than private cars. Similar findings were also found for shared e-scooters (Abouelela et al., 2024; Nikiforiadis et al., 2021; Sanders et al., 2022). These findings question the positive impact of shared micro-mobility on the environment. For example, by simulating the modal shifts before and after Amsterdam is fully covered by shared mobility (shared e-bikes, e-mopeds, and e-cars) hubs, Xanthopoulos et al. (2024) concluded that only 32 % of the "shared trips" replace previous car trips, leading to an only 1.27 % reduction of CO_2 emissions. Nevertheless, the study of Fishman et al. (2014) concluded that bikeshare did reduce car use in most of the cities in the United States, the United Kingdom (except London), and Australia. Studies have also found that bikeshare could help raising the awareness, acceptance, and use amount of conventional cycling as a mode in daily travels (Fuller et al., 2013; Goodman et al., 2014; Murphy & Usher, 2015). Besides, bikeshare is suggested to be able to reduce the user's total travel time by providing alternatives for short car and public transit trips, especially in congested streets (Bullock et al., 2017; Faghih-Imani et al., 2017; Woodcock et al., 2014).

2.2. Shared micro-mobility and transport equity

The impact of shared micro-mobility development on transport equity also received research attention. An equitable transport system needs to allocate transport resources to groups evenly (i.e., horizontal equity) on the one hand and favor disadvantaged groups in particular to improve their current travel condition (i.e., vertical equity) on the other hand (Guzman et al., 2017). Previous studies have suggested that individuals who are female, low-income, less-educated, migrants, disabled, and non-auto travelers are usually vulnerable groups of transport poverty (Gössling, 2016; Guzman et al., 2017; Lucas et al., 2019; Verlinghieri & Schwanen, 2020). In general, studies have widely found that transport poverty hinders people's access to life opportunities (Wang et al., 2021), social capital (Ma et al., 2018; Schwanen et al., 2015), social inclusion (Currie & Delbosc, 2010; Lucas, 2012), subjective wellbeing (Churchill & Smyth, 2019; Delbosc & Currie, 2011), as well as physical/mental health (Churchill et al., 2023; Ma et al., 2018).

Shared micro-mobility services are claimed to facilitate transport equity by offering more widely available travel modes for transport disadvantaged populations (Dill & McNeil, 2021). However, achieving transport equity requires that disadvantaged groups are able to access and use shared micro-mobility services equally compared to more advantaged groups. Moreover, shared micro-mobility needs to be able to significantly improve the users' overall mobility and accessibility levels, thus help reduce the transport poverty among disadvantaged groups.

2.2.1. Spatially/socially unequal access to and usage of shared micro-mobility

The spatial/social equity of shared micro-mobility access and usage has received great research attention. Scholars have pointed out that shared micro-mobility development may reproduce transport poverty due to the unequal distribution of services (Groth, 2019). Some providers may implement shared micro-vehicles in denser and wealthier areas for profit reasons, resulting in the relatively lower opportunity to benefit from shared micro-mobility for residents in marginalized areas (Bai & Jiao, 2021; Mooney et al., 2019; Ricci, 2015). Moreover, even within the service areas, some groups are less represented in adopting shared micro-mobility due to the lack of smartphones (or knowledge on using the app) and online-payment methods (i.e., digital divide), or the physical ability to ride the shared vehicles (i.e., physical divide, such as for those elderly, female, and disabled), or the affordability to use shared micro-mobility services regularly (i.e., economic divide) (Bateman et al., 2021; Chen et al., 2020a; Nikiforiadis et al., 2021; Uteng et al., 2019). Besides, the privacy concern on using digital surveillance systems and safety concerns on riding may also prevent some individuals from adopting shared micro-mobility, regardless of the access to the services (Groth, 2019; Sanders et al., 2020).

In general, studies have revealed a lower access to and usage rate of shared micro-mobility in marginalized areas and traditionally transport disadvantaged groups by different approaches (see review Dill & McNeil, 2021). Some studies examined the spatial distribution of available shared micro-vehicles (Bai & Jiao, 2021;Mooney et al., 2019 ; Qian et al., 2020) and/or their services areas (Brown, 2021; Hosford & Winters, 2018; Qian et al., 2020), and then linked them with the neighborhood sociodemographic features. Similarly, a few papers also mapped the spatial pattern of shared micro-mobility ridership (e.g., McKenzie, 2019, 2020; Nickkar et al., 2019; Qian et al., 2020). Some others analyzed the socio-demographic profile of shared micro-mobility users (Bieliński & Ważna, 2020; Laa & Leth, 2020; Reck & Axhausen, 2021) and compared that with the general population within the service areas (Gavin et al., 2016). Besides, as mentioned above, many studies have regressed personal and neighborhood attributes on shared micro-mobility use to examine how it is adopted differently among spatial areas and groups (e.g., Barbour et al., 2019; Chen et al., 2020b; Guo & Zhang, 2021; Reck & Axhausen, 2021).

Specifically, shared bikes, e-bikes, and e-scooters were all found to be less accessible in low-density areas (Brown, 2021; McKenzie, 2020) and for lower-income and minority populations (Bai & Jiao, 2021; Brown, 2021). In particular, dockless shared micro-mobility services are more equitable than the docked ones in terms of spatial access (Mooney et al., 2019; Qian et al., 2020). In terms of usage, minority groups, lower-educated people, females, and older adults are generally less likely to be members and/or habitual users of bikeshare compared with their counterparts (Bieliński & Ważna, 2020; Dill & McNeil, 2021). Similar social disparities have been found for shared e-scooter adoptions, especially for gender and age (Mouratidis, 2022), though shared e-scooter users are relatively more representative of the general population than shared bike users (Reck & Axhausen, 2021). Findings on the association between income and shared micro-mobility use are mixed. For example, while many studies indicated that low-income people use shared bikes less (Chen et al., 2020b; Reck & Axhausen, 2021), some others found a negative relationship between income and shared bike use (e.g., Barbour et al., 2019). Besides, a few studies found that car owners have lower access to (Brown, 2021) and usage rate of (Guo & Zhang, 2021) shared micro-mobility compared with those without cars, which means that the unequal distribution of services may limit the role of shared micro-mobility in substituting cars, and thus their environmental and sustainable benefits. However, some unfavored groups in transport like the disabled people have less been discussed in the equity research of shared micro-mobility (Dill & McNeil, 2021).

2.2.2. How shared micro-mobility helps reduce transport poverty?

Despite the evidence on the equity of shared micro-mobility access and use, to what extent it can help reduce transport poverty is still less understood. Some scholars suggested that shared micro-mobility services can improve people's mobility and accessibility levels as an additional flexible travel option, which is convenience for short trips and trip chaining (Bullock et al., 2017; Chen et al., 2020a). Meanwhile, they could also improve people's access to public transport as a first/last mile solution to access transit stations (Bieliński & Ważna, 2020; Chen et al., 2020b; Hirsch et al., 2019). However, as found in many studies, the speed and capacity limitations of shared micro-mobility constrain its capability to substitute private cars and cover long-distance trips (Barbour et al., 2019; Fishman, 2016; Nikiforiadis et al., 2021). The extra monetary cost and sensitivity to weather in adopting shared micro-mobility may also limit its regular use in daily travels (Hosseinzadeh et al., 2021; Nikiforiadis et al., 2021). Besides, shared micro-mobility users are more exposed to road accidents and vehicle emission pollution than auto travelers (Ricci, 2015). All these issues may weaken the role of shared micro-mobility in help alleviating transport poverty.

Limited research has investigated the impact of shared micro-mobility on transport poverty, and most of them focused on accessibility improvement based on simulation approaches (e.g., Abouelela et al., 2024). Tsigdinos et al. (2024) simulated and found that the greatest change in workplace accessibility would occur in areas with lowest accessibility after the implementation of a metropolitan cycling network in Athens, suggesting that bicycle-oriented multimodal transport system can help increase accessibility and transport equity. However, this study did not examine the influence of bikeshare services on accessibility directly. Qian and Niemeier (2019) simulated the accessibility benefits from developing bikeshare services by comparing the accessibility to jobs and services at the census block level under two scenarios: one by walking using the current pedestrian system, and the other by (assumed) perfectly equipped bikeshare services. The findings revealed the potential of bikeshare services in improving the accessibility of disadvantaged communities in Chicago and Philadelphia. The research of Chen et al. (2022) provided empirical evidence on this conclusion. They collected the bikeshare users' self-reported accessibility improvement that bikeshare use has brought in Beijing, China, and most users agreed that bikeshare use made accessing activities easier.

Even fewer studies have examined whether shared micro-mobility use influences transport poverty equally for different population groups. Chen et al. (2022) made an initial attempt by examining the influences of the bikeshare users' personal attributes on their self-reported accessibility improvement. They found that male users tend to enjoy more benefits in accessibility from using bikeshare than female users. In another simulation-based study in Louisville, USA, Abouelela et al. (2024) found that disadvantaged groups do not receive more accessibility gains from replacing other modes by shared e-scooters than the rest of population.

However, how bikeshare influences other dimensions of transport poverty, such as mobility level (i.e., availability of transport options), travel cost (e.g., monetary, time, and emotional cost), and exposure to externalities (e.g., unhealth or unsafe travel conditions), is still unclear. Moreover, the influence of shared electric micro-vehicles (i.e., shared e-bikes/e-scooters/e-mopeds) on transport poverty, which may differ from that of bikeshare because of higher travel speed (Sanders et al., 2020), also remains less explored so far. Therefore, more studies on how shared micro-mobility services affect different population groups' transport poverty are needed to better understand their equity implications.

3. Methodology

3.1. Conceptual framework

Fig. 1 illustrates the conceptual model of this research. We are interested in (1) how the use of shared micro-mobility is linked to personal (e.g., age, gender, car ownership, etc.) and environment attributes (e.g., urban vs. suburban neighborhoods), and (2) how its use contributes to reduced transport poverty for different population groups (e.g., high-income vs. low-income groups). In line with previous studies, we assumed that shared micro-mobility use is determined by personal attributes including socio-demographics and the access to different transport modes (e.g., private cars and bicycles), as well as environmental attributes like built environment factors (Fishman, 2016; Reck & Axhausen, 2021; Shen et al., 2018). All these variables, together with the shared micro-mobility use, also directly influence individuals' perception of their transport poverty levels (Delbosc & Currie, 2011; Guzman et al., 2017). In addition, since previous studies have suggested that some disadvantaged groups may not receive comparable accessibility benefits from shared micro-mobility services (Abouelela et al., 2024; Chen et al., 2022), we also examined whether individual socio-demographics moderate the impact of shared micro-mobility use on transport poverty.

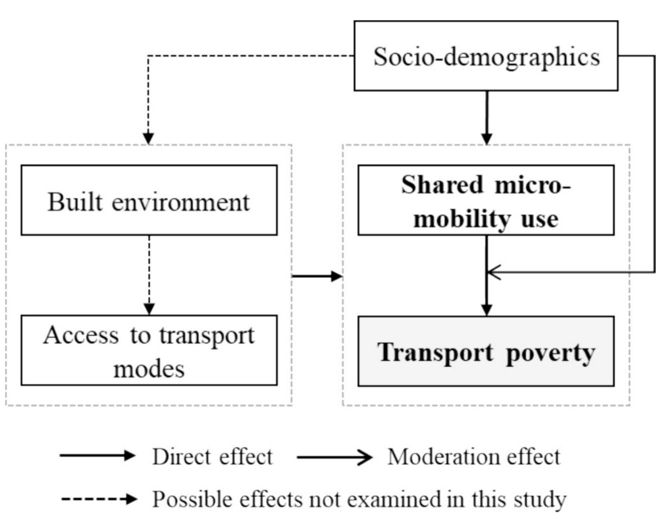


Fig. 1. Conceptual framework.

Other links among the factors of shared micro-mobility use are also possible. For example, the residential location choice could be influenced by individual socio-demographics (Guan et al., 2020; Mokhtarian & Cao, 2008). Besides, as suggested by previous studies (Guan & Wang, 2020; Van Acker & Witlox, 2010), access to private cars and other transport modes can also be affected by socio-demographics as well as the built environment. However, since this paper focuses on the social and spatial equity of shared micro-mobility use and its impact on transport poverty, we will not examine the associations between these variables and their indirect impacts on shared micro-mobility use in following modelling process. Besides, natural environment (e.g., the weather condition) is not included because shared micro-mobility use is measured weekly rather than daily in our survey. The modelling results will provide a more comprehensive picture on the equity implications of different shared micro-mobility services.

3.2. Data

Data used in this research comes from an online questionnaire survey conducted from June to September 2022 in three European cities, including Utrecht (Netherlands), Malmö (Sweden), and Great Manchester (UK). The three cities differ in terms of transport infrastructure and shared micro-mobility services implemented.

Utrecht is the fourth most populous municipality in the Netherlands with about 360,000 inhabitants living in an area of 99.21 km^2. Like other Dutch cities, Utrecht is a cycle-oriented city with well-developed bicycle paths and nearly 50 % of trips within the city were made by bicycle in 2021. In 2022, public transport rental bicycles (*OV-fiets*), shared e-bikes & e-mopeds (*Tier*), and shared e-cargo bikes (*Cargoroo*) were available in Utrecht.

Malmö is the third-largest city in Sweden with an areas of 76.81 km^2 and about 350,000 inhabitants. The city has a bike path network of 520 km. The recent travel survey conducted in 2018 indicates that cycling accounts for around 25 % of the trips within the city. In 2022, shared e-scooters (*Lime*, *Tier*, and *VOI*) and both docked (*Malmöbybike*) and dockless bikeshare (*Donkey Republic*) were provided in the city of Malmö.

Greater Manchester is a city region in North West England, covering an area of 1276 km^2, home to over 2.8 million people. Trips in Greater Manchester are dominated by cars and public transport, while cycling level is very low (around 5 %). In 2022, shared bikes/e-bikes (*the Bee Network Cycle Hire*) and shared e-scooters (*Lime*) were available in the city of Manchester and some other regions of Great Manchester (e.g., Salford and town of Trafford).

In all the three cities respondents were recruited from residents in the areas where shared micro-mobility services were available via local survey companies. The primary aim of the survey is to understand how shared micro-mobility is used in combination with existing transport modes and what implications this has on sustainability, equity, and inclusion. To achieve this goal, the questionnaire (available in both English and the local language) included information on the awareness and use frequency of different shared micro-mobility services, individual socio-demographics, access to different kinds of transport modes, and a series of statements on perceived transport poverty. For users of any kind of shared micro-mobility, we also asked their perceived changes in travel mode choice, accessibility, number of activities, and monthly travel expense that the adoption of shared micro-mobility has brought. The first part of postal code (i.e., first 3 digits in Malmö, 4 digits in Utrecht, and 2–4 digits in Manchester) at the residential location was collected from each respondent. In total, we received 2110 completed surveys from three cities (please refer to An et al., 2023 for more detailed information of the survey). After data cleaning, the final sample for this study includes 1518 respondents, with 278 from Utrecht, 442 from Great Manchester, and 798 from Malmö.

Table 1
Factor analysis result on perceived transport adequacy (poverty).

Items	Perceived mobility	Digital barrier	Perceived accessibility	Travel cost	Healthy travel
There is always a transport option available to me at the times I need it	**0.867**				
I always have more than one transport options while travelling from home to my regular destinations & activities	**0.857**				
I can usually travel in a way that is suited to my physical condition & abilities	**0.575**				
I have difficulties using transport-related apps on smart phones		**0.944**			
I have difficulties getting information about available transport services		**0.861**			
I can easily reach my gym, team, place of worship, or (hobby) clubs in my ideal travel time			**0.863**		
I can easily reach healthcare facilities in my ideal travel time			**0.846**		
I can easily reach friends or relatives at their home in my ideal travel time			**0.844**		
I can easily reach the supermarket or local shopping areas in my ideal travel time			**0.833**		
I can easily reach my workplace (or place of education) in my ideal travel time			**0.622**		
I spend much more time travelling than I'd like				**0.921**	
I have to spend more money on necessary travel in a week than I can afford				**0.781**	
I feel tired or distressed while travelling to my regular destinations & activities				**0.771**	
I feel safe while travelling to my regular destinations & activities					**0.936**
I can travel without negative consequences to my health					**0.795**
Cronbach's Alpha	*0.768*	*0.791*	*0.878*	*0.792*	*0.701*

Extraction method: Principal Component Analysis. Rotation method: Oblimin with Kaiser Normalization. Total variance explained: 72.57 %. Loadings lower than 0.3 are suppressed.

3.3. Variables and measurements

Table A1 in appendix lists the original questions in the survey for all the variables we used in this study. For shared micro-mobility use, respondents were asked to report the frequency of using each kind of shared micro-mobility services in their city in the 12 months prior to participating in the survey. Responses were recorded using a 7-point scale: (1) (Almost) never; (2) 1–5 days a year; (3) 6–11 days a year; (4) 1–3 days a month; (5) 1–3 days a week; (6) 4–6 days a week; (7) Daily. For each kind of shared micro-mobility services, we classified the respondents who had used the mode for at least 1–5 days a year as being "users", and those who had used the mode for at least 1–3 days a week as "frequent users".

Variables on transport poverty were derived from 15 statements on perceived disadvantage in daily travel in 5-point scale. We used principal component analysis with oblique rotation to identify the latent constructs in SPSS version 28.0. Oblique rather than orthogonal rotation was adopted because the latent factors on perceived transport poverty might be correlated with each other (Field, 2005; Lucas et al., 2016). The criterion "Eigenvalue > 1" was used to determine the number of factors. As Table 1 shows, the factor analysis resulted in five latent constructs of perceptions on transport poverty: perceived mobility (the options available for daily travel), digital barrier, perceived accessibility (access to the workplace and other facilities), travel cost (monetary, time and emotional costs in daily travel), and healthy travel (safe and healthy travel conditions). The Cronbach's alpha is larger than 0.7 for all the factors, indicating a high internal consistency for every factor. The scores of these factors (except digital barrier) will be used as the dependent variables in following transport poverty models. Respondents were considered to be suffering from transport poverty if the factor scores of digital barrier and travel cost are high, or if scores on other factors are low. Otherwise, we assumed that the respondents are likely to experience "transport adequacy", i.e., a positive subjective assessment of the quality and sufficiency of one's transport options and associated life outcomes (Ettema & Geigenmüller, 2023; Fu et al., 2024). For shared micro-mobility users (shared bike users as an example), we also collected the self-reported changes in destination accessibility and travel expense after adopting shared micro-mobility by the following questions: "*Has the use of shared bikes impacted your travel in other ways: 1) the convenience to access daily travel destinations; 2) monthly travel expense*" (responses in 5-Likart scale, from much decreased to much increased).

To investigate the socially inequality in shared micro-mobility use and its benefits on transport adequacy, we include some commonly used individual and household socio-demographics in our models, including age, gender, employment status, education level, the presence of children, and household income. In particular, we also asked the respondent to indicate if he/she has "a condition that substantially limits basic physical activities such as walking, climbing stairs, or carrying", and added this variable into the models to capture the equity impact of shared micro-mobility for individuals and groups with different physical abilities. In addition, having a driver's license (for a car) is also included in the models, given that it enables the adoption of shared e-scooters and e-mopeds in our study areas.

Measures on the access to different transportation modes include the ownership of public transport seasonal tickets and the access to private cars, bikes, e-bikes as well as other private micro-vehicles (i.e., motorcycle, e-scooter, e-moped, or e-skateboard). For private bikes and e-bikes, we distinguished "ownership" and "regular use from others" when creating the access variable, considering that people who regularly borrow bikes/e-bikes from others may be more likely to take shared bike/e-bike services as an alternative choice than those with their own bike/e-bikes. Unfortunately, similar information on private e-scooters and e-mopeds were not collected in the survey.

The residential built environment is measured at the spatial level that defined by the first part of the postal code in each city. Two variables are used to capture the urbanity level of the home location: population density and the distance from home (the central point of the residential neighborhood) to the city center. We also collected the locations of train, bus, and tram stations as well as cycling routes in the three cities from Open Street Map and created three variables on transport infrastructure by spatial joining their locations with the postal code boundary in ArcGIS Pro: 1) the distance from home to the nearest train station; 2) density of local public transport (bus and tram) stations; 3) density of cycle routes (length per kilometer square).

Table 2 lists the sample profiles in the three cities. In general, our sample is somewhat overrepresented by younger, high-educated, and employed adults, probably because the survey was conducted online. Gender and income level are more balanced in the sample. On average, around 10 % of respondents reported a (more or less) disability that limits physical activities. The sample characteristics differ across the three cities. While car ownership levels were similar among the three cities, Utrecht sample had a higher ownership rate of public transport season tickets, and the sample in Manchester had a lower bicycle ownership level than the samples from other cities. The built environment features also differ across cities. Population density was higher in Utrecht than in Manchester and Malmö. Besides, Manchester had a higher transit density but a lower cycle route density than the other two cities (Fig. A1 in the appendix shows the distribution of rail stations and cycling routes in the three cities). In terms of shared micro-mobility use, as shown in Fig. 2, on average the respondents in Manchester had the highest usage rate of shared micro-mobility, followed by those in Utrecht, while the respondents in Malmö adopted shared micro-mobility least frequently.

3.4. Model design

To fully understand the equity impact of shared micro-mobility services, we ran two groups of models in each city following Fig. 1, and selected the appropriate regression method based on the type of the dependent variable: 1) a binary logistic regression model on the use (or not) of each kind of shared micro-mobility services (dichotomous variable), with individual socio-demographics, access to transport modes, and the built environment as independent variables. This resulted in 9 models in total: 4 in Utrecht, 3 in Manchester, and 2 in Malmö. 2) two ordinary least squares (OLS) regression models on each of the perceived transport adequacy factor (continuous variable): one with shared micro-mobility user (or not) added as a new predictor, and the other with frequent shared micro-mobility user (used at least once a week vs. otherwise) added. This resulted in $2 \times 4 \times 3 = 24$ models in total. The interaction terms between "low income" and shared micro-mobility use were also included to capture how population groups with different income levels received transport benefits from adopting shared micro-mobility differently.[1] Since the two kinds of transport adequacy models differ only in the shared micro-mobility use variable, the estimated coefficients of other independent variables were quite similar. For this reason, their coefficients were only reported for the first model in the following subsections. Besides, we conducted descriptive analyses on the users' self-reported changes in perceived accessibility and monthly travel expense after adopting shared micro-mobility. The results contribute to a better understanding on the casual relationships between shared micro-mobility use and perceived transport adequacy.

Though the factor "digital barrier" reflects the respondent's transport poverty, we included it into the first group of models as a predictor (rather than as a dependent variable in the second group of models) considering that it may affect shared micro-mobility use (negatively) but not the other way around. All the regression models were estimated using the samples in different cities separately in SPSS version 28.0. Before running the regression models, we checked the scatterplot for each pair of the continuous predictors and dependent variables and removed obvious outliers that may bias the estimation. Multicollinearity was checked via the indicator "Variance Inflation Factor (VIF)", which is lower than 5 for all the independent variables in all the models, suggesting no serious multicollinearity in the data (Mason et al., 2003). For all the OLS models, we further tested the heteroskedasticity by plotting residuals against the predicted value as well as White's/Breusch-Pagan test, finding no trends of serious heteroskedasticity that may bias the model estimation. The normality of residuals was checked by the standardized normal probability (P—P) plot. The results showed no serious deviation from normality for all the OLS models. Besides, we also checked the linearity between the dependent variables and continuous predictors by two approaches: 1) to plot the standardized residuals against each of the continuous predictors; 2) augmented component-plus-residual plot (i.e., augmented partial residual plot). Both plots suggested that non-linearity is not a critical concern in our models.

4. Results

4.1. Social/spatial equity regarding shared micro-mobility use

Table 3 shows the regression modelling results on shared micro-mobility use. In general, we found that younger and male individuals were more likely to adopt shared micro-mobility services than others in all the three cities, which is in line with previous studies (Dill & McNeil, 2021), while driving license, the presence of children, and employment status have no or limited impacts on shared micro-mobility use. The effects of education level and household income tend to be mixed. High-educated and high-income people used shared bikes more but shared e-scooters less compared to their counterparts. Household income level is also positively associated with the use of shared e-bikes, e-mopeds, and e-cargo bikes in Utrecht. Surprisingly, we found that people with physical disabilities used shared e-mopeds more than others (in Utrecht), but this is not the case for other shared micro-mobility services. This finding could be explained by the fact that e-moped, as a "sitting" e-scooter, requires much less physical efforts than (e-)bikes or conventional e-scooters. Digital barrier does not show a significant impact on the use of most shared micro-mobility services (except shared e-cargo bikes). This is probably because the respondents in this research, who completed our questionnaire survey online, were generally familiar with the use of smart phones and transport apps.

Access to other transportation modes influences shared micro-mobility use substantially. In all the three cities, people with public transport season tickets used shared bikes significantly more than others, which is reasonable as they may take shared bikes as the first/last mile solution to access public transport stations (Chen et al., 2020b; Hirsch et al., 2019). Interestingly, we found that shared micro-mobility users also had better access to private micro-vehicles, such as bikes and e-bikes in all the three cities. This reveals that the absence of private micro-vehicles is not an important reason for using shared micro-mobility. Instead, the familiarity with these micro-mobilities may facilitate people to approach shared micro-mobility more easily. Besides, access to private cars also shows a positive impact on the use of shared micro-mobility in Manchester and Malmö.

The residential built environment features also affect shared micro-mobility use. In accord with existing studies (Brown, 2021; McKenzie, 2020), we found that shared micro-mobility services were adopted more in high-density and central areas in Malmö. Meanwhile, shared bikes and e-cargo bikes were used more in denser areas in Utrecht, where the supply of these services was relatively sufficient. Notably, the distance to the city center shows a negative impact on shared e-bike use in Utrecht, probably because shared e-bikes were not allowed to park in the central areas of Utrecht at the time of survey. In Manchester, shared e-bikes/e-scooters were used more in areas with more transit stations, again, likely as a mode to access public transport. The impacts of the distance to train station and cycle route density on shared micro-mobility use are relatively limited.

4.2. Influences of shared micro-mobility use on transport adequacy

Table 4 presents the results of regression models on perceived transport adequacy factors. In line with previous research (e.g., Gössling, 2016; Lucas et al., 2019), household income level is positively related with perceived transport adequacy in Malmö. Interestingly, we found that elderly people were less likely to consider themselves as being disadvantaged in daily travel in all the three European cities.

[1] Interaction terms regarding other individual socio-economics, such as gender, elderly (age > 50), and access to car were also examined initially, but were excluded from the final models due to high multicollinearity.

Table 2
Sample profile.

Variable name[a]	Explanation	Mean/% (Standard deviation)			Difference[b]
		Utrecht ($N =$ 278)	Manchester ($N =$ 442)	Malmö ($N =$ 798)	
Socio-demographics					
Age	1: 18–29	24 %	36 %	17 %	***
	2: 30–39	29 %	30 %	29 %	$P > 0.1$
	3: 40–49;	12 %	17 %	16 %	$P > 0.1$
	4: 50–59;	17 %	10 %	14 %	***
	5: ≥ 60	18 %	7 %	23 %	***
Gender	1: male; 0: non-male	46 %	45 %	44 %	$P > 0.1$
Employed	1: employed; 0: unemployed	74 %	76 %	67 %	***
Education level	1: high educated (bachelor or above); 0: otherwise	62 %	52 %	55 %	***
Driver's license	1: has a driver license; 0: No	85 %	76 %	87 %	***
Presence of child	1: live with children; 0: otherwise	27 %	43 %	29 %	***
Household income	1: low income	44 %	43 %	20 %	***
	2: medium income	21 %	21 %	26 %	*
	3: high income	35 %	36 %	54 %	***
Disability	1: physical disabled (limits walking or riding); 0: No	14 %	10 %	7 %	***
Access to transport modes					
Access to private car	1: Yes; 0: No	83 %	77 %	80 %	$P > 0.1$
Public transport season ticket	1: Yes; 0: No	60 %	31 %	36 %	***
Access to private bike	1: Yes (own);	71 %	36 %	80 %	***
	2: Yes (regular use from others)	15 %	15 %	6 %	***
	0: No	14 %	49 %	14 %	***
Access to private e-bike	1: Yes (own);	22 %	10 %	14 %	***
	2: Yes (regular use from others)	23 %	11 %	4 %	***
	0: No	55 %	79 %	82 %	***
Access to other private micro-vehicles	1: Yes (motorcycle, e-scooter, e-moped, or e-skateboard); 0: No	21 %	18 %	14 %	**
Built environment (postal code level)					
Population density	Number of population (thousand/km^2)	7.26 (3.78)	4.17 (2.02)	4.28 (3.20)	***
Distance to the city center	Euclidean distance from the neighborhood spatial center to the city center (km)	4.41 (4.35)	6.68 (4.79)	3.93 (2.09)	***
Distance to train station	Euclidean distance from the neighborhood spatial center to the nearest train station (km)	1.97 (1.66)	1.77 (1.13)	1.85 (0.72)	**
Transit density	Number of bus & tram stations per km^2	11.58 (6.52)	31.33 (23.61)	10.65 (5.57)	***
Cycle route density	The average length (km) of cycle route per km^2	5.21 (2.11)	1.03 (0.67)	4.71 (1.52)	***
Shared micro-mobility use					
Shared bike user	1: Yes; 0: No	40 %	42 %	20 %	***
Frequent shared bike user	1: use shared bike for at least one day a week; 0: otherwise	12 %	19 %	6 %	***
Shared e-bike user	1: Yes; 0: No	30 %	39 %	–	***
Frequent shared e-bike user	1: use shared e-bike for at least one day a week; 0: otherwise	12 %	15 %	–	***
Shared e-scooter user	1: Yes; 0: No	–	38 %	30 %	***
Frequent shared e-scooter user	1: use shared e-scooter for at least one day a week; 0: otherwise	–	16 %	7 %	***
Shared e-moped user	1: Yes; 0: No	25 %	–	–	N/A
Frequent shared e-moped user	1: use shared e-mopeds for at least one day a week; 0: otherwise	10 %	–	–	N/A
Shared e-cargo bike user	1: Yes; 0: No	17 %	–	–	N/A
Frequent shared e- cargo bike user	1: use shared e-cargo bike for at least one day a week; 0: otherwise	5 %	–	–	N/A

[a] Please refer to Table 5 for the descriptive statistics of self-reported changes in perceived accessibility and monthly travel expense.
[b] The difference in variables among cities was examined using Chi-square test or one-way ANOVA.
*** $p < 0.01$;
** $p < 0.05$;
* $p < 0.1$.

Employed individuals reported lower perceived mobility levels and higher travel cost in Malmö, which might be attributed to their commuting burdens. Unsurprisingly, physical disabled people reported a significantly lower transport adequacy level than their counterparts in both Utrecht and Malmö. All other socio-demographic variables show very limited impacts in perceived transport adequacy models. Access to private cars shows a positive impact on perceived mobility level in Utrecht, but a negative impact in Manchester. This result indicates that car owners in Manchester were more likely to be captive car users who had little alternative transport options. Context difference was also found for the access to private bikes, which contributes to perceived transport adequacy only in Utrecht and Malmö, possibly because of the better cycling infrastructure in these two cities. Access to other private micro-vehicles and the ownership of public transport tickets do not benefit perceived transport adequacy in all the cities.

Regarding the built environment, as expected, we found that residents in neighborhoods with high population density were more favored in transportation than their counterparts in Utrecht. Meanwhile, the proximity to the city center shows a positive association with perceived mobility and accessibility levels in Malmö. What should be noted is that the distance to the city center, as a city-scale location variable, may be associated with or even determine other local built environment variables, such as street design and accessibility to transit stations and jobs (Guan & Wang, 2019; Næss, 2022), and therefore affect people's

Fig. 2. Usage patterns of shared micro-mobility services by city.

Table 3
Binary logistic regression analysis results on shared micro-mobility use.

Variable	Utrecht (Netherlands)				Manchester (UK)			Malmö (Sweden)	
	Bike	E-bike	E-moped	E-cargo bike	Bike	E-bike	E-scooter	Bike	E-scooter
Age (ref: 18–29)									
30–39	−0.691	0.227	−0.603	0.203	−0.176	0.069	−0.158	−0.003	−0.421
40–49	−0.531	−0.310	−2.184***	−0.119	−0.895**	−0.762	−0.672	−0.274	−1.484***
50–59	−1.991***	−2.066***	−3.386***	−1.413	−2.855	−2.689***	−3.390***	−1.011**	−2.700***
≥60	−2.021***	−2.143**	−3.391***	−19.724	−20.889	−1.633*	−1.765**	−0.813**	−3.377***
Gender (male)	0.476	0.736**	0.719*	0.368	0.798***	1.324***	1.284***	0.463**	0.644***
Employed	0.415	0.450	0.478	−0.897	0.330	0.519	0.815**	0.353	0.154
Education level	0.016	−0.166	−0.811	−1.016**	0.368	0.380	0.198	0.617***	−0.464**
Driver license	−1.000*	0.758	0.975	0.331	0.656	−0.123	0.736*	−0.172	0.429
Presence of child	0.097	−0.069	0.634	0.311	−0.329	0.116	−0.308	0.132	−0.031
Household income (ref: low)									
Medium income	0.605	0.717	1.042**	1.168**	−0.368	−0.369	−0.804**	−0.243	0.134
High income	0.628*	0.664*	0.774*	1.273***	0.207	0.422	0.048	−0.134	0.310
Disability	−1.075*	−0.194	1.359*	−0.334	0.663	0.233	0.351	−1.072	0.591
Digital barrier	−0.031	0.241	0.155	−0.506*	−0.065	−0.113	−0.084	−0.131	−0.005
Access to private car	0.126	−0.391	0.716	0.685	0.106	0.926**	−0.150	0.047*	0.517*
PT season ticket	0.954***	0.380	0.482	0.866	0.495*	0.362	0.380	0.480**	0.175
Access to private bike (ref: no)									
Yes (own)	0.525	−0.548	−0.458	−0.500	0.689**	0.692**	0.642**	0.130	0.207
Yes (from others)	0.851*	0.507	0.927*	1.239*	2.291***	2.237***	2.151***	0.969***	1.090***
Access to private e-bike (ref: no)									
Yes (own)	1.017**	1.499***	0.502	1.134*	2.103***	3.009***	1.601***	0.363	0.749***
Yes (from others)	0.594	1.712***	0.629	0.503	1.004**	2.265***	0.713	1.452***	0.407
Other private micro-vehicles	0.918**	1.164***	1.614***	1.386***	1.032**	1.840***	1.302***	0.776***	0.661***
Population density	0.133**	0.083	0.036	0.352***	0.144	0.114	−0.053	0.000	0.065**
Distance to the city center	0.071	0.101**	−0.007	0.019	0.019	0.039	−0.010	−0.123*	−0.140**
Distance to train station	0.063	−0.023	0.045	0.108	0.382***	−0.048	0.050	−0.125	0.462
Transit density	−0.023	−0.022	−0.019	−0.073	0.005	0.015*	0.017**	0.029	−0.005
Cycle route density	0.058	0.079	−0.033	−0.219*	−0.005	−0.084	−0.120	0.310	0.149
−2 Log likelihood	*261.002*	*222.849*	*184.299*	*148.277*	*363.189*	*315.472*	*363.138*	*695.287*	*739.946*
Cox & Snell R Square	*0.333*	*0.341*	*0.367*	*0.321*	*0.416*	*0.462*	*0.393*	*0.129*	*0.254*

Notes. B values are shown in the table;
*** $p < 0.01$,
** $p < 0.05$,
* $p < 0.1$.

perceived transport adequacy. Such influence mechanism may partially explain the non-significant impacts of other local built environment variables, like transit density and cycle route density in Malmö, when we controlled for the distance to the city center.

The association between shared micro-mobility use and perceived transport adequacy is mixed. Not surprisingly, Table 4 shows that a high use frequency strengthens the role of shared micro-mobility use in transport adequacy in general. "Frequent use" of shared micro-mobility exerts more significant effects on transport adequacy factors (Model II) than "use or not" (Model I). Such influences differ across different types of shared micro-mobility services and cities. Frequent use of shared bike is positively associated with perceived mobility and healthy travel

Table 4
OLS regression analysis results on perceived transport adequacy (poverty).

Variable	Utrecht (Netherlands)				Manchester (UK)				Malmö (Sweden)			
	Perceived mobility	Perceived Accessibility	Travel cost	Healthy travel	Perceived mobility	Perceived accessi-bility	Travel cost	Healthy travel	Perceived mobility	Perceived accessi-bility	Travel cost	Healthy travel
Model I: with the use (or not) of shared micro-mobility as predictors												
Age (ref: 18–29)												
30–39	−0.020	0.064	−0.027	0.016	**0.145****	0.091	−0.041	0.059	0.017	0.072	−0.076	0.017
40–49	**0.131***	0.110	−0.080	0.073	0.080	0.026	−0.052	0.037	0.005	0.058	−0.057	0.024
50–59	**0.266*****	**0.280*****	**−0.239*****	**0.206****	**0.131****	0.060	**−0.152*****	0.037	0.048	**0.140*****	**−0.173*****	0.013
≥60	**0.263*****	**0.227*****	**−0.188****	**0.158***	0.087	−0.005	−0.071	0.009	0.071	**0.156*****	**−0.329*****	**0.143****
Gender (male)	0.023	−0.025	**−0.115***	0.066	−0.058	−0.034	0.035	0.007	−0.038	−0.024	−0.050	0.017
Employed	0.047	−0.036	0.067	−0.074	−0.038	0.054	0.067	−0.003	**−0.100****	−0.050	**0.115*****	−0.035
Education level	0.059	0.007	−0.014	0.063	0.051	−0.041	−0.057	0.067	0.033	0.015	−0.011	−0.032
Driver license	−0.101	**−0.149****	0.092	−0.085	0.016	0.055	−0.043	0.065	0.000	0.024	−0.028	0.022
Presence of child	0.013	−0.024	0.028	0.000	0.047	0.070	0.036	0.082	−0.010	−0.017	0.013	−0.021
Low income (L-I)	0.060	−0.070	**0.127***	−0.064	−0.093	−0.069	0.004	−0.043	**−0.155*****	**−0.117****	**0.067***	**−0.127*****
Disability	**−0.140****	**−0.233*****	0.095	**−0.240*****	0.005	−0.057	0.013	−0.009	**−0.080****	−0.058	0.026	**−0.061***
Access to private car	**0.176****	0.093	**−0.161****	0.037	**−0.142****	−0.069	0.012	−0.060	−0.063	0.018	**0.083****	**−0.072***
PT season ticket	0.075	0.019	−0.039	0.100	0.008	−0.051	**0.175*****	−0.015	**−0.060***	**−0.090****	**0.307*****	**−0.065***
Access to bike (ref: no)												
Yes (own)	**0.141****	**0.123***	0.009	**0.149****	−0.031	−0.073	−0.071	0.012	0.049	0.041	**−0.060***	**0.068***
Yes (from others)	−0.022	−0.021	0.048	**−0.120***	0.029	−0.010	−0.017	−0.012	−0.037	**−0.086****	0.045	0.017
Access to e-bike (ref: no)												
Yes (own)	0.004	−0.041	0.029	0.035	0.061	0.087	0.011	0.008	0.042	0.031	−0.037	−0.032
Yes (from others)	0.017	0.017	−0.055	0.066	−0.064	−0.039	−0.013	0.010	0.016	0.013	0.014	−0.004
Other private micro-vehicles	0.006	0.054	**0.129***	−0.030	0.010	0.019	−0.035	−0.056	−0.043	−0.007	**0.063***	−0.028
Population density	**0.189****	**0.144***	−0.037	0.031	0.024	−0.018	−0.101	0.095	0.078	0.050	**−0.099***	0.006
Distance to the city center	0.019	−0.041	0.040	−0.035	−0.067	−0.031	0.024	0.069	**−0.177*****	**−0.166*****	**0.088***	0.027
Distance to train station	0.010	−0.080	−0.005	−0.050	−0.014	−0.060	−0.034	0.035	0.105	0.085	0.004	−0.066
Transit density	−0.040	**−0.137***	−0.017	**−0.133***	−0.019	−0.059	0.065	−0.032	0.079	0.065	−0.045	0.092
Cycle route density	0.011	−0.033	−0.050	−0.060	−0.051	−0.044	0.021	**0.099***	0.048	0.014	0.043	0.069
Shared bike user	0.101	−0.008	0.000	0.032	−0.035	−0.018	0.088	−0.003	−0.015	−0.035	0.025	−0.034
Shared e-bike user	−0.102	−0.015	0.098	−0.090	0.017	0.059	**0.263****	−0.007	–	–	–	–
Shared e-scooter user	–	–	–	–	−0.006	−0.116	−0.127	−0.068	−0.050	−0.023	0.006	0.005
Shared e-moped user	**0.168***	0.108	−0.059	**0.188***	–	–	–	–	–	–	–	–
Shared e-cargo bike user	−0.073	−0.100	0.132	−0.129	–	–	–	–	–	–	–	–
L-I*Shared bike user	−0.145	−0.019	0.025	−0.038	0.044	−0.011	0.090	−0.024	0.009	0.048	−0.019	0.014
L-I*Shared e-bike user	0.148	**0.171***	**−0.206***	0.105	−0.069	−0.045	−0.154	−0.041	–	–	–	–
L-I*Shared e-scooter user	–	–	–	–	0.113	**0.183***	0.022	0.129	**0.124*****	0.047	−0.015	0.050
L-I*Shared e-moped user	−0.117	−0.124	0.132	−0.020	–	–	–	–	–	–	–	–
L-I*Shared e-cargo bike user	0.066	−0.006	0.024	0.047	–	–	–	–	–	–	–	–
R square	*0.174*	*0.184*	*0.192*	*0.195*	*0.069*	*0.059*	*0.146*	*0.046*	*0.085*	*0.090*	*0.256*	*0.048*
Pr(>F)	*0.018*	*0.012*	*0.005*	*0.004*	*0.019*	*0.021*	*<0.001*	*0.033*	*<0.001*	*<0.001*	*<0.001*	*0.032*
Model II: with frequent use (or not) of shared micro-mobility as predictors												
(F) shared bike user	0.131	0.092	**0.176***	−0.114	**−0.131***	**−0.126***	−0.002	**−0.160****	−0.047	**−0.097****	0.056	**−0.075***

(*continued on next page*)

Table 4 (*continued*)

Variable	Utrecht (Netherlands)				Manchester (UK)				Malmö (Sweden)			
	Perceived mobility	Perceived Accessibility	Travel cost	Healthy travel	Perceived mobility	Perceived accessi-bility	Travel cost	Healthy travel	Perceived mobility	Perceived accessi-bility	Travel cost	Healthy travel
(F) shared e-bike user	−0.153	**−0.241****	0.013	−0.056	**0.147***	−0.035	0.019	0.116	–	–	–	.—
(F) shared e-scooter user	–	–	–	–	−0.080	−0.031	−0.039	−0.060	−0.039	−0.026	−0.035	0.030
(F) shared e-moped user	**0.198***	0.004	0.065	−0.003	–	–	–	–	–	–	–	–
(F) shared e-cargo bike user	−0.002	0.154	0.113	**0.177***	–	–	–	–	–	–	–	–
L-I*(F)shared bike user	−0.083	−0.035	**0.185***	0.078	**0.205*****	**0.221*****	0.069	**0.287*****	**0.069***	0.056	−0.040	**0.076***
L-I*(F)shared e-bike user	0.091	**0.172***	−0.121	0.163	**−0.142***	−0.026	−0.022	−0.074	–	–	–	–
L-I*(F)shared e-scooter user	–	–	–	–	**0.142***	0.073	−0.023	−0.044	**0.109*****	0.041	0.028	0.035
L-I*(F)shared e-moped user	−0.024	−0.003	0.004	0.041	–	–	–	–	–	–	–	–
L-I*(F)shared e-cargo bike user	−0.022	−0.103	−0.122	**−0.170***	–	–	–	–	–	–	–	–
R square	*0.184*	*0.181*	*0.247*	*0.200*	*0.096*	*0.084*	*0.115*	*0.078*	*0.090*	*0.090*	*0.258*	*0.053*
Pr(>F)	*0.009*	*0.011*	*<0.001*	*0.002*	*0.007*	*0.013*	*0.005*	*0.016*	*<0.001*	*<0.001*	*<0.001*	*0.024*

(F): Frequent; **L-I**: low-income. All coefficients are standardized.
*** $p < 0.01$,
** $p < 0.05$,
* $p < 0.1$.

Table 5
Self-reported changes of perceived accessibility and travel cost after using shared micro-mobility.

Variables	Degree of change	Utrecht (Netherlands)			Manchester (UK)			Malmö (Sweden)	
		Shared bike (*N* = 111)	Shared e-bike (*N* = 83)	Shared e-moped (*N* = 70)	Shared bike (*N* = 187)	Shared e-bike (*N* = 172)	Shared e-scooter (*N* = 166)	Shared bike (*N* = 162)	Shared e-scooter (*N* = 239)
High-income group		(*N* = 75)	(*N* = 58)	(*N* = 50)	(*N* = 118)	(*N* = 112)	(*N* = 102)	(*N* = 134)	(*N* = 200)
Perceived accessibility	*Decreased*	9 (12.0 %)	6 (10.3 %)	9 (18.0 %)	25 (21.2 %)	21 (18.8 %)	18 (17.6 %)	25 (18.7 %)	34 (17.0 %)
	No change	38 (50.7 %)	33 (56.9 %)	24 (48.0 %)	50 (42.4 %)	43 (38.4 %)	43 (42.2 %)	72 (53.7 %)	102 (51.0 %)
	Increased	28 (37.3 %)	19 (32.7 %)	17 (34.0 %)	43 (36.4 %)	48 (42.9 %)	41 (40.2 %)	37 (27.6 %)	64 (32.0 %)
Travel expense	*Decreased*	15 (20.0 %)	10 (17.2 %)	7 (14.0 %)	46 (39.0 %)	32 (28.6 %)	30 (29.4 %)	36 (26.9 %)	32 (16.0 %)
	No change	36 (48.0 %)	27 (46.6 %)	22 (44.0 %)	44 (37.3 %)	53 (47.3 %)	48 (47.1 %)	74 (55.2 %)	120 (60.0 %)
	Increased	24 (32.0 %)	21 (36.2 %)	20 (40.0 %)	28 (23.7 %)	27 (24.1 %)	24 (23.5 %)	24 (17.9 %)	48 (24.0 %)
Low-income group		(*N* = 36)	(*N* = 25)	(N = 20)	(*N* = 69)	(*N* = 60)	(*N* = 64)	(*N* = 28)	(*N* = 39)
Perceived accessibility	*Decreased*	2 (5.6 %)	1 (4.0 %)	2 (10.0 %)	12 (17.4 %)	15 (25.0 %)	9 (14.1 %)	6 (21.4 %)	4 (10.3 %)
	No change	14 (38.9 %)	9 (36.0 %)	9 (45.0 %)	34 (49.3 %)	22 (36.7 %)	39 (60.9 %)	12 (42.9 %)	22 (56.4 %)
	Increased	20 (55.6 %)	15 (60.0 %)	9 (45.0 %)	23 (33.3 %)	23 (38.3 %)	16 (25.0 %)	10 (35.7 %)	13 (33.3 %)
Travel expense	*Decreased*	9 (25.0 %)	7 (28.0 %)	2 (10.0 %)	6 (8.7 %)	23 (38.3 %)	28 (43.8 %)	11 (39.3 %)	6 (15.4 %)
	No change	16 (44.4 %)	9 (36.0 %)	10 (50.0 %)	36 (52.2 %)	24 (40.0 %)	26 (40.6 %)	13 (46.4 %)	25 (64.1 %)
	Increased	11 (30.6 %)	9 (36.0 %)	8 (40.0 %)	27 (39.1 %)	13 (21.7 %)	10 (15.6 %)	4 (14.3 %)	8 (20.5 %)

condition for low-income people, but only in the two UK and Sweden cities. In contrast, it has a tendency to increase the users' perceived mobility more greatly for high-income (than low-income) groups in Utrecht, the Netherlands (though the *p*-values of corresponding coefficients are slightly over 0.1). This result may be partially attributed to the fact that shared bike services in Utrecht (*OV-fiets*) were mostly connected with train stations as public transport rental bicycles, therefore can better serve the high-income groups who travelled by train more often. Similarly, frequent shared e-scooter use benefits the users' perceived mobility only for the low-income groups in UK/Sweden cities. However, the opposite is true for frequent shared e-bike use in UK. These results suggest that shared e-scooters could help low-income people to get rid of transport poverty more effectively than shared e-bikes. Besides, frequent shared e-moped users also reported a higher mobility level than others in Utrecht, regardless of their household income level. Shared e-cargo bike use has limited influence on perceived transport adequacy factors.

Findings regarding accessibility and travel cost are somewhat unexpected. Frequent shared e-bike use is negatively associated with perceived accessibility in Utrecht, especially for high-income groups. Similarly, for high-income people in Sweden, frequent shared bike users tend to had a lower perceived accessibility level than others. Meanwhile, frequent shared bike use is positively related with perceived travel cost for both groups in Utrecht, and such positive association was also found between shared e-bike use and travel cost in UK. These results may suggest that the shared micro-mobility use does not benefit accessibility and travel affordability. However, the reverse influences may play a role here. Respondents who perceived themselves as bearing high travel cost or low accessibility may be more likely to adopt shared micro-mobility as an alternative transport mode in daily life.

To better understand the causal influences between shared micro-mobility use and perceived accessibility and travel cost, Table 5 summarized the users' self-reported changes in perceived accessibility and monthly travel expense after adopting each kind of shared micro-mobility. In line with previous studies (Chen et al., 2022; Qian & Niemeier, 2019), the majority of respondents (in all the three cities) reported a similar or increased accessibility, suggesting that the use of shared micro-mobility did help improve accessibility to some extent, and this applied for both high-income and low-income groups. In this case, the reverse influence should be the main explanation of the negative association between shared micro-mobility use and perceived accessibility in the Netherlands and Sweden cites. This means that people with lower levels of perceived accessibility in these areas used shared bikes/e-bikes more and still experienced a relatively lower accessibility afterwards. This is also the case for shared e-bike use and travel cost in Manchester, UK. However, we found that there are more shared bike users in Utrecht who reported an increase than a decrease in travel expense. This result reveals that shared bike use did bring extra travel cost in Utrecht, possibly due to the increased expense of additional train use resulted from adopting public transport rental bicycles (*OV-fiets*). Nevertheless, cautions should be paid when interpretating these results since the self-reported changes are inevitably influenced by recall bias to some extent.

5. Discussion

Our findings suggest that current shared micro-mobility services in European cities are still facing challenges in promoting transport equity. First, some transport disadvantaged groups adopted shared micro-mobility less than their counterparts. In line with previous research (Dill & McNeil, 2021), it was found that in our sample the elderly, females, and those without private cars and micro-vehicles were less likely to use shared micro-mobility. Residents in low-density and marginalized areas also had a lower chance to benefit from shared micro-mobility services (Brown, 2021; McKenzie, 2020). Second, we found that shared e-bikes did not benefit the transport inequality between income groups in the car-oriented city (i.e., Manchester), since its frequent use increased the perceived mobility level only for high-income people there (Table 4). Third, shared micro-mobility played a limited role in improving perceived accessibility and travel affordability. In line with the study of Chen et al. (2020a), the respondents from Utrecht and Malmö in our survey reported that shared micro-mobility use helped improving the convenience to access daily travel destinations slightly (Table 5). Nevertheless, shared e-bike (or bike) users still had a significantly lower perceived accessibility level than non-users (Table 4). Moreover, shared micro-mobility use may also generate additional travel expense in these areas (Table 5), thus aggravate the economic burden of daily travel for some people.

Nonetheless, shared e-scooters/e-mopeds showed a greater potential in facilitating transport equity than shared bikes/e-bikes. We found that low-income people received comparable or more mobility benefits from adopting shared e-scooters and e-mopeds than high-income people, probably because these shared electric vehicles could be used as an alternative of private cars by low-income groups. In addition, shared e-mopeds can provide an additional mobility option for individuals with physical disabilities and therefore have the potential to reduce transport inequality between them and the others (Table 4). However, safety could be a concern for the use of these high-speed shared electric vehicles. Shared e-mopeds have been banned in Utrecht at the year 2023 because the municipality found that their usage may generate safety risks and didn't fit the aimed image of a “bicycle city”. Meanwhile, there are speed-restriction zones for shared e-scooters in many cities for safety issues. Future policy makers need to balance the travel speed restrictions and safety considerations of shared micro-mobility to maximum their benefits on transport equity.

Context difference exists in terms of the impact of shared micro-mobility on transport equity. While shared bikes were implemented in all the three cities, they showed the greatest potential in improving transport equity between different income groups in the car-oriented city (i.e., Manchester) and lowest potential in the cycle-dominant city (i.e., Utrecht). On the one hand, shared bikes were more used by high-income (than low-income) groups in Utrecht, while its users were more balanced in terms of income levels in Manchester. On the other hand, frequent shared bike use contributed to perceived mobility and accessibility levels more greatly for low-income (than high-income) groups in Manchester, while the opposite trend was found in Utrecht. These results suggest that conventional bikeshare does not add too much in daily travel in cycling-oriented cities, especially for the low-income people, therefore can hardly alleviate transport inequality there.

The research findings generate some insights for future development of shared micro-mobility services. First, to promote the social/spatial equity in shared micro-mobility use, it is necessary to further increase people's awareness and acceptance of shared micro-mobility (e.g., via social media). This is suggested by the finding that non-owners of private bike/e-bikes were less represented in shared micro-mobility users in our sample, probably because they had relatively lower familiarity and interest of micro-vehicles from the beginning. Meanwhile, how to attract and enable females and the elderly to adopt shared micro-mobility also requires attention. Compact development and improved cycling routes could be possible strategies to encourage women to use shared micro-mobility, since studies have found that the presence of cycling infrastructure, good traffic safety, and shorter travel encourage women to a larger extent than men to adopt bikeshare (Dill & McNeil, 2021). Besides, providing shared e-cargo bikes may also help reduce the gender disparity in shared micro-mobility use. This is supported by our finding that shared e-cargo bike is the only mode without significant gender difference in use (Table 3), possibly because women could make use of it for childcare conveniently. For elder people, it may be unrealistic to expect that they use shared micro-mobility (especially shared e-scooters) as much as younger groups do due to on average their weaker physical strength and probably greater safety concerns. Shared (e-)tricycles, which are typically easier to ride and safer for the users, might be an option to facilitate older people to benefit from shared micro-mobility more equally.

Second, actions are needed to maximize the contribution of shared micro-mobility services to accessibility. Shared micro-mobility use does increase accessibility, but only to a limited extent at present in the sampled cities. More supportive infrastructure for shared micro-mobility use (e.g., parking areas) may help on this issue. Third, affordability should be highly considered in future development of shared micro-mobility since now its use does not reduce travel cost and even generates extra travel expense in some areas. Lowering the price can help improve its mobility and equity benefits by enabling its frequent usage, especially for low-income people. Besides, a reasonable distribution of shared micro-mobility services is also useful to optimize their equity benefits. Our study suggests the implementation of bikeshare services (ideally combined with public transport) in car-dominant areas, and shared electric micro-vehicles in cycling-oriented areas. Both of them would favor low-income people's mobility more greatly than that of high-income people, thus reduce the disparity between them in terms of transport adequacy (though the latter may result in an increased travel expense for some users).

6. Conclusions

Our research provides a more comprehensive understanding on the transport equity impact of shared micro-mobility use by investigating its influential factors and its association with perceived transport adequacy (or poverty) between different income groups. Using online questionnaire survey data in three European cities, our research indicates that current shared micro-mobility services play a limited role in promoting transport equity. On one hand, shared micro-mobility services are unequally used among population groups. They are less adopted by transport disadvantaged groups like the elderly, females, non-owners of private cars or micro-vehicles, and suburban residents. On the other hand, shared micro-mobility services have limited potential in reducing the users' transport poverty. It is found that the users tend to have relatively lower perceived accessibility and travel affordability than those non-users. Although shared e-moped/e-scooter use can benefit transport equity by favoring low-income people's mobility equally or more greatly compared with their high-income counterparts, this is not the case for shared bike/e-bike use. In general, the research findings reveal the limited impacts of current shared micro-mobility services on improving transport equity, and generate implications for future development and policy making of shared micro-mobility services.

This study has some limitations and could be extended from several directions. First, the built environment variables were measured at aggregated spatial scales. The estimated impact of built environment variables may suffer from ecology fallacy. Studies with built environment variables at more finite geographical levels are needed to verify the built environment's impact on shared micro-mobility use and transport adequacy. Second, to better understand the impact of shared micro-mobility services on transport equity, future studies should include the access to these services in transport adequacy models once relevant data is available. Since most shared micro-mobility services in this research are free-floating, their mobility and accessibility benefits are likely dependent on the overall supply of these services around the city. The use of shared micro-mobility should be viewed as a result of both the supply and usage demand of these services. Some individuals may consider that the access to shared micro-mobility services is important for improving accessibility, but use them only occasionally because of their low travel demands. Third, the cross-sectional nature of this study prevented us from drawing a solid conclusion on the causal relationship between shared micro-mobility use and perceived transport adequacy. While we provided some retrospective evidence on perceived accessibility change in response to shared micro-mobility use, studies based on true panel data are required to further validate their causality. Besides, future studies should also explore the underlying reasons behind the unequal use of shared micro-mobility, especially barriers of non-users, which are the base to improve the equity performance of future shared micro-mobility services.

CRediT authorship contribution statement

Xiaodong Guan: Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Dea van Lierop:** Writing – review & editing, Supervision. **Zihao An:** Writing – review & editing, Data curation. **Eva Heinen:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Dick Ettema:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

Data availability

The data that has been used is confidential.

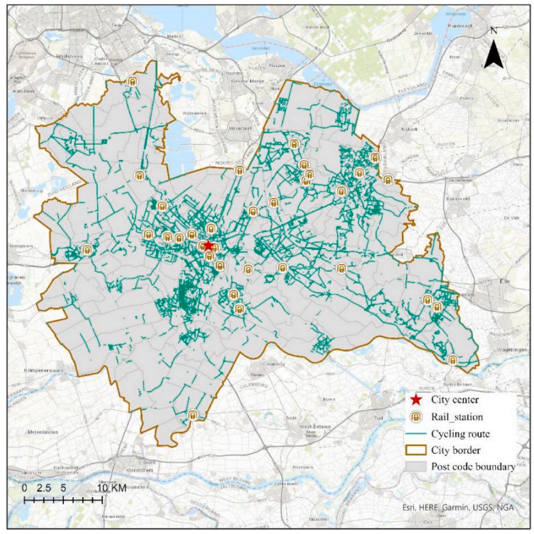
Acknowledgements

This research was supported by JPI Urban Europe via national grants from: NWO, Netherlands, Grant [438-21-434]; UK, Economic and Social Research Council (ESRC) [ES/W000547/1]; SWeden, Energimyndigheten, Dnr 2021-001267, [51970-1].

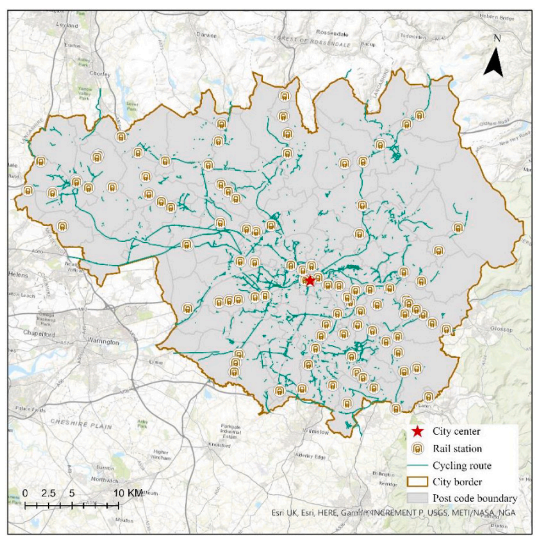
Declaration of competing interest

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

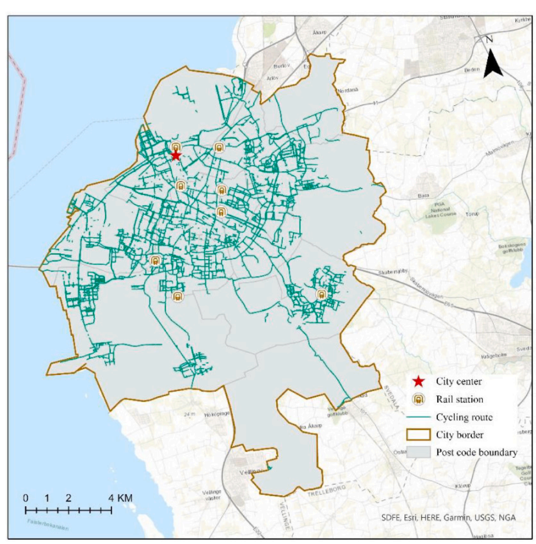
Appendix A



❖ Utrecht



❖ Manchester



❖ Malmö

Fig. A1. The distribution of rail stations and cycling routes in three cities.

Table A1
Original questions in survey.

Variable name	Original question in survey	Options for answer
Age	*In what year were you born?*	To fill in
Gender	*What is your gender?*	Male Female Non-binary Other, please specify Prefer not to say
Employment status	*Which of the below best describes your situation?*	Employed Self-employed/Freelance Interning Part-time Unemployed- Looking for work Unemployed – Not looking for work Homemaker Studying Military/Forces Retired Unable to work Other, please specify
Education level	*Which of the below best describes your educational qualifications?*	Different according to the local education system in each city
Driver's license	*Do you have a driver's license to drive a car?*	Yes No
Presence of child	*Which of the below best describes your (main) household?*	Living by yourself Sharing with a partner/spouse Sharing with a partner/spouse and children Sharing with children and no partner/spouse Living with parent(s)/grandparent(s) Sharing with parent(s) and partner/ spouse Sharing with parent(s), partner/ spouse and children Sharing with others (e.g., house share) Other, please specify
Household income	*Which of the below best describes your monthly net household income?*	> 80 % quantile 60 % - 80 % quantile 40 % - 60 % quantile 20 % - 40 % quantile < 20 % quantile Prefer not to say
Disability	*Do you have any of the following long-standing conditions?—— A condition that substantially limits basic physical activities such as walking, climbing stairs, or carrying*	Yes No
Access to private car	*Do you have regular access to a car?*	I have sole access to my private car I share a car with other household members I can sometimes use a car from another household member I have a lease or rental car I have regular use of one from friends I have access through shared schemes Other, please specify I do not have regular access to a car
Public transport season ticket	*Do you regularly own a season ticket for public transport?*	Yes, (almost) always Yes, sometimes No
Access to private bike	*Do you own a bicycle (excluding e-bikes)?*	Yes, I own one or multiple Yes, I have regular use of one from household members or friends Yes, through shared schemes No Other, please specify
Access to private e-bike	*Do you own an electric bicycle (or 'e-bike')?*	Same as above
Access to other private micro-vehicles	*Do you own any other forms of transport?* *(Select all that apply)*	Motorcycle *E*-step E-skateboard E-scooter None of the above
Shared micro-mobility use (Utrecht)	*How often do you use the following shared micro-mobility services in Utrecht?* • *shared bike* • *shared e-bike* • *shared e-moped* • *shared e-cargo bike*	(Almost) never 1–5 days a year 6–11 days a year 1–3 days a month 1–3 days a week 4–6 days a week Daily.
Shared micro-mobility use (Manchester)	*How often do you use the following shared micro-mobility services in Manchester?*	Same as above

(*continued on next page*)

Table A1 (*continued*)

Variable name	Original question in survey	Options for answer
	• *shared bike* • *shared e-bike* • *shared e-scooter*	
Shared micro-mobility use (Malmö)	*How often do you use the following shared micro-mobility services in Malmö?* • *shared bike* • *shared e-scooter*	Same as above
Self-reported change of perceived accessibility	*Has the use of shared bikes impacted your travel in other ways —— the convenience to access daily travel destinations?* (the same question applied for users of other kinds of shared micro-mobility)	Much decreased Decreased About the same Increased Much increased
Self-reported change of travel expense	*Has the use of shared bikes impacted your travel in other ways —— Monthly travel expense* (same as above)	Same as above

References

Abouelela, M., Durán-Rodas, D., & Antoniou, C. (2024). Do we all need shared E-scooters? An accessibility-centered spatial equity evaluation approach. *Transportation Research Part A: Policy and Practice, 181*, Article 103985.

An, Z., Mullen, C., Zhao, C., & Heinen, E. (2023). Stereotypes and the public acceptability of shared micromobility. *Travel Behaviour and Society, 33*, Article 100643.

Bai, S., & Jiao, J. (2020). Dockless E-scooter usage patterns and urban built environments: A comparison study of Austin, TX, and Minneapolis, MN. *Travel Behaviour and Society, 20*, 264–272.

Bai, S., & Jiao, J. (2021). Toward equitable micromobility: Lessons from Austin E-scooter sharing program. *Journal of Planning Education and Research, 0739456X211057196*.

Bai, S., Jiao, J., Chen, Y., & Guo, J. (2021). The relationship between E-scooter travels and daily leisure activities in Austin, Texas. *Transportation Research Part D: Transport and Environment, 95*, Article 102844.

Barbour, N., Zhang, Y., & Mannering, F. (2019). A statistical analysis of bike sharing usage and its potential as an auto-trip substitute. *Journal of Transport & Health, 12*, 253–262.

Bateman, L. B., Fouad, M. N., Sullivan, A., Heider, L., & Oates, G. R. (2021). Barriers and facilitators to bikeshare programs: A qualitative study in an urban environment. *Journal of Transport & Health, 21*, Article 101062.

Bieliński, T., & Ważna, A. (2020). Electric scooter sharing and bike sharing user behaviour and characteristics. *Sustainability, 12*(22), 9640.

Böcker, L., Anderson, E., Uteng, T. P., & Throndsen, T. (2020). Bike sharing use in conjunction to public transport: Exploring spatiotemporal, age and gender dimensions in Oslo, Norway. *Transportation Research Part A: Policy and Practice, 138*, 389–401.

Brown, A. (2021). Docked vs. dockless equity: Comparing three micromobility service geographies. *Journal of Transport Geography, 96*, Article 103185.

Bullock, C., Brereton, F., & Bailey, S. (2017). The economic contribution of public bike-share to the sustainability and efficient functioning of cities. *Sustainable Cities and Society, 28*, 76–87.

Campbell, A. A., Cherry, C. R., Ryerson, M. S., & Yang, X. (2016). Factors influencing the choice of shared bicycles and shared electric bikes in Beijing. *Transportation Research Part C Emerging Technologies, 67*, 399–414.

Caulfield, B., O'Mahony, M., Brazil, W., & Weldon, P. (2017). Examining usage patterns of a bike-sharing scheme in a medium sized city. *Transportation Research Part A: Policy and Practice, 100*, 152–161.

Chen, Z., van Lierop, D., & Ettema, D. (2020a). Dockless bike-sharing systems: What are the implications? *Transport Reviews, 40*(3), 333–353.

Chen, Z., van Lierop, D., & Ettema, D. (2020b). Exploring dockless bikeshare usage: A case study of Beijing. *China. Sustainability, 12*(3), 1238.

Chen, Z., van Lierop, D., & Ettema, D. (2022). Perceived accessibility: How access to dockless bike-sharing impacts activity participation. *Travel Behaviour and Society, 27*, 128–138.

Churchill, S. A., Koomson, I., & Munyanyi, M. E. (2023). Transport poverty and obesity: The mediating roles of social capital and physical activity. *Transport Policy, 130*, 155–166.

Churchill, S. A., & Smyth, R. (2019). Transport poverty and subjective wellbeing. *Transportation Research Part A: Policy and Practice, 124*, 40–54.

Currie, G., & Delbosc, A. (2010). Modelling the social and psychological impacts of transport disadvantage. *Transportation, 37*, 953–966.

Delbosc, A., & Currie, G. (2011). The spatial context of transport disadvantage, social exclusion and well-being. *Journal of Transport Geography, 19*(6), 1130–1137.

Dill, J., & McNeil, N. (2021). Are shared vehicles shared by all? A review of equity and vehicle sharing. *Journal of Planning Literature, 36*(1), 5–30.

Ettema, Dick, Iris Geigenmüller, Pauline EW van den Berg, and Dea S. van Lierop. "What is Transport Adequacy? Quantifying Experienced Transport Poverty in the Netherlands." In *Transportation Research Board: 102nd Annual Meeting.* 2023.

Faghih-Imani, A., Anowar, S., Miller, E. J., & Eluru, N. (2017). Hail a cab or ride a bike? A travel time comparison of taxi and bicycle-sharing systems in new York City. *Transportation Research Part A: Policy and Practice, 101*, 11–21.

Field, A. (2005). *Discovering statistics using SPSS* (2nd ed.). London: SAGE Publications Ltd.

Fishman, E. (2016). Bikeshare: A review of recent literature. *Transport Reviews, 36*(1), 92–113.

Fishman, E., Washington, S., & Haworth, N. (2012). Barriers and facilitators to public bicycle scheme use: A qualitative approach. *Transportation Research Part F: Traffic Psychology and Behaviour, 15*(6), 686–698.

Fishman, E., Washington, S., & Haworth, N. (2014). Bike share's impact on car use: Evidence from the United States, Great Britain, and Australia. *Transportation Research Part D: Transport and Environment, 31*, 13–20.

Fishman, E., Washington, S., Haworth, N., & Watson, A. (2015). Factors influencing bike share membership: An analysis of Melbourne and Brisbane. *Transportation Research Part A: Policy and Practice, 71*, 17–30.

Frias-Martinez, V., Sloate, E., Manglunia, H., & Wu, J. (2021). Causal effect of low-income areas on shared dockless e-scooter use. *Transportation Research Part D: Transport and Environment, 100*, Article 103038.

Fu, X., van Lierop, D., & Ettema, D. (2024). Is multimodality advantageous? Assessing the relationship between multimodality and perceived transport adequacy and accessibility in different travel contexts. *Transportation Research Part A: Policy and Practice, 179*, Article 103893.

Fukushige, T., Fitch, D. T., & Handy, S. (2021). Factors influencing dock-less E-bike-share mode substitution: Evidence from Sacramento, California. *Transportation Research Part D: Transport and Environment, 99*, Article 102990.

Fuller, D., Gauvin, L., Kestens, Y., Daniel, M., Fournier, M., Morency, P., & Drouin, L. (2013). Impact evaluation of a public bicycle share program on cycling: A case example of BIXI in Montreal. *Quebec. American journal of public health, 103*(3), e85–e92.

Gavin, K., Bennett, A., Auchincloss, A. H., & Katenta, A. (2016). A brief study exploring social equity within bicycle share programs. *Transportation Letters, 8*(3), 177–180.

Goodman, A., Green, J., & Woodcock, J. (2014). The role of bicycle sharing systems in normalising the image of cycling: An observational study of London cyclists. *Journal of Transport & Health, 1*(1), 5–8.

Gössling, S. (2016). Urban transport justice. *Journal of Transport Geography, 54*, 1–9.

Groth, S. (2019). Multimodal divide: Reproduction of transport poverty in smart mobility trends. *Transportation Research Part A: Policy and Practice, 125*, 56–71.

Guan, X., & Wang, D. (2019). Residential self-selection in the built environment-travel behavior connection: Whose self-selection? *Transportation Research Part D: Transport and Environment, 67*, 16–32.

Guan, X., & Wang, D. (2020). The multiplicity of self-selection: What do travel attitudes influence first, residential location or work place? *Journal of Transport Geography, 87*, Article 102809.

Guan, X., Wang, D., & Jason Cao, X. (2020). The role of residential self-selection in land use-travel research: A review of recent findings. *Transport Reviews, 40*(3), 267–287.

Guo, Y., & Zhang, Y. (2021). Understanding factors influencing shared e-scooter usage and its impact on auto mode substitution. *Transportation Research Part D: Transport and Environment, 99*, Article 102991.

Guzman, L. A., Oviedo, D., & Rivera, C. (2017). Assessing equity in transport accessibility to work and study: The Bogotá region. *Journal of Transport Geography, 58*, 236–246.

de Haas, M., Kroesen, M., Chorus, C., Hoogendoorn-Lanser, S., & Hoogendoorn, S. (2022). E-bike user groups and substitution effects: Evidence from longitudinal travel data in the Netherlands. *Transportation, 49*(3), 815–840.

Hirsch, J. A., Stratton-Rayner, J., Winters, M., Stehlin, J., Hosford, K., & Mooney, S. J. (2019). Roadmap for free-floating bikeshare research and practice in North America. *Transport Reviews, 39*(6), 706–732.

Hosford, K., & Winters, M. (2018). Who are public bicycle share programs serving? An evaluation of the equity of spatial access to bicycle share service areas in Canadian cities. *Transportation Research Record, 2672*(36), 42–50.

Hosseinzadeh, A., Karimpour, A., & Kluger, R. (2021). Factors influencing shared micromobility services: An analysis of e-scooters and bikeshare. *Transportation Research Part D: Transport and Environment, 100*, Article 103047.
Kim, J., Choi, K., Kim, S., & Fujii, S. (2017). How to promote sustainable public bike system from a psychological perspective? *International Journal of Sustainable Transportation, 11*(4), 272–281.
Laa, B., & Leth, U. (2020). Survey of E-scooter users in Vienna: Who they are and how they ride. *Journal of Transport Geography, 89*, Article 102874.
Lucas, K. (2012). Transport and social exclusion: Where are we now? *Transport Policy, 20*, 105–113.
Lucas, K., Martens, K., Di Ciommo, F., & Dupont-Kieffer, A. (Eds.). (2019). *Measuring transport equity*. Amsterdam/Oxford (UK)/Cambridge (USA): Elsevier.
Lucas, K., Mattioli, G., Verlinghieri, E., & Guzman, A. (2016, December). Transport poverty and its adverse social consequences. In *proceedings of the institution of civil engineers-transport* (Vol. 169, no. 6, pp. 353-365). Thomas Telford ltd.
Ma, L., Kent, J. L., & Mulley, C. (2018). Transport disadvantage, social exclusion, and subjective well-being. *Journal of Transport and Land Use, 11*(1), 31–47.
Mason, R. L., Gunst, R. F., & Hess, J. L. (2003). *Statistical design and analysis of experiments: With applications to engineering and science*. John Wiley & Sons.
McKenzie, G. (2019). Spatiotemporal comparative analysis of scooter-share and bike-share usage patterns in Washington, DC. *Journal of Transport Geography, 78*, 19–28.
McKenzie, G. (2020). Urban mobility in the sharing economy: A spatiotemporal comparison of shared mobility services. *Computers, Environment and Urban Systems, 79*, Article 101418.
Mitra, R., & Hess, P. M. (2021). Who are the potential users of shared e-scooters? An examination of socio-demographic, attitudinal and environmental factors. *Travel Behaviour and Society, 23*, 100–107.
Mokhtarian, P. L., & Cao, X. (2008). Examining the impacts of residential self-selection on travel behavior: A focus on methodologies. *Transportation Research Part B: Methodological, 42*(3), 204–228.
Mooney, S. J., Hosford, K., Howe, B., Yan, A., Winters, M., Bassok, A., & Hirsch, J. A. (2019). Freedom from the station: Spatial equity in access to dockless bike share. *Journal of Transport Geography, 74*, 91–96.
Mouratidis, K. (2022). Bike-sharing, car-sharing, e-scooters, and Uber: Who are the shared mobility users and where do they live? *Sustainable Cities and Society, 86*, Article 104141.
Murphy, E., & Usher, J. (2015). The role of bicycle-sharing in the city: Analysis of the Irish experience. *International Journal of Sustainable Transportation, 9*(2), 116–125.
Næss, P. (2022). Meta-analyses of built environment effects on travel: No new platinum standard. *Journal of Planning Education and Research, 42*(2), 199–205.
Nickkar, A., Banerjee, S., Chavis, C., Bhuyan, I. A., & Barnes, P. (2019). A spatial-temporal gender and land use analysis of bikeshare ridership: The case study of Baltimore City. *City, Culture and Society, 18*, Article 100291.
Nikiforiadis, A., Paschalidis, E., Stamatiadis, N., Raptopoulou, A., Kostareli, A., & Basbas, S. (2021). Analysis of attitudes and engagement of shared e-scooter users. *Transportation Research Part D: Transport and Environment, 94*, Article 102790.
Pereira, R. H., Schwanen, T., & Banister, D. (2017). Distributive justice and equity in transportation. *Transport Reviews, 37*(2), 170–191.
Qian, X., Jaller, M., & Niemeier, D. (2020). Enhancing equitable service level: Which can address better, dockless or dock-based Bikeshare systems? *Journal of Transport Geography, 86*, Article 102784.
Qian, X., & Niemeier, D. (2019). High impact prioritization of bikeshare program investment to improve disadvantaged communities' access to jobs and essential services. *Journal of Transport Geography, 76*, 52–70.
Reck, D. J., & Axhausen, K. W. (2021). Who uses shared micro-mobility services? Empirical evidence from Zurich, Switzerland. *Transportation Research Part D: Transport and Environment, 94*, Article 102803.
Reck, D. J., Haitao, H., Guidon, S., & Axhausen, K. W. (2021). Explaining shared micromobility usage, competition and mode choice by modelling empirical data from Zurich, Switzerland. *Transportation Research Part C: Emerging Technologies, 124*, Article 102947.
Reilly, K. H., Noyes, P., & Crossa, A. (2020). From non-cyclists to frequent cyclists: Factors associated with frequent bike share use in new York City. *Journal of Transport & Health, 16*, Article 100790.
Ricci, M. (2015). Bike sharing: A review of evidence on impacts and processes of implementation and operation. *Research in Transportation Business & Management, 15*, 28–38.
Sanders, R. L., Branion-Calles, M., & Nelson, T. A. (2020). To scoot or not to scoot: Findings from a recent survey about the benefits and barriers of using E-scooters for riders and non-riders. *Transportation Research Part A: Policy and Practice, 139*, 217–227.
Sanders, R. L., da Silva Brum-Bastos, V., & Nelson, T. A. (2022). Insights from a pilot investigating the impacts of shared E-scooter use on physical activity using a single-case design methodology. *Journal of Transport & Health, 25*, Article 101379.
Schwanen, T., Lucas, K., Akyelken, N., Solsona, D. C., Carrasco, J. A., & Neutens, T. (2015). Rethinking the links between social exclusion and transport disadvantage through the lens of social capital. *Transportation Research Part A: Policy and Practice, 74*, 123–135.
Shen, Y., Zhang, X., & Zhao, J. (2018). Understanding the usage of dockless bike sharing in Singapore. *International Journal of Sustainable Transportation, 12*(9), 686–700.
Si, H., Shi, J. G., Tang, D., Wu, G., & Lan, J. (2020). Understanding intention and behavior toward sustainable usage of bike sharing by extending the theory of planned behavior. *Resources, Conservation and Recycling, 152*, Article 104513.
Sun, Z., Wang, Y., Zhou, H., Jiao, J., & Overstreet, R. E. (2021). Travel behaviours, user characteristics, and social-economic impacts of shared transportation: A comprehensive review. *International Journal of Logistics Research and Applications, 24*(1), 51–78.
Tsigdinos, S., Tzouras, P. G., Kosmidis, I., Bakogiannis, E., & Kepaptsoglou, K. (2024). Examining the impact of bicycle-oriented multimodality on accessibility and transport equity in the metropolitan area of Athens. *Greece. International Journal of Urban Sciences*, 1–27.
Uteng, T. P., Christensen, H. R., & Levin, L. (Eds.). (2019). *Gendering smart mobilities*. Routledge.
Van Acker, V., & Witlox, F. (2010). Car ownership as a mediating variable in car travel behaviour research using a structural equation modelling approach to identify its dual relationship. *Journal of Transport Geography, 18*(1), 65–74.
Verlinghieri, E., & Schwanen, T. (2020). Transport and mobility justice: Evolving discussions. *Journal of Transport Geography, 87*, Article 102798.
Wang, S., Wu, X., & Chen, Y. (2021). Association between perceived transportation disadvantages and opportunity inaccessibility: A social equity study. *Transportation Research Part D: Transport and Environment, 101*, Article 103119.
Woodcock, J., Tainio, M., Cheshire, J., O`Brien, O., & Goodman, A. (2014). Health effects of the London bicycle sharing system: Health impact modelling study. *BMJ, 348*.
Xanthopoulos, S., van der Tuin, M., Azadeh, S. S., de Almeida Correia, G. H., van Oort, N., & Snelder, M. (2024). Optimization of the location and capacity of shared multimodal mobility hubs to maximize travel utility in urban areas. *Transportation Research Part A: Policy and Practice, 179*, Article 103934.
Zhang, Y., Thomas, T., Brussel, M., & Van Maarseveen, M. (2017). Exploring the impact of built environment factors on the use of public bikes at bike stations: Case study in Zhongshan, China. *Journal of Transport Geography, 58*, 59–70.