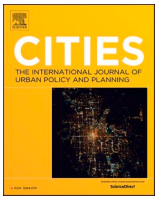
Cities 146 (2024) 104770

Contents lists available at ScienceDirect

Cities

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



Dynamics in residential relocation, car ownership, and carsharing adoption in neighborhoods with a high prevalence of carsharing

Jingran Xu *, Dea van Lierop, Dick Ettema

Department of Human Geography and Spatial Planning, Utrecht University, Utrecht 3584 CB, the Netherlands

ARTICLE INFO

Keywords:
Carsharing
Adoption
Residential relocation
Car ownership
Dynamics

ABSTRACT

Many studies have looked into the private car ownership and residential environment factors that affect current carsharing adoption from a cross-sectional perspective, while very few have focused on dynamic variables related to home relocation and changes in vehicle access. Using survey data collected in eight typical neighborhoods with a high level of carsharing in Utrecht, the Netherlands, this study explored how dynamics in car ownership, residential relocation, and current carsharing membership are related, and how this relationship shapes intention for future carsharing membership. The explanatory variables were the changes in residential location, and past and expected changes in private car ownership. Results of our binary logistic regression and ordinary least squares regression modeling show that residential relocation has a limited effect on carsharing adoption: Newcomers from lower urbanization level neighborhoods need some time to get used to carsharing and adopt it. For car ownership dynamics, future intentions to change private car ownership are more likely to affect current and future carsharing adoption than previous changes: Previous and future changes in car ownership and carsharing adoption have different effects on actual and expected behaviors. Our study shows that different functional goals of carsharing services for different types of potential users should be distinguished.

1. Introduction

In recent years, the development of cities has led to the emergence of a variety of sustainable travel modes on city streets, such as autonomous and connected vehicles, electromobility, bus rapid transit, etc. (Juschten et al., 2019a; Nikitas et al., 2017). One of these modes—carsharing—provides a flexible alternative that may mitigate the negative impacts of private car ownership and use on the environment (Liao et al., 2020; Shaheen et al., 2009; Shaheen & Cohen, 2013). Carsharing can be described as short-term and on-demand car rentals for travelers (Cantelmo et al., 2022). As is still new to lots of people, carsharing is currently an early adopter market, characterized by a low membership percentage (<15 %) in most cities (Burghard & Dütschke, 2019; Dias et al., 2017; Münzel et al., 2019; Namazu et al., 2018; Rotaris et al., 2019). Therefore, in order to ensure that carsharing provides maximum benefits to society, its current adoption and future development potentiality needs to be understood (Namazu et al., 2018; Rogers et al., 2014).

Studies have looked into the personal or locational factors affecting the current adoption of carsharing from a cross-sectional perspective (Aguilera-García et al., 2022; Prieto et al., 2017; Safdar et al., 2022). However, carsharing adoption is potentially intertwined with dynamics in other factors such as car ownership and residential relocation (Burghard & Dütschke, 2019; Hjorteset & Böcker, 2020; Namazu et al., 2018). There is an interrelationship between changes in private car ownership and carsharing; that is, changes in private car ownership are considered by many researchers to be a key exogenous or endogenous variable associated with carsharing adoption (Amirnazmiafshar & Diana, 2022; Ikezoe et al., 2020; Mishra et al., 2019): On the one hand, several studies have shown that private car ownership correlates with the demand for carsharing services (Celsor & Millard-Ball, 2007; Kopp et al., 2015; Lempert et al., 2019); on the other hand, carsharing members may change their travel behavior and reconsider current and future private car ownership and use (Becker et al., 2018; Ye et al., 2022; Zhou et al., 2020). This relationship also applies to residential relocation and carsharing (De Vos et al., 2018). According to De Vos and Ettema (2020) and Guan et al. (2020), the residential location choice is influenced by travel attitudes (including that toward carsharing) through residential self-selection effects, while the new residential environment resulting from residential relocation or residential redevelopment in

* Corresponding author.
E-mail addresses: j.xu@uu.nl (J. Xu), d.s.vanlierop@uu.nl (D. van Lierop), d.f.ettema@uu.nl (D. Ettema).

https://doi.org/10.1016/j.cities.2023.104770
Received 18 May 2023; Received in revised form 26 November 2023; Accepted 18 December 2023
Available online 5 January 2024

turn influences travel behavior and the adoption and likelihood of carsharing. For instance, one study found that the availability of carsharing vehicles near a person's home is a key factor to increase the likelihood of carsharing, which can be achieved through residential relocation and redevelopment (Namazu et al., 2018). While carsharing has been growing in the Netherlands and other countries, there is limited knowledge of how carsharing adoption correlates with residential relocation (Ding et al., 2018). This may be because residential relocation itself is a rare event, and the availability and use of carsharing is still limited.

Based on the above observations, this study focused on how past and intended changes in car ownership and residential relocation, as well as the current car ownership status, influence carsharing adoption decisions, in order to better understand the dynamic variables related to home relocation and changes in vehicle access, rather than the fixed private car ownership and residential environment context that most previous studies focused on.

Another relevant aspect of this paper concerns the carsharing landscape in which the above relationships take place. Based on the different adopter groups (innovators, early adopters, early majority, late majority, and laggards) defined by Rogers et al. (2014) in his diffusion of innovation theory, the threshold between early adopters and early majority is typically 15 % of the population. The neighborhoods examined in the present study have a high carsharing presence along with relatively high levels of usage (carsharing membership in Utrecht is 11 %, while the carsharing membership percentage in the research area is 11–22 % (Gemeente Utrecht, 2022b)). This suggests that carsharing adoption in the study area is currently on the threshold of the early adoption and early majority phase, implying that the user characteristics and use patterns will be different as compared to studies focusing on the early adoption phase. Previous studies have been mostly based on innovators and early adopters and less involve the early majority group[1] (Burghard & Dütschke, 2019; Dias et al., 2017; Münzel et al., 2019; Rotaris et al., 2019). Meanwhile, the findings concerning early adopters may not always be generalizable to the early majority market, which may make the relationship between carsharing, car ownership, and relocation different.

For these reasons, this paper presents an empirical study carried out in several typical neighborhoods with a high carsharing prevalence in Utrecht, the Netherlands, to better understand how dynamics in car ownership, residential location/relocation, and carsharing adoption are related, by addressing the following questions:

- What is the relationship between past and/or expected changes in private car ownership as well as changes in residential location and current carsharing membership?

- How does this relationship shape the intention for future carsharing membership?

The remainder of the article is structured as follows. Section 2 reviews the literature on factors associated with carsharing adoption; the dynamics in residential location/relocation and carsharing adoption; and the dynamics in car ownership and carsharing adoption. Section 3 presents the research area and data. The methodology and analysis results are dealt with in Sections 4 and 5, respectively. Section 6 concludes the article by presenting the conclusions and discussing future research.

2. Residential relocation, car ownership, and carsharing

2.1. Factors associated with carsharing adoption

The adoption of carsharing as an emerging travel mode is influenced by three aspects, namely socioeconomic factors (family members, income, etc.), urban built environment form factors (residential density, destination accessibility, distance to transit, etc.), and travel related factors (private car ownership, travel attitudes, mode preferences, etc.) (Coll et al., 2014). The relevant studies are presented in Table 1.

Regarding socioeconomic factors, studies have suggested that being male (Becker, Ciari, & Axhausen, 2017), being young (Wang & Yan, 2015), being married (Burghard & Dütschke, 2019), having children or a

Table 1
Studies on factors associated with carsharing adoption.

Factors	Influence	Location	References
Socioeconomic factor			
Male	+	Switzerland; China; Italy	Becker, Ciari, and Axhausen (2017); Wang and Yan (2015); Ceccato and Diana (2021)
Age	−	Switzerland; China; Italy; Germany	Becker, Ciari, and Axhausen (2017); Wang and Yan (2015); Ceccato and Diana (2021); Burghard and Dütschke (2019)
Married	+; +; −	China; Germany; Greece	Wang and Yan (2015); Burghard and Dütschke (2019); Efthymiou and Antoniou (2016)
Large household size	−	Switzerland; Italy	Becker, Loder, et al. (2017); Ceccato and Diana (2021)
High level of education	+	Switzerland; Germany	Becker, Ciari, and Axhausen (2017); Becker, Loder, et al. (2017); Kopp et al. (2015)
Employed	+	Switzerland; United States; Norway	Becker, Ciari, and Axhausen (2017); Dias et al. (2017); Hjorteset and Böcker (2020)
High income	+	Italy; Germany; China	Ceccato and Diana (2021); Kawgan-Kagan (2015); Yoon et al. (2017)
Urban built environment factors			
High degree of mix in building types near neighborhood	+	China; Norway	Feng et al. (2023); Hjorteset and Böcker (2020)
Good accessibility of public transportation	+	Switzerland	Becker, Loder, et al. (2017);
High level of transit connectivity	−	Switzerland	Becker, Ciari, and Axhausen (2017)
Presence of private parking near home	−	Italy; the United States	Ceccato and Diana (2021); Kim (2015)
High accessibility of shared-car parking	+	Switzerland; Japan; China	Ciari et al. (2016); Kato et al. (2013); Wang and Yan (2015)
Dedicated shared-car parking spaces	+	Italy; Australia; Switzerland	Cartenì et al. (2016); Dowling and Kent (2015); Kopp et al. (2015)
Walking and public transport accessibility to shared-car station	+	Canada	Roblot et al. (2021)
Travel mode factors			
Public transportation subscriptions	-; −; +; +	Switzerland; Switzerland; China; Switzerland	Becker, Loder, et al. (2017); Becker, Ciari, and Axhausen (2017); Wang and Yan (2015); Juschten et al. (2019b)
Car ownership	−	Switzerland; Italy; Germany	Becker, Ciari, and Axhausen (2017); Ceccato and Diana (2021); Burghard and Dütschke (2019)
Yearly mileage of car	−	Switzerland	Juschten et al. (2019b)

"+" Promote; "-" Inhibit

large household (Ceccato & Diana, 2021), having a high level of education (Kopp et al., 2015), having a job (Dias et al., 2017), and having an above-average or high income level (Yoon et al., 2017) seem positively correlated with carsharing adoption. However, the relevant conclusions may vary or even be contradictory due to the different carsharing operational schemes and geographical regions (Hjorteset & Böcker, 2020). However, results do indicate that the sociodemographic dimension is intertwined with other factors that determine how sociodemographics influence carsharing adoption.

In addition to sociodemographic attributes, which are extensively studied in relation to the adoption of carsharing, the residential built environment has a significant and multifaceted connection to carsharing. Walking, cycling, and public transportation network construction, mixed land-use, neighborhood density, and other elements affect the intention to participate in carsharing (Hjorteset & Böcker, 2020; Namazu et al., 2018). This is also why several cities are currently trying to build "carsharing-facilitating neighborhoods" that combine carsharing, residential planning, and housing to reduce private car ownership and improve the community environment (Hjorteset & Böcker, 2020; Wang et al., 2021). Previous studies have suggested that in some cases a high degree of mix in building types near the neighborhood and good micro-accessibility of public transportation seem positively correlated with carsharing adoption (Becker, Loder, et al., 2017; Feng et al., 2023), while a high level of public transit connectivity and the presence of private parking near the home have a negative effect on individuals' carsharing demand (Becker, Ciari, & Axhausen, 2017; Kim, 2015). At the same time, factors related to carsharing services—such as high accessibility of shared-car parking and dedicated shared-car parking spaces—have been shown have a positive effect on carsharing usage.

With regard to individual travel mode factors, it has been observed that an increase in car ownership and in private car trips inhibits the demand for and adoption of carsharing (Burghard & Dütschke, 2019; Juschten et al., 2019a). Public transportation season tickets are positively or negatively related to carsharing adoption in different cases (Becker, Ciari, & Axhausen, 2017; Wang & Yan, 2015).

2.2. Dynamics in residential location/relocation and carsharing adoption

Many travel behavior studies have indicated the theoretical and empirical relationship between residential neighborhoods and the mode choices and travel behavior of their residents (Cervero, 2002; Ewing & Cervero, 2010; Lin et al., 2017; Stevens, 2017). It is typically found that people living in central-city communities more often use buses, trams, and subways due to the mixed-use land development and relatively good public transportation facilities (Cervero & Kockelman, 1997; Ewing & Cervero, 2010). By contrast, people living in suburban neighborhoods use their cars for most of their trips because of the sprawling and diffusely developed environments and limited access to public transportation (Hamidi et al., 2015). As a result, residential relocation can be seen as an important decision involving a new a transportation context and could impact other mobility decisions such as car ownership and certain travel choices (Bamberg, 2006; De Vos et al., 2018; Klinger & Lanzendorf, 2016). In other words, when people move to a new neighborhood, in some cases their travel behavior will tend to become more aligned with the travel behavior stimulated by the new neighborhood. For example, when residents relocate to more urban neighborhoods, they will reduce their car use and increase their public transit use and active travel (De Vos et al., 2018; Scheiner & Holz-Rau, 2013; Wang & Lin, 2019). Therefore, as a travel mode, the adoption of carsharing may also be affected by residential relocation. The dynamics in residential and carsharing adoption in Fig. 1 shows the proven and not fully proven relationships for the change in mode choice in response to residential relocation (De Vos & Ettema, 2020; Jain et al., 2020).

In the context that residential relocation itself can trigger reflections on travel behavior, different built environment characteristics in a newly built environment after relocation may also act as incentives for

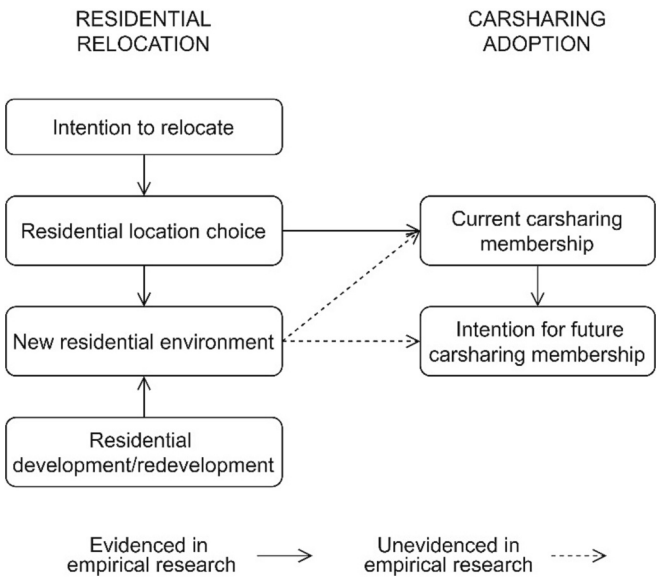


Fig. 1. Dynamics in residential relocation and carsharing adoption.

or constraints on behavioral changes, leading to changes in travel behaviors (Fatmi & Habib, 2017; Yang et al., 2017). At the same time, the social environment in new contexts also becomes a key factor influencing changes in travel behavior; for example, studies have found that residents were motivated to adopt cycling by relocating to environments with high levels of bicycle use and societal adoption (Chatterjee et al., 2013; Klinger & Lanzendorf, 2016). In addition to residential relocation, residential development/redevelopment also leads to a new residential environment. Previous studies have found that increasing the carsharing supply near people's homes is the key factor in attracting potential adopters, who may adopt carsharing and give up private cars (Namazu et al., 2018). The carsharing supply may be related to residential relocation or built environment changes in existing neighborhoods, such as relocating to a new neighborhood with carsharing services or the current neighborhood introducing such services (Jain et al., 2020). It is important to note that even though a new built environment and social context motivate a particular travel mode due to residential relocation, other factors such as individual socioeconomic characteristics and cultural preferences may delay, change, or prevent adoption (Scheiner & Holz-Rau, 2013). Recent research on residential relocation, living environment, and travel modes has involved multiple modes such as private cars, public transportation, and active transportation, but not focused on the new travel mode of carsharing. In theory, the built environment and psychosocial factors related to residential relocation described above also apply to carsharing adoption and interact with individuals' sociodemographic characteristics to influence decisions on carsharing (Acheampong & Siiba, 2020; Efthymiou et al., 2013). Therefore, the new residential environment resulting from residential relocation can be hypothesized to affect both current (i.e. directly following the relocation) carsharing membership and future carsharing adoption intentions.

2.3. Dynamics in car ownership and carsharing adoption

The dynamics in car ownership and carsharing adoption presented in Fig. 2 include car ownership affecting carsharing demand and carsharing adoption affecting car ownership. Distinguishing the two opposing directions of the causal relationship is important from a transportation policy perspective, yet previous studies did not provide an adequate and disaggregated explanation for this (Amirnazmiafshar & Diana, 2022).

Many studies have shown that members of carsharing services usually have more sustainable travel behaviors and fewer private cars than non-members (Costain et al., 2012; Namazu et al., 2018; Ter Schure

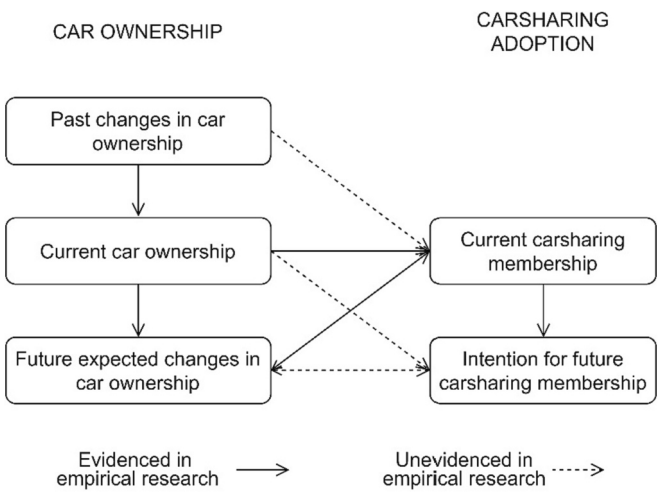


Fig. 2. Dynamics in car ownership and carsharing adoption.

et al., 2012). Research by Celsor and Millard-Ball (2007) suggested that carsharing usage rates are highest among U.S. households with no or only one car. Dias et al. (2017) demonstrated based on the model of the use of carsharing and ride-sourcing services that high levels of private car ownership inhibit the adoption of carsharing regardless of residential density. However, for current carsharing members and non-members, private cars have different meanings, which appears to account for the difference in the impact of private car ownership on current and future carsharing adoption. Hjorteset and Böcker (2020) found that private car ownership is significantly negatively related to current carsharing membership, but has no significant relationship with the likelihood of non-members participating in carsharing in the near future. This means that for current non-members, carsharing is an extra commodity, but for current members, it is a substitute for private cars. However, the present study considered only the possibility of non-members using carsharing in the near future, and not whether members will continue to use carsharing in the longer term.

The methodological approaches to the possible impact of carsharing on private car ownership in previous studies can be roughly divided into three categories, namely those based on 1) retrospective surveys of carsharing users or user and transaction databases maintained by carsharing operator systems to compare the actual change in private car ownership before and after using a carsharing service (Klincevicius et al., 2014; Martin et al., 2010; Martin & Shaheen, 2011); 2) hypothetical surveys and stated preference experiments with carsharing users and/or non-users to understand their likely changes in private car ownership due to their use of a carsharing service (Carrone et al., 2020; Ceccato et al., 2021; Zhou et al., 2020); and 3) analysis of the city/country carsharing service penetration rate and motorization growth rate (Bucsky & Juhász, 2022). Most studies agree that carsharing services can reduce private car ownership by encouraging people to sell their cars or delay or refrain from buying new ones. The substitution results of carsharing for private cars are divided into two aspects: substitution rates for users and substitution rates for vehicles. Most studies have focused on substitution rates for users, concluding that 7–30 % of users will give up their cars and adopt carsharing (Becker et al., 2018; Cervero & Tsai, 2004; Giesel & Nobis, 2016; Le Vine & Polak, 2019; Nijland & van Meerkerk, 2017). There are also studies based on the substitution rates for vehicles. A study based on data from the association of carsharing firms in 35 German cities found that each free-floating shared car reduced the number of private cars by between 0.9 and 1.9 (Kolleck, 2021). Some studies suggest that the current impact of carsharing on private car ownership is overestimated and that the availability of carsharing has a limited or negligible impact on car ownership (Kolleck, 2021; Zhou et al., 2020). This may due to the low proportion of carsharing in all travel modes and sample selection or self-selection bias (Bucsky & Juhász, 2022; Zhou et al., 2020).

It should be noted that in reality, the current and future decisions on carsharing and private car ownership are often mixed, and the adoption of carsharing and private car ownership may have a complex relationship. Car ownership and use is the product of a series of complex decisions about lifestyle and mobility that are made over time, as is whether or not to become a carsharing member. A qualitative study by Jain et al. (2020) discussed several different scenarios based on user segmentation of carsharing, that is, "car-limiters" tend to use carsharing to limit further increases in car ownership, and thus keep a private car and use carsharing to meet the additional demand for a second car; "car sellers" sell one or more private cars after joining a carsharing scheme, and reduce their travel and car use; and "car aspirers" buy or planned to buy a private car after joining a carsharing service. The different changes in the ownership and use of private cars after joining carsharing schemes show that carsharing has diverse functions for different types of people. For non-carsharers, there should also be multiple possibilities for past and current private car ownership, future private car ownership plans, and future carsharing membership possibilities when carsharing services are available to them. Based on this, it can be assumed that the past private car ownership situation may affect the current carsharing membership decision; that the current private car ownership situation may affect the possibility of using carsharing in the future; and that the future possibility of using carsharing and private car ownership plans may be correlated.

3. Research area and data

3.1. Neighborhood selection

Our research area include the Thomas à Kempisplantsoen and Nieuw Engeland, Laan van Nieuw Guinea-Spinozaplantsoen, Halve Maan-Noord, Halve Maan-Zuid, Oog in AL, Welgelegen, Den Hommel, Leidse-weg e.o. and Lombok neighborhoods located to the west of Utrecht city center (Fig. 3 and Table 2). Utrecht has a mature carsharing service network, including 10 shared transportation providers such as WeDriveSolar, AMBER, Cargoroo, Greenwheels, HELY and MyWheels, which suited our research topic (Gemeente Utrecht, 2022b). Since 2016, Utrecht has gradually built a city-wide network of nearly 500 two-way charging stations (public charging points where vehicles can be charged or unloaded), which has provided favorable support for the spread of electric carsharing services. Meanwhile, since 2018, seven cities, including Utrecht, have been piloting an innovative energy project called "City Deal Electric Shared Mobility," which involves housing construction combined with electric carsharing service and sustainable energy (Gemeente Utrecht, 2022a). The research area—Lombok—and surrounding neighborhoods were densely populated working-class neighborhoods built in the late nineteenth and early twentieth century to accommodate factory workers. This area is now a multicultural district, popular among young urbanites because of its characterful streets and strategic location near the city center. At the local level, Lombok and the surrounding communities possess the characteristics needed for the case as the area is currently changing from a societal and physical point of view: The housing stock is becoming more diverse, with new buildings and services being announced and developed, making it possible to attract different types of new residents (those with a higher education and higher incomes), while the composition of its inhabitants and residential relocation affect their car ownership and travel behavior. Therefore, this area has also become a start and key service area for multiple shared transport providers, such as WeDriveSolar (We Drive Solar, 2016).

In sociodemographic terms, there are some differences between the

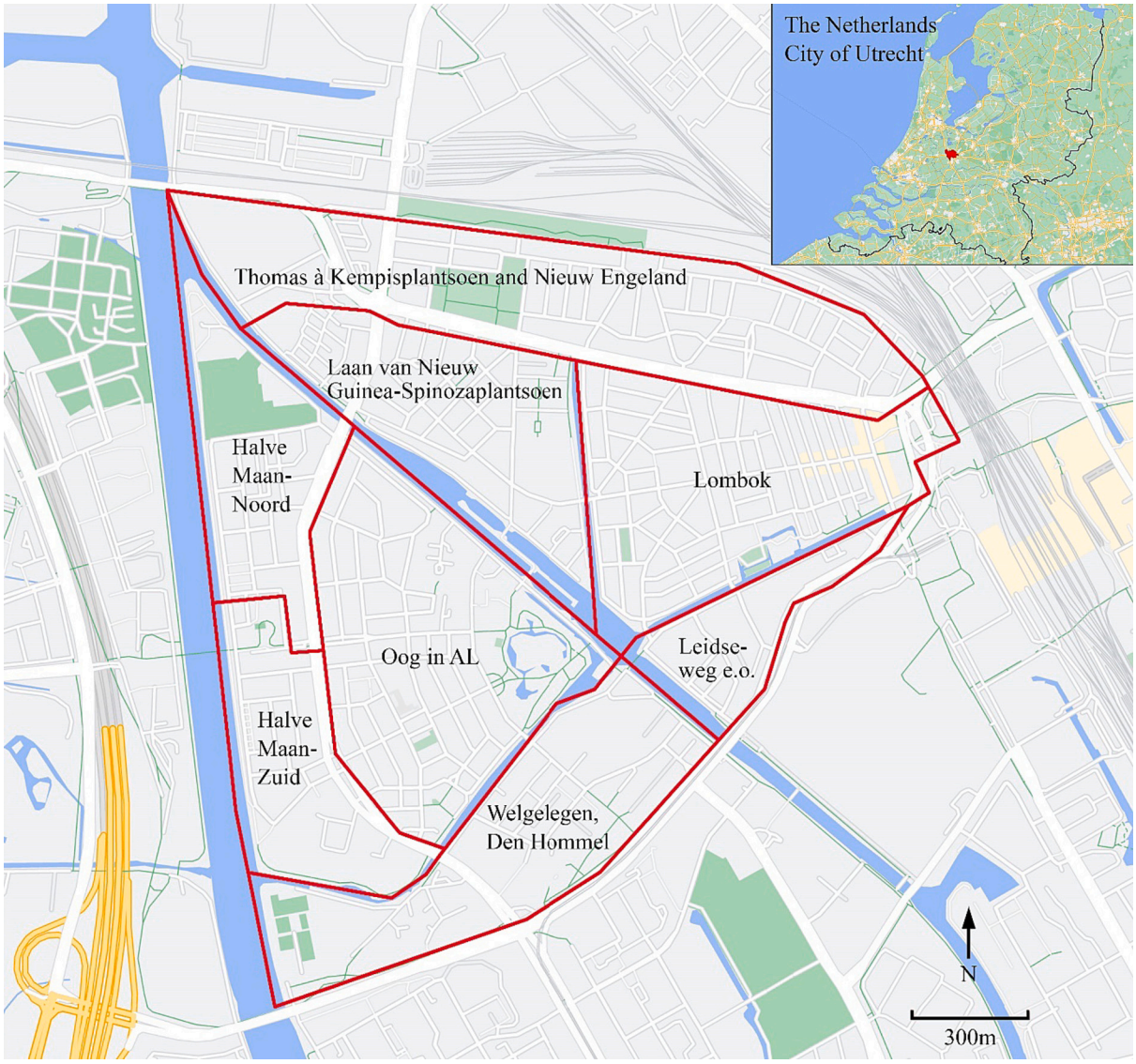


Fig. 3. Distribution of the research area within the city of Utrecht.

research area residents and those of the city of Utrecht (Table 2). In comparison with the city, the research area is characterized by almost twice as many old dwellings, a slightly higher percentage of rental homes, a slightly higher percentage of young people, and a higher average household disposable annual income. New living space created by the renovation of old buildings, a high percentage of rental homes, a high percentage of youths, and high household incomes are all characteristics that are conducive to the adoption and promotion of carsharing services in these neighborhoods.

3.2. Recruitment

This study drew on sociodemographic attributes and mobility decisions data collected through a retrospective, cross-sectional survey. The survey comprised six sections covering sociodemographic information, carsharing membership, residential environment, daily travel behavior, private car ownership, and travel attitudes. We defined a 200 m linear distance buffer zone around each carsharing station within the research area, using Google Maps. This designed area encompassed approximately 10,000 households. The selection of the 200 m buffer zone was informed by research conducted by Hess (2012), which suggested that the distances of 200-400 m are generally considered acceptable walking distance from a house to a bus station. The survey was available online, programmed in LimeSurvey, in both English and Dutch, and took about 15–25 min to complete. In June and October 2021, 8000 postcards inviting people to participate in the online survey were distributed to households in the selected neighborhoods. Around 80 % of all households in the selected neighborhoods thus received the postcard, based on a simple random sampling method[2]. Being 18 years or older and holding a valid car driver's license were the criteria for sample selection. Invitations were distributed in two waves (June and October), as the first wave did not result in a sufficient number of participants. The first wave was aimed at residents of Laan van Nieuw Guinea-Spinozaplantsoen, Oog in Al, Welgelegen, Den Hommel and Lombok and resulted in 227 participants. The second wave was aimed at residents of Thomas à Kempisplantsoen and Nieuw Engeland, Halve Maan-Noord, Halve Maan-Zuid and Leidse-weg e.o., with 285 participants. In the end, 512 respondents participated in the survey, leading to 360 valid responses. Compared with common response rates of existing neighborhood case studies related to carsharing and travel behavior (11 %–16.5 % (De Vos et al., 2018; Sioui et al., 2013)), our response rate (6.4 %) was markedly lower. One reason may be that invitations were

Table 2
Sociodemographic characteristics of the residents of the city of Utrecht and of the research area (in 2022) (Gemeente Utrecht, 2022c).

	City of Utrecht	Research area
Physical characteristics		
Density indicators		
Population	357,719	15,281
Area (km^2)	99.21	2.7
Population density (population/km^2)	3606	5659
Household	184,728	14,043
Dwelling indicators		
Total number of dwellings	156,678	11,900
Average living space per dwelling (m^2)	100	–
Dwellings built before 1959 (%)	37.2	72.6
Dwellings built between 1960 and 1999 (%)	33.9	14.8
Dwellings built since 1999 (%)	28.9	12.6
Population characteristics		
Age distribution		
0–19 (%)	21.8	20.1
20–39 (%)	39.5	42.3
40–59 (%)	22.8	22.8
60+ (%)	14.9	14.8
Gender		
Female/male/not stated (%)	50.9/49.1/0	51.4/48.6/0
Ethnicity		
Non-indigenous citizen (%)	37.2	27.8
Income		
Average household disposable income per year (in euros)	45,900	49,800
Household composition		
Single person (%)	52.0	52.7
Single parent (%)	6.0	5.0
Couple without children (%)	21.0	22.2
Couple with children (%)	21.0	20.1
Household size		
Average number of household members	1.9	1.8

not personal and may have been interpreted as junk mail (Netherlands Enterprise Agency, 2022). At the same time, the clear reference to "carsharing" in the survey title may have made non-users feel that the survey was not relevant to them. This effect has been reported in the context of dock-less bikeshare systems (Chen et al., 2020). The proportion of carsharing users in the sample—namely 40.3 %, which is higher than the average value of 22.4 % in the research areas (Gemeente Utrecht, 2022c)—suggests that this may indeed be the case.

4. Methodology

4.1. Modeling approach

We used binary logistic regression (LR) and ordinary least squares regression (OLS) to investigate the association between sociodemographic attributes, residential relocation dynamics, household car ownership dynamics, and carsharing adoption. The carsharing adoption including individuals' current carsharing membership as well as intention for future carsharing membership. Sociodemographic attributes, residential relocation attributes, and household car ownership attributes were explored as explanatory variables. Dependent variables were whether an individual being carsharing membership currently and the likelihood of being or continuing carsharing membership in the near future. All the variables are showed in Table 3.

4.2. Variables measurements

4.2.1. Sociodemographic attributes

To measure the variation of current and future carsharing membership decisions dependent on observable differences between individuals (see Section 5.2 Binary logistic regression (LR) results of current carsharing membership and 5.3 Ordinary least squares (OLS) regression results of intention for future carsharing membership), a number of individuals' sociodemographic factors were asked for in the survey. The different effects of socio-demographic factors on carsharing adoption are reflected in different regions and different types of carsharing services, and are intertwined with other factors to jointly affect the adoption of carsharing (Amirnazmiafshar & Diana, 2022), thus serving as the control variables for the study. The selection of relevant attributes was based on previous research (Amirnazmiafshar & Diana, 2022). The "home ownership" variable was removed from the subsequent models because adding or removing this variable had no significant effect on the model results, and there was no confirmed correlation with this variable in the above-mentioned study.

4.2.2. Residential relocation attributes

Residential relocation decision is a binary choice between deciding to move or not to move. According to how long respondents had lived in their current neighborhoods, we divided them according to whether they had relocated or not within the previous four years. We also asked for the 4-digit zip code of their previous residential location in order to

Table 3
Variables list.

Variables		Values
Dependent variables		
Currently carsharing membership		0 = non-members; 1 = members
Intention for future carsharing membership (likelihood of using carsharing in the future)		1–10: 1 = very unlikely; 10 = very likely
Independent variables		
Sociodemographic	Age	In years from low to high
	Gender	0 = female; 1 = male; 2 = not stated
	Work status	0 = unemployed; 1 = employed; 2 = other (student, retired, unable to work, fulltime unpaid care-giver)
	Number of people in the household with a valid driver's license	0 = 1 license; 1 = 2 licenses; 2 = 3 or more licenses
	Number of children under 12 years old	0 = 0; 1 = 1 child; 2 = 2 or more children
	Household income per month	0 = low income (< €2500); 1 = medium income (€2300–€4500); 2 = high income (> €4500); 3 = not stated
	Home ownership	0 = own; 1 = rent
Residential relocation	Relocation in previous 4 years	0 = no; 1 = yes
	Level of urbanization of the previous neighborhood	1 = same level; 2 = lower level
Household car ownership	Current number of cars	0 = no car, 1 = 1 car, 2 = 2 or more cars
	Household car ownership change in the previous four years	0 = no change, 1 = decrease, 2 = increase
	Expected change in household car ownership in the coming two years	0 = no change, 1 = decrease, 2 = increase

compare the urbanization level of the current neighborhood with that of the previous neighborhood. According to the classification method of community urbanization level (CBS & RWS-WVL, 2020), which ranges from 1 (extremely urbanized) to 5 (not urbanized), the research area is scored as 1. Furthermore, considering the 4-digit zip code and information from the carsharing provider's website, all participants that moved from the same urbanization level were in regions where at least one carsharing provider was available.

4.2.3. Household car ownership attributes

To measure household car ownership, we asked respondents for three pieces of information, namely the current number of personal cars (owned, private lease, or company lease) to which their household has access, household car ownership change in the previous four years, and the expected change in household car ownership in the coming two years.

4.2.4. Current membership of and intention for future carsharing membership

The current membership status of the carsharing scheme indicates whether someone is currently a member of the carsharing service, or if the household they belong to collectively became carsharing members. For the future intention to adopt carsharing, respondents were asked to rate this on a scale ranging from 1 to 10, with a higher score implying higher likelihood. Since the questionnaire was distributed during the COVID-19 regulations, the question set in the survey was: "What is the likelihood that you will use carsharing when the COVID regulations are lifted?"

5. Results

The analysis of one binary logistic regression and two ordinary least squares regressions provided results 1) indicating which individual attributes were significantly associated with the decision to join a carsharing scheme and 2) comparing the factors influencing the future likelihood of using carsharing between current carsharing members and non-members.

5.1. Descriptive results

The descriptive analysis of sample and explanatory variables is presented in Table 4. The entire sample comprised 360 carsharing users and non-users aged 20 to 71 years, with a slightly higher proportion of men (56.4 %). Employed individuals aged between 30 and 50 were the main contributors. The majority of the respondents' households lived in their own home, held two or more valid car driver's licenses, had no children under 12 years old, and had a medium or high household income. Compared with the total population of our research area and the city of Utrecht, adults aged from 40 to 59 years were oversampled (44.4 %).

Regarding the residential relocation context, length of time living in the current neighborhood was 0–1 year (11.9 %), 1–2 years (7.9 %), 2–3 years (6.7 %), 3–4 years (4.1 %), and more than four years (69.4 %). One-third of respondents had relocated to the neighborhoods within the previous four years. Therefore, when discussing the impact of relocation on carsharing, the sample was divided according to whether or not the respondents had relocated in the previous four years. In the questionnaire, the question concerning "Level of urbanization of the previous neighborhood?" was answered only by those who had relocated within the previous two years (n = 80), so the reference value of the variable "Level of urbanization of previous neighborhood" was "No relocation in previous two years." Of the respondents, 75 % had relocated from a neighborhood with the same level of urbanization as their current neighborhood. For household car ownership attributes, about two-thirds of the respondents owned one or more private cars. More than 75 % of the respondents had not changed their private car ownership in the previous four years and did not expect to change their private car ownership in the coming two years.

Furthermore, a descriptive analysis was conducted on two dependent variables. About 40 % of the respondents were currently carsharing service members. The main carsharing service companies involved in the sample include Greenwheels (21 %), SnappCar (14.8 %), MyWheels (10.8 %), and WeDriveSolar (9.2 %). In addition, other types of business-to-consumer (B2C) and peer-to-peer (P2P) carsharing services. The future carsharing adoption intention was analyzed for the whole sample

Table 4
Respondents' characteristics (N = 360).

Variables	Definitions	No.	%
Sociodemographic attributes			
Age (years)	20–39	141	39.2
	40–59	160	44.4
	60+	59	16.4
Gender	Female	135	37.5
	Male	203	56.4
	Not stated	22	6.1
Work status	Unemployed	7	1.9
	Employed (full time, part time, or self-employed)	311	86.4
	Other (student, retired, unable to work, full-time unpaid care-giver)	42	11.7
Number of people in the household with a driver's license	1	120	33.3
	2	220	61.1
	3+	20	5.6
Number of children under 12 years old	0	267	74.2
	1	47	13.1
	2+	46	12.8
Household income per month	Low income (<€2300)	40	11.1
	Medium income (€2300–€4500)	128	35.6
	High income (>€4500)	143	39.7
	Not stated	49	13.6
Home ownership	Own	287	79.7
	Private rental	51	14.2
	Social rental	22	6.1
Carsharing membership	Yes	145	40.3
	No	215	59.7
Residential relocation attributes			
Relocation in previous 4 years	Yes	110	30.6
	No	250	69.4
Level of urbanization of the previous neighborhood	No relocation in previous 4 years	288	80
	Same urbanization level	60	16.7
	Lower urbanization level	12	3.3
Household car ownership attributes			
Current car ownership	0	130	36.1
	1 car	197	54.7
	2 or more cars	33	9.2
Change in car ownership in previous 4 years	No change	273	75.8
	Increase	35	9.7
	Decrease	52	14.4
Expected change in car ownership in coming 2 years	No change	299	83.1
	Increase	37	10.3
	Decrease	24	6.7

Table 5
The intention for future carsharing membership (N = 360).

Dependent variables	No.	%	Mean	Median	Std. dev.	Min	Max
Full sample	360	100	4.43	3.50	3.252	1	10
Users	145	40.3	6.41	7.00	3.278	1	10
Non-users	215	59.7	3.10	2.00	2.468	1	10

and separately for users and non-users (see Table 5). For the whole sample, the analysis revealed that the possibility of using carsharing in the future is slightly below the midpoint (mean = 4.43). For two categories, it showed that current users of carsharing are more likely to continue to use it in the future than current non-users (mean = 6.41), and current non-users are still less likely to switch to carsharing in the future compared to current users (mean = 3.10).

In terms of the distinct relationship between each independent variable and the dependent variable, an additional bivariate analysis confirmed that the number of driving licenses owned by all family members minus the number of private cars was significantly positively correlated with both current carsharing membership and intention for future carsharing membership ($p < 0.001$). This finding suggests that the existing number of private cars within households might not adequately meet demand, resulting in competition for private car use within the household. This observation could contribute to fostering the adoption of carsharing.

5.2. Binary logistic regression (LR) results of current carsharing membership

The first analysis addressed how current carsharing membership is related to dynamics in residential location/relocation and car ownership. Table 6 illustrates the results of the logistic regression models assessing the role that sociodemographic attributes, residential relocation, and household car ownership play in an individual's decision whether to use carsharing. The model has a satisfactory Nagelkerke R^2 value of 0.412. VIF (variance inflation factor) values of all selected variables are below 5.0.

Table 6
Binary logistic regression analysis on decision regarding current carsharing membership (dependent variable: carsharing membership yes/no).

Variables	Coef.	Std. error
Intercept	−1.711	1.204
Sociodemographic attribute		
Age	0.016	0.015
Gender (Ref. = female)		
Male	0.040	0.289
Not stated	0.334	0.587
Work status (Ref. = unemployed)		
Employed	1.133	1.042
Others	0.253	1.073
Number of licenses (Ref. = 1 license)		
2 licenses	0.944**	0.341
3 or more licenses	1.791**	0.615
Number of children (Ref. = 0 child)		
1 child	0.282	0.425
2 or more children	0.826*	0.416
Income (Ref. = low income)		
Medium income	0.557	0.531
High income	0.485	0.570
Not stated	0.327	0.615
Residential relocation attributes		
Relocation in previous 4 years (Ref. = no)	−1.113*	0.508
Level of urbanization of previous neighborhood (Ref. = no relocation in previous 2 years)		
With same urbanization level	1.043.	0.552
With lower urbanization level	0.886	0.857
Household car ownership attributes		
Current car ownership (Ref. = 0 car)		
1 car	−2.849***	0.346
2 or more cars	−4.384***	0.720
Changes of car ownership in previous 4 years (Ref. = no change)		
Decrease	0.499	0.394
Increase	0.950	0.511
Expected change in car ownership in coming 2 years (Ref. = no change)		
Decrease	1.060.	0.553
Increase	−0.020	0.442
Model estimation		
Observations	360	
Log likelihood	354.477	
Cox and Snell R^2	0.305	
Nagelkerke R^2	0.412	

"." Significant at 0.1; "*" Significant at 0.05; "**" Significant at 0.01; "***" Significant at 0.001.

The results of the binary logistic regression indicate that there is a strong association between individuals' sociodemographic attributes and their tendency to be a carsharing member, especially in the number of car driver's licenses in the household and number of children. When more than one person in a household holds a driver's license, individuals are more likely to be carsharing users. Understandably, a household with more valid car driver's licenses tends to have a preference and need for carsharing use (Jain et al., 2020), suggesting that the number of existing private cars in the household might not be sufficient to meet their demand, so carsharing will become a supplement to private cars. The odds of adopting carsharing for the respondents with two or more children under twelve years old was found to be 128 % higher than for those without children (Exp(B) = 2.284). However, no significant difference in the tendency to use carsharing was found between respondents with one child under twelve years old and those without children. This may be because one child's travel can easily be facilitated by bicycle or another transportation mode, but two or more children's travel often requires transportation such as shared or private cars. Although previous research has suggested that age, gender, work status, and household income affect carsharing adoption (see Table 1), there is no significant difference in the likelihood of adopting carsharing among these variables in this study. A possible explanation for this is that the research area is in the early majority stage of carsharing diffusion, gradually becoming a common choice for all groups. Therefore, the strong correlation between sociodemographic factors with carsharing membership—a correlation found in many other studies—may be less obvious in this specific research area.

Relocation in the previous four years to neighborhoods with carsharing services shows an unexpected, strong negative impact on the tendency to adopt carsharing. This suggests that residents who relocate to new neighborhoods with carsharing services take some time to become familiar with carsharing; that is, they may not immediately switch to carsharing as a new travel mode following residential relocation. This is consistent with previous studies on travel mode switch associated with the change of residential location in Halifax, Canada (Fatmi & Habib, 2017), where individuals prefer to persist with past commute mode after relocation. It should also be noted that relocation from a neighborhood with the same level of urbanization to the new neighborhoods has a marginally significant positive effect on the adoption of carsharing, compensating for the negative newcomer effect. This may suggest that it takes longer for newcomers from less urbanized contexts to get used to and adopt carsharing, as they are less familiar with carsharing. In this respect, it is worth noting that carsharing has been present in our research area for a long time (over six years), implying that current inhabitants have had a long time to adapt to and adopt carsharing, resulting in a supportive social environment. At the same time, it needs to be acknowledged that, like other transportation services, the existence of carsharing services in neighborhoods has a certain impact on the choice of travel modes, since residents who have lived for a longer period of time are more likely to be carsharing members than those who have recently relocated. This is similar to the conclusion of Fatmi and Habib (2017) that people who live close to transit stops are more likely to show a preference for changing travel mode than those who live further from transit stops.

Owning a private car was found to have a negative impact on the respondents' tendency to adopt carsharing. However, changes in car ownership in the previous four years were not significantly associated with their current carsharing membership. This means that a decrease or increase in the number of private cars does not directly lead to the use of carsharing, and apparently does not take place in anticipation of

Table 7
Ordinary least squares regression analysis of intention for future carsharing membership (dependent variable: likelihood of using carsharing in the future 1–10).

Variables	Current members		Current non-members	
	Coef.	Std. Error	Coef.	Std. Error
Intercept	-***	2.006	-***	1.364
Sociodemographic attribute				
Age	−0.144.	0.024	−0.174.	0.016
Gender (Ref. = female)				
Male	0.072	0.472	−0.208**	0.342
Not stated	0.162*	0.945	−0.165*	0.704
Work status (Ref. = unemployed)				
Employed	0.587***	2.009	−0.393*	1.104
Others	0.678***	2.092	−0.245	1.125
Number of licenses (Ref. = 1 license)				
2 licenses	0.013	0.547	0.120	0.385
3 or more licenses	−0.073	1.004	0.043	0.791
Number of children (Ref. = 0 child)				
1 child	0.103	0.636	0.094	0.501
2 or more children	0.012	0.616	−0.091	0.548
Income (Ref. = low income)				
Medium income	−0.076	0.957	0.192.	0.557
High income	0.003	1.001	0.280*	0.603
Not stated	−0.007	1.084	0.105	0.641
Residential relocation attribute				
Relocation in previous 4 years (Ref. = no)	0.009	0.856	0.013	0.526
Level of urbanization of previous neighborhood (Ref. = no relocation in previous 2 years)				
With same urbanization level	−0.060	0.925	0.060	0.622
With lower urbanization level	0.010	1.513	−0.085	0.919
Household car ownership attributes				
Current car ownership (Ref. = 0 car)				
1 car	−0.666***	0.528	−0.191*	0.486
2 or more cars	−0.273***	1.339	−0.366***	0.744
Changes in car ownership in previous 4 years (Ref. = no change)				
Decrease	0.055	0.526	0.033	0.533
Increase	0.006	0.911	−0.043	0.585
Expected changes in car ownership in coming 2 years (Ref. = no change)				
Decrease	0.153*	0.948	0.309***	0.720
Increase	−0.178**	0.636	−0.040	−0.597
Model estimation				
Observations	215		145	
R^2	0.536		0.275	
Adjusted R^2	0.457		0.196	
Std. error of the estimate	2.415		2.213	
F statistic (df = 21; 338)	6.771***		3.484***	

"." Significant at 0.1; "*" Significant at 0.05; "**" Significant at 0.01; "***" Significant at 0.001.

carsharing adoption or ending the membership. It is worth noting that if an individual's estimated private car ownership in the future decreases, he or she is currently more likely to become a carsharing member, which indicates that the functions of private cars and carsharing overlap to a certain extent, and that the decisions are to some extent interacting (Ceccato & Diana, 2021; Ye et al., 2022). It can be inferred that people start carsharing in anticipation of reducing private car ownership.

5.3. Ordinary least squares (OLS) regression results of intention for future carsharing membership

Table 7 presents the results of the two ordinary least squares regression models specifically assessing the role of dynamics in residential location/relocation and car ownership for future intention of carsharing membership. Both models were statistically significant. The selected attributes accounted for 45.7 % of the variance in the impact that the explanatory variables had on the future likelihood of using carsharing, suggesting a good fit for the data. For the model of current non-members, these explanatory variables helped explain 19.6 % of the variance. VIF (variance inflation factor) values of all selected variables are below 5.0.

The presentation of the model results in this part focuses on the differences between current carsharing members and non-members. Compared with members, non-members had different results in gender and income attributes. For current non-members of carsharing, it was less likely that they would become carsharing member as they get older. Male non-members tended to score higher on the likelihood of future usage of carsharing compared to female non-members. In terms of work status, employed people are more likely to use carsharing in the future than both current members and non-members in the categories unemployed or other work. This reflects some value of carsharing for commuting trips (Bulteau et al., 2019). As incomes increase, current non-members are more likely to consider using carsharing in the future. Carsharing non-members with high or medium incomes were more likely than low-income non-members to choose to use carsharing in the future. This situation was not found among carsharing members, which may be due to the self-selection effect; that is, current carsharing members are more likely to be higher income individuals (Bulteau et al., 2019). Our study found no significant influence of number of licenses in the household or number of children under 12 years of age.

A difference from the results of model of current carsharing membership is that we did not find significant associations between relocation and the previous neighborhoods' level of urbanization on the one hand, and an individual's intention for future carsharing membership on the other hand. Regarding the car ownership dynamics, the results of the ordinary least squares regression indicate that there is a negative relationship between current car ownership and intention for future carsharing membership, for both current members and current non-members. Among current carsharing members, those who anticipate a reduction in their future car ownership are more likely to continue as carsharing members in comparison to individuals who foresee no change in their car ownership status. If they anticipate an increase in car ownership in the future, they are more prone to discontinue their carsharing membership compared to individuals who foresee no change in their car ownership status. Among current carsharing non-members, those who anticipate a decrease in future car ownership are more likely to become future carsharing members compared to individuals who foresee no change in their car ownership status. However, if they anticipate an increase in car ownership in the future, it does not necessarily imply that they will discontinue their carsharing membership. This is due to the absence of a discernible relationship between these two variables. Thus, both an individual's present car ownership status and their intention to alter private car ownership in the future are associated with their intention for future carsharing membership.

The general conclusion is that more cars means less willingness for future carsharing membership, so carsharing is indeed a way to compensate for the lack of a private car. For both current carsharing members and non-members, if their current private car ownership figure was higher, they were less likely to consider being carsharing member in the future. Therefore, carsharing is less likely to be effectively promoted in neighborhoods with a high level of private car ownership (Celsor & Millard-Ball, 2007). Additionally, an intended decrease in private car ownership in the future is related to the use of carsharing, which supports previous studies that found that the membership of carsharing can

reduce private car ownership (Ko et al., 2019; Le Vine & Polak, 2019). It also suggests that decisions related to car ownership and to carsharing are to some extent made in combination (Jain et al., 2020). For private car owners (i.e., people who own one or more private cars), one possible hypothetical explanation is that current private car ownership affects intention for future carsharing membership; that is, carsharing serves as a second available car to satisfy the demand for more vehicles. Research by Prieto et al. (2017) suggested that heavy users of private cars are more likely to join carsharing schemes to meet their travel needs; or that some private car owners realize that they do not need a private car, and then consider reducing private car ownership and using carsharing to meet their mobility needs. For non-owners of private cars, one possible hypothetical explanation is that future plans to increase private car ownership are expected to cause them to stop or not consider carsharing (Ikezoe et al., 2020).

6. Conclusion and discussion

6.1. Findings

This was an exploratory study to understand the role of residential location/relocation and car ownership dynamics in the process of carsharing adoption in high carsharing prevalence neighborhoods. It contributes to the relatively small number of empirical studies on the combined effect of sociodemographic attributes, residential relocation attributes, and private car ownership attributes on the adoption of carsharing (Amirnazmiafshar & Diana, 2022).

Fig. 4 shows the dynamics changes in residential relocation, car ownership, and current carsharing ownership, as well as intention for future carsharing membership based our study. Regarding the differential impact of car ownership dynamics and residential location dynamics on current carsharing ownership and future carsharing adoption, the study suggests that:

1) Relocation has a limited effect on carsharing adoption. Newcomers from lower urbanization level neighborhoods need some time to get used to carsharing and adopt it. In the short term, the new opportunity to participate in carsharing stimulated by the new residence due to relocation does not trigger carsharing use. This is consistent with the conclusion of Wang and Lin (2019), who found that people tend to maintain their travel behavior after residential relocation. Relocation from the same urbanization context in the previous four years seems to promote the use of carsharing, but those who have lived in the neighborhood for longer than four years are more likely to be members of carsharing schemes than the recent relocators. Previous relocation has no impact on future carsharing adoption intention, probably because respondents will have familiarized themselves with the concept by now (if they were new). Since carsharing has existed in these neighborhoods for more than six years, it means that compared with relocating to a new neighborhood with carsharing services, the existence of carsharing services in these neighborhoods will be more effective in gradually promoting carsharing membership over time. This suggests that the physical characteristics of the neighborhood environment, in particular the wide availability of car sharing services, stimulate both current and future carsharing adoption (De Vos et al., 2018). Therefore, the introduction of carsharing services in highly urbanized neighborhoods with compact and mixed-use characteristics can promote the diffusion of carsharing services.

2) Future intentions to change private car ownership are more likely than past changes to affect current and future carsharing adoption. In general, the current car ownership level relates negatively to current and intended carsharing membership, as also found by previous studies (Dias et al., 2017; Münzel et al., 2019). Previous changes in car ownership have no relationship with current carsharing use, but future changes in car ownership are related to current carsharing use. Decisions about future carsharing and car ownership seem to be intertwined, and current carsharing decision seems to precede an intended car ownership change. Taken together, these findings suggest that car ownership on the one hand is a strong determinant condition for deciding about car sharing, but that in the context of the future household mobility context, decisions about car ownership and car sharing are interrelated. The sequence of implementing changes in car ownership and car sharing is not evident. Adoption of car sharing is found to follow car ownership,

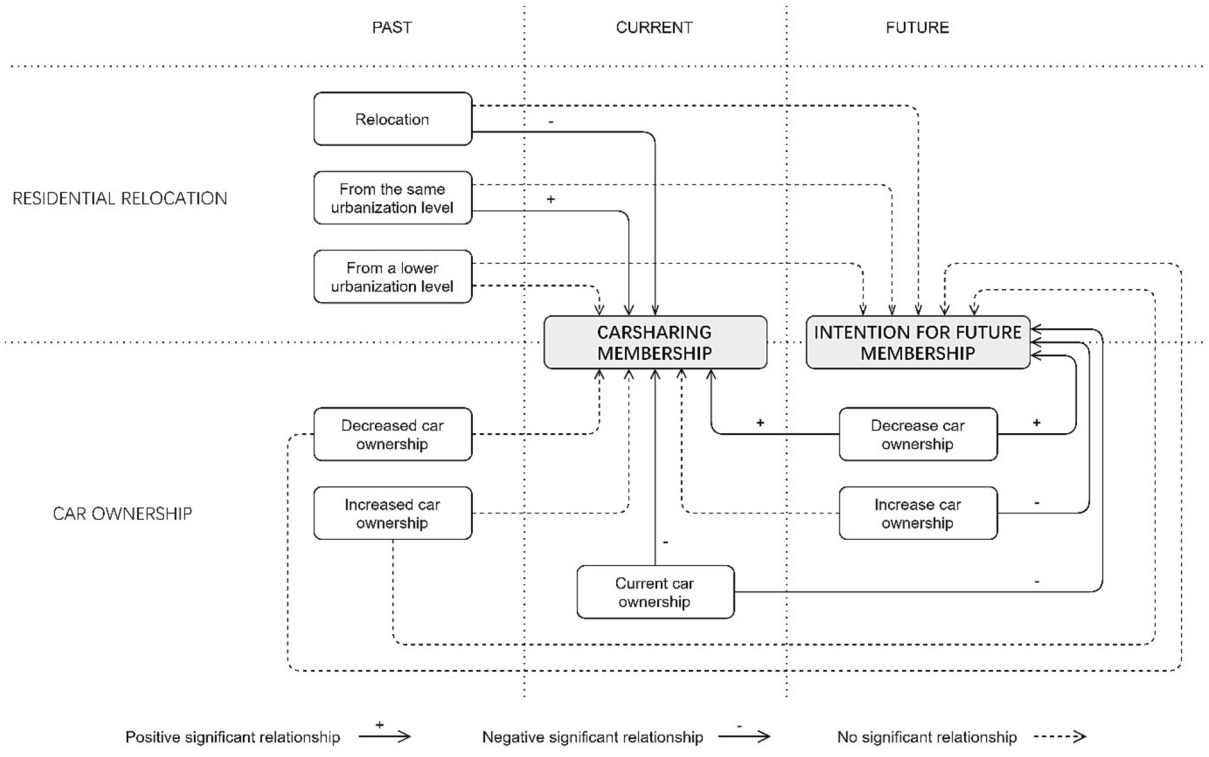


Fig. 4. Dynamics changes in residential relocation, car ownership, and current carsharing ownership, as well as intention for future carsharing membership.

but also to precede a future car disposal. In addition, our findings seem to corroborate the existence of unique groups revealed by previous research (Ikezoe et al., 2020; Liao et al., 2020), such as those heavy carsharing users who still want the security of owning a private car, those who are willing to give up their car even if they do not use carsharing for most of their trips, and those who still do not consider carsharing and use other travel modes after giving up private cars even if shared cars are available.

Conceptually, the linkage between car ownership dynamics and carsharing adoption can be divided into two cases. The first is where the change in private car ownership is triggered by life events, and carsharing plays a small but important role in helping households over the car ownership threshold, by familiarizing them with carsharing use. In the second case, the availability of carsharing prompts households with infrequent car use to reconsider changing car ownership in the future.

6.2. Limitations and future research

This study was subject to several limitations. First, since the research area has a relatively high level of urbanization, resulting from our focus on neighborhoods with a high prevalence of car sharing, we could only consider two types of relocation patterns, namely from high-urbanization neighborhoods to high-urbanization neighborhoods, and from low-urbanization neighborhoods to high-urbanization neighborhoods. Future studies could consider multiple neighborhoods in the same city or in different cities to further explain the impact of residential relocation on carsharing adoption.

Second, carsharing adoption can be described in two variables—membership and frequency of use (Burghard & Dütschke, 2019)—while this study only considered current and future carsharing memberships. Future studies could explore the actual frequency use of carsharing and its influencing factors based on a larger sample size.

Third, considering the use of online questionnaires and the length of the questionnaires, this approach may be limited for individuals experiencing difficulties on the online platform and those with limited time. According to the response statistics, >100 people started but did not complete the questionnaire.

Fourth, our study was an exploratory study that attempted to estimate the impact of relocation and private car ownership dynamics on carsharing adoption based on diverse cross-sectional data, with the aim of initially analyzing the formation process of carsharing membership decisions and trying to infer the evolution of the relationship between built environment change, car ownership change, and sustained use of carsharing. Future studies using longitudinal or panel data could explain their sequence and causality by further exploring such dynamics associated with carsharing adoption. At the same time, future research should focus more on individual situations related to this process rather than general discussions, because the characteristics, psychosocial construct, and lifecycle events of different types of people will affect the decision-making of current and future carsharing adoption.

6.3. Policy implications

The findings of this study can help industry and policymakers to identify potential carsharing markets and design effective carsharing policies. For carsharing service providers, our study shows that different functional goals of carsharing services for different types of potential users should be distinguished, such as reducing the personal car ownership of car owners, preventing the increase in car ownership by car owners (maintaining a low level of car ownership), and improving transportation convenience for non-car owners. When designing urban transportation policies and operations, the relationship between people's behavior patterns and private cars needs to be considered. The positioning of carsharing services relative to other urban transportation systems also needs to be clarified in order to increase the substantial socially relevant advantages of carsharing while also owning and using a car. In terms of the neighborhood built environment, measures that make carsharing accessible spatially, temporally, and technologically to as many people as possible are effective to the extent that people who try carsharing are potentially likely to continue to use it if they need to access a car, thus obviating the purchase of a private car or leading households to not buy a second or third car. Carsharing will have a long-lasting positive impact on the sustainability of the mobility system only if it reduces reliance on private cars and if adopters can easily use other multimodal mobility systems.

Note

1. Based on the different adopter groups (innovators, early adopters, early majority, late majority, and laggards) defined by Rogers et al. (2014) in his diffusion of innovation theory, the threshold between early adopters and early majority is typically 15 % of the population. Therefore, if a study's region, city, or neighborhood has an overall carsharing membership rate <15 %, we can consider this study is aimed at innovators and early adopters of carsharing.

2. Roughly 20 % of the houses were not issued postcards due to discrepancies between Google Maps and the actual number of dwellings, as well as being unoccupied.

CRediT authorship contribution statement

Jingran Xu: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Dea van Lierop:** Conceptualization, Data curation, Supervision, Validation, Writing – review & editing. **Dick Ettema:** Conceptualization, Data curation, Project administration, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that there is no conflict of interest.

Data availability

Data will be made available on request.

Acknowledgement

The authors would like to thank the China Scholarship Council (CSC) for funding this Ph.D. research in the form of a scholarship.

References

Acheampong, R. A., & Siiba, A. (2020). Modelling the determinants of car-sharing adoption intentions among young adults: The role of attitude, perceived benefits, travel expectations and socio-demographic factors. *Transportation, 47*(5), 2557–2580.

Aguilera-García, Á., Gomez, J., Antoniou, C., & Vassallo, J. M. (2022). Behavioral factors impacting adoption and frequency of use of carsharing: A tale of two European cities. *Transport Policy, 123*, 55–72.

Amirnazmiafshar, E., & Diana, M. (2022). A review of the socio-demographic characteristics affecting the demand for different car-sharing operational schemes. *Transportation Research Interdisciplinary Perspectives, 14*, Article 100616.

Bamberg, S. (2006). Is a residential relocation a good opportunity to change people's travel behavior? Results from a theory-driven intervention study. *Environment and Behavior, 38*(6), 820–840.

Becker, H., Ciari, F., & Axhausen, K. W. (2017). Comparing car-sharing schemes in Switzerland: User groups and usage patterns. *Transportation Research Part A: Policy and Practice, 97*, 17–29.

Becker, H., Ciari, F., & Axhausen, K. W. (2018). Measuring the car ownership impact of free-floating car-sharing–A case study in Basel, Switzerland. *Transportation Research Part D: Transport and Environment, 65*, 51–62.

Becker, H., Loder, A., Schmid, B., & Axhausen, K. W. (2017). Modeling car-sharing membership as a mobility tool: A multivariate Probit approach with latent variables. *Travel Behaviour and Society, 8*, 26–36.

Bucsky, P., & Juhász, M. (2022). *Is car ownership reduction impact of car sharing lower than expected?* Case Studies on Transport Policy: A Europe wide empirical evidence.

Bulteau, J., Feuillet, T., & Dantan, S. (2019). Carpooling and carsharing for commuting in the Paris region: A comprehensive exploration of the individual and contextual correlates of their uses. *Travel Behaviour and Society, 16*, 77–87.
Burghard, U., & Dütschke, E. (2019). Who wants shared mobility? Lessons from early adopters and mainstream drivers on electric carsharing in Germany. *Transportation Research Part D: Transport and Environment, 71*, 96–109.
Cantelmo, G., Amini, R. E., Monteiro, M. M., Frenkel, A., Lerner, O., Tavory, S. S., … Behrischi, C. (2022). Aligning users' and stakeholders' needs: How incentives can reshape the carsharing market. *Transport Policy, 126*, 306–326.
Carrone, A. P., Hoening, V. M., Jensen, A. F., Mabit, S. E., & Rich, J. (2020). Understanding car sharing preferences and mode substitution patterns: A stated preference experiment. *Transport Policy, 98*, 139–147.
Cartenì, A., Cascetta, E., & de Luca, S. (2016). A random utility model for park & carsharing services and the pure preference for electric vehicles. *Transport Policy, 48*, 49–59.
CBS, C. B.v.d. S., & RWS-WVL, R. (2020). *Onderzoek Onderweg in Nederland - ODiN 2019 DANS*. https://doi.org/10.17026/dans-xpv-mwpg
Ceccato, R., Chicco, A., & Diana, M. (2021). Evaluating car-sharing switching rates from traditional transport means through logit models and random Forest classifiers. *Transportation Planning and Technology, 44*(2), 160–175.
Ceccato, R., & Diana, M. (2021). Substitution and complementarity patterns between traditional transport means and car sharing: A person and trip level analysis. *Transportation, 48*(4), 1523–1540.
Celsor, C., & Millard-Ball, A. (2007). Where does carsharing work? Using geographic information systems to assess market potential. *Transportation Research Record, 1992*(1), 61–69.
Cervero, R. (2002). Built environments and mode choice: Toward a normative framework. *Transportation Research Part D: Transport and Environment, 7*(4), 265–284.
Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment, 2*(3), 199–219.
Cervero, R., & Tsai, Y. (2004). City CarShare in San Francisco, California: Second-year travel demand and car ownership impacts. *Transportation Research Record, 1887*(1), 117–127.
Chatterjee, K., Sherwin, H., & Jain, J. (2013). Triggers for changes in cycling: The role of life events and modifications to the external environment. *Journal of Transport Geography, 30*, 183–193.
Chen, Z., van Lierop, D., & Ettema, D. (2020). Exploring dockless bikeshare usage: A case study of Beijing, China. *Sustainability, 12*(3), 1238.
Ciari, F., Weis, C., & Balac, M. (2016). Evaluating the influence of carsharing stations' location on potential membership: A Swiss case study. *EURO Journal on Transportation and Logistics, 5*(3), 345–369.
Coll, M.-H., Vandersmissen, M.-H., & Thériault, M. (2014). Modeling spatio-temporal diffusion of carsharing membership in Québec City. *Journal of Transport Geography, 38*, 22–37.
Costain, C., Ardron, C., & Habib, K. N. (2012). Synopsis of users' behaviour of a carsharing program: A case study in Toronto. *Transportation Research Part A: Policy and Practice, 46*(3), 421–434.
De Vos, J., & Ettema, D. (2020). Travel and residential change: An introduction. *Travel Behaviour and Society, 19*, 33–35.
De Vos, J., Ettema, D., & Witlox, F. (2018). Changing travel behaviour and attitudes following a residential relocation. *Journal of Transport Geography, 73*, 131–147.
Dias, F. F., Lavieri, P. S., Garikapati, V. M., Astroza, S., Pendyala, R. M., & Bhat, C. R. (2017). A behavioral choice model of the use of car-sharing and ride-sourcing services. *Transportation, 44*(6), 1307–1323.
Ding, D., Nguyen, B., Learnihan, V., Bauman, A. E., Davey, R., Jalaludin, B., & Gebel, K. (2018). Moving to an active lifestyle? A systematic review of the effects of residential relocation on walking, physical activity and travel behaviour. *British Journal of Sports Medicine, 52*(12), 789–799.
Dowling, R., & Kent, J. (2015). Practice and public–private partnerships in sustainable transport governance: The case of car sharing in Sydney, Australia. *Transport Policy, 40*, 58–64.
Efthymiou, D., & Antoniou, C. (2016). Modeling the propensity to join carsharing using hybrid choice models and mixed survey data. *Transport Policy, 51*, 143–149.
Efthymiou, D., Antoniou, C., & Waddell, P. (2013). Factors affecting the adoption of vehicle sharing systems by young drivers. *Transport Policy, 29*, 64–73.
Ewing, R., & Cervero, R. (2010). Travel and the built environment: A meta-analysis. *Journal of the American Planning Association, 76*(3), 265–294.
Fatmi, M. R., & Habib, M. A. (2017). Modelling mode switch associated with the change of residential location. *Travel Behaviour and Society, 9*, 21–28.
Feng, X., Sun, H., Wu, J., & Lv, Y. (2023). Understanding the factors associated with one-way and round-trip carsharing usage based on a hybrid operation carsharing system: A case study in Beijing. *Travel Behaviour and Society, 30*, 74–91.
Gemeente Utrecht. (2022a). City Deal elektrische deelmobiliteit. *Municipality of Utrecht*. Retrieved 11 June 2022 from https://www.rijksoverheid.nl/documenten/rapporten/2022/03/31/evaluatie-city-deal-elektrische-deelmobiliteit-in-stedelijke-gebiedsontwikkeling.
Gemeente Utrecht. (2022b). Deelvervoer. Retrieved 11 June 2022 from https://www.utrecht.nl/wonen-en-leven/verkeer/deelvervoer/.
Gemeente Utrecht. (2022c). GBA City of Utrecht Buurtmonitor. Retrieved 11 June 2022 from https://utrecht.incijfers.nl/.
Giesel, F., & Nobis, C. (2016). The impact of carsharing on car ownership in German cities. *Transportation Research Procedia, 19*, 215–224.
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.
Hamidi, S., Ewing, R., Preuss, I., & Dodds, A. (2015). Measuring sprawl and its impacts: An update. *Journal of Planning Education and Research, 35*(1), 35–50.
Hess, D. B. (2012). Walking to the bus: Perceived versus actual walking distance to bus stops for older adults. *Transportation, 39*, 247–266.
Hjorteset, M. A., & Böcker, L. (2020). Car sharing in Norwegian urban areas: Examining interest, intention and the decision to enrol. *Transportation Research Part D: Transport and Environment, 84*, Article 102322.
Ikezoe, K., Kiriyama, E., & Fujimura, S. (2020). Car-sharing intention analysis in Japan by comparing the utility of car ownership for car-owners and non-car owners. *Transport Policy, 96*, 1–14.
Jain, T., Johnson, M., & Rose, G. (2020). Exploring the process of travel behaviour change and mobility trajectories associated with car share adoption. *Travel Behaviour and Society, 18*, 117–131.
Juschten, M., Ohnmacht, T., Thao, V. T., Gerike, R., & Hössinger, R. (2019a). Carsharing in Switzerland: Identifying new markets by predicting membership based on data on supply and demand. *Transportation, 46*(4), 1171–1194.
Juschten, M., Ohnmacht, T., Thao, V. T., Gerike, R., & Hössinger, R. (2019b). Carsharing in Switzerland: Identifying new markets by predicting membership based on data on supply and demand. *Transportation, 46*, 1171–1194.
Kato, H., Inagi, A., & Igo, T. (2013). Potential choices of travel mode including carsharing and carsharing membership: Evidences from four japanese cities. *Journal of the Eastern Asia Society for Transportation Studies, 10*, 630–646.
Kawgan-Kagan, I. (2015). Early adopters of carsharing with and without BEVs with respect to gender preferences. *European Transport Research Review, 7*, 1–11.
Kim, K. (2015). Can carsharing meet the mobility needs for the low-income neighborhoods? Lessons from carsharing usage patterns in new York City. *Transportation Research Part A: Policy and Practice, 77*, 249–260.
Klincevicius, M. G., Morency, C., & Trépanier, M. (2014). Assessing impact of carsharing on household car ownership in Montreal, Quebec, Canada. *Transportation Research Record, 2416*(1), 48–55.
Klinger, T., & Lanzendorf, M. (2016). Moving between mobility cultures: What affects the travel behavior of new residents? *Transportation, 43*(2), 243–271.
Ko, J., Ki, H., & Lee, S. (2019). Factors affecting carsharing program participants' car ownership changes. *Transportation Letters, 11*(4), 208–218.
Kolleck, A. (2021). Does car-sharing reduce car ownership? Empirical evidence from Germany. *Sustainability, 13*(13), 7384.
Kopp, J., Gerike, R., & Axhausen, K. W. (2015). Do sharing people behave differently? An empirical evaluation of the distinctive mobility patterns of free-floating car-sharing members. *Transportation, 42*(3), 449–469.
Le Vine, S., & Polak, J. (2019). The impact of free-floating carsharing on car ownership: Early-stage findings from London. *Transport Policy, 75*, 119–127.
Lempert, R., Zhao, J., & Dowlatabadi, H. (2019). Convenience, savings, or lifestyle? Distinct motivations and travel patterns of one-way and two-way carsharing members in Vancouver, Canada. *Transportation Research Part D: Transport and Environment, 71*, 141–152.
Liao, F., Molin, E., Timmermans, H., & van Wee, B. (2020). Carsharing: The impact of system characteristics on its potential to replace private car trips and reduce car ownership. *Transportation, 47*(2), 935–970.
Lin, T., Wang, D., & Guan, X. (2017). The built environment, travel attitude, and travel behavior: Residential self-selection or residential determination? *Journal of Transport Geography, 65*, 111–122.
Martin, E., & Shaheen, S. (2011). The impact of carsharing on public transit and non-motorized travel: An exploration of north American carsharing survey data. *Energies, 4*(11), 2094–2114.
Martin, E., Shaheen, S. A., & Lidicker, J. (2010). Impact of carsharing on household vehicle holdings: Results from North American shared-use vehicle survey. *Transportation Research Record, 2143*(1), 150–158.
Mishra, G. S., Mokhtarian, P. L., Clewlow, R. R., & Widaman, K. F. (2019). Addressing the joint occurrence of self-selection and simultaneity biases in the estimation of program effects based on cross-sectional observational surveys: Case study of travel behavior effects in carsharing. *Transportation, 46*(1), 95–123.
Münzel, K., Piscicelli, L., Boon, W., & Frenken, K. (2019). Different business models–different users? Uncovering the motives and characteristics of business-to-consumer and peer-to-peer carsharing adopters in the Netherlands. *Transportation Research Part D: Transport and Environment, 73*, 276–306.
Namazu, M., MacKenzie, D., Zerriffi, H., & Dowlatabadi, H. (2018). Is carsharing for everyone? Understanding the diffusion of carsharing services. *Transport Policy, 63*, 189–199.
Netherlands Enterprise Agency. (2022). Distributing advertising material. Retrieved December 15, 2022 from https://business.gov.nl/regulation/distributing-advertising-material/.
Nijland, H., & van Meerkerk, J. (2017). Mobility and environmental impacts of car sharing in the Netherlands. *Environmental Innovation and Societal Transitions, 23*, 84–91.
Nikitas, A., Kougias, I., Alyavina, E., & Njoya Tchouamou, E. (2017). How can autonomous and connected vehicles, electromobility, BRT, hyperloop, shared use mobility and mobility-as-a-service shape transport futures for the context of smart cities? *Urban Science, 1*(4), 36.
Prieto, M., Baltas, G., & Stan, V. (2017). Car sharing adoption intention in urban areas: What are the key sociodemographic drivers? *Transportation Research Part A: Policy and Practice, 101*, 218–227.
Roblot, M., Boisjoly, G., Francesco, C., & Martin, T. (2021). Participation in shared mobility: An analysis of the influence of walking and public transport accessibility to vehicles on carsharing membership in Montreal, Canada. *Transportation Research Record, 2675*(12), 1160–1171.

Rogers, E. M., Singhal, A., & Quinlan, M. M. (2014). Diffusion of innovations. In *An integrated approach to communication theory and research* (pp. 432–448). Routledge.
Rotaris, L., Danielis, R., & Maltese, I. (2019). Carsharing use by college students: The case of Milan and Rome. *Transportation Research Part A: Policy and Practice, 120*, 239–251.
Safdar, M., Jamal, A., Al-Ahmadi, H. M., Rahman, M. T., & Almoshaogeh, M. (2022). Analysis of the influential factors towards adoption of car-sharing: A case study of a megacity in a developing country. *Sustainability, 14*(5), 2778.
Scheiner, J., & Holz-Rau, C. (2013). Changes in travel mode use after residential relocation: A contribution to mobility biographies. *Transportation, 40*(2), 431–458.
Shaheen, S. A., & Cohen, A. P. (2013). Carsharing and personal vehicle services: Worldwide market developments and emerging trends. *International Journal of Sustainable Transportation, 7*(1), 5–34.
Shaheen, S. A., Cohen, A. P., & Chung, M. S. (2009). North American carsharing: 10-year retrospective. *Transportation Research Record, 2110*(1), 35–44.
Sioui, L., Morency, C., & Trépanier, M. (2013). How carsharing affects the travel behavior of households: A case study of Montréal, Canada. *International Journal of Sustainable Transportation, 7*(1), 52–69.
Stevens, M. R. (2017). Does compact development make people drive less? *Journal of the American Planning Association, 83*(1), 7–18.
Ter Schure, J., Napolitan, F., & Hutchinson, R. (2012). Cumulative impacts of carsharing and unbundled parking on vehicle ownership and mode choice. *Transportation Research Record, 2319*(1), 96–104.
Wang, D., & Lin, T. (2019). Built environment, travel behavior, and residential self-selection: A study based on panel data from Beijing, China. *Transportation, 46*(1), 51–74.
Wang, J., Dane, G. Z., & Timmermans, H. J. (2021). Carsharing-facilitating neighbourhood choice: A mixed logit model. *Journal of Housing and the Built Environment, 36*(3), 1033–1054.
Wang, N., & Yan, R. (2015). Research on consumers' use willingness and opinions of electric vehicle sharing: An empirical study in shanghai. *Sustainability, 8*(1), 7.
We Drive Solar. (2016). De eerste aanmeldingen in Lombok zijn binnen. Retrieved 11 June 2022 from https://www.wedrivesolar.nl/actueel/de-eerste-aanmeldingen-in-lombok-zijn-binnen.
Yang, M., Wu, J., Rasouli, S., Cirillo, C., & Li, D. (2017). Exploring the impact of residential relocation on modal shift in commute trips: Evidence from a quasi-longitudinal analysis. *Transport Policy, 59*, 142–152.
Ye, J., Wang, D., Jia, Y., & Zhang, H. (2022). Competition or cooperation: Relationship between carsharing and other travel modes. *International Journal of Sustainable Transportation, 16*(7), 610–626.
Yoon, T., Cherry, C. R., & Jones, L. R. (2017). One-way and round-trip carsharing: A stated preference experiment in Beijing. *Transportation Research Part D: Transport and Environment, 53*, 102–114.
Zhou, F., Zheng, Z., Whitehead, J., Perrons, R. K., Washington, S., & Page, L. (2020). Examining the impact of car-sharing on private vehicle ownership. *Transportation Research Part A: Policy and Practice, 138*, 322–341.