E-Bike Ownership and Usage – Results from Germany

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Abstract

E-bikes increase cycling mode shares and are expected to contribute to sustainable mobility. This paper analyzes data from the German national travel survey from 2017, as there is a lack of research on their effect on travel behavior, differentiating between socio-demographic groups. We present two logit models, one analyzing the ownership of different bicycle types and the other analyzing the influence of bicycle types on mode choice.

During the data collection in 2016/2017, e-bikes were rare compared to conventional bicycles and were primarily owned by older age groups. While an above-average household economic status increases e-bike ownership, urban residents have lower e-bike ownership and usage rates. Daily cycled distances are higher for people with e-bikes; they extend cycling ranges, as their owner's cycling mode shares are less sensitive to distance. Contrastingly, e-bikes do not seem to substitute car ownership. Compared to conventional bicycles, their use is more dependent on the season. Our results confirm findings from other countries and partially indicate cross-national transferability. Several diverging findings, such as that e-bikes increase cycling among young owners less and that age does not reduce e-bike use, suggest a closer look at how national framework conditions shape the uptake and use of e-bikes.

Keywords: Cycling; Bicycle; E-bike; Electric bikes; Modal shift; Mode choice; Household travel surveys; Travel behavior

1. Introduction

There are high expectations that the e-bike will become a game changer in current unsustainable mobility systems (Schleinitz et al., 2016; Sun et al., 2020). This is because the diffusion of e-bikes increases the joint mode share of conventional and e-bike cycling. E-bikes should enhance overall health, reduce car traffic and associated emissions, and decrease the traffic-related consumption of space and road accidents (Kroesen, 2017; Castro et al., 2019). They are faster, and their use is less physically demanding and exhausting than conventional bicycles. Furthermore, the strong growth in e-bike sales, especially in Western Europe, raises hopes that they can contribute to meeting emission targets. Findings from previous research show that e-bikes are used for longer trips and reduce car usage, thus supporting these expectations (Kroesen, 2017).

This raises the question of how e-bikes affect actual mobility behavior and whether they have an advantage over conventional bicycles from a transportation planning perspective. It is unclear how much they can contribute to the reduction of car traffic. This paper presents two logit models based on the German national travel survey from 2016/2017 to answer these questions (Nobis and Kuhnimhof, 2019). The first model focuses on the ownership of both e-bikes and conventional bicycles at the individual level and examines the influence of socioeconomic factors on this.

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The second focuses on the influence of e-bike ownership compared to conventional bicycle ownership on mode choice at the trip level. It also considers additional aspects such as trip length, purpose, season, and age.

In this paper, 'e-bike' refers to pedelecs in the context of European regulation, while 'c-bike' is shorthand for conventional bicycles without motor power assistance. It is important to note that cycling as a mode includes riding both c-bikes and e-bikes.

The main research questions of this paper are the following:

- What influences the ownership and use of conventional and e-bikes?
- To what extent do the results of the German national travel survey confirm the international findings on e-bike use?

First, we review previous research and describe our data and methods used. In the next section, we present our results. Finally, we discuss them and conclude.

2. Literature review

There is a wide variety of e-bikes and related legal regulations (MacArthur and Kobel, 2017). Overall, they can be classified into bicycle-style and motorbike-style vehicles. Especially in China, most e-bikes fall into the latter category (Fishman and Cherry, 2016). Some countries, such as the USA and Australia, require operable pedals for such two-wheelers to be classified as bicycles. In other countries, motor power assistance must be available only when pedaling, as in the EU (Rose, 2012). Particularly in Europe, the terms pedelec or Electric Pedal Assisted Cycles (EPAC) are commonly used to refer to these vehicles. Standard pedelecs (assisted up to 25 km/h (EU) or 32 km/h (USA)) are classified as bicycles. In contrast, speed pedelecs or shortened s-pedelecs (assisted up to 45 km/h) are classified as motorcycles and require a driver's license (Fishman and Cherry, 2016; Philips et al., 2022), as shown in Table 1.

Table 1: Classification of e-bikes in Germany

	Pedelec	S-Pedelec
Motorassistence until [km/h]	25 while pedaling	45 while pedaling
Regulatory	Bicycle	Motorcycle
Requiring driving license and license plate	No	Yes

Already in 2015, Fishman and Cherry (2016) called their review "E-bikes in the Mainstream". Since then, the relevance and sales of e-bikes have increased substantially, especially in Germany and the Netherlands. In Germany, sales of e-bikes quadrupled between 2015 and 2020, from 500,000 to nearly 2 million per year (Zweirad-Industrie-Verband, 2016; Brust, 2021), making it one of the most important markets globally after China. However, while several studies point to the positive impact of e-bikes on individual health (Castro et al., 2019; Lobben et al., 2019), their benefit for the mobility system in Germany remains unclear.

In 2020, Bourne et al. (2020) published a comprehensive literature review on the impact of e-bikes on travel behavior. It includes experimental studies by lending e-bikes and non-experimental studies conducted often as web-based surveys. Most studies in this field analyze e-bike use after purchasing an e-bike. Overall, e-bike users cycle longer distances per trip compared to c-bike users. Bourne et al. (2020) identify a lack of research on the effect of e-bike ownership on travel behavior, differentiated by age, gender, and socioeconomic status. The paper at hand sheds light on the influence of these covariates.

Table 2 summarizes the relevant literature findings on the impact of e-bikes on travel behavior. An example of an experimental study comes from Fyhri and Fearnley (2015). They provided e-bikes to Norwegian Automobile Federation members for two or four weeks and recorded their trips with their distances during this period. The results show an increase in cycling shares among the e-bike test users, regardless of age. In addition, the weekly cycling activity for commuting increased more than for exercise, conforming to other literature findings (Kroesen, 2017).

Fyhri and Sundfør (2020) also investigated the effects of purchasing an e-bike. They found an increase in daily cycling kilometers from 2.1 km to 9.2 km and a mode share change from 17 to 49 % after acquiring an e-bike.

Table 2: Key finding of the influence of e-bikes on mobility behavior

Citation	Location of study	Methods	Survey period	Key findings
Bigazzi and Wong (2020)	World-wide	Meta study	2006-2017	E-bikes displace more transit trips in China and more car trips in Europe, North America, and Australia.
Castro et al. (2019)	Europe	Longitu-dinal survey, travel diaries, sampling strategy across cities	2014-2017	• The average cycling trip duration of e-bike owners (35.0 for a c-bike and 41.9 min for an e-bike) is significantly higher than that of c-bike owners (25.6 min). • Average trip distance is significantly different when comparing e-bike owners (9.4 km for e-bike trips and 8.4 km for c-bike trips) with c-bike owners (4.8 km for c-bike trips). • Average daily cycling time is similar for e-biking among e-bike owners and c-biking among c-bike owners (32.2 vs. 30.3 min), but e-bike owners also cycle 13.4 min on a c-bike. • E-bike owners travel significantly longer daily distances by e-bike than c-bike owners travel by c-bike (8.0 vs. 5.3 km per person per day). In addition, e-bike owners travel 2.5 km per day by c-bike. • E-bikers tend to substitute their primary mode of transportation.
Cherry et al. (2016)	CN	Travel diaries	2006-2012	• Many of those transitioning from non-motorized modes (i.e., walking and bicycle) to e-bikes would transition from e-bikes to more motorized modes (bus, taxi, car). 24 % of e-bike trips would have been made by car (including taxis).
Fyhri and Sundfør (2020)	NOR	Travel diaries, panel	2014	• After purchasing an e-bike, the average distance traveled by bicycle increased from 2.1 to 9.2 km, and the mode share by bicycle increased from 17 to 49 %. The increase in cycling km is slightly lower in the purchase case than in the experimental loan case, but the mode share is higher.
Fyhri and Fearnley (2015)	NOR	Travel diaries, experi-mental	2013	• Loaning an e-bike to users increases cycling, expressed in the number of trips, distance cycled, and cycling share. The effect is more remarkable for women than for men. The impact on distance cycled is the greatest for non-commuting trips.
Kroesen (2017)	NL	1-day Travel diaries	2013-2015	• On average, e-bike owners travel 3.0 km with their e-bike, while non-e-bike owners travel 2.6 km with their c-bike. E-bike owners travel an additional 0.9 km per day by c-bike. • E-bike owners travel less by car (-5.8 km) and by public transportation (-9.4 km). They also travel less overall than non-e-bike owners. • E-bike ownership reduces c-bike ownership from 81 to 49 % but correlates with slightly higher car ownership. Neither the ownership of an e-bike nor a c-bike acts as a car substitute. • In terms of mode use, e-bike ownership increases the use of e-bikes and decreases the use of c-bikes, car driving, and public transportation.

				• The signs of the effects of socio-demographic and household variables on e-bike use are opposite to the impact of these variables on e-bike ownership. For example, age increases the probability of owning an e-bike but has a negative effect on e-bike use.
MacArthur et al. (2018)	USA	Online survey	2017	• The main reasons for buying an e-bike are: to replace car trips, to ride with less effort, for recreation purposes, because someone lives or works in a hilly area, or to improve fitness. • Most e-bike users (93.4 %) rode a c-bike before owning an e-bike. The e-bike leads to falling c-bike use but increases total cycling. • Exercise, recreation, and commuting are the trip purposes most likely to be made primarily by e-bikes. Older people and those with physical limitations are likelier to use e-bikes for recreational and exercise-based trips. In contrast, younger people and those without physical limitations use the e-bike as their primary mode of commuting. • The results show that e-bikes also replace many trips that people would have made by active or public transit modes, most of which are commuting (39.8%) and recreation or exercise trips (29.4%).
Plazier et al. (2017)	NL	GPS-based travel diaries and depth interviews	2015-2016	• E-bike use is highest for work-related, single-destination trips. • Participants state that commuting by e-bike gives them the advantages of cycling over motorized transport (enjoyment of outdoor, physical activity; independence) while mitigating its relative disadvantages (longer travel time; increased effort). • Results demonstrate that e-bikes can substitute motorized commuting modes for distances perceived as too long to be covered by c-bike, and stress the importance of a positive experience in e-bike commuting.
Sun et al. (2020)	NL	Travel diaries, panel	2013-2016	• The results indicate that purchasing an e-bike reduces the use of a c-bike more significantly than driving a car or walking. Looking at the level of cycling by e-bike and c-bike together, the share of cycling almost doubles, while the car remains the main mode of transport despite a 16 % drop in mode share. • C-bike ownership drops from 81.3 % to 43 % after purchasing an e-bike, while car ownership drops from 92.5 to 86.9 %. • E-bikes boost cycling trips mostly for distances between 5 and 20 km, indicating a range extender effect for cycling. • For commuting, e-bike trips challenge the dominance of car trips, as the car mode share drops from 76.3% to 50.8%. • People living in highly urbanized areas are less likely to reduce their car use after adopting an e-bike than new e-bikers in non-urbanized areas.

Other studies focus on the reasons for using e-bikes. MacArthur et al. (2018) conducted a web-based survey of e-bike owners and users from the USA. They reported the intention to replace car trips as the main reason to buy an e-bike. Other motivations are related to the comfort of motor-assisted cycling, especially in hilly areas or the users' medical conditions. Fitness and recreation are also essential motivations for buying an e-bike. The vast majority of the respondents rode a c-bike before owning an e-bike. In their study, purchasing an e-bike reduced the c-bike riding frequency, while the total cycling km increased due to the use of the e-bike. They also found that e-bike users use it as their primary mode for a variety of different trips. While older people use it for recreational trips, younger people use it for commuting. On the one hand, respondents reported that they would not have made recreational trips conducted by e-bike without owning an e-bike. On the other hand, 46 % of e-bike commuting trips replaced car trips.

While e-bikes play a minor role in mode choice in Western countries, the situation in China is different not only in terms of their regulation. With gasoline-based motorcycles banned in many cities, e-bikes play an important role in commuting, especially in cities with less than 500,000 inhabitants, where they are the main mode of transportation (Gu et al., 2021; Hu et al., 2021). In China, e-bike use primarily replaces public transportation trips, while in Europe, North America, and Australia, e-bikes are more likely to replace cars (Bigazzi and Wong, 2020).

There is likely to be a self-selection bias in studies based on self-recruitment strategies, such as web-based surveys focused on cycling and e-bike use or experimental studies involving the temporary provision of e-bikes. As a result, participants in such studies may not be representative of the general population, as people participating in these surveys may identify strongly with their bicycle-based mobility.

Other data sources are panel survey-based studies. Rather than comparing e-bike owners and non-e-bike owners, these studies analyze the effect of buying an e-bike between survey periods. Due to the low penetration of e-bikes in the population in developed countries, the number of actual e-bike buyers is very small. As a consequence, the resulting samples lead to insignificant results, especially for the influence of socio-demographic factors (Fyhri and Sundfør, 2020; Sun et al., 2020).

Instead, national travel surveys provide an opportunity to obtain data with sufficiently large subsamples of e-bike owners. Similar to our study, Kroesen (2017) analyzed the Dutch national travel survey on e-bike ownership, usage, and impact on mobility behavior. Based on descriptive analyses, the author found that e-bike ownership strongly reduces the ownership of c-bikes. Furthermore, e-bike owners travel less by c-bike (-1.7 km) and even less by car (-5.8 km) and public transport (-9.4 km) than non-e-bike owners. Nevertheless, e-bike ownership does not seem to substitute car ownership. Kroesen (2017) showed with a structural equation model (SEM) that e-bike ownership strongly increases e-bike use, strongly reduces c-bike use, and contributes to lower use of the car-driver mode and public transportation. The author also found that age positively correlates with e-bike ownership and negatively with e-bike use. However, Kroesen (2017) did not investigate mode choice at the trip level, taking into account aspects such as trip length and purpose. Hence, our paper has similarities with Kroesen's study in that it investigates similar questions but differs in that it uses a different methodology (discrete choice models as opposed to SEM) and focuses on a different geography (Germany instead of the Netherlands).

So far, e-bike use in Germany's national household travel survey has not yet been the focus of scientific publications. Therefore, at the outset of this paper, it is unclear to what extent results based on the national travel survey would be consistent with findings from other locales that are using different data and methodologies.

3. Data and Methodology

This paper uses data from the German national household travel survey from 2016 and 2017, which includes 316,361 individuals from 156,420 households who made a total of 960,619 trips (Nobis and Köhler, 2019). The travel survey contains information on e-bike ownership at the individual level and e-bike use at the trip level. Thus, it allows running two logit models, one for factors explaining e-bike ownership based on the individual level and another for the mode choice on the trip level.

For the modeling, the dataset was filtered because there are many missing values for several variables in the two models. For example, at the individual level, persons under the age of 16 were excluded because they were not asked about e-bike ownership. As a result, only 184,061 people formed the sample for the model estimation of bike ownership at the individual level. Models in the literature cited above analyze bicycle ownership by distinguishing only between two categories, c-bike and e-bike ownership. In contrast, we distinguish between an individual with a) no bicycle ownership, b) only c-bike ownership, c) only e-bike ownership, and d) both c- and e-bike ownership. During an iterative procedure, we tried to estimate a model with few variables and good parameters as a high McFadden pseudo-r^2. Therefore, for the calculation of the logit model, we kept only the variables that significantly influence ownership. An important independent variable is the household's economic status, which is, in short, a five-level household classification according to equivalent income (net household income relative to household size). For details, see Nobis and Köhler (2019).

We used a similar data preparation procedure at the trip level. Filtering out individuals with missing or unclear values reduced the number of trips suitable for model estimation to 665,698. Given the negligible prevalence of bike-sharing in Germany, cycling is not an option for people without a bike, so we excluded them from the model. We also excluded people without self-reported permanent car ownership or without a driver's license because we wanted to focus exclusively on travelers with multiple options and only considered trips up to 50 km in length. As a result, we had 436,385 trips by 104,263 people as input for the mode choice model. Finally, because the number of people who own an e-bike and do not own a c-bike is relatively small, we grouped them with those who own an e-bike and a c-bike together.

The variables considered in our model of bicycle ownership and our model of mode choice differ because the relevance and significance of several variables vary depending on the object of observation. E.g., the household's economic status had more influence on bicycle ownership than on the mode choice. Therefore, there are five levels of the household’s economic status in the first model and only two in the mode choice model.

This paper uses multinomial logistic regression for multivariate models (McFadden, 1974; Profillidis and Botzoris, 2019). All models are run in R using the mlogit package. For both the descriptive and the multivariate analyses in this paper, we used the weights provided in the original MiD 2017 person and trip datasets. For more information on the weights, we refer to Eggs et al. (2019).

4. Results

4.1. Descriptive analysis of c-bike and e-bike ownership

In Germany in 2017, e-bikes were less common than c-bikes, probably due to the higher purchase price and their recent emergence resulting in a much smaller accumulated stock. Ownership of c-bikes and even more the ownership of e-bikes depends on the economic status of the household, as shown in Figure 1. People from medium-level income households have the highest share of only e-bike ownership. Furthermore, people in wealthier households are more likely to own an e-bike in addition to their c-bike.

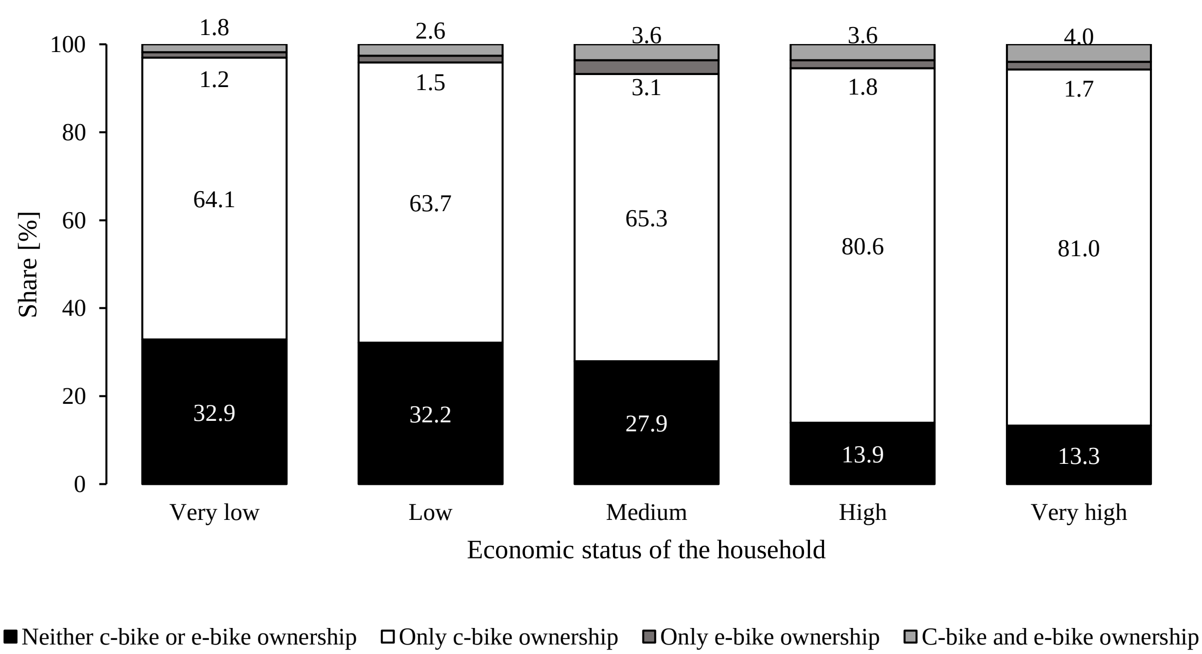

Figure 1: Bike ownership on the individual level by the economic status of the household (n=188,900)

Figure 2 shows that primarily middle-aged and older people own an e-bike. The absence of any type of bicycle increases rapidly from the age of 70 onwards, probably due to the declining physical ability to cycle.

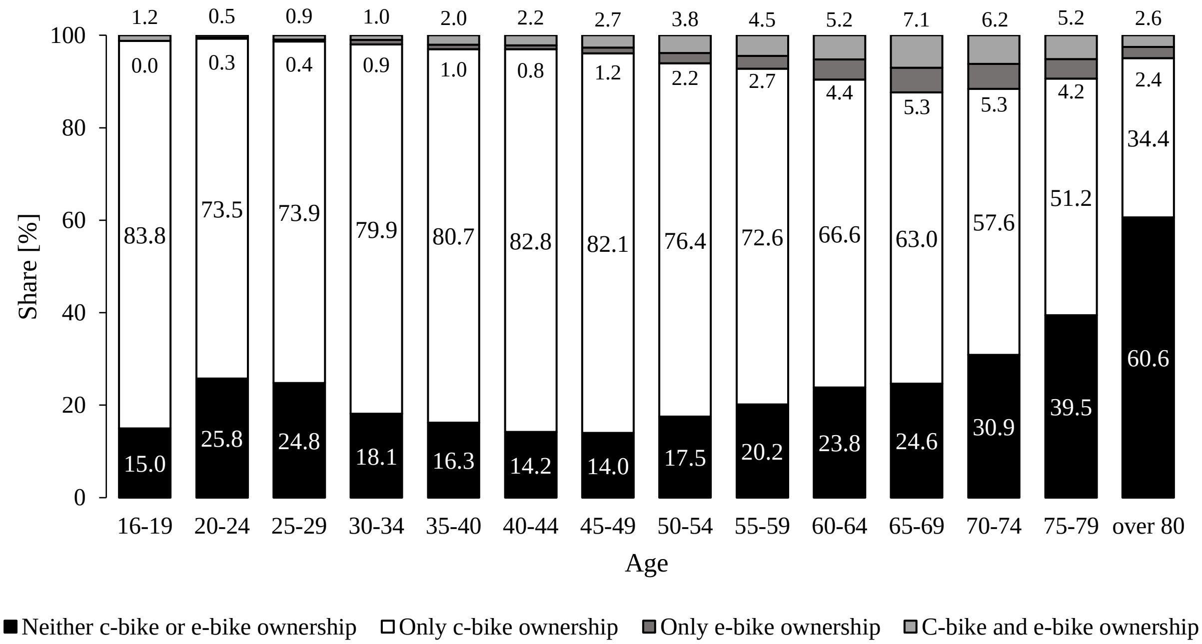

Figure 2: Bike ownership related to age (n=188,900)

Compared to owning a c-bike, owning an e-bike is associated with an increase in daily cycling distance, as shown in Table 3. The mean daily distance cycled by people with both a c-bike and an e-bike is more than double that of people with only a c-bike. There is no clear trend for car mileage per day according to bicycle type: those with only a c-bike have the most car mileage, while those with no bicycle have the least. Correlations with other socio-demographic factors may explain this finding.

Table 3: Average cycled kilometer related to bike ownership (n = 188.900)

Ownership	Daily kilometers (mean)	
	Cycled	Car
C- and e-bike	4.0	32.3
Only e-bike	2.5	28.4
Only c-bike	1.8	37.1
No bike	0.1	25.5
All	1.6	34.3

4.2. Multivariate analysis of c-bike and e-bike ownership

Table 4 shows the results of the logit model for bicycle ownership with 'no bike ownership' as the reference level. The intercept is positive for only c-bike ownership, while it is negative for c-bike and e-bike ownership and far below zero for only e-bike ownership. Since positive values increase the probability, and negative values decrease it, these coefficients already partially explain why e-bikes are much less common than c-bikes. The table also shows that all bicycle ownership categories have negative coefficients for households with a below-average economic status. The negative influence on e-bike ownership is stronger than on c-bike ownership. For financially better-situated households, there are positive coefficients for the ownership of all types of bicycles but the highest for ownership of a c-bike and an e-bike together. These results suggest that low- to medium-income households prefer to buy a c-bike first. In contrast, individuals in wealthier households are more likely to own an additional e-bike.

Table 4: Coefficients multinomial logit model for the bike ownership (Mc-Fadden $R^2 = 0.101$)

Reference:	No bike ownership	Only c-bike ownership	Only e-bike ownership	C-bike and e-bike ownership
Intercept		0.208 ***	-5.603 ***	-4.207 ***
Econ. status of the household (ref. = middle)	Very low	-0.113 ***	-0.853 ***	-0.564 ***
	Low	-0.168 ***	-0.639 ***	-0.398 ***
	High	0.441 ***	0.296 ***	0.623 ***
	Very high	0.502 ***	0.312 ***	0.808 ***
Living place (ref. = middle-sized town in an urban region or central city in a rural region)	Metropole	-0.082 ***	-0.824 ***	-0.729 ***
	City	-0.237 ***	-0.183 ***	-0.376 ***
	Provincial area in urban region	0.119 ***	0.146 **	0.23 ***
	Middle-sized town or provincial area in a rural region	-0.123 ***	-	-
Gender	Male	0.232 ***	0.231 ***	0.26 ***
Age	Years >16	-0.057 ***	0.085 ***	-0.109 ***
	Years > 25	0.113 ***	-	0.227 ***
	Years > 40	-0.081 ***	-0.047 ***	-0.093 ***
	Years > 70	-0.059 ***	-0.157 ***	-0.146 ***
Driver’s license		0.585 ***	0.628 ***	0.84 ***
Car ownership	Every time	0.374 ***	0.527 ***	0.515 ***
	Sometimes	0.35 ***	0.345 ***	0.523 ***
Occupation	School student	0.998 ***	-	0.966 ***
	University student	0.998 ***	-	0.725 ***
	Employed	0.359 ***	-	0.252 **
	Homemaker	0.176 ***	0.722 ***	0.443 ***
	Retired	0.177 ***	0.197 ***	0.335 ***
Public transportation pass		-0.057 ***	-0.669 ***	-0.244 ***

Significance codes: ‘***’ 0 < Pr(>|z|) <0.001, ‘**’ 0.001 < Pr(>|z|) < 0.01

Regarding the spatial distribution of bicycle ownership, there are negative coefficients for all bicycle types in metropolises and cities. Specifically, residence in metropolises has a strong negative impact on owning an e-bike or both a c-bike and an e-bike. In contrast, its influence on owning only a c-bike is almost negligible. Reasons for this could be lower benefits of e-bikes in dense cities due to good public transportation options or higher theft risks in areas where, e.g., private garages are less common.

The ownership coefficients of all bicycle types are positive for men. Furthermore, our logit model incorporates the age based on a stepwise linearization, i.e., the respective coefficients are additive as a function of an individual's age. (Take the example of calculating the age coefficient for c-bike ownership for a 30-year-old: (30-16) · -0.057 + (30-25) · 0.113). Figure 3 shows the resulting probabilities by age, considering the intercepts and holding the other covariates constant at their reference values. There is a peak in the likelihood of not owning a bicycle at age 25. In contrast, the probability of owning at least one bicycle of any type is highest at the age of 40. After this age, the probability of not owning any type of bicycle grows, specifically after the age of 70. This is probably due to reduced physical abilities. The probability of c-bike ownership follows the opposite trend. The age-related probabilities follow an identical pattern for e-bike ownership only and for c-bike and e-bike ownership. They increase slowly at a low level until the age of 40, then increase more rapidly until the age of 70, and then decrease again.

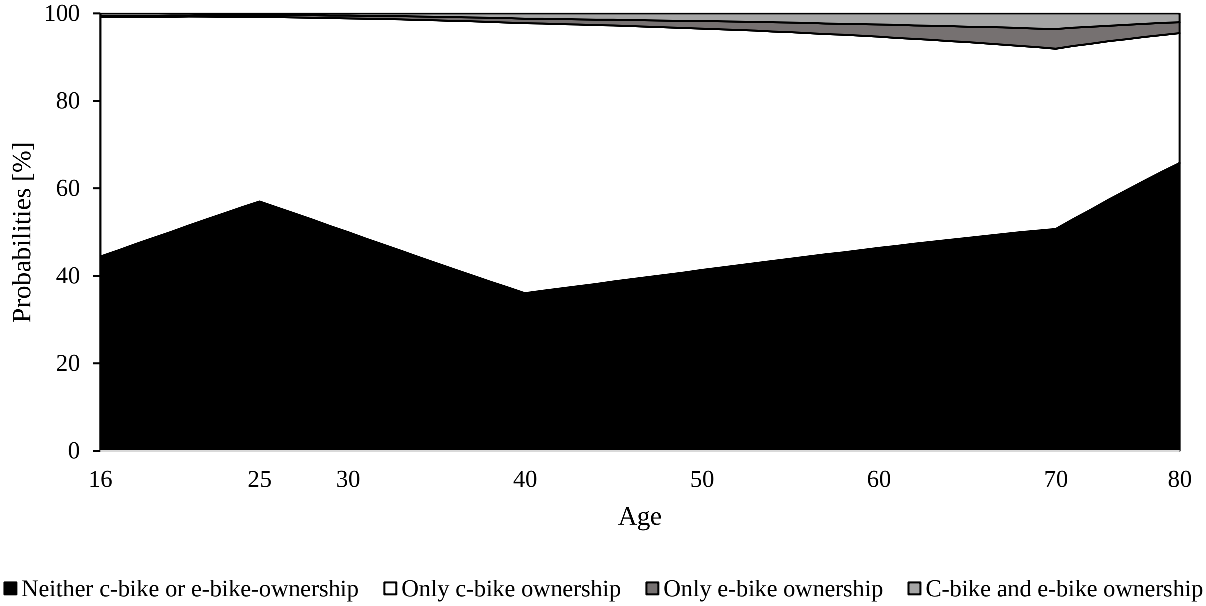

Figure 3: Probabilities for bike ownership related to age

Contrary to the wishful thinking that e-bikes will replace car ownership, driver's licenses and car ownership positively influence c-bike and e-bike ownership – even after controlling for the other covariates, specifically the economic status. Apart from that, public transportation passes reduce the probability of owning a bicycle. This influence is much stronger for e-bikes and the combined ownership of a c-bike and an e-bike than for c-bikes.

4.3. Descriptive analysis of c-bike and e-bike usage

At the trip level, we consider the modes of walking, cycling, public transportation (PT), and motorized private transportation. For the latter, we use the term 'car' in the following, as it is predominantly car-based. For the descriptive analysis, we use the dataset after filtering unclear values for potential factors of the logit model to be implemented later. The overall trip-related mode share distribution is displayed in Table 5 and shows that the car has a mode share of more than two-thirds, followed by walking, cycling, and PT.

Table 5: Mode share (n = 505,740)

Mode	Share [%]
Walk	18.1
Cycling	8.9
PT	4.9
Car	68.1

Figure 4 shows the mode choice for different levels of bicycle ownership depending on trip length. While cycling is almost negligible for people with no bicycle at all, the cycling share is highest for trip distances between 0.5 and 2 km for each type of bicycle ownership. After 2 km, the cycling shares decrease continuously for people with only a c-bike. However, this decrease is less steep for the two groups with e-bike ownership. Consequently, the proportion of trips over 2 km made by bicycle is much higher than for those who only own a c-bike. In addition, the total cycling shares are higher for those with an e-bike and highest for those with both an e-bike and a c-bike. For long trips, the car is dominant for all four groups, but the share of public transportation also increases with trip length.

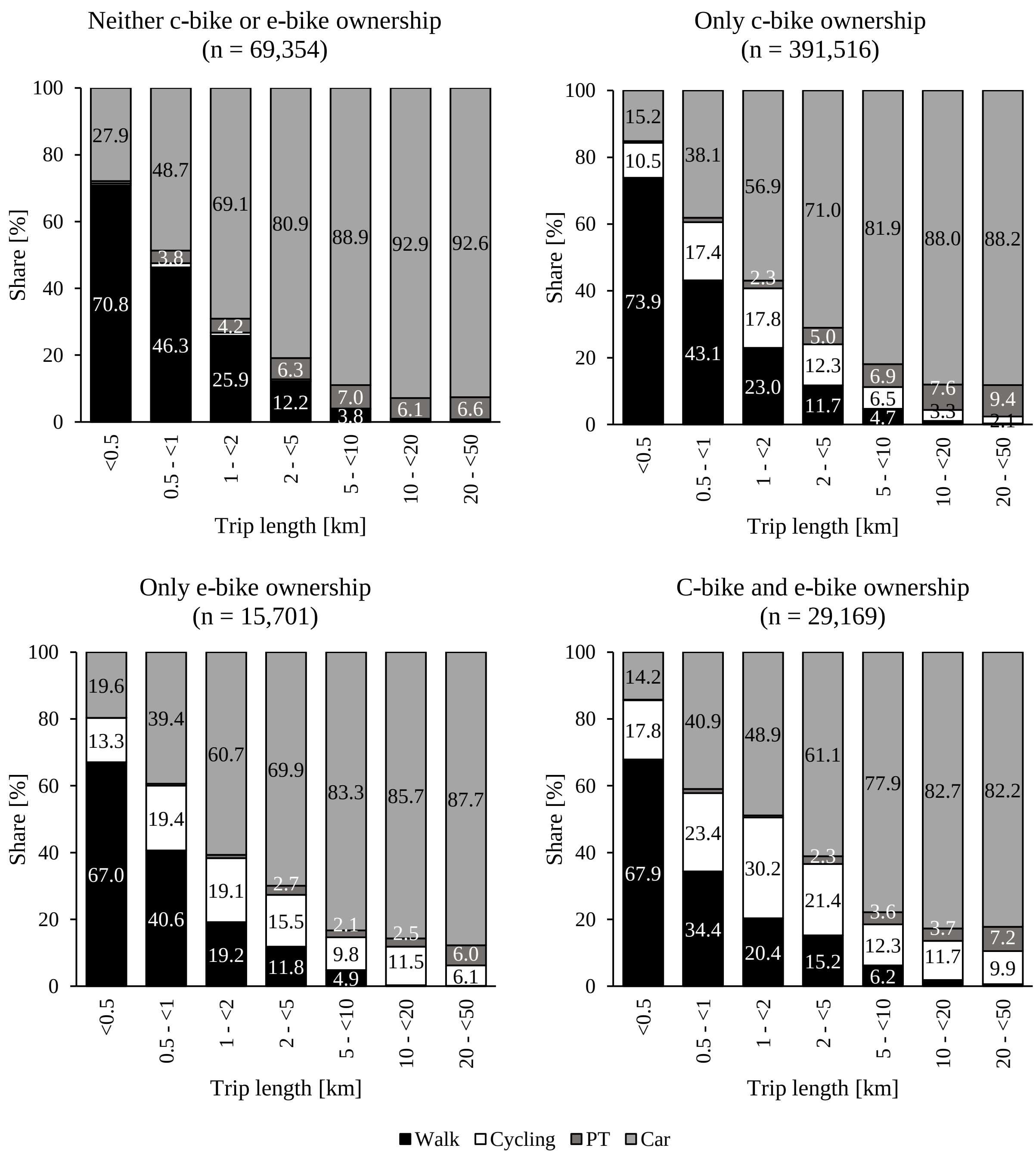

Figure 4: Mode choice related to trip length for different bike ownership

4.4. Multivariate analysis of mode choice

We estimated a second multinomial logit model to analyze the mode choice of those with multiple options. As explanatory variables, the final model includes bicycle ownership, socioeconomic and situational variables, as well as interaction variables that examine the combined effect of socioeconomic and situational variables and e-bike ownership, e.g., e-bike ownership and gender. Table 6 shows the results.

Table 6: Coefficients multinomial logit mode choice (McFadden $R^2 = 0.319$)

Reference:	Car	Walking	Cycling	PT
Intercept		1.633 ***	-	-4.605 ***
E-bike ownership		-0.144 ***	-1.836 ***	-
Gender	Men	0.062 ***	0.111 ***	-
	Men and e-bike ownership	-	0.168 ***	-
Age	Years > 16	0.055 ***	0.007 ***	-
	Years > 16 and e-bike ownership	-	0.163 ***	-0.026 ***
	Years > 30	-0.07 ***	-	-
	Years > 30 and e-bike ownership	-	-0.173 ***	-
	Years > 50	0.034 ***	-	0.016 ***
	Years > 50 and e-bike ownership	-	0.02 ***	0.046 ***
	Years > 70	-0.029 ***	-0.012 ***	-
Living place (ref = Middle-sized town in an urban region)	Metropolis	0.666 ***	0.894 ***	1.014 ***
	Metropolis and e-bike ownership	-	-0.668 ***	-
	City	0.4 ***	0.554 ***	0.405 ***
	City and e-bike ownership	-	-0.13 ***	-
	Provincial area in an urban region or a central city in a rural region	0.185 ***	0.093 ***	-
	Provincial area in an urban region or a central city in a rural region and e-bike-ownership	-	-0.182 ***	-
	Middle-sized town or provincial area in a rural region	-0.173 ***	-0.252 ***	-0.446 ***
Economic status of the household medium or higher		-	0.082 ***	0.164 ***
Public transportation pass		0.569 ***	0.403 ***	2.669 ***
Winter	-	-	-0.809 ***	0.19 ***
	E-bike ownership	-	-0.426 ***	-
Spring	-	-0.067 ***	-0.304 ***	-
	E-bike ownership	-	-0.225 ***	-
Autumn	-	-0.1 ***	-0.4 ***	-
	E-bike ownership	-	-	0.429 ***
Trip purpose (ref = work and 'other trip purposes')	Education	0.897 ***	0.596 ***	1.224 ***
	Business	-0.583 ***	-1.233 ***	0.464 ***
	Business and e-bike ownership	-	1.202 ***	-
	Shopping	0.281 ***	-0.378 ***	-0.993 ***
	Private errands	0.681 ***	-0.228 ***	-0.423 ***
	Private errands and e-bike ownership	-	0.199 ***	-
	Leisure	2.185 ***	0.649 ***	0.091 ***
Trip length	- [km]	-3.527 ***	-0.935 ***	0.529 ***
	E-bike ownership [km]	0.033 ***	0.042 ***	0.016 ***
Trip length over 1 km [km]		2.897 ***	0.509 ***	-0.427 ***
Trip length over 5 km [km]		0.479 ***	0.367 ***	-0.089 ***

Significance codes: '***' $0 < Pr(>|z|) < 0.001$, '**' $0.001 < Pr(>|z|) < 0.01$

For the reference category car, the intercept is positive for walking and noticeably negative for PT. Counterintuitively, e-bike ownership has a substantial negative effect on cycling. It must be borne in mind that the interaction variables, specifically age, capture much of the influence of e-bike ownership.

For men, there is a positive impact on the active modes of walking and cycling. In addition, the probability of cycling increases even further when men own an e-bike.

Figure 5 shows the resulting probabilities from the influence of age on mode choice for a reference case with a trip length of 2.5 km. For those without an e-bike, the probability of choosing the car decreases almost continuously with increasing age. For people with an e-bike, the probability of using the car decreases substantially, and the probability of cycling increases until the age of 30. After this age, owning an e-bike roughly doubles the likelihood of cycling compared to owning only a c-bike.

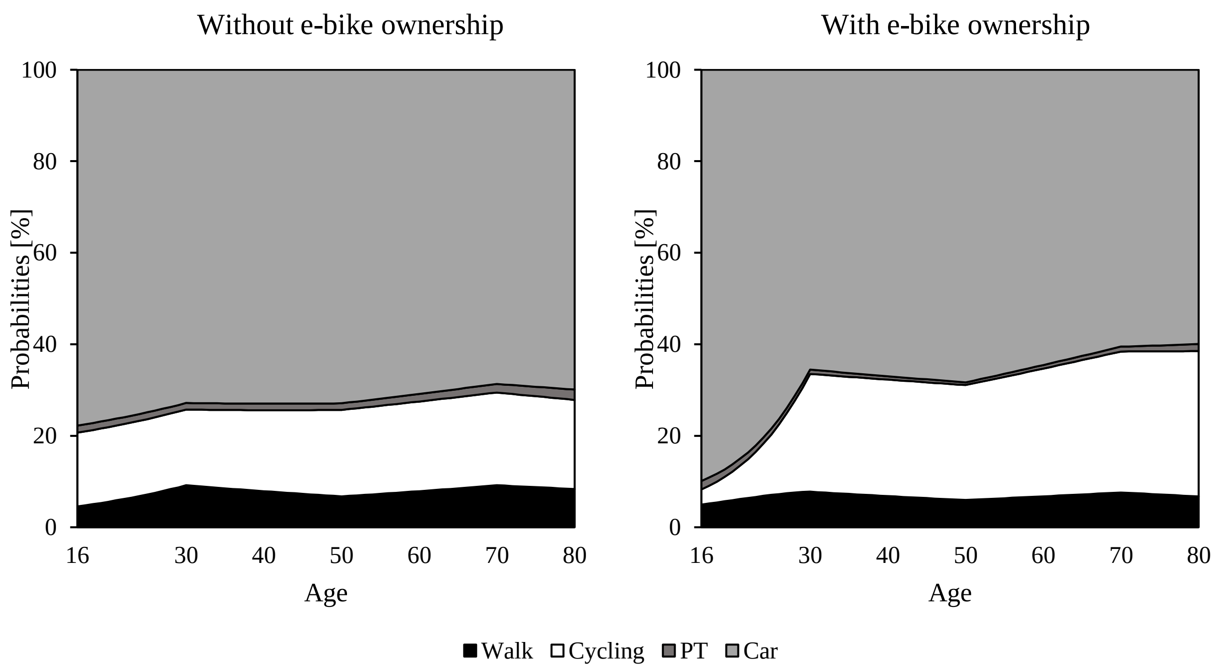

Figure 5: Probabilities for different modes by age for the reference case of a trip length of 2.5 km

The probability of choosing walking, cycling, or public transportation is generally highest in metropolises and cities. However, the combination of e-bike ownership and metropolis has a negative influence on cycling. This could be due to the higher risk of theft for e-bikes. This effect is less pronounced but still measurable in cities. Apart from this, public transportation and cycling seem to be less attractive in rural than in urban areas.

Higher household economic status has a small positive effect on cycling and public transportation. Owning a public transportation pass has a substantial positive influence on public transportation and a less strong on walking and cycling.

Mode choice depends on the season. With summer as a reference, other seasons, especially winter, reduce cycling. Moreover, there is an additional decrease in cycling in the case of e-bike ownership in winter. For spring, the results are similar but less pronounced. For autumn, e-bike ownership increases public transportation use during this season, while the influence on cycling yielded insignificant coefficients in previous calculations. Therefore, the coefficient for the direct influence of autumn on cycling is not included in the final model.

Education trips are associated with a reduced car mode choice. While business trips are generally associated with a reduced probability of cycling, the combination of e-bike ownership and the trip purpose has an adverse effect. The same is valid to a lesser extent for the trip purpose private errands. For leisure trips, the mode choice for the car is reduced, and the probability of walking is substantially increased. The combined influence of e-bike ownership and leisure trips was insignificant and is therefore not included in the model presented.

Figure 6 shows the trip length-dependent mode choice probabilities for a 50-year-old reference person based on the model. The likelihood of walking decreases rapidly with increasing trip length from the first meter onward. For cycling, this decline starts after one kilometer. The share of cycling is higher for people who own an e-bike and remains much higher even for trips longer than 5 km. While the car dominates the mode choice except for short distances, the shares of public transportation are negligible due to the geographic reference case and the assumption of no public transportation pass ownership.

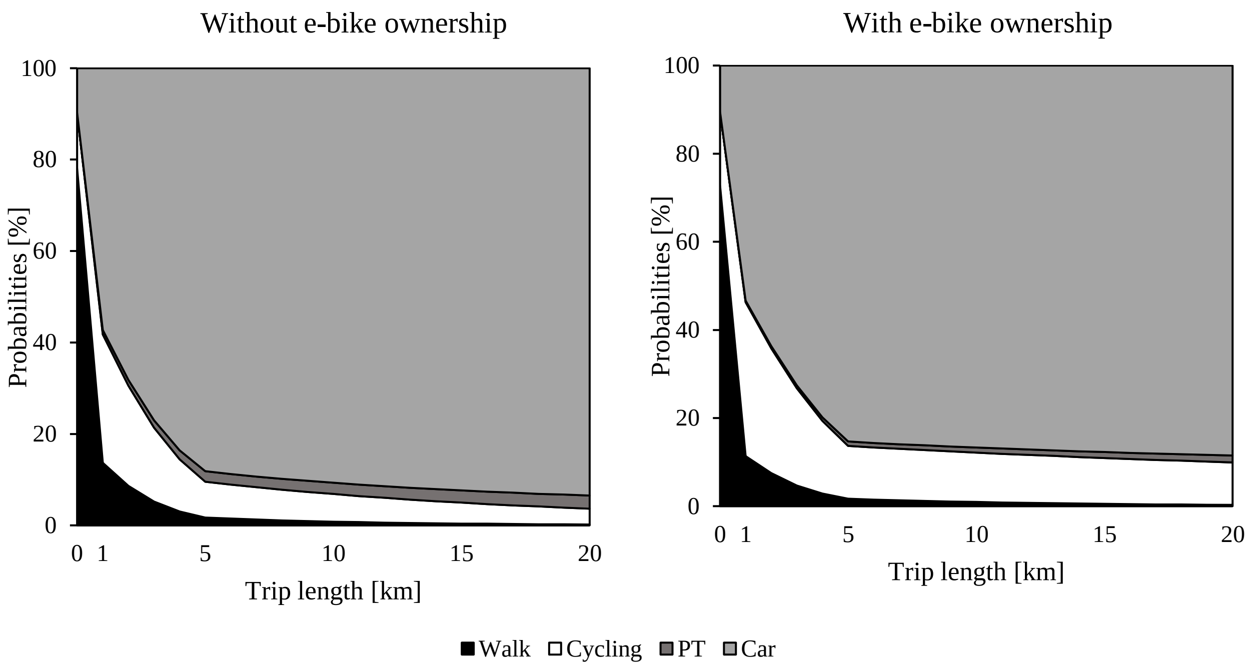

Figure 6: Probabilities for different modes related to trip length and e-bike ownership for a 50-year-old reference person

5. Discussion

This paper examines the effect of e-bike ownership on travel behavior by age and socioeconomic status, filling a gap identified by Bourne et al. (2020). E-bike ownership depends on economic status, likely due to the higher purchase price compared to c-bikes. Additionally, the share of e-bike ownership is higher in older age groups, and e-bikes increase cycling in later age groups, confirming other literature (Kroesen, 2017). Both seem to correspond to the comfort of motor-assisted cycling due to physical and medical conditions as known reasons to buy an e-bike (MacArthur et al., 2018). Apart from that, this paper presents several new findings, such as that the positive influence of e-bike ownership on mode choice is reduced for young people and increases with age. Instead, results from the Netherlands mention that the use of e-bikes decreases with age (Kroesen, 2017).

Furthermore, the influence of e-bike ownership crossed with the trip purpose leisure on cycling was insignificant, in contrast to MacArthur et al. (2018), who found that people in the USA purchase e-bikes in part precisely for leisure trips and recreation purposes.

There are no indications that e-bike ownership is replacing car ownership. These findings are in line with previous research (Kroesen, 2017), and the results are similar to those of the German Mobility Panel (Ecke and Chlond, 2021). Apart from that, e-bikes are mainly owned outside of metropolises and cities. While the probability of cycling is generally higher in large cities, this is less pronounced for e-bike owners. Therefore, as noted in other research, they appear to be more useful in sparsely populated areas (Sun et al., 2020; Philips et al., 2022).

Seasons with unfavorable weather conditions have a greater negative impact on cycling when people have an e-bike. The negative impact of bad weather on cycling is already known. But the stronger influence on e-bike use is new and contradicts the thesis that e-bike use is less weather sensitive. In the past, Kruijf et al. (2021) concluded that bad weather conditions, such as wind, affect e-bike use less than c-bike use due to motor support. However, our findings may be related to e-bikes as vehicles for seniors: One possible explanation is that e-bike owners have more freedom to choose which mode to use or whether they make trips in bad weather at all due to fewer work commitments.

The results also support the role of e-bikes as range extenders for the cycling mode. Previous studies have found this effect and suggested higher travel speeds and less physical effort as reasons (Sun et al., 2020). However, there is a typical chicken-egg dilemma. It is unclear whether passionate cyclists buy an e-bike to make their long trips faster or whether people make longer trips by bicycle because of the benefits of an e-bike. Although previous analyses of mode change after e-bike purchase support the finding of the range extender effect (Plazier et al., 2017), we do not know if a self-selection bias also influences this. While our analysis shows which factors influence bicycle ownership and mode choice, the analysis of household travel surveys cannot explain why this is the case. Therefore, further analysis of longitudinal data is advisable and may be possible as e-bikes become more widespread.

Another question concerns the competition between public transportation and e-bikes. While Kroesen (2017) found that e-bike owners travel much less by public transportation, our results are mixed: On the one hand, having a public transportation pass reduces the probability of owning an e-bike. On the other hand, e-bike ownership positively affects public transportation use by increasing trip length. The interaction between e-bike ownership and age and the impact on public transportation use is also complex.

The data for our analysis comes from a survey conducted in 2016 and 2017. Since then, the number of e-bike owners, the e-bikes themselves, and general mobility behavior have changed, mainly due to the COVID pandemic. While we believe that the results of this study reflect the pre-COVID situation relatively well, some results will likely look different with newer data. A new national travel survey will be conducted in Germany in 2023, which will provide an updated picture of e-bike ownership and use. The new data may also reflect the establishment of e-scooter sharing schemes and other micro electric vehicles. In addition, the uptake of s-pedelecs is expected to be significantly higher.

Infrastructure, settlement patterns, and mobility patterns vary between countries. Therefore, it is not surprising that we found differences in e-bike use between Germany and other locations from previous studies, particularly the Netherlands. This points to problems in transferring results from one country to another and underlines the need for country-specific research on this topic. It is not even easy to generalize results within a country due to different legislation on e-bike types, e.g., between states in the USA (MacArthur and Kobel, 2017). Household travel surveys also often follow the local regulations on bicycle types, resulting in different categorizations. Standardized categories would facilitate international comparisons. Apart from that, new subscription models for e-bikes and the provision of e-bikes by companies to their employees as part of their salary make comparisons more difficult as these vary between countries and depend on specific tax laws. Furthermore, differences in the market penetration of e-bikes between countries result in varying proportions of e-bike owners in socioeconomic groups and therefore diverging patterns of e-bike use.

Thus, our results reflect a transitional phase of e-bike market take-up that other countries are still in or may enter in the coming years. Furthermore, while many previous findings have come from the Netherlands due to their lead in market penetration and higher cycling rates in general, the results in this paper refer to German conditions. This includes a cycling infrastructure that is worse than in the Netherlands but probably better than or closer to the quality of infrastructure in most countries. In addition, Germany, like most countries, is much more hilly than the Netherlands. Therefore, our results contribute to a more complete picture of the impact of e-bikes on mobility, which may – in some cases – better reflect local conditions that are not as conducive to cycling as in the Netherlands.

6. Conclusion

Our results confirm several findings on e-bike ownership and use from other countries. However, some of our findings go beyond those of previous studies, while others are contradictory. In our study, mainly people from older age groups with higher wealth own e-bikes. E-bikes also increase the mode share of cycling mainly in these age groups. In general, the peak of bicycle ownership is between the ages of 40 and 50, while for e-bikes it is at 70. E-bike ownership increases cycling mode share less for young people, which is inconsistent with previous research. Later, in age groups over 70, ownership of both c-bikes and e-bikes declines, but usage remains high in the case of e-bike ownership.

Being male increases both the ownership of c-bikes and e-bikes and the probability of cycling. The increase in the likelihood of cycling is even stronger for men who own an e-bike. However, it is questionable whether e-bikes can be a game changer for increasing the sustainability of mobility behavior, especially for work-related trips, as long as most owners are at the end of their working life or even retired. Furthermore, there is a significant negative coefficient for the influence of e-bike ownership on cycling during bad weather seasons.

In contrast, our results support the thesis that e-bikes serve as a range extender, keeping the cycling mode share higher even for trips longer than 10 km, and they generally almost double the cycling mode share. The results contradict claims that e-bikes are primarily bought and used for leisure trips. E-bikes are mostly owned in rural areas where public transportation is less attractive; thus, their main competitor is the car. As our results show that e-bikes are mainly owned and used by older people, they can increase their mobility options, support their health, and contribute to their quality of life. The findings of the range extender effect and the positive influence of e-bike ownership on public transportation use also support the argument that e-bikes can contribute to more sustainability, at least in Western societies. As a policy measure, it would be reasonable for public authorities to drive the market penetration of e-bikes with subsidies, as is the case for electric cars, or by supporting e-bike subscription models.

Apart from that, policymakers could address some barriers. Firstly, companies that provide charging infrastructure and electricity to their employees and customers should not have to deal with tax issues. Also, there is still no standardization of charging equipment yet, which means that e-bike owners have to take the right charger with them when they want to recharge during a trip chain. This should be addressed through political pressure. Apart from that, special public transportation passes as a backup for cyclists during bad weather seasons may encourage commuting by bicycle.

However, it is unclear how the increasing diffusion of e-bikes among the population affects their usage patterns. The perception of e-bikes as an opportunity for retired people with reduced physical abilities seems to be changing in Germany. Working-age people increasingly consider e-bikes as an opportunity to expand their mobility options. It will be interesting to repeat this analysis with future data based on a broader diffusion of e-bikes in the population, especially among working age groups. This is also valid for the influence of the COVID 19-pandemic and the establishment of e-scooters, especially in sharing systems.

7. Author contribution

The authors confirm their contribution to the paper as follows: research, analysis, and interpretation: David Kohlrautz. Supervision and advisory: Tobias Kuhnimhof. All authors reviewed the results and approved the final version of the manuscript.

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