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“Cycling was never so easy!” An analysis of e-bike commuters’ motives, travel behaviour and experiences using GPS-tracking and interviews

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Abstract

The market for electrically-assisted cycling is growing fast. When substituting motorized travel, it could play an important role in the development of sustainable transport systems. This study aimed to assess the potential of e-bikes for low-carbon commuting by analysing e-bike commuters' motives, travel behaviour and experiences. We GPS-tracked outdoor movements of 24 e-bike users in the Netherlands for two weeks and used their mapped travel behaviour as input for follow-up in-depth interviews. Most participants commuted by e-bike, alternated with car use. E-bike use was highest in work-related, single-destination journeys. It gave participants the benefits of conventional cycling over motorized transport (physical, outdoor activity) while mitigating relative disadvantages (longer travel time, increased effort). The positive experience of e-bike explained the tolerance for longer trip duration compared to other modes of transportation. Participants were inclined to make detours in order to access more enjoyable routes. Results demonstrate that e-bikes can substitute motorized commuting modes on distances perceived to be too long to cover by regular bike, and stress the importance of positive experience in e-bike commuting. This provides impetus for future actions to encourage commuting by e-bike.

Key words: Electrically-assisted cycling, commuting, sustainable transport, active transportation, mobility behaviour, route choice

1. Introduction

A major development in transportation in the past years has been the growth of electrically assisted cycling or e-biking. Defined here as pedal-assisted or bicycle-style electric bicycles, e-bikes make it possible to cover longer distances at higher speeds against reduced physical effort. In many countries like Germany and the Netherlands, e-bikes account for a rapidly growing share of new bikes sold (CONEBI 2016). Findings from previous studies suggest that e-bike adoption can to some extent lead to substitution of trips formerly made using motorized transportation (Jones et al. 2016; Lee et al. 2015). It thus appears a viable alternative to commuting by automobile and public transportation. An increasing amount of research has focused on e-biking, but less attention has been paid to e-bike use for commuting, and the extent to which it can substitute motorized commuting. A better understanding of the mode choices and their effects are needed to guide future actions to encourage functional e-bike use, in attempts to further establish low-carbon commuting habits. This paper addresses these issues by providing further insight into the potential for mode substitution.

The aim of this study was to assess the potential of e-bikes for sustainable commuting by analysing e-bike commuters' motives, travel behaviour and experiences. To accomplish this aim, we GPS-tracked the daily travel behaviour of 24 e-bike commuters in the north of the Netherlands and held follow-up in-depth interviews discussing their motives and experiences. In the remainder of this paper, we first discuss prior research on e-bike use and the need for comprehensive travel behaviour data as input for policy. We then present and discuss the methods and results of the study.

1.1 Prior research on e-bikes

There is growing consensus that current levels of motorized transport negatively impact environmental quality, quality of life, and accessibility to the extent of being unsustainable (Kenworthy & Laube 1996; Steg & Gifford 2005). E-bikes, especially if they are of the pedal-assisted type, provide a sustainable, healthy alternative for motorized transportation on distances too long to cover by regular bike. As such, the e-bike has attracted a considerable amount of research attention (Fishman & Cherry 2015; Rose 2012; Dill & Rose 2012; MacArthur et al. 2014; Popovich et al. 2014; Jones et al. 2016). This research has mostly focused on relative advantages and disadvantages of the e-bike compared to other modes of transportation regarding aspects like health, comfort, safety, travel speed and travel distance (Fishman & Cherry 2015).

As pointed out by Fishman & Cherry (2015) e-bike use is especially high in countries with traditionally high levels of conventional cycling, such as most northern European countries. In these countries, safety and infrastructural barriers to cycling have largely been overcome, making it possible to utilize the full benefits of e-bikes. Research to date indicates that e-bikes, as opposed to conventional bikes, permit bridging longer travel distances, reduce travel times, mitigate physical effort, overcome geographical or meteorological barriers, and facilitate cycling for elderly or physically impaired individuals (Dill & Rose 2012; Johnson & Rose 2015; Jones et al. 2016; Popovich et al. 2014; Fyhri & Fearnley 2015; Lee et al. 2015; MacArthur et al. 2014). However, there has been some concern for the effects of e-bikes on safety, health and environment. Evidence so far shows that e-bike users are subject to slightly higher risks of injury (Fishman & Cherry 2015). The likelihood of hospitalization is higher for older or physically impaired victims. Contributing factors are heaviness of the e-bike, increased speeds and cycling without protection. Yet, crashes are often one-sided (Schepers et al. 2014; Vlakveld et al. 2015). The lower levels of physical activity compared to conventional cycling have also caused concern for health. However, preliminary evidence suggests that assisted cycling can still satisfy moderate-intensity standards and thus promote good health (Sperlich et al. 2012; Simons et al. 2009; Gojanovic et al. 2011).

Finally, concerns have been raised regarding e-bike batteries. During the rapid uptake of lead-acid powered e-bikes in China in the late-1990s and early 2000s, poorly regulated production, disposal and recycling of lead batteries negatively affected environment and public health (Cherry et al. 2009; Weinert et al. 2007). In recent years, the industry has shifted to the use of Lithium-Ion batteries, which offer performance and environmental benefits over lead-acid batteries (Fishman & Cherry 2015). In Europe, collection and recycling of batteries are regulated in the "battery directive" adopted by the European Parliament in 2006 (EUR-Lex 2006). This directive prohibits disposal of batteries in landfills or by incineration, and states that all collected batteries should be recycled.

Although e-bikes are increasingly popular, their contribution to sustainable transport behaviour is still limited. In the Netherlands, e-bike use is especially high among older adults, who predominantly use it for leisure purposes (KiM 2016, pp.17, 18). And despite findings that e-bike trips can substitute trips by car and public transport, Kroesen (2017) suggests that e-bike ownership to date mostly substitutes conventional bike use. Nonetheless, e-bikes hold growing appeal to increasingly younger populations including students, commuters and parents, who carry children and groceries or travel long distances on a day-to-day basis (Stichting BOVAG-RAI Mobiliteit 2016; KiM 2016; Peine et al. 2016; Plazier et al. 2017). Considering the disproportionate impacts of motorized commuting on congestion and environmental pollution, transport officials are increasingly interested in the potential of e-bikes as a sustainable alternative for motorized commuting. As yet, however, little is known about the opportunities and barriers for commuting by e-bike.

1.2 Travel behaviour in research and policy

In general terms, sustainability in transport is related to balancing current and future economic, social and environmental qualities of transport systems (Steg & Gifford 2005). In recent years, research on sustainable transport behaviour has used insights from psychological theories to provide practical guidelines for the development of personal travel campaigns, awareness raising and promotion of alternative transport options (Heath & Gifford 2002; Bamberg et al.

2003; Groot & Steg 2007; Hiselius & Rosqvist 2016). These guidelines have to a large extent relied on financial rewarding schemes and elements of gamification, which focus on individual reasoned action in order to achieve major social change (Barr & Prillwitz 2014; Te Brömmelstroet 2014). A major limitation of these approaches, however, is that they do not take into account that a large part of people's travel decisions are not deliberately made, but are based on routines and activated by daily situational cues (Müggenburg et al. 2015). The question remains to what extent sustainability in itself forms a motive to change travel behaviours.

In recent years, mobility research has increasingly taken a perspective in which travel is considered a routine activity shaped by a complex and ever-changing context, instead of the result of individual decision making (Guell et al. 2012; Cass & Faulconbridge 2016; Müggenburg et al. 2015). Within this approach, deliberate intentions, like concerns about sustainability, have been accorded less importance, while social and structural contexts have been argued to be significant shapers of individual travel behaviour.

However, while this more comprehensive approach to travel behaviour is gaining importance in travel behaviour research, application to e-bike use is limited. Qualitative insights on the subject are offered by Jones et al (2016), who consider e-bike users' motives, experiences and perceived changes in travel behaviour in the Netherlands and the United Kingdom. They found that motives for purchasing an e-bike were commonly related to a personal sense of decline in physical ability, but emphasized that it was often the outcome of multiple reasons including personal and household circumstances or critical events that led them to reflect on lifestyle and travel behaviour.

The present study examines the habitual travel behaviour of e-bike users by combining perceived and actual travel behaviour characteristics. In general, the value of combining these data has widely been recognized in the social sciences (Driscoll et al. 2007) and mobility and transport studies (Meijering & Weitkamp 2016; Grosvenor 1998; Clifton & Handy 2003). We formulated three research questions: (1) What were motives for purchasing and starting to use an e-bike? (2) Under what conditions can e-bikes substitute motorized commuting? (3) Which role do travel experiences play in the daily commute by e-bike? The behaviour of this group can provide important insights into the potential of the e-bike for commuting.

2. Method

2.1 Study area and participants

To study the commuting behaviour of e-bike users, we integrated two-week GPS data logs with follow-up in-depth interviews. The GPS data from individual participants informed the development of individual interview guides, whereas data retrieved from the interviews helped to control and validate the recorded GPS data.

The study took place in the north-eastern part of the Netherlands around the city of Groningen, at the intersection of the provinces of Groningen, Friesland and Drenthe (figure 1). Groningen is the largest city in the north of the Netherlands, with a population of approximately 200.000. It attracts a considerable amount of daily commuter traffic from the surrounding region. Around the city, most of the population lives in villages and small towns. The land mostly consists of grass- and farmland, and has a flat topography. Like the rest of the Netherlands, it has a temperate oceanic climate influenced by the North Sea, with average temperatures in the coldest months above zero, but regular frost periods. Periods of extended rainfall are common.

Twenty-four participants (12 men, 12 women), aged 25-65 years old (M=45 years, SD =9.3) participated in the study. All participants lived and worked in the study area. Nineteen participants commuted from their home village to the city of Groningen, two participants commuted from an outer suburb to Groningen, and three participants commuted from village to village in the area southwest of the city. Participants owned their own e-bike, and had been using it regularly for a period ranging from a month up to four years at the time of the study. Twenty-one participants owned a regular e-bike, which is the most common model in the Netherlands, and legally defined as a bike propelled by user pedalling and assisted up to 25 km/h. Three participants owned a speed pedelec. This type of e-bike can potentially assist up to 45 km/h (CROW-Fietsberaad 2015). All participants were regular cyclists, and most still owned and used a conventional bike after e-bike adoption.

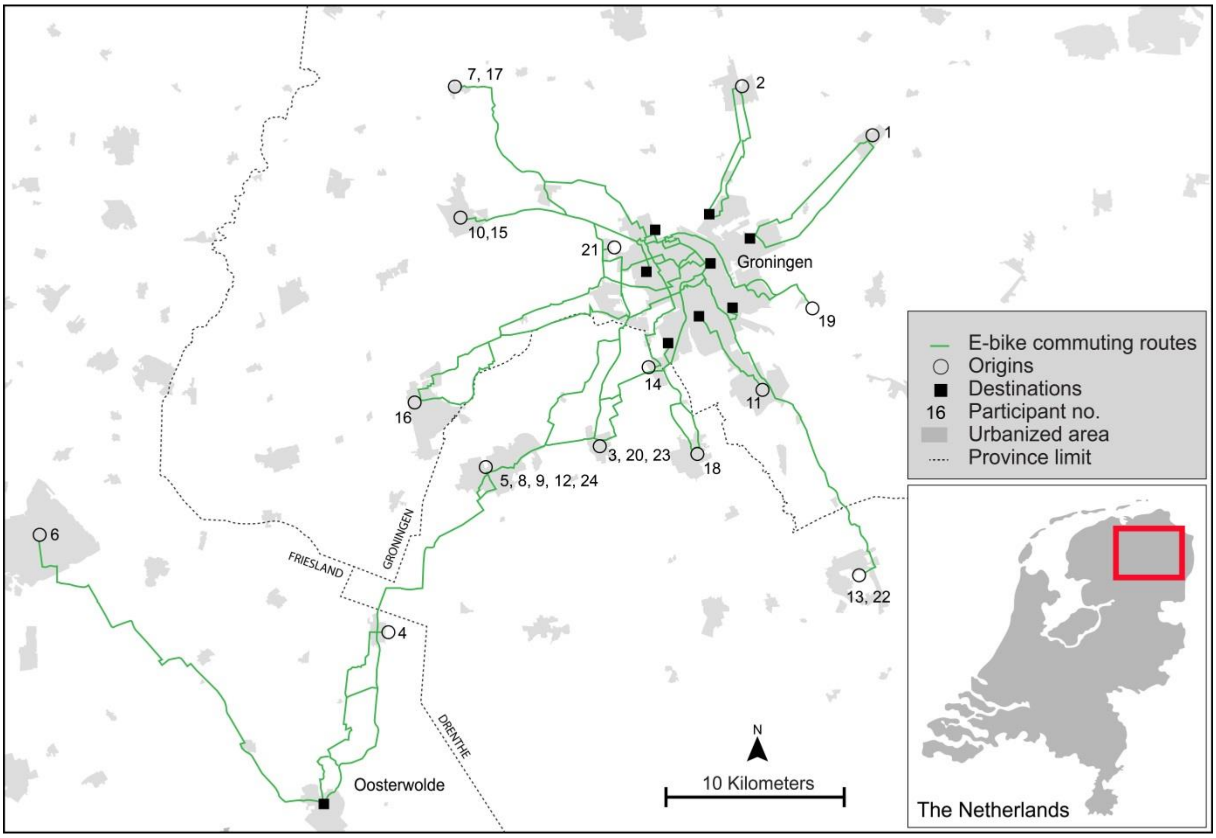


Figure 1 – E-bike commuting routes between participants' home and work locations

We recruited participants through snowball sampling and with help of Groningen Bereikbaar, the organization in charge of mobility management in the greater Groningen area. E-bike users were asked by e-mail to participate in the study, which was approved by the ethics committee of the Faculty of Spatial Sciences, University of Groningen. Oral and written instructions were provided before starting GPS tracking. All participants gave their written informed consent to both methods prior to the study, and gave permission for their anonymized data to be used for research purposes.

2.2 GPS tracking and analysis of GPS data

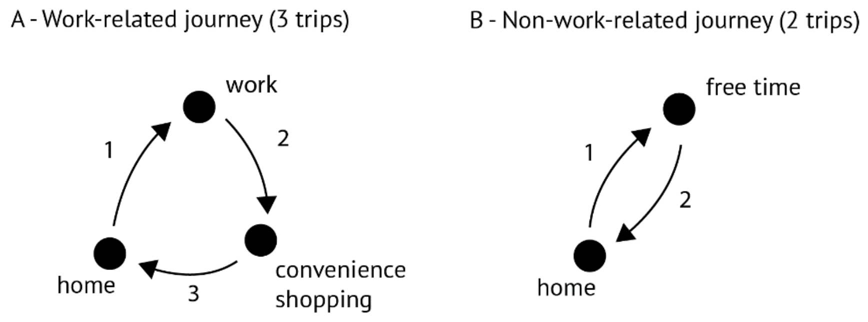
Tracking took place from November 2015 to April 2016. We asked participants to carry a GPS tracking device for 14 days including week-ends, tracking all their outdoor movements. This constituted a complete record of all travel movements and modes used in those two weeks. QStarz Travel Recorder BT-Q1000XT devices were used. These were found to have relatively high accuracy, good battery life and storage, and to be relatively easy-to-use (Schipperijn et al. 2014). Trackers were set to record GPS at a 10-second interval. 20 participants tracked for 14 days or more. On some of the days, travel behaviour was not recorded, as some participants had forgotten to charge the battery or bring the tracker. One participant tracked 12 days, two 10 days and one 8 days.

After collection of the devices, V-Analytics CommonGIS was used to remove noise from the GPS data and to define trajectories and destinations. The trajectories were categorized by mode based on recorded speeds and visualized paths using ArcGIS. For each participant, data were mapped in ArcGIS Online, which was discussed with the participants during the interviews. The GPS data were validated and re-coded based on the interview-data, where necessary. We distinguished seven types of destinations: work, personal, free time, shopping, appointment, visiting, school (Krizek 2003, see table 1).

Table 1 – Overview of types of destinations

Destination	Purpose
Work	Work locations
Personal	Getting a service done or completing a transaction, e.g. banking, fuel station
Free time	Non-task oriented activities, e.g. entertainment, dining, theater, sports, church, clubs
Shopping	Travel to buy concrete things, categorized here as **convenience shopping** (groceries) and **goods shopping** (furniture, clothing, home supplies)
Appointment	Activities to be done at a particular place and time, e.g. doctor’s appointment, meeting
Visiting	Visit social contacts such as family, friends
School	Dropping off and picking up children for school (pre-school, elementary school)

Trajectories were coded in trips (going from one place to another) and journeys (in other literature also referred to as ‘tours’, e.g. Krizek, 2003) (figure 2). Journeys were formed by round-trips (from home-to-home) and classified as either work-related or non-work-related. They contained multiple trips and could contain multiple destinations. For instance, in figure 2, journey A (work-related) contains 3 trips and 2 destinations (work and convenience shopping), whereas journey B (non-work-related) contains 1 destination and 2 trips. Differentiating between trips and journeys allowed analysing whether number and types of destinations in a journey influenced mode choice and the likeliness to commute by e-bike.



Trip	from - to
1	home - work
2	work - convenience shopping
3	convenience shopping - home

Trip	from - to
1	home - free time
2	free time - home

Figure 2 –
Classification of trajectories in trips and journeys

2.3 Interviews

The interviews were semi-structured, and included the following topics: first, participants were presented with the map of their travel behaviour during the days of tracking, and were given the opportunity to reflect on their trips and destinations. The map was also used to check whether modes had correctly been defined for each of the trajectories. The interviewer then asked questions about the participant's travel behaviour prior to e-bike adoption and reasons for buying an e-bike. Next, the interview zoomed in on the commuting route to work using the map and additional Google Streetview imagery. Finally, several aspects of e-bike use including safety, reliability, comfort and commuting experience were discussed.

The interviews were audio-recorded and transcribed verbatim. They were then coded in Atlas.ti using a grounded theory approach (Hennink et al. 2011, p.208). An interview guide was designed before the interviews with the aim of ensuring complete and consistent coverage in each interview of themes under study. A first round of deductive coding served to organize the interview transcripts according to these themes. We then inductively coded the issues emerging directly from the data. The resulting codebook was expanded and refined throughout the coding process. Relevant citations were translated from Dutch to English by the authors. To preserve confidentiality, all participants were referred to by their participant numbers.

3. Results

We first discuss participants' motivations for e-bike adoption. Then, the recorded travel behaviour is discussed. Finally, we consider participants' day-to-day mode choice and commuting experiences.

3.1 Motives for e-bike adoption

The interviews revealed that, before purchasing an e-bike, 19 participants mostly commuted by car, 3 by bike and 2 by bus. To car and bus users, conventional cycling had never been a serious alternative to their present commute: only three of them cycled to work sporadically, using it as a last mile mode of transport, or in case of good weather:

"I was the typical 'nice-weather cyclist'. I would only bike to work if there wasn't any wind and if it was dry" [participant 11, aged 55, 7 km commute]

Most participants had rarely questioned their routines:

"It was a habit… My car is parked right outside my house, so in the morning, I'd just jump in. No hassle, no schedules, good parking at work… It was just so convenient" [participant 23, aged 50, 11 km commute]

To those using motorized transportation, regular cycling to work would have meant a dramatic increase in travel time relative to their habitual commute to work, or excessive physical exercise causing them to arrive sweaty and tired. Despite these practical barriers to more active commuting, many participants (n=13) mentioned feeling uncomfortable with their prevailing commuting patterns, and buying an e-bike came from a longer held desire to change this behaviour. For the large majority (n=20), reconsideration of commuting habits followed work-related changes (changing jobs, moving work locations) or changes in the home environment (moving, having children, children growing older). Some mentioned participating in a pilot, or simply being offered a subsidy for a new bike.

"Both my children started high school this year, and they go there by bike. Well, I want to bike too! But I don't want to arrive here all warm and sweaty. So that's when it came to me" [participant 4, aged 40, 10 km commute]

"*We wanted to get out of that car, so the will was already there. Then, we were offered a bike subsidy, and we decided to do it"* [participant 9, aged 35, 16 km commute]

To all participants in this study, commuting was the prime motive for purchasing an e-bike, and few indicated the intention to use it for other purposes. Asked to what extent environmental issues played part in the choice to adopt an e-bike, only one participant stated this to be a driver behind the decision to purchase. The others saw it mostly as a fortunate coincidence:

"*To be honest.. I just need to get to work on time (laughs). And it's not like I ride my e-bike in order to not take the car, you know, for environmental reasons. It is a nice coincidence, but it was never decisive"* [participant 17, aged 54, 18 km commute]

"Well.. not so much. It is sustainable in the sense that I use my car less. But I don't think 'wow, that's neat, I saved the environment!' More like, 'wow, that's neat, I saved on gas' (laughs). If you ask me, was the environment a motive, I say no" [participant 2, aged 46, 8 km commute]

Rather than environmental issues, participants mentioned health (n=8) as one of the important reasons to buy an e-bike:

"*I thought, coming to work 4-days a week by bus, I don't get enough exercise. And 50-year old women like me need to start worrying about their Vitamin D levels!"* [participant 16, aged 50, 18 km commute]

"*At some point I noticed that, every time the weather was bad, or with a little wind, I would take the car (..) But I suffer a type of rheumatism. And they told me it's best to keep exercising regularly, so cycling is really important (..) That's when I decided to buy one"* [participant 24, aged 25, 13 km commute]

Most participants mentioned the high prices as a consideration in the decision to buy an e-bike, but this had not deterred them from purchasing one. Instead, some had chosen a simpler e-bike design that was less expensive. Others in turn found out they were eligible to employer compensation, or argued buying an e-bike substituted the purchase of a second car or allowed to save on gas or transit fares.

3.2 Two-week travel behaviour

A total of 1090 single-destination trips (going from one place to another) were recorded constituting 443 round-trip (home-to-home) journeys. In this section, we first discuss characteristics of trips, followed by home-to-home journeys. We complement GPS data results with interview data when considered relevant.

3.2.1 Trips

Out of the 1090 trips, more than one-third (34.5%) were made by e-bike (see table 2). E-bike use even accounted for the majority of the 250 trips to and from work (*n*=134, 53.6%). E-bike use was also relatively high for the 21 trips to and from school (*n*=29, 50%), which, according to the participants, were often combined with commuting. Car use (47.5% of the total number of trips) was the main alternative to e-biking for most destinations. The car was even preferred over the e-bike and other modes when spending free-time (63.3%), going shopping (55.9%) and visiting friends and family (83.3%). Active and public transport use was generally low, and conventional bike use was most frequent when shopping. Participants mentioned the habit of running errands by conventional bike, and did not consider e-bike use worthwhile for this purpose.

"It's a small village, and everything is so accessible. So for runs to the [grocery store], I use my normal bike" [Participant 10, aged 57, 11 km commute]

Table 2 – Frequencies of trips by mode and purpose

Purpose	**Car**	**E-bike**	**Walk**	**Bike**	**Bus**	**Train**	**Other**	**Total**
Work	80	134	15	1	13	5	2	250 *(22.9%)*
Personal	6	8	0	0	0	0	0	14 *(1.3%)*
Free time	81	24	15	5	1	3	0	128 *(11.7%)*
Convenience shop	51	12	14	17	1	0	0	95 *(8.7%)*
Goods shopping	20	5	1	5	0	1	0	32 *(2.9%)*
Appointment	4	6	0	0	0	0	0	10 *(0.9%)*
Visit	65	10	6	2	1	1	2	87 *(8.0%)*
School	21	29	1	7	0	0	0	58 *(5.3%)*
Home	190	148	33	29	9	5	2	416 *(38.2%)*
Total	518 (47.5%)	376 (34.5%)	85 (7.8%)	66 (6.0%)	25 (2.3%)	14 (1.3%)	6 (0.6%)	1090 *(100%)*

Of the 1090 trips, 305 were commuting trips. This includes trips from home to work and work to home. Of these commuting trips, 63.3% were done by e-bike, followed by car (28.2%) and bus (6.2%) (table 3). Comparison of average commuting distances shows that e-bike trips to work covered an average of 14.1 kilometres. Longer commuting distances were covered by bus, car, train and motorbike respectively. While e-bike commutes were shortest in distance, they took longer (*M*=46 minutes) than commutes by car (*M*=29.7 minutes), and about equally long as commutes by bus (*M*=46.6 minutes). This suggests that equal or longer travel times did not deter participants from using an e-bike instead of car or bus.

Table 3 – Numbers of commuting trips with average distance and duration by mode

Mode	**N *(%)***	**Km *(SD)***	**Min *(SD)***
Car	86 *(28.2%)*	24.0 *(30.1)*	29.7 *(19.0)*
E-bike	193 *(63.3%)*	14.1 *(5.5)*	46 *(13.5)*
Walk	0 *(0.0)*	0.0 *(0.0)*	0.0 (0.0)
Bike	0 *(0.0)*	0.0 *(0.0)*	0.0 (0.0)
Bus	19*(6.2%)*	20.5 *(3.5)*	46.6 *(8.6)*
Train	5 *(1.6%)*	197.4 *(12.3)*	148.2 *(13.0)*
Motor	2 *(0.7%)*	25.9 *(0.2)*	34.6 *(4.3)*
Total	305 *(100%)*	-	-

3.2.2 Journeys

In addition to trips (single trajectories going from one place to another) we also analysed the distribution of journeys (round-trips from home-to-home). These journeys were classified as work-related (i.e. including a work destination) or non-work related. Table 4 shows that the majority of work-related journeys with work as the single destination were made by e-bike (72.6%), followed by car (20%), bus (6%) and train (2%). When the journey had to be combined with other destinations, the distinction was less clear, and car use was about as high (43.9%) as e-bike use (45.1%). E-bike use was generally lower in the non-work-related journeys. Here, car use was common on longer distances, and walking and cycling were frequent on shorter distances. For both work and non-work related journeys, the travel distance was generally higher for multiple destination-journeys (e.g. grocery shopping or picking up kids after work) than for single destination journeys. For example, work-related journeys done by car were almost 30 kilometres longer if multiple destinations were included. In the case of e-bike use, work-related journeys were more than 7 kilometres longer on average. An average of 1.8 additional destinations were reached by e-bike on work-related journeys, whereas by car an average of 2.1 destinations per journey were reached in addition to work. Thus work-related car journeys included more additional destinations than work-related e-bike journeys. Additional destinations in work-related car journeys were also more often work destinations than additional destinations in e-bike journeys. This was supported by participants' statements that they were more likely to commute by car if they had to reach multiple work destinations throughout the day. We further discuss this in the next section.

Table 4 – Count and average distance of work and non-work journeys, categorized by destination

	Work-related journeys				**Non-work-related journeys**			
	Single destination		**Multiple destination**		**Single destination**		**Multiple-destination**	
Mode	**N *(%)***	**KM (SD)**	**N *(%)***	**KM (SD)**	**N *(%)***	**KM (SD)**	**N *(%)***	**KM (SD)**
Car	23 (*19.6%)*	39.5 (33.6)	36 *(43.9%)*	69.8 (96.8)	92 *(52.0%)*	30.5 (51.8)	44 *(68.8%)*	38.2 (46.0)
E-bike	85 *72.6%)*	26.4 (11.6)	37 *(45.1%)*	33.1 (12.4)	23 *(13.0%)*	7.7 (8.6)	13 *(20.3%)*	9.6 (7.8)
Walk	0 *(0.0%)*	0.0 (-)	0 *(0.0%)*	0.0 (-)	34 *(19.2%)*	3.1 (2.8)	1 *(1.6%)*	2.4 (-)
Bike	0 *(0.0%)*	0.0 (-)	0 *(0.0%)*	0.0 (-)	24 *(13.6%)*	2.9 (4.3)	5 *(7.8%)*	2.9 (1.3)
Bus	7 *(6.0%)*	32.2 (11.9)	6 *(7.3%)*	48.5 (18.2)	1 *(0.6%)*	31.7	0 *(0.0%)*	0.0 (-)
Train	2 *(1.7%)*	405.1 (8.3)	3 *(3.7%)*	336.8 (179.2)	2 *(1.1%)*	358.9 (235.2)	1 *(1.6%)*	439.2 (-)
Motor	0 *(0.0%)*	0.0 (0.0)	1 *(1.2%)*	463.5 (-)	1 *(0.6%)*	2.7 (0.0)	0 *(0.0%)*	0.0
Total	117 *(100%)*	-	82 *(100%)*	-	177 *(100%)*	-	64 *(100%)*	-

3.3 Commuting mode choice and experiences

In the interviews, which were supported by the individual route maps created from GPS data, participants were also asked about their daily mode choice and experiences on the road. GPS tracking revealed that e-bike use was mostly alternated with car use. Two important factors were discerned: participants' daily agenda's, and the weather. Seventeen participants explicitly stated to choose modes according to their day planning. Some referred to the e-bike's limited battery range:

"I went to work in the morning, and then had a conference meeting in the afternoon. I would have loved to do that by e-bike, but it's just not doable given my bike's battery life" [participant 1, aged 61, 9 km commute].

For others, car use followed from the need to combine activities in limited amounts of time:

"I also work at [location], all the way on the other side of town (..) It just takes too much time [by e-bike], so I'll take the car" [participant 2, 46, 8 km commute]

"Yesterday, we had open day here at [work], so I needed to stay over in the evening. But I prefer to go home to have dinner, so I knew I had a tight schedule, because I only have 45 minutes to go back and forth. So I took the car" [participant 4, aged 40, 10 km commute]

Participants stated preferring the car over the e-bike when work locations were further away, when combining destinations, or when picking up or dropping off children at various activities. This is consistent with the GPS data, which showed an increase in car use on journeys with multiple destinations (table 4).

Another factor was the weather. To a majority, rain was a major influence (*n*=18). While participants did not mind a bit of rain, heavy showers triggered higher levels of car use. Six of them stated rain to be an influence more on the way to work than on the way back.

"I check the weather in the morning, and if rain is predicted for the entire trip to work I just take the car (..) But getting home wet, it doesn't really matter. I can change clothes at home and that's it" [participant 12, 47, 16 km commute]

Potential exposure to rain meant more carefully planning the trip to work. Most mentioned minor alterations to their commute routine: the night before, participants checked weather apps, and eventually prepared rain-clothing. However, wind influence seemed to have lost its significance. Before they owned an e-bike, wind formed a major factor in participants' commute through the open landscape, and mitigation of its influence was mentioned as the greatest asset of the e-bike. This made it easier to choose cycling over driving.

To six participants, weather circumstances did not influence their commutes anymore after adopting an e-bike. Some even mentioned the satisfaction of going out in bad weather:

"Rain, or thunder, I don't care, I love it. I put my rain suit on, I don't let the weather stop me. (..) I don't know, I think I just like braving the elements a bit" [participant 1, 61, 9 km commute]

Despite variations in levels of use due to weather and day planning, the e-bike was overall considered to be the standard commuting mode. Asked what motivated them to use the e-bike on a regular basis, participants accorded little attention to classic mode choice influences like speed (*n*=3) or directness of the route (*n*=3). Rather, they mentioned being outside (*n*=16), physical exercise (*n*=12) and freedom or independence from carpooling or public transit schedules (*n*=10) as the main reasons for daily e-bike travel. In addition, the commute by e-bike allowed mentally preparing for the day ahead or disconnecting from work (*n*=8). In the words of one participant, e-bike use meant a re-valuation of his commuting time:

"I consider driving to work a waste of time. Really, it's useless. I don't see cycling and being outside as a waste of time" [participant 2, 46, 8 km commute]

The GPS-data showed that commutes by e-bike took about as long as commutes by bus, and longer than commutes by car, but this did not deter participants from commuting by e-bike. In fact, when asked, sixteen participants mentioned they would be willing to extend their commuting time if that meant they would still be able to travel by e-bike. Their maximum acceptable extra commuting time by e-bike was 19 minutes on average (*SD*=7.3) on top of their recorded 38 minutes on average (*SD=11.6*). Finally, in the interviews, participants were also asked about their day-to-day route choice and experience using the e-bike. Two participants had only one route to work, but the remainder had several alternative commuting routes and showed variations in their trajectories. Again, speed (*n*=9) and directness (*n*=6) of a route were of lesser interest. Most mentioned the beautiful surroundings of the route (*n*=16), the fact that it ran through nature or green areas (*n*=12), and the tranquillity of the commute (*n*=11). Alternative routes were sometimes used as they were faster (*n*=8), considered safer (e.g. during early morning or night-time commutes, *n*=4) or preferable depending on the weather (*n*=3). For others, the available alternative routes were simply too long (*n*=10), unpleasant (*n*=10) or crowded with other cyclists or motorized traffic (*n*=10).

Route choice considerations can be illustrated by the route choice of participant 8 [aged 44, 15 km commute]. GPS tracking revealed he had two routes to work (figure 3). Route A consisted of a section of shared, rural road, and a section of concrete bike path. Route B consisted of a separate bike path running between his hometown and the border of the city, where it would connect to the urban bike infrastructure network. In recent years, route B had been upgraded in response to growing bike traffic to and from the city: the path was widened, flattened, and had priority over all roads crossing the path, permitting a continuous commute to the city. Despite this, and the slightly shorter and faster commute, he mostly refrained from using route B and preferred route A:

"[Route A] is a fantastic route, I take it practically every day. It is way more fun, straight through nature, no other roads, no traffic (..) It would be a bit shorter going through [route B]. But it's insignificant, I prefer to take the scenic route (..) It is more inviting, it incentivizes to take the e-bike"

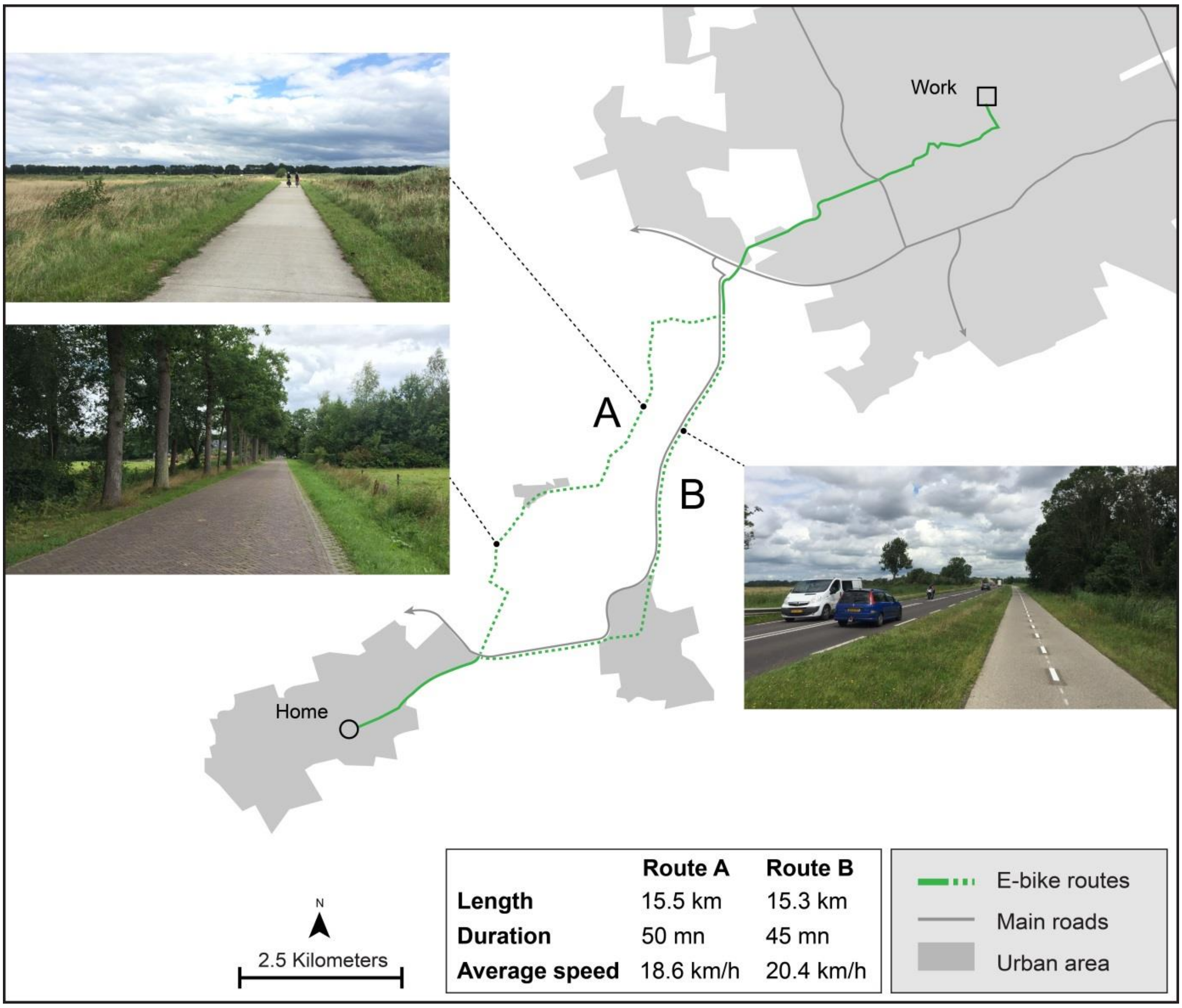


Figure 3 – Route options and characteristics of participant 8

"On [Route B] you cycle next to the road all the way. There's the bike path, two meters in between, and then the road, where the speed limit is 80, 90 [km/h]. (..) It's not very nice. And I think it's quite dangerous. The separation between bikes and cars is minimal. (..) Also the bike path is a bit lower than the road, you're blinded by the lights (..) It was upgraded a couple of years ago, and the path itself is fine. But to me it is a functional route, for if the weather is bad"

This was echoed by 6 other participants, who all had dedicated, upgraded bike paths and alternative routes available to them. They preferred the alternatives where they would enjoy their surroundings less bothered by motorized traffic or crowds of cyclists.

"The shortest route goes along the main road, all the way. You constantly have the noise of cars next to you. I'll take it if the weather's bad, if I'm in a hurry, or in case of headwind (..)

but if circumstances are good, I'll take the longer route, the nicer one" [participant 4, aged 40, 10 km commute].

For those with no (realistic) alternatives, however, the combination of speed and directness was a joy in itself:

"*It's a long stretch, and I look forward to that part now. I bike out of the city, and think, finally! I turn my music a little louder, and then just go. I have to refrain myself from singing out loud on that part"* [participant 15, aged 33, 15 km commute]

Finally, participants mentioned the difference between assisted cycling in and outside the city was a major influence on cycling experience. Overall, they felt they got less advantage of the e-bike in the city due to the increase in traffic, traffic lights and complex traffic situations, which led to loss of momentum and interrupted flow.

"My speed is a constant 26 [km/h] (..) but that changes the moment I arrive in the city. There are schools, a shopping mall, I need to take into account other traffic (..) children crossing, crosswalks.." [participant 20, aged 51, 13 km commute]

In the city, safety issues arose due to difference in relative speeds and lacking of judgement of e-bike speed by other road users. Most acted on this by reducing speed or turning off the assistance altogether. The urban environment led to new tactics for finding the shortest route and avoiding traffic or traffic lights. Participant 17 mentioned regularly altering her route through the city (figure 3):

"As you can see, I'm still kind of figuring out the best way of making it through [that neighborhood] without joining the major roads too quickly. I basically try to postpone using the main road as long as I can, because that really slows me down. I reduce the assistance. (..) I really have to adjust to the other traffic there" [participant 17, aged 54, 18 km commute]

Participants mentioned lower speeds and increased number of stops in urban areas as a drawback to their commute. The loss of momentum and interrupted flow, caused by the higher number of stops on urban sections of the commute, was also revealed through additional analysis of GPS data. On urban sections of their commute, participants had an average of 7.3

measured stops (recorded GPS points with speed under 5 km/h), as opposed to 4.2 stops per commute on rural sections of the route. Despite the downsides of cycling in the city, participants from time to time also enjoyed being exposed to city life. As participant 1 put it, he'd rather experience the city from his bike than from inside his "*car bubble*".

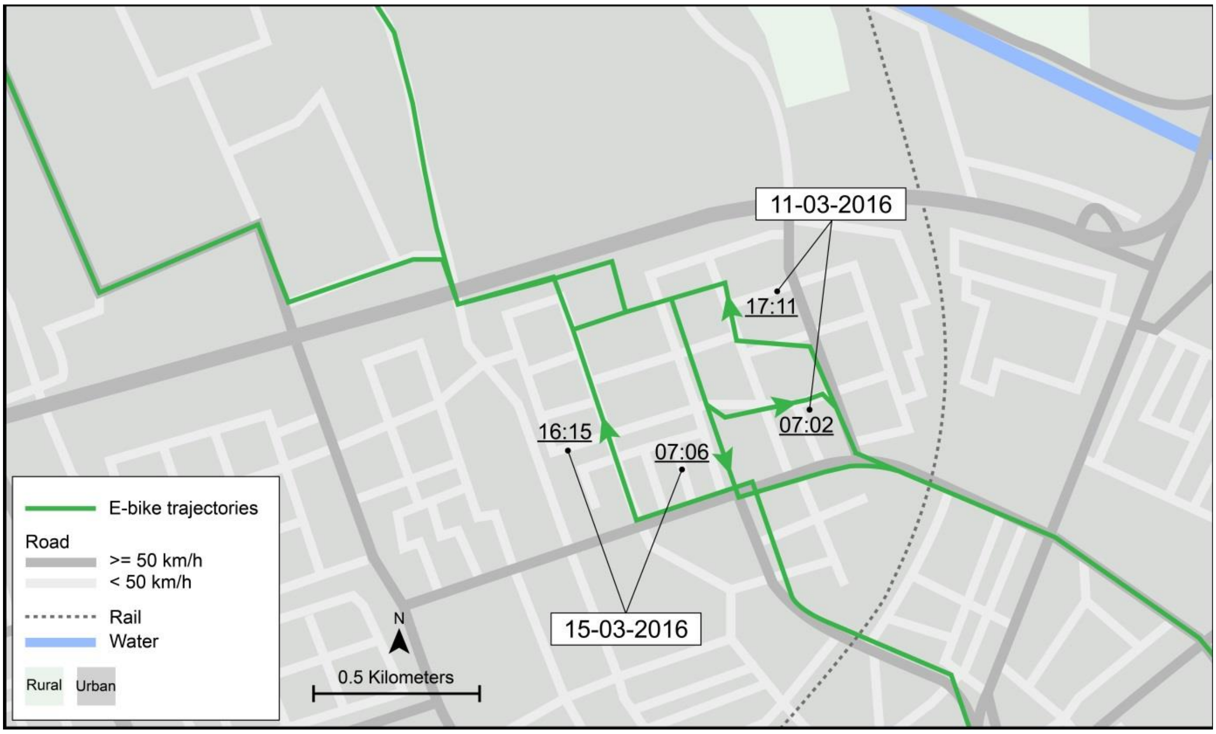


Figure 4 – Route choice of participant 17

4. Discussion

This study evaluated the potential of e-bike commuting by analyzing e-bike commuters' motives, travel behaviour and experiences using GPS tracking and in-depth interviews. We had three main questions: (1) What were motives for purchasing and starting to use an e-bike? (2) Under what conditions can e-bikes substitute motorized commuting? (3) Which role do travel experiences play in the daily commute by e-bike?

The majority of participants adopted an e-bike following changes in the work or home environment. These changes prompted participants to reconsider prevailing commuting habits. Sustainability was not found to be a key driver, but rather health was mentioned as an important motive for adoption and daily use. GPS tracking revealed that e-bike use accounted for the majority of recorded commuting trips, and competed mostly with car use. E-bike use was lower when more activities were combined and in non-work-related journeys, in which car use, conventional cycling and walking were more common. The findings provide little support for substitution of conventional cycling by e-biking. E-bike commutes mostly substituted use of car and bus in the old situation, and participants indicated shorter trips were still made by conventional bike. E-bike commutes took about twice as long as car commutes and about as long as bus commutes, although they covered shorter distances. Participants stated that commuting by e-bike gave them benefits of conventional cycling compared to motorized transport (enjoyment of outdoor, physical activity; independency) while mitigating its relative disadvantages (longer travel time; increased effort). Daily schedules and weather conditions were possible impediments, although electric assistance negated wind influence. Participants generally preferred enjoyable and quiet routes over faster and more direct ones. Cycling experience outside the city (enjoying the surroundings, maximizing e-bike speed) was different from within the city, where traffic density, multiple forced stops and complex situations made that assistance was not fully utilized. In general, the findings provide support for the idea that e-bikes can be effective in replacing motorized transport for the purpose of commuting, and emphasizes the role of positive experience in e-bike commuting.

The finding that e-bike adoption mostly followed a key event corroborates earlier studies. Chatterjee et al. (2013) showed that events such as changes in employment, relationships, health, children or residence can trigger a turning point, such as starting cycling or changing cycling behaviour (in our case, the decision to buy an e-bike for purpose of commuting). The probability that a life event triggers actual change is mediated by factors such as personal history (our case: participants being accustomed to bike use, due to experiences in earlier life stages), intrinsic motivators (our case: health) and existing facilitating conditions in the external environment (our case: quality infrastructure, or employer benefits) (Chatterjee et al. 2013; Clark et al. 2014). Our results also comply with earlier studies that found e-bikes to be highly suitable for distances too long to cover by regular bike (Astegiano et al. 2015; Jones et al. 2016). Average e-bike distances for both total trips (9,7 km) and commuting trips (14,1 km) in the current study surpassed distances measured in the Dutch national travel survey. Here, e-bike trips averaged 5,5 kilometres, although differences were found between age categories (KiM 2015, p.22). The discrepancy between the two studies is a possible consequence of our small study sample and the relative low population densities of the study area, where as a result, distances between destinations are higher than in more urbanized areas in the Netherlands. Indeed, average travel distances per person per day in the provinces of Drenthe (>37 km) and Friesland (34-37 km), where the majority of the participants reside, are higher than the national average of 32 km per day. Residents of the province of Groningen in turn travel distances more in line with the national average (CBS 2016, pp.19, 20, 21). The lower e-bike use in journeys with more destinations contradict previous statements that users might reach a larger diversity of destinations by adopting an e-bike (Astegiano et al. 2015). Claims that elevated speed of the e-bike permits competition with rush hour driving and local public transport (Fyhri & Fearnley 2015) are, however, partly confirmed. While the average duration of recorded car commutes was considerably shorter than e-bike commutes, average duration of recorded bus commutes was similar to e-bike commutes. More importantly however than being faster than car or bus, electrically assisted biking was considered a realistic alternative. This is related to previous findings that suggested that for e-bike commuters, like e-bike users in general, being faster is less important than being able to travel for longer distances (Lee et al. 2015). Covering the distance and thereby including physical activity, being outside, enjoying the route and being independent proved of higher value to e-bike commuters than being faster. This relates to the positive utility for travel as described by Mokhtarian et al (2001). More than just being utile for simply arriving at a destination, traveling by e-bike has intrinsic utility for the participants (e.g. exposure to environment, breathing fresh air) and utility for activities that can be conducted while riding (mentally preparing for the day ahead, or clearing the mind), resulting in longer commuting durations than strictly necessary. These findings stress the importance of considering quality aspects of the commute alongside conventional factors such as mode speed and travel time when studying travel behaviour. Furthermore, e-bikes seem to change the way cyclists ride (MacArthur et al. 2014, p.126). Assisted cycling gave participants options to choose enjoyable routes over faster and more direct ones. However, assisted cycling in rural and urban environments was experienced differently, as the latter was often considered less safe or enjoyable. These results highlight the importance of travel experience in e-bike commuting, both in the day-to-day mode choice and in route choice. They also suggest electrical assistance might serve different purposes in different contexts: in lower-density peri-urban and rural areas, assistance might be valued for enabling continuous commuting at high average speeds, and increasing cycling range. In dense urban areas, cycling flow is more likely to be interrupted, and assistance might instead be valued for supporting acceleration in the numerous stop-and-go situations.

A methodological strength of our research is that it combined objective measurement through GPS and subjective insights from in-depth interviews. By complementing and contrasting results, new insights were generated. However, we identify some limitations. We stress the probability of self-selection of participants. Therefore, results may not be representative of the broader population. Another potential limitation is that the research was conducted in the winter and early spring period, which may not be representative for other parts of the year. However, the weather in the study period was generally very mild, with the exception of one week of snow and frosting right after Christmas-break which delayed GPS tracking for some participants. Most participants acknowledged that their e-bike use would probably have been higher had their behaviour been recorded later in the spring or in summer. However, all indicated that recorded behaviour was approximately representative for their behaviour at that time of the year. Other limitations concern GPS tracking. Despite objective measurement enabled by GPS tracking, incorrect operation of trackers led to some inaccuracy in the data. Also, inclusion of both regular e-bikes and speed pedelecs in the study might affect results, although only three participants used a speed pedelecs. Furthermore, we were not able to track participants travel behaviour before e-bike adoption. We could therefore not make a quantitative assessment of mode use change. Finally, a limitation of this study concerns representativeness for other countries. High levels of cycling are already in place in the Netherlands. Compact urban areas, relatively low travel distances, the quality of cycling infrastructure, the cycling culture in place and the flat topography in the study area make that the findings may not apply to contexts.

Future research should study e-bike use with larger and more representative samples in order to address self-selection issues. Better insights in the relationship between e-bike use and diverse weather and climate circumstances can be generated by tracking e-bike users in different seasons and different climate zones. To generate more accurate and consistent datasets, errors in GPS data collection will have to be addressed. Also, future studies should be sensitive to the differences between types of e-bikes, and take into account the increasingly popular speed pedelecs which support cycling at even higher speeds. Changes in travel behaviour could be objectively monitored by tracking participants prior to and after e-bike adoption. Finally, more insight in the potential of e-bike use for commuting is needed from other geographical contexts, including areas with less bicycle infrastructure, lower acquaintance with cycling in general, and different climatic circumstances and topography. Further research could address a broader scope than commuting alone. An example could be to study e-bikes' possible contribution to mobility in low-density rural areas, to compensate declining public transport provision and increase access to amenities.

Results imply that e-bikes can provide a good alternative to the use of car and public transportation. This supports future efforts directed at getting car and public transport commuters to use an e-bike. The growing appeal of e-bike commuting can lead to further acceptance of the e-bike as a functional mode of transport by populations of more diverse ages.

Wider promotion of e-bikes for commuting, together with financial incentives from for instance employers, could contribute to growth in e-bike use for this purpose. Finally, actual and future development of fine-grained, appealing, high capacity bicycle infrastructure networks can further improve e-bikes' competitiveness with car and public transport, and take additional advantage of the valuation of travel time. The important role of positive experiences in commuting by e-bike suggests that this factor should be explicitly taken into account in future actions in transport research, policy, and environmental design domains.

5. Conclusion

Electrically assisted cycling or e-biking manifests itself as an appealing alternative to motorized commuting for those for which conventional cycling is not a realistic option. Its direct competition with car use means that efforts to increase e-bike use should be directed at car commuters. While e-bike commuting might not always be the faster option, enabling an appealing e-bike ride to work can mitigate the role of increased travel time in commuting. High levels of conventional cycling are already in place in the study area, but there is still much to be gained. The findings suggests that health and enjoyment can make a significant contribution to realizing sustainable travel behaviour. Promoting health and enjoyment of e-biking can support the development of sustainable transport systems that support active and healthy lifestyles.

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