6.1. Introduction

It is increasingly recognized that the transport systems currently in place around the world are unsustainable in terms of their impacts on environment, society, public health and economy (Banister, 2008, 2005; Greene and Wegener, 1997; Litman and Burwell, 2006). One way to counter the negative effects of these systems is to promote active mobility and the use of alternatively-fueled vehicles. A potentially promising mode of transport that is the topic of this thesis is the electrically-assisted bicycle or e-bike. In recent years, e-bike use has been growing in various countries around the world, and thus has caught the attention of policy makers, practitioners and the academic community alike. A central question is whether e-bike mobility can play a role in the shift towards more healthy and sustainable transport systems. Moreover, the rapid growth of e-bike use offers unique opportunities to study mode choice, modal shift and associated changes in travel behavior in diverse contexts and at different scales. The aim of this thesis is to provide insight in the potential of e-bikes as a means to achieve more sustainable and active transportation, by studying actual and potential e-bike use in different populations and in different geographic contexts in the Netherlands.

This chapter concludes the thesis by first providing a summary and discussion of the main research findings in relation to the research questions. Then, limitations of the studies conducted in this thesis are discussed. This is followed by suggestions for future research, and an extension on the implications of the findings for policy and practice.

6.2. Main findings

Which conditions encourage e-bike adoption by different user groups? [Research question 1]

Research has suggested that most daily behaviors ensue from automatic processes, or routines. These permit to avoid continuously thinking about what we do, and therefore to more efficiently allocate cognitive capacity to other tasks (Klöckner and Verplanken, 2013). Chapter 2 described how routines tend to play an important role in people’s travel behavior. Examples of routine travel behavior are habitual mode use, fixed times of travel, and preferred routes. Chapter 2 also discussed how key events in the life course may tilt routines and instigate behavior change (Guell et al., 2012; Müggenburg et al., 2015).

The findings in this thesis provide support for the idea that routine travel behaviors can be interrupted and reconsidered following key events that occur naturally as part of the life course (Chatterjee et al., 2013; Clark et al., 2014). As discussed in Chapter 3, commuters reconsidered their travel habits and adopted an e-bike following changes in the home environment (e.g. moving, the birth of a child, children growing older, ageing) and work environment (e.g. changing jobs). For instance, one participant mentioned that her children had recently started high school, and went there by bike. She wanted to escort them to school before continuing her commute to work, but doing
this by regular bike would be too tiring. Thus, she decided to purchase an e-bike. For another participant, the birth of a second child meant that the family had to get rid of their expensive second car. After selling the car, they purchased an e-bike, so that both parents could remain mobile without being dependent from using the car or from one another.

Mobility milestones have been distinguished in the literature as a specific type of key events that are more directly related to mobility. Examples of such mobility milestones are mobility-related social norms, infrastructural conditions, regulations, initiatives and economic and social circumstances that affect individual's mobility options, such as acquiring a driver's license or buying public transport season tickets. From a policy point of view, mobility milestones might be more practical to address in policy than key events. In this thesis, however, mobility milestones did not emerge as an imperative to e-bike adoption. Many of the factors that can facilitate cycling and would potentially be mobility milestones were already in place: participants had cycled from a young age, owned a bicycle, and generally indicated that the availability of infrastructure was sufficient. In general, it was not so much changes in the mobility domain that caused participants to reconsider mobility behavior and adopt an e-bike, but rather, broader changes in their living situation.

The findings in this thesis do support the importance of initiatives as mobility milestones that facilitate first-hand experience with e-bikes. In particular, it was found the effects of a life event, i.e. the reconsideration of travel habits, can to a certain extent be reproduced ‘artificially’ through the provision of incentives or the organization of pilots. Financial incentives might lower the barrier to purchase an e-bike by making it less expensive. E-bike adoption by some of the commuters in Chapter 3, for example, was fostered by employer incentives to buy an e-bike. For some commuters, this triggered a re-evaluation of travel routines by mitigating the cost-barrier that had initially withheld them from e-bike purchase. These findings are useful, given that working adults are likely more immersed in these routines, due to complex family schedules and fixed employment, than their younger or older counterparts. Thus, their travel behavior may be less receptive to interruptions. However, it is important to note that many of the participants were dissatisfied with their old travel behavior, and key events and incentives probably formed tipping points to re-evaluate and change behavior. Additional evidence for the potential role of incentives was found in Chapter 5. Here, it was concluded that strategies to develop e-bike use in rural areas may entail financial incentives for persons of lower socio-economic status or living in households with children, to make it more attractive for them to purchase an e-bike.

Pilots offer the opportunity to test and adjust policy strategies before broader implementation (Mckenzie-Mohr, 2000). The use of pilots to generate interest in e-bike use is by now well-established (see Cairns et al., 2017 for a review of the evidence). Participation in pilots provides direct experience that can help participants to form attitudes and increase the likelihood of engaging in targeted behaviors, such as e-bike use (Smith and Swinyard, 1983). In line with these notions, it was found in Chapter 5 that attitudes of rural residents who currently used an e-bike were significantly more
positive than those of non-users. Although these findings may be partly the result of self-selection of persons who had a-priori positive attitudes to the e-bike, experiencing an e-bike firsthand may also have played a role in the formation of users' more positive attitudes. Therefore, it was suggested in Chapter 5 that offering rural residents the opportunity to pilot-test e-bikes might help form positive attitudes. Chapter 4 more closely considered mode choice at a moment of habit interruption, during a pilot held among university students. Findings from this chapter show that students' willingness to buy an e-bike was low. However, they expressed the desire to own an e-bike in the future, or indicated they would consider the e-bike as an option in future mode choices. This is an important benefit of organizing pilots and enabling a first-hand experience: compared to commuters in Chapter 3, students did not have initial discontent with their travel habits, but were simply offered to try out an e-bike, and mostly signed up out of curiosity and without much prior knowledge on e-bikes. Despite the lack of initial motivation, participating in the pilot considerably increased the likeliness of future e-bike use.

Overall, three observations offer support for the usefulness of incentives and pilot testing as orchestrated efforts to encourage e-bike adoption. First, study findings reveal that e-biking offers a physical and mental experience which seems fundamentally different from using cars, public transport, cycling or walking, on aspects such as outside exposure, enjoyment and ease of use. Incentives and pilots offer users unique opportunities to undergo such experiences firsthand. Second, e-bikes are fit for encouragement through financial incentives and pilot-testing due to their relative low-cost compared to other forms of electric mobility (e.g. electric cars). It is cheaper for governments or employers to offer financial incentives (e.g. cash back upon purchase) on e-bikes than on for instance electric cars. Also, e-bike pilots are relatively easy to organize as the battery can be taken inside and thus no specific infrastructure is needed for e-bike charging. Furthermore, secure parking facilities in the Netherlands are generally already well-developed. This leads to the third observation: in the Netherlands, infrastructure and safety barriers to cycling have largely been overcome. Thus, potential users can test e-bikes under favorable circumstances, with low external friction or hazard. Encouragement of firsthand experiences with e-bikes through financial incentives and pilot testing thus seems promising to encourage e-bike mobility in the Netherlands.

Finally, it is important to note that factors that cause people to deliberate current travel behaviors and consider adopting an e-bike may differ per context. For example, in countries where e-bike adoption by elderly is still low, safety issues may be more important than found in the current thesis. In countries where air pollution is a serious health problem, sustainability might be more important. In countries with low levels of cycling, mobility milestones that provide basic preconditions for bicycle use such as bicycle ownership, knowing how to ride a bike, and adequate infrastructure, could be more important determinants of e-bike adoption than found in the present thesis. In countries with high levels of cycling, infrastructural improvements such as the development of high capacity bicycle infrastructure (“bicycle highways”) could also trigger future behavior change.
What are the advantages and limitations of e-bike use for different user groups? [Research question 2]

In Chapter 2, commuters, students and rural residents were identified as user groups with high potential for e-bike mobility, and some specific advantages and limitations to e-bike use in each group were outlined. Here, it is discussed whether these advantages and limitations played a role in the decision to adopt an e-bike and whether they were recognized and experienced by the participants.

Throughout the studies in these chapters, four factors consistently emerged as important advantages and limitations of e-bike use for all three user groups: affordability, mental wellbeing, physical health and e-bike image. The importance of safety, environmental friendliness, and distinct characteristics of the e-bike that may add to the travel options of its user (i.e. range, autonomy, combine activities, connectivity) varied across the user groups. Figure 6.1 provides a graphical illustration of the findings for the three user groups, which are further reflected upon below.

![Figure 6.1](image)

**Fig. 6.1** – Summary of advantages and limitations of e-bike use for different user groups.

First of all, affordability was found to be an important factor in e-bike choice, which is in line with findings from previous studies (e.g. Dill and Rose, 2012; Fyhri and Fearnley,
2015). For some commuters (Chapter 3), the high purchase price of e-bikes formed a barrier to adoption. As discussed, this barrier was in some cases mitigated by employer incentives, whereas some participants had chosen simpler and thus cheaper e-bike designs. To others, however, purchasing an e-bike permitted to save on gas, transit fares, or came in place of buying a second car. Thus, it seems that encouraging e-bike adoption might to some extent be dependent on the framing of the cost-aspect: it is more expensive than using a bicycle, but might be cost-effective compared to buying and using a car or using public transport. For students (Chapter 4), e-bike costs proved an important barrier to buying an e-bike at the end of the pilot, which is a result of the lower power of purchase in this group. Furthermore, in this group, e-bike use competes with cheap bicycles and free public transport using student transit passes. Possible solutions can be found by offering leasing plans (Cairns et al., 2017) or integrating e-bike schemes with student transit passes. Alternatively, cheaper designs and developments in (battery) technology could further bring down e-bike prices. Among rural residents (Chapter 5), no direct evidence was found for the role of costs in current or potential use of e-bikes. However, the share of people with a good financial situation was significantly higher among users than among non-users. This variable could be perceived as a proxy for the role of costs in current and potential use. Interestingly, the share of people with a good income situation was significantly lower among those interested in using an e-bike compared to people that were not interested. Thus, there seems to be a latent demand for e-bike use in groups with lower socioeconomic status. Here, the same effect of lower e-bike prices as with students might apply.

Mental wellbeing derived from sensory experiences with the environment was a second predominantly positive factor that proved important in mode choice and e-bike use throughout the thesis. It is well-established that sensory experiences and interactions with the environment play an important role in active travel (Te Brömmelstroet et al., 2017; Van Duppen and Spierings, 2013). Such experiences can make that the act of traveling, and travel time itself, hold inherent value to the traveler (Jain and Lyons, 2008; Mokhtarian et al., 2001; Ory and Mokhtarian, 2005). E-bike commuters’ mental wellbeing was predominantly related to scenery and natural elements, such as riding the e-bike through the open landscape, enjoying the sunrise and the dew in the fields, as a way to “mentally disconnect”, prepare for the day ahead or close off the day. The positive travel experience made longer travel times by e-bike acceptable compared to other modes (Chapter 3). Students in turn recalled the joy of riding e-bikes in headwind or over bridges, and indicated this would be a major contributor to future e-bike adoption (Chapter 4). For rural residents, enjoying riding an e-bike proved a positive contributor to both actual and potential e-bike use (Chapter 5). Thus, mental wellbeing is an important element in the decision to start using an e-bike over other modes of transport as well as in the daily choice to use an e-bike.

Third, physical health played a major role in e-bike adoption. The health benefits of e-bike use have been the subject of a number of studies (e.g. Berntsen et al., 2017; Gojanovic et al., 2011; Simons et al., 2009; Sperlich et al., 2012). It is generally argued that e-bikes can bring benefits when used in sedentary lifestyles, whereas a switch
from bicycle use would be less beneficial. Health turned out to be a major motive for e-bike adoption by commuters (Chapter 3). Most of them had traveled by car or public transport before adopting an e-bike, and were happy to include physical activity in their daily schedules. Health was also positively related to actual and potential e-bike use by rural residents (Chapter 5). This factor was however more controversial with students (Chapter 4). This is related to the fact that most students switched from bicycle use to e-bike use during the pilot, which meant a loss in the intensity of physical activity. Thus, these findings confirm that the health benefits, at least as experienced by e-bike users, are largely dependent on the mode of transport from which the modal shift was realized.

Fourth, the image of e-bikes as “old-people’s bikes” dominated the discourse surrounding e-bikes for a considerable time. However, due to the increasingly mainstream use of e-bike this is changing fast, (Peine et al., 2016), as the results of the present thesis confirm. E-bike image was brought up by participants in Chapters 3 and 4, and tested in the survey in Chapter 5, but little evidence for image or stigma obstructing e-bike adoption was found. Some students (Chapter 4) indicated that they had hesitated to participate in an e-bike pilot as they considered the e-bike something for older adults, but after participating in the pilot, a large majority of students disagreed with a survey statement that the e-bike is “Mostly interesting for elderly people”. Similarly, commuters generally also recognized this potential stigma (Chapter 3), but this did not turn out to be a factor in mode choice. An unexpected result from Chapter 5 was that current e-bike users had a more negative image of e-bikes than non-users, where one would expect them to have a more positive image. A possible explanation for this finding is that e-bike users are aware of the negative stigma of e-bikes as “old people’s bikes”, perhaps because they have been reminded of this by their peers.

E-bike safety was regularly brought up by the participants. For commuters (Chapter 3), safety issues were primarily related to the type of built environment: assisted cycling in rural and urban environments was experienced differently, and the latter was often considered less safe due to increased traffic and complex traffic situations. However, safety had not deterred them from adopting an e-bike, nor did it play a decisive role in their day-to-day use. Students (Chapter 4) mostly attributed potential safety hazards to other e-bike users than to themselves. They expressed being aware of the risks, but stressed how own responsibility and adaptive cycling mitigates that risk. Thus, for this user group safety was not considered a personal advantage or limitation. For rural residents (Chapter 5), a lower valuation of the safety of e-bikes negatively contributed to current e-bike use. This factor did not contribute to explaining potential e-bike use.

The environmental friendliness of e-bikes was brought up by participants in Chapter 3 and 4, and tested in the survey in Chapter 5. For commuters (Chapter 3), sustainability of e-bike use was an advantage, but not an initial motivation. As one participant stated: “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”. Students (Chapter 4) were skeptical towards the sustainability of e-bikes, as a consequence of their old...
travel behavior which mostly consisted of bicycle use. For rural residents (Chapter 5), environmental friendliness did not contribute to actual or potential e-bike use. Thus, whereas the environmental impact of e-bikes versus motorized transport and cycling is recognized by the participants, it seems unlikely that this aspect resonates with potential users as a reason for adopting an e-bike or not. This reflects findings from literature suggesting that environmental concerns (such as the need to switch to more sustainable modes) play less important roles in behavior change than factors that affect the individual in a more direct manner, such as costs, effort and convenience (Lindenberg and Steg, 2007). Thus, arguably, sustainability should not be the prime focus of e-bike mobility adoption or encouragement. Rather, the e-bike could be framed as a less costly, more enjoyable and healthier mode of transport, with “sustainability” as a more implicit goal.

E-bikes can add to the travel options of users through distinct factors such as range (to cover longer distances), autonomy (to be independent from public transport schedules), connectivity (being able to reach other transport) and combining multiple activities. These aspects were recognized and experienced. Whether they constituted an advantage or limitation differed depending on the user group and the mode with which the e-bike was compared or substituted. For commuters (Chapter 3), range and autonomy were highly relevant. Electric assistance enabled bridging longer distances in shorter travel times compared to regular bicycle use. Also, traveling without having to take into account bus or train departure times was mentioned as a benefit. However, for some, the car still had advantages over e-bikes, such as the possibility to combine multiple activities and to do this in greater comfort. Indeed, some commuters said they would not commute by e-bike at all in case of rainy conditions on the way to work, and use the car instead. For students (Chapter 4), higher flexibility compared to (free) public transport was an important benefit. Also, e-bike use enabled them to combine activities throughout the day. For rural residents (Chapter 5), shorter travel distances were a positive contributor to current e-bike use, but no evidence was found for the role of autonomy, connectivity and combining multiple activities. In the next section, it will be discussed whether these notions are supported by data from mapping and GPS tracking.

Some of the factors that were initially thought of as potential advantages or limitations to e-bike use in different groups did not emerge as such from the empirical studies. First of all, e-bike commuters indicated that bike parking facilities at work were generally well-arranged and thus a lack of such facilities was not a limitation for e-bike use. For charging, the e-bikes’ removable battery could be taken inside into the workplace, and thus according to the participants, no specific charging infrastructure was needed. Second, a hypothesized advantage of e-bike use for students was that experience with e-bikes in younger age could contribute to sustainable habit forming. Chapter 4 highlighted that students were generally not interested in buying an e-bike at the end of the pilot, but most indicated they would consider it an option in future mode choices. This suggests that e-bike use in younger age potentially contribute to sustainable habit forming, but this could not be confirmed in this study. Finally, the lack of dedicated bicycle infrastructure as a barrier to rural e-bike use was insufficiently backed by the
evidence in Chapter 5. However, a positive valuation of e-bike safety significantly contributed to current e-bike use. This might indicate that those that currently use an e-bike do so in response to a safer cycling environment, but no causal relationship could be discerned here.

What are the impacts of e-bike use on travel behavior? [Research question 3]

The previous research question assessed whether participants recognized and experienced the advantages and limitations to e-bike use. Among the assumed impacts on travel behavior were e-bike characteristics that may add or may not to the travel options of its users, such as e-bike range, autonomy, connectivity and combining multiple activities. In Chapter 3 and 4, e-bike users’ travel behavior was measured using mapping and GPS-tracking. Thus, it is possible to complement and contrast the recognized and experienced impacts on travel behavior with quantitative assessment of some of these factors.

GPS-tracking of e-bike commuters (Chapter 3) offered insight in the length of both work and non-work-related journeys, which were made using diverse transport modes during the tracking period (Fig. 6.2).

Fig. 6.2 – Distances of work- and non-work-related journeys measured using GPS-tracking

For commutes, a trip from home to work and back by e-bike averaged over twenty-six kilometers, which was somewhat shorter than the work-related journeys by car and public transport. This suggests that beyond a certain threshold, the physical expense and increased travel time by e-bike form such important hindrances that motorized modes are favored. E-bike commutes were often considerably longer than what is commonly thought to be an acceptable travel distance to cover by regular bicycle. This confirms that e-bikes are highly suitable for use on distances deemed too long to cover
by bicycle. This is substantiated by an analysis of the non-commuting journeys. Here, the traditional active modes were used on short distances (avg. 3km), the e-bike was used on intermediate distances (avg. 7-10 km), and motorized transport was used for longer distances (avg. >30 km). The longer distances traveled by e-bike were also partly reflected in student travel behavior (Chapter 4). Mapping their trips revealed that they traveled an average of about eight kilometers (single trip) to the university. Individual travel distances however ranged from four to nineteen kilometers. Thus, for students who travel shorter distances (e.g. within the city), the benefits of e-bikes in terms of travel time and reduced physical expense are likely not substantial enough to be considered as a substitution to regular bicycles. Additionally, from an environmental and health point of view, e-bike substitution of these active mode trips may be considered undesirable. However, for those living outside the city and traveling longer distances, e-bike use might be a suitable alternative to the use of public transport.

Second, measurement of travel behavior offered insight in the extent to which e-bike use permitted or hindered the combination of different activities throughout the day. Among commuters (Chapter 3), e-bikes did generally not permit easier engagement in activities. Work-related journeys were more often single-destination journeys, and whenever multiple destinations had to be reached (e.g. bringing children to daycare in the morning, running errands after work) participants more often used the car. Thus, GPS measurement revealed that it was somewhat harder to combine multiple activities by e-bike, although this might still be done more easily by e-bike than by regular bike. This was different for students (Chapter 4). Mapping their travel behavior revealed that they often used the e-bike to reach multiple destinations throughout the same day. However, this also slightly varied between students: students traveling to the university from outside the city did not combine this commute with other activities. Students who traveled shorter distances to the university, however, more often did. This difference, between commuters and students generally, but also more specifically between students, might be related to the fact that the individuals who covered longer distances by e-bike had less time or energy to include multiple destinations. Also, possibly, the majority of students who combined more activities by e-bike were less constrained by busy family schedules, and therefore less driven by the need to use faster modes of transport.

From the GPS measurement of travel behavior, some factors emerged that were initially not identified as potential advantages or limitations to e-bike use in different groups. First of all, as discussed under research question 2, an important finding from Chapter 3 was that longer travel times by e-bike did not form a barrier to e-bike use, importantly due to positive travel experiences. This was reflected in the GPS data: car commuting trips covered longer distances than e-bike and bus use, but were shortest in terms of travel time (avg +/- 30 minutes). E-bike trips, which were shorter on average, took participants considerably longer (avg +/- 46 minutes). This travel time was somewhat similar to using a bus (avg +/-47 minutes), but the latter covered longer distances within this travel time. This confirms the positive experiences of commuters, in the sense that that e-bike use (which consisted of the majority of trips) was not hindered by the longer travel times measured compared to car travel.
A second factor that emerged from the GPS measurement of travel behavior of commuters was that different routes to work were used when traveling by e-bike. From the interviews held with both commuters and students, it became clear that they felt that e-bike use gave them more freedom, notably in the choice of routes. Potential longer distances and travel times of such routes were mitigated by the electric assistance. Commuters’ travel behavior data showed that they indeed tended to vary their itineraries. In Chapter 3 this was illustrated with a participant who had the choice between a shorter direct route, and a somewhat longer scenic route. GPS data showed that he, as well as other e-bike commuters who originated in the same village, preferred traveling using the scenic route. This finding was replicated for multiple participants who traveled from different areas, and who had several routes to choose from on the way to work. Generally, they preferred the scenic routes over the more direct ones, exceptions being made when weather was bad, or when they were in a hurry. Another participant varied routes on a specific section of her commute only: on the outskirts of the city, she would choose her route according to the time of day and her expectations of the amount of bicycle traffic on the different itineraries at that moment.

Finally, both commuters and students mentioned that they experienced greater autonomy when using an e-bike: this was related to independence from public transit schedules or the need to travel with others, for instance when car-pooling. However, the analyses conducted using GPS-tracking and mapping did not permit assessment of autonomy, and thus no quantitative evidence can be used to back these qualitative findings. Similarly, the data do not offer insight into whether e-bikes can help achieve greater connectivity to other modes, for instance by increasing the accessibility of public transport hubs.

6.3. Reflection on research methods

This thesis took an integrative approach to studying the potential for e-bike mobility by combining diverse research methods. The integration of different methods is an important strength of this thesis for various reasons: it allows to draw from the strengths and minimize the weaknesses of both quantitative and qualitative methods; it allows mixing and matching design components that offer the best chance of answering specific research questions; and it allows generating new insights by complementing and contrasting results from the different methods used (Johnson and Onwegbuzie, 2004; Meijering and Weitkamp, 2016).

However, combining different methods is not without limitations: it is generally time consuming, and requires the researcher to learn and execute multiple research techniques. Furthermore, the research process can be intensive for the respondent, in case he or she participates in multiple phases of inquiry. Resulting from these limitations, study samples in mixed-methods research are generally relatively small, and this impacts the generalizability of findings for other contexts. Below, strengths and limitations of the methods employed in the respective chapters are briefly discussed.

In Chapter 3, GPS-tracking was combined with follow-up in-depth interviews.
GPS-measured mobility can offer precision over self-reported mobility (e.g., Meijering and Weitkamp, 2016) by offering a more accurate and detailed understanding of travel locations, durations and speeds. However, GPS-tracking as employed in this study had some limitations. First, technical difficulties or incorrect operation of GPS-trackers led to inaccuracies or incomplete data. Second, the definition of travel modes was dependent on a correct interpretation of speeds and location, which can be negatively affected by data inaccuracies. To mitigate these weaknesses, in Chapter 3, GPS-traces were complemented with follow-up in-depth interviews to control and validate travel modes, routes and destinations. In turn, GPS-traces informed the development of interview guides, and offered the possibility to ask questions on personal, motives, behaviors, experiences, and highlight specific situations.

In Chapter 4, a questionnaire survey was complemented with follow-up in-depth interviews. The choice for this study design was related to limitations concerning the survey. First, the survey was not designed by the researchers. Second, the survey relied on self-reported measures to assess changes in travel behavior. However, the survey results were considered informative, and to cope with the identified limitations, interview questions were carefully formulated to complement the survey data. As in Chapter 3, developing interview guides based on the survey data in Chapter 4 made it possible to ask in-depth questions on personal motives, behaviors and experiences, and contrast these findings with the survey data.

Chapter 5 employed a quantitative approach by studying current and potential e-bike use through a survey. Surveys permit generalizing findings when a sample is random, big enough, and when results are replicated. However, there are some limitations to the survey used. First of all, participant selection was not random. This led to an over-representation of e-bike users included in the sample. Second, a large number of missing values which were omitted from the logistic regression analyses. This reduces the power of the analyses, and may have led to response bias in case the missing cases are non-random. A third limitation is that the analysis did not distinguish between (potential) e-bike use for specific purposes for each of which motivations and behavior might differ. Finally, again, the survey employed self-reported mobility measures.

An overall limitation of the studies conducted in this thesis is that the difference in study designs and different (combinations of) methods employed in each chapter limits the comparability of findings from the different (potential) e-bike user groups. To better understand how findings vary between (potential) e-bike users groups, prospective studies among different groups should adopt similar study designs to better compare findings. These study designs should also seek to minimize the limitations of the different research methods previously mentioned. For instance, mixed-method research should be conducted among larger samples. When working with GPS data, potential errors in the data collection process will have to be addressed to generate more accurate and consistent datasets. Also, more objective measurement of travel behavior change should be conducted to minimize self-report bias, and survey designs should seek to minimize the number of missing responses and aim to include missing responses in their analyses. Quantitative and mixed-methods research could furthermore be
complemented by evaluative field research, for instance through pilot-testing of e-bikes. These studies can provide further insight in travel behavior prior to and after e-bike adoption, and the variety of motivations concerned with mode choices and uses.

6.4. E-bike mobility in a broader societal context

As outlined in this thesis, the increase of e-bike mobility can positively contribute to sustainability and public health by providing an alternative to traditional motorized transportation. However, it is important to be aware of possible negative societal implications that could come with an increase of e-bike use. In this paragraph, four possible negative societal implications of e-bike use are discussed.

First, the substitution of active modes by e-bikes can reduce the health and sustainability benefits ascribed to e-bike mobility. Therefore, it is important to consider the sustainability and health impacts of e-bikes in relation to both motorized and active modes. For energy use and CO2 emissions, e-bike use performs almost as well as walking and cycling, and far better than private cars and public transport (Dave, 2010; Thaler et al., 2012). Fuel production and the manufacturing process of e-bikes require more energy input than regular cycling and walking, but far less energy than the motorized modes. In turn, the operation of e-bikes causes lower greenhouse gas emissions than walking and cycling due to the lower physical expense by its user. However, fuel production, manufacturing and the need for infrastructure cause greenhouse gas emission similar or higher than cycling and walking (Dave, 2010). Thus, when considering substitution, the impacts of e-bike use are somewhat negative if they replace active modes, but far more positive if they replace motorized modes (Fishman and Cherry, 2015). However, until today it remains largely unclear at what cost e-bike mobility is growing. Preliminary evidence suggests that, next to the motorized modes, e-bikes to a certain extent also act as a substitute to other active modes. It is especially likely to replace regular cycling in countries where the modal share for cycling is already high (Kroesen, 2017). In light of the environmental performance described above, this development could be termed undesirable. In Chapter 3, it was apparent that e-bike use primarily substituted the use of cars and public transport for the daily commutes to work. This suggests that the net effect of e-bike substitution on energy use and greenhouse gas emissions in this case is positive, as are the health benefits of using e-bikes over motorized modes. However, in Chapter 4, most students substituted active mode use (cycling) during the pilot. Inhabitants of rural areas who did not use an e-bike and were committed to cycling, however, were less likely to be willing to use an e-bike (Chapter 5). When aiming to stimulate e-bike mobility, specific groups of potential users could be targeted: for instance, those who currently travel by car or public transport, or those that currently use a bicycle, but can extend their ‘life on the bike’ by adopting an e-bike in older age or in case of physical impairment.

Second, the increased cost of cycling due to e-bikes’ higher purchasing prices can have implications for transport equity and the accessibility of the mode for everyone. In various countries in the past years, the share of e-bikes in overall bicycle sales has
grown. Due to this, bicycle sales turnover and the average amount of money spent on a bike is also growing. In the past, an important catalyst of the growth of bicycle use in the Netherlands was the decline in average price. As such, the bicycle moved from being a recreational transport mode for the higher classes to a being used as a functional mode of transport by the masses (Agervig Carstensen and Ebert, 2012). Still today, in a ‘bicycle culture’ such as in the Netherlands, the low initial cost of acquiring a bike is an important asset of bicycle use. This was especially apparent for students in Chapter 4, who primarily used cheap bicycles to get around. Additionally, no advanced skills other than to know how to ride a bicycle are needed to get around and participate in society. In other words, the “entry-level barrier” of bicycle riding is relatively low, and the status associated with it seems less important for bicycle use than for instance for car use (Steg, 2005). Now that the average money being spent on bikes is increasing, the question can be raised whether the accessible character of cycling is at stake. One question that remains to be answered is whether the benefits of using e-bikes can be enjoyed by a wide audience, or will be confined only to those who are able to afford relatively expensive e-bikes. To prevent e-bikes from becoming exclusive modes of transport, financial incentives and e-bike pilots could be targeted at audiences of lower socioeconomic statuses.

Third, characteristics of e-bikes such as speed and range can have implications for the amount and type of spatial and social interactions with the environment. While traveling, different elements such as sensory experiences with the elements and the natural environment, exposure to diversity, and verbal and non-verbal communication with other travelers can have important implications for feelings of connectedness, which in turn influence happiness and wellbeing (Te Brömmelstroet et al., 2017). According to Te Brömmelstroet et al (2017) different modes of transport offer different ranges of exposure to different environments. Driving a car, for instance, can extend the potential range of the social network of the user and requires active engagement with the traffic environment, but the degree of direct exposure to the outside environment, and thus the external sensory experience, is relatively low. Active engagement with the environment outside the vehicle is lower when using public transportation, but instead, travelers are more exposed to (unknown) others inside the vehicle. Active modes can have positive effects on wellbeing through the greater exposure of their users to the environment (Van Wee and Ettema, 2016). Pedestrians interact with their environment through all senses, and the slow pace compared to other modes allows full immersion with this environment. Cyclists are also very open for interaction due to the fact that all senses are exposed, and that they are not shielded from their environment in any way. Their higher traveling speeds reduce the depth of the interactions compared to pedestrians, but allow higher amounts of interactions due to the increased range of travel (Te Brömmelstroet et al., 2017). Thus far, no studies have specifically focused on e-bike users’ exposure to such environments. However, the potentially higher average speeds, longer travel durations, and longer distances traveled imply that e-bike users’ depth of interactions with the environment can be shallower than when using other active modes. For example, some commuters (Chapter 3) mentioned cycling with music,
whereas others would “mentally disconnect”, which implies lower levels of immersion in and interaction with the environment. On the other hand, however, the amount and variety of interactions with the environment can be greater. In general, e-bike use affords distinct spatial interactions of e-bike users with their environment, which can be either positive or negative, depending on the mode of comparison and user’s preferences.

Finally, the uptake of e-bikes can have implications for road safety and safety behavior. Preliminary research (e.g. Fishman and Cherry, 2015; Poos et al., 2017) suggests that e-bike users are subject to higher injury rates than regular cyclists. This is importantly related to the higher age of e-bike users and the higher susceptibility of elderly people to (serious) injury. Other factors of influence are for instance the higher mental workload when dealing with complex traffic situations at higher speeds, the effects of collisions at higher speeds and speed differences on the bike path. In this thesis, students mentioned that they considered safe behavior to be mostly the personal responsibility of e-bike users. This was much like the commuters, who mentioned adjusting the assistance according to the traffic situations. However, depending on the context, improved infrastructure, such as widened bicycle lanes and improved visibility, could improve safety. Furthermore, with an increasing amount of (electrically-assisted) bicycles on the Dutch bike paths, additional regulation concerning speed might be envisioned. Finally, awareness raising and education, for instance offering e-bike training, possibly specifically directed to elderly people or the younger generations, could play a role. It is important however to also mention that assisted cycling can potentially alleviate some safety hazards, for instance in contexts where cycling is less common. Here, the higher average speeds of e-bikes could decrease the speed difference between cyclists and motorized traffic, and enable users to better “go with the flow”.

6.5. Future research

The introduction of this thesis stated that the academic body of knowledge on e-bike mobility is limited today, but rapidly expanding. This thesis aimed to provide insight in the potential of e-bikes as a means to achieve more sustainable and active transportation, by studying actual and potential e-bike use in different populations and in different geographic contexts in the Netherlands. Some starting points for future research were identified in the reflection on research methods, which can aim at bridging the methodological limitations of the studies in this thesis. However, more avenues for future research can be identified based on context and content.

Due to the limited generalizability of findings from the Dutch context, there is a need to add to the existing body of knowledge on e-bike mobility in different contexts for a better understanding of the phenomenon (Winslott Hiselius and Svensson, 2017). Evidence from research in different context could first aim to better understand the role of key events and mobility milestones in the deliberation of travel behavior and consideration of e-bike adoption, in particular the potential role for financial incentives and organization of e-bike pilots; second, future research could aim to clarify the potential advantages and limitations of e-bike use for a broader range of user groups,
and the extent to which factors such as cost, enjoyment, health benefits, image, safety and perceived sustainability have a role or vary throughout different contexts. Third, a better understanding of the impacts of e-bike adoption on travel behavior and travel experience should be gained from contexts where cycling is less widespread and infrastructure is less well-developed. Overall, in other contexts, the e-bikes’ assets such as ease of use, reduced physical expense, higher speeds relative to motorized traffic, and health benefits, could help leap-frog some of the barriers that form an obstacle to bicycle use in the first place. The identification of factors affecting behavior change, modal shift, e-bike adoption, and e-bike travel behavior in this thesis can form input for research projects in other contexts: beyond the Netherlands, e-bikes might familiarize new populations with mobility by bicycle.

Based on the societal implications of the findings in this thesis outlined in the previous section, some additional avenues for research can be identified. First of all, it is important to gain a better understanding of e-bike mode substitution to better assess how e-bike use can contribute to sustainability and health objectives. Not only is it important to focus on substitution effects, but also, insights should be gained in e-bikes as a complementary mode of transport. For instance, it could be assessed whether e-bikes can be used as a feeder mode for public transportation, and whether they can help improve and complement urban bike sharing systems which are being built in numerous cities around the world. Second, the effect of relatively high purchasing prices of e-bikes should be further investigated, to better understand the financial barrier to purchase by different groups. Also, the effect of the uptake of e-bikes on transport equity could be highlighted. Third, to gain a better understanding of the effect of e-bike use on wellbeing, future studies could focus on the way in which e-bike users interact with social and spatial environments, and the ways in which this differs from other modes of transport. In line with this, a better understanding of e-bikes’ effects on safety is needed to better address the negative effects of e-bike use. The latter two points can form valuable input for policies which aim to better implement active transportation in general and e-bike use in particular.

6.6. Outlook

To conclude, the empirical studies in this thesis confirm that e-bikes can have a role to play in the shift towards more sustainable and healthier systems of transportation around the world. While this potential can differ for each population and geographical context, overall, e-bikes present a middle ground between the traditional active and motorized transport modes, by uniting some of their respective benefits and limiting their disadvantages. Electric mobility is increasingly dominant in the global discourse on sustainable transport, and it is likely that this will only increase in the near future. It is up to the academic community, policy makers and practitioners, to further define the extent to which we should and could bring more power to the pedals.