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Understanding long-term changes in commuter mode use of a pilot featuring free e-bike trials

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ABSTRACT

Globally, the need for more sustainable modes of transport is rising. One of the main contenders of the car is the electrical bike (e-bike). To promote the use of e-bikes, pilots are being organised worldwide (e.g. in the USA, Norway, and the Netherlands). Studies have shown that providing a free e-bike to people for a limited period of time changes their mode choice behaviour during the pilot period. Only few studies have also investigated the long-term effects of these free e-bike trial periods, which show increase in e-bike use in general. However, these studies have failed to investigate why some participants of the trials change behaviour on the long-term, whereas others continued their former behaviour. This study aims to bridge this gap. A pilot with e-bikes was organised at Delft University of Technology, The Netherlands, with the goal of reducing car use for commuter trips towards the university. Data was collected at various moments during and after the trial period to evaluate the long-term changes in commuting behaviour and to identify potential reasons for these changes. A total of 82 participants are included in this study. Overall, car use for commuting decreased from 88% before the pilot to 63% three months after the pilot. E-bike use went up from 2% to 18% in the same time period. A binary logistic regression model shows that the most important variables to explain the decrease in car use are 1) purchase of an e-bike, 2) the participant's perception regarding e-bike safety, and 3) the aim of the participant to use the pilot to change their current behaviour. Besides that, the most important predictor of increase in e-bike use is the purchase of an e-bike. Furthermore, participants identify the investment costs of an e-bike as the strongest reason for not purchasing an e-bike and, thus, not changing their commuting behaviour. Future pilot programs could consider the potential of incrementally purchasing an e-bike over a longer period of time, instead of at once, to increase e-bike adoption rate.

1. Introduction

Increasingly, governments worldwide acknowledge the need for more sustainable mobility. To ensure that urban environments remain liveable, sustainable, and accessible many governments have set goals to increase the use of sustainable modes (i.e. walking, cycling, and public transport) at the cost of the car. Some countries have already achieved (relatively) high use of sustainable mobility, such as the Netherlands and Denmark, especially through cycling and walking (Pucher and Buehler, 2008). However, even in those countries the car is currently the dominant mode of transportation, suggesting that walking and cycling cannot compete with the car.

The e-bike is one of the modes that can (potentially) compete with the car. The e-bike, a bicycle with integrated battery that enhances the pedal-power of the rider, can provide pedal support up to 25 km/h in Europe and 32 km/h in North America (Fishman and Cherry, 2016). Consequently, longer distances are travelled in less time and effort compared to the traditional bicycle. E-bike use is traditionally higher in countries with a larger cycling tradition (Fishman and Cherry, 2016). In China, the first country to adopt the e-bike on a large scale, research shows that the e-bike was partially used to replace car trips, but it was mostly used to replace public transport trips (Cherry and Cervero, 2007; Cherry et al., 2016). In the Netherlands, Kroesen (2017) found that the e-bike mostly affected the use of the traditional bicycle, and to a lesser extent car trips. In Australia (Johnson and Rose, 2013) and North America (MacArthur et al., 2014), where the bicycle is less apparent in the mobility patterns of individuals, the e-bike is mostly used to replace car trips. Consequently, these studies all conclude that the e-bike is able to compete with the car, albeit that the extent to which it competes depends strongly on the context.

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The effect of the purchase of an e-bike on mode choice and modal shift has been widely studied (de Kruijf et al., 2018; Jones et al., 2016; Kroesen, 2017; Plazier et al., 2017a). However, an e-bike purchase is a substantial investment, especially if an individual is not yet sure whether and when they will use an e-bike. Popovich et al. (2014) found that the purchase of an e-bike is often associated with close friends, relatives or respected community members recommending it. Furthermore, previous research found that individuals often have a limited (sometimes even unimodal) mode choice set, which is stable over time for most individuals (Heinen and Chatterjee, 2015; Ralph, 2017; Ton et al, 2019b, 2020). These findings suggest that habit formation is working against the potential adoption of alternative modes of transportation, such as the e-bike.

In order to break this habit, various studies have investigated the usefulness of e-bike pilots to induce e-bike adoption (Bjørnarå et al., 2019; Cairns et al., 2017; Fyhri et al., 2017; Fyhri and Fearnley, 2015; MacArthur et al., 2017; Moser et al., 2018; Plazier et al., 2017b). In these pilots, individuals can test the e-bike for a certain period of time, usually free of charge. Fyhri and Fearnley (2015), for example, organised a pilot in Norway, where participants could test an e-bike for a period of two or four weeks. Their conclusion was that the e-bike use increased significantly, both in number of trips and distance travelled. Another pilot study in Portland, USA, provided participants with an e-bike for a period of ten weeks (MacArthur et al., 2017). This pilot focused on commute trips, but participants were encouraged to also use the e-bike for other trips. They found a significant increase in e-bike usage during the pilot. Finally, another pilot study took place in Groningen, the Netherlands, where students were able to test the e-bike for four to five weeks (Plazier et al., 2017b). They found a significant increase in the use of the e-bike and very positive perceptions towards the e-bike during the pilot period. Regardless of the positive experiences, the students in Groningen had no intention of buying an e-bike, as they had other low-cost travel modes at their disposal. These three pilot studies have in common that they evaluate the use of the e-bike before and during the pilot, but fail to determine whether the e-bike trials influenced the decision to purchase an e-bike and the extent to which it affects the travel behaviour of participants after the conclusion of the pilot period.

Both Moser et al. (2018) and Bjørnarå et al. (2019) looked at the effect of a pilot with e-bikes on purchasing an e-bike and travel behaviour after the conclusion of the pilot period in respectively Switzerland and Norway. Moser et al. (2018) investigated the habit association and found that participants decreased their car habit association and increased their e-bike habit association on the long term when they purchased an e-bike after the pilot. Bjørnarå et al. (2019) found that a significant share of the participants transitioned from being a car user into being a cyclist (more than 50% of the trips made by (e-)bike) nine months after the pilot. However, even though these studies have investigated the change in mobility behaviour on the long term, they have not investigated which factors determined whether participants changed their behaviour on the long-term. This study aims to bridge this gap.

This study examines how testing an e-bike during a pilot period affects the commuter mode use around three months after the pilot has ended and aims to understand why some participants change their behaviour and others do not. A pilot with e-bikes was organised in 2019 at Delft University of Technology (TUD), The Netherlands, with the goal of reducing car use to campus. Employees and students at the university who were frequent car users were invited to join the pilot and test an e-bike for a period of eight weeks. To evaluate the effect of the pilot on the commuting behaviour of participants, data was collected prior to, during and after the pilot. Hence, the purpose of this study is twofold. First, to evaluate the long-term changes in car use and e-bike use for commuting to campus, and second to determine which factors result in a participant decreasing their car use or increasing their e-bike use three months after the pilot. This study therefore contributes to the literature by evaluating the long-term effects of a pilot with e-bikes on the commuting behaviour of individuals, where we specifically focus on understanding the change in e-bike and car use.

The remainder of this paper is organised in the following way. Section 2 describes the case study, being the e-bike pilot at Delft University of Technology, and the data collection and filtering. Section 3 discusses the methodology used to evaluate the long-term changes in commuting behaviour. Then, section 4 provides a description of all participants and their experiences during and after the pilot. Section 5 presents the results and provides a discussion on the findings. Section 6 provides policy implications from this study and Section 7 concludes the paper and provides recommendations for future research.

2. Case study and data collection

This section details the case study and data collection that is used to determine the long-term impact of the e-bike trial of TUD. In particular, this section introduces the pilot that was organised in Delft (2.1), describes the data collection (2.2) and data filtering (2.3).

2.1. Case study: A pilot with e-bikes at Delft University of Technology

The number of students at TUD has increased by 63% over the last ten years (van der Klugt et al., 2018). At the same time, the campus area is increasingly home to start-ups and larger companies (around 260 companies of various sizes in 2019). Daily, around 27.000 people are present at the TUD campus. This number is expected to continue to grow in the future. As a result, the pressure on the accessibility and liveability of the campus is increasing and space is becoming sparser. At the same time, the university wants to become more sustainable and aims to become CO_2-neutral. To simultaneously achieve increased sustainability and reduce pressure on space, they have set the goal to reduce car use for commuting trips, in favour of the bicycle and public transport, by 10% in 2025 compared to the level of 2018 (van der Klugt et al., 2018).

To help achieve a reduction in car use for commuting trips, the university has introduced a pilot in 2019, dubbed "Travel to campus the other way". This pilot allowed students and employees of the university, who commuted to the campus by car at least three times per week, to test an e-bike for a period of eight weeks. The university purchased 100 e-bikes, that were provided free of charge to the frequent car users. It was an opt-in trial, meaning that only people interested in testing an e-bike were captured in the trials, which could result in a bias in the results (i.e. those who would never consider changing to e-bike for commute are not captured). At the end of the trials, the e-bikes could be purchased at reduced costs. During the trial period, participants were asked to use the e-bike at least twice a week for commuting. They were allowed to use the e-bike more often and for other trip purposes. To ensure that many employees and students could participate, the pilot was organised in four blocks of eight weeks. Here, we hypothesize that eight weeks is a long enough period to break the habit of commuting by car and therefore has a higher probability of creating a lasting effect than some of the previous pilots with shorter trial periods.

2.2. Data collection

To evaluate the effect of this pilot on the travel behaviour of the participants, data has been collected at various moments in time (see Fig. 1).

Three surveys have been designed, each of which had a different goal and was distributed at a different moment in time. Table 1 shows an overview of all topics per survey. The first survey (S_0) was distributed to the participants before the start of the pilot. This survey had as goal to identify socio-demographics, current commuting behaviour, reasons for commuting by car instead of by traditional bicycle, and reasons for joining the pilot. This survey was obligatory and needed to be filled in before the participant could retrieve an e-bike, partly because this questionnaire recorded several essential details pertaining to the

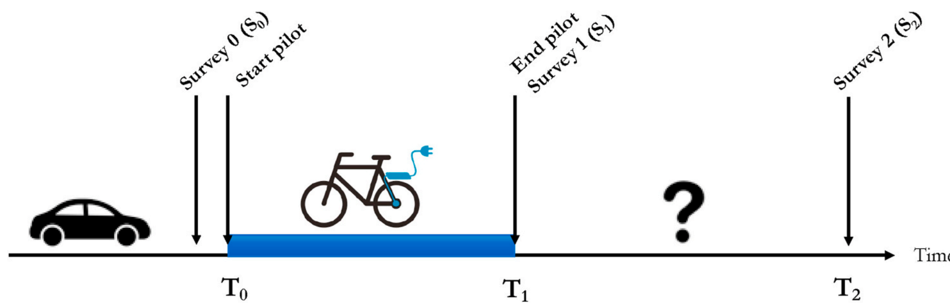

Fig. 1. Visualization of the pilot and data collection moments.

Table 1
Topics per survey.

Survey	Topics
S_0	Socio-demographics Commuting behaviour Reasons for participation Reasons for commuting by car instead of bicycle Information on pilot Considerations on e-bike use before pilot
S_1	Experience with e-bike Travel behaviour during pilot Intentions towards future commuting behaviour Reasons for these intentions Social environment in relation to e-bike use Evaluation of pilot
S_2	Commuting behaviour E-bike use in comparison to pilot Reasons for changes Intentions towards the future (in case decrease in use compared to pilot) Attitudes towards modes (car/transit/bicycle/e-bike)

validity of participation. During the week of handing back the e-bike, participants received an e-mail with a link to the second survey (S_1). This survey had as goal to evaluate the experience with the e-bike during the pilot, intention to continue using the e-bike, and reasons for these intentions. Finally, around three months after the pilot, the last survey (S_2) was distributed to the participants. This survey had as a goal to identify the commuting behaviour at time T_2, attitudes towards modes, and purchase behaviour of e-bikes. All (attitudinal/opinion) statements included in all surveys used a five-point Likert scale, ranging from "strongly disagree" to "strongly agree".

2.3. Data filtering

The last two surveys were not obligatory, therefore various reminder e-mails were sent out to ensure a high response rate. Unfortunately, the last block of participants was not invited to the second survey (S_1) and the last two blocks of participants were not invited for the last survey (S_2) due to the finalisation of the project. As a result, only participants from the first two blocks (March–June) are included in this study and the participants from the last two blocks (Sept–Dec) are excluded. Ideally, we would have included participants from all blocks as this would cover all seasons present in the Netherlands. In the current set-up we only cover spring and summer. Hence, we only include participants that encountered generally more cycling-friendly weather, although climate and weather in the Netherlands are mild. This might affect our results, such that a more negative outcome might be found in case all seasons would have been represented. However, since previous studies from the Netherlands show that weather does not have a major influence on the decision to cycle to work (Faber et al., 2020; Ton et al., 2019a), we expect that the seasonal impact is limited. If such pilot would be organised elsewhere, seasonal effects might play a larger role.

Fig. 2 shows the steps in our data filtering approach. A total of 400 employees and students participated in the pilot, of which 82 participants filled in all three surveys. Note that even though the first survey was mandatory, eight participants did not fill it out. Due to the opt-in for the pilot and the voluntary participation in the surveys, a self-selection effect is expected such that participants that had more positive or more negative experience might have participated in all surveys.

3. Methodology to evaluate changes in commuter mode use

To evaluate the long-term changes in commuter mode use of the participants, we compare their commuting behaviour before the pilot with the situation three months after the pilot has ended. Multiple modes can be used for commuting to TUD campus in an average week, therefore we express mode use as the number of days using a mode divided by the total number of commuting days. The car commute use (CCU) is then the number of days commuted by car divided by the total number of commuting days and the e-bike commute use (ECU) is the number of days commuted by e-bike divided by the total number of commuting days. The CCU and ECU can be regarded as an individual's mode share for commuting. They are calculated before and after the pilot, hence the change in car use (CCCU) and e-bike use (CECU) can be calculated (see Fig. 3).

The purpose of this pilot is to increase e-bike use and reduce car use, hence the pilot can be considered successful if a decrease in car use and/or an increase in e-bike use is observed. Hence, we can simplify CCCU and CECU into binary variables. As this study aims to determine which

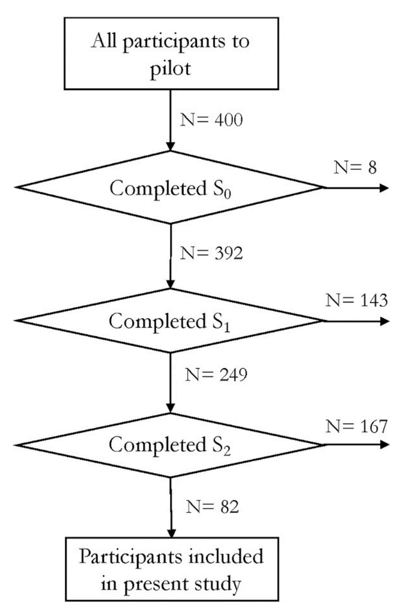

Fig. 2. Data filtering procedure.

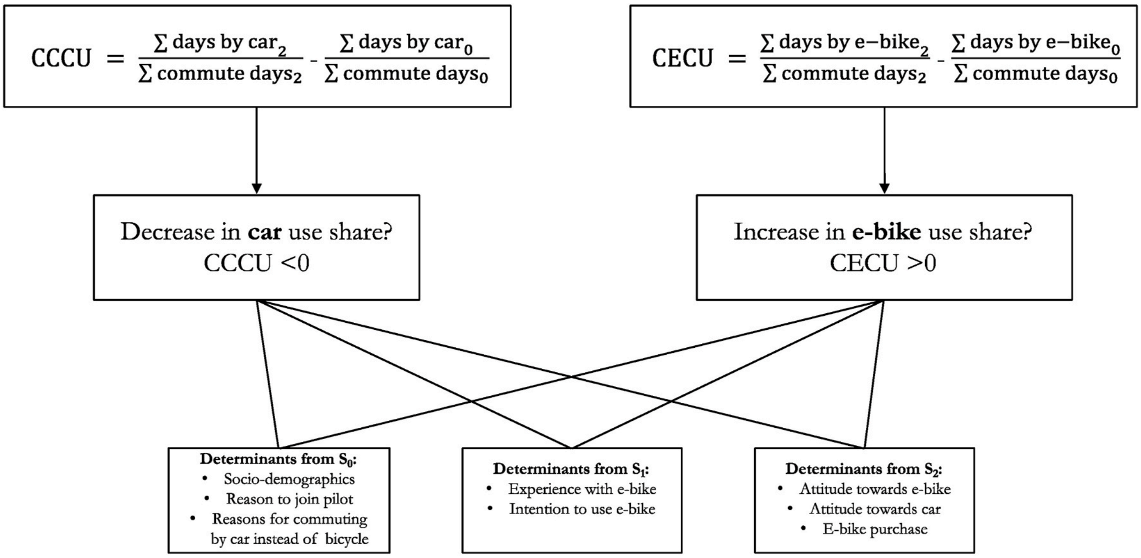

Fig. 3. Evaluation framework of change in commuter mode use.

factors result in a participant decreasing their car use or increasing their e-bike use three months after the pilot, we identified the potential relevant factors from each of the surveys in Table 1. Note that we cannot determine causality when investigating the decrease in car use and increase in e-bike use, we can only identify if the factors and change in share are correlated.

Multiple methods can be used to evaluate which factors influence the long-term changes in car and e-bike use for commuters, ranging from simple to very complex. We have chosen to apply a relatively simple method that can be easily interpret; binary logistic regression. This method is adopted because no previous study has investigated which variables are associated with a long-term change in mode use after a mobility pilot. Thus, we first need to establish the main influential variables before attempting to estimate more complex models. The results of this study can be used as the input for future research featuring these more complex models, such as latent transition analysis to identify changes over time between classes representing commuter mode use, like applied in for example De Haas et al. (2018) or discrete choice modelling with a panel approach to identify the determinants and changes in experienced mode choice set for commuting, like applied in for example Ton et al. (2020).

Binary logistic regression is able to identify the impact of different factors on the dependent or outcome variable (i.e. car use reduction or e-bike use increase). The dependent variable in this case is binary, where the reference outcome is the non-preferred situation and the impact of different factors is estimated for the preferred outcome in relation to the non-preferred outcome. We expect that determinants from all three surveys (S_0, S_1, and S_2) can potentially impact the CCCU and CECU, hence we include factors from different moments in time (T_0, T_1, and T_2). The formula for identifying the probability of change in mode use (both for e-bike and car) follows the widely known shape of logistic regression (Field, 2009), where we have adjusted the formula representing the independent variables to match with our data stemming from three time periods. The probability for individual i is specified the following way (Field, 2009):

$$P(CU_i) = \frac{1}{1 + e^{-\left(\beta_0 + \sum_{l \in T_0} \beta_l X_{li} + \sum_{m \in T_1} \beta_m X_{mi} + \sum_{n \in T_2} \beta_n X_{ni}\right)}} \tag{1}$$

Where β_0 respresents the constant, β_l the parameters belonging to the variables measured in the survey of T_0 and X_{li} the independent variables of that survey for individual i, β_m those parameters belonging to variables measured in the survey of T_1 and X_{mi} the independent variables of that survey for individual i, and β_n the parameters from survey T_2 and X_{ni} the independent variables of that survey for individual i.

Our sample size is limited with only 82 participants that completed all three surveys. This might affect our findings, such that some factors might not be significantly associated with our dependent variables, whereas in real-life these associations are present. Furthermore, this also means that we will most likely not be able to specify a model with many independent variables nor are we unlikely to include the five-point Likert scale answers into our models, as we do not have enough data. However, our sample consists of relatively similar participants with similar experiences, as we investigate a university population of frequent car users, which potentially helps in identifying differences among the population.

Using chi-square tests (for categorical variables) and independent sample t-tests (for continuous variables), we establish which variables are associated with CECS and/or CCCS. The significantly impactful variables are accordingly included in the binary logistic regression models. The selection method for the inclusion of variables in the regression model is the Forward LR method. This two-step approach is adopted because this study is the first to investigate the factors associated with change in behaviour, hence there is no previous literature available regarding which factors are relevant. To prevent blindly testing all possible combinations of factors from three surveys, we first identify the factors with a direct association with our dependent variable.

4. Description of the participants and their experience

The pilot aimed to include people who commuted by car more than three times a week. Of the total TUD population, around 25% commutes by car, hence our target group forms a minority in the total TUD population. The participants are predominantly employees, as students often live close enough to the campus to cycle and often have a (free) subscription for the Dutch public transport financed by the government. Most participants of the pilot do not live in Delft, whereas the majority of the TUD population does. Furthermore, because of the opt-in, we will target only people who are willing to change and not target those who are 'car loving'. Hence, we can conclude that our sample shows a subgroup of the total TUD population that is not representative for the entire TUD population and cannot be generalised to that population.

A description of the 82 participants and their reasoning and experiences in the pilot are shown in Table 2. In total 92% of the participants are an employee of TUD (e.g. PhD-candidate, faculty, or support staff)

Table 2
Description of participants and their experiences.

Variable	Descriptive statistics		
Socio-demographic variables			
Involvement at University *(S_0)*	employee: 92%	student: 8%	
Gender *(S_0)*	male: 54%	female: 46%	
Age *(S_0)*	mean: 39	std. dev: 5.9	
Reasons for commuting by car instead of bicycle	***Yes***	***No***	
Cycling is too time consuming compared to the car *(S_0)*	55%	45%	
I don't like arriving sweaty at work *(S_0)*	49%	51%	
The odds of cycling through rain are too high *(S_0)*	37%	63%	
I don't like cycling *(S_0)*	7%	93%	
There are not enough showers on campus *(S_0)*	10%	90%	
Change behaviour without pilot?	**Yes**	**No**	
Wouldn't consider changing behaviour without pilot *(S_0)*	47%	53%	
Experience after using e-bike	***Agree***	***Neutral***	***Disagree***
The e-bike lived up to my expectations *(S_1)*	72%	21%	7%
I now think more positive about the e-bike *(S_1)*	75%	16%	9%
I now think more positive about my car commute *(S_1)*	9%	44%	47%
It was easy to commute 2x per week by e-bike *(S_1)*	70%	19%	11%
I used the e-bike also for other trip purposes *(S_1)*	70%	13%	17%
The e-bike is a good alternative for the car *(S_1)*	82%	12%	6%
The e-bike is better than the car for commuting *(S_1)*	67%	22%	11%
My commuting distance is suitable the e-bike *(S_1)*	82%	5%	12%
I am willing to invest in an e-bike *(S_1)*	57%	26%	17%
Actual behaviour and intention			
I commuted … by e-bike than required *(S_1)*	more: 61%	as required: 15%	less: 24%
Intended frequency of e-bike use after pilot *(S_1)*	2-5x p/week: 35%	less frequently: 65%	
Willing to purchase an e-bike without subsidy *(S_1)*	yes: 40%	maybe: 37%	no: 23%
I purchased/leased an e-bike after the pilot *(S_2)*	yes: 24%	no: 76%	
Attitude towards car and e-bike	***Agree***	***Neutral***	***Disagree***
Using the car is comfortable *(S_2)*	96%	3%	1%
Using the car is time saving *(S_2)*	67%	18%	15%
Using the car is safe *(S_2)*	79%	18%	4%
Using the car is good for my health *(S_2)*	0%	14%	86%
Using the e-bike is comfortable *(S_2)*	74%	14%	12%
Using the e-bike is time saving *(S_2)*	26%	41%	33%
Using the e-bike is safe *(S_2)*	39%	42%	19%
Using the e-bike is good for my health *(S_2)*	89%	4%	7%

and only 8% were Master and Bachelor students. The share of males is higher than females in the sample. TUD is a technical university with a larger share of males (+/- 63%), consequently in the sample females are slightly overrepresented (CBS, 2018). The employees are young on average, with a significant share of students and PhD-candidates, however also employees over the age of 60 participated. The participants of the pilot live on average 11.8 km from the campus (with a standard deviation of 10.7 km). Fig. 4 shows the distribution of distance by bicycle for all individuals (left) and home location of all participants (right). The majority of the people commute maximum 20 km. Most participants live in the neighbouring big cities: The Hague and Rotterdam. Some of the participants commute over large distances from Leiden and Papendrecht.

The most important reason provided by the participants to use car for their commute rather than the bicycle was the time needed to reach the destination (55%). This finding is in line with our expectations, as commuting by car is generally faster (especially for the longer distances) compared to the bicycle, except in dense urban areas. Furthermore, arriving at work sweaty (49%) and the potential rain in the Netherlands (37%) were two other common reasons identified by participants for using the car for their commute. 47% of the participants indicated that they would not consider changing their behaviour without this pilot. In other words, they would continue their behaviour as it was before. This suggests that almost half of the participants believed they needed a trial to experience another mode before they would potentially adopt different commuting behaviour.

In general, people had a positive experience testing the e-bike. For 72% of the participants, testing the e-bike lived up to their expectations and resulted with a more positive perception of the e-bike (75%). Most participants agreed it was easy to travel twice a week to campus (70%), 61% even commuted more often than required and 70% used the e-bike also for other trip purposes. Furthermore, 82% thought the e-bike a good alternative for the car, and 67% thought the e-bike better than the car for commuting. Even though the experiences and actual behaviour are positive, only 57% indicated they are willing to invest in an e-bike. Without a subsidy from the employer, only 40% would be willing to invest in an e-bike. Finally, 82% suggested that their commuting distance is suitable for travelling by e-bike. This high percentage might be caused by the self-selection effect, as it would be unexpected for people to participate in an e-bike trial if the commuting distance is deemed too large by the participant. Fig. 5 shows the perceived suitability of the commuting distance versus the actual commuting distance. The mean suitable distance is 10.7 km with a maximum of 19.7 km. Participants who were neutral regarding the suitability (N = 4), show a higher average distance (20.2 km) compared to the participants who agree. However, because of limited observations, this finding is not reliable. The participants who found their distance unsuitable, have a mean distance of 17.3 km. This suggests that suitability of participants' commuting distance is not solely a function of distance.

24% of the participants indicated they have purchased an e-bike after the pilot. It is highly likely that the purchased e-bike is also used for the participant's commute. In terms of attitude towards the car, most participants (95%) believed the car is comfortable. 67% thought the car is time saving, 78% believed the car is safe, and nobody believes using the car is good for your health. Regarding the e-bike, 75% thought the e-bike is comfortable, which is much less compared to car comfort. Only 27% of the participants thought the e-bike is time saving and 40% believe the e-bike is safe. Finally, 89% of the participants believed using the e-bike is good for one's health.

5. Results

The pilot is evaluated based on the change it has imposed on the mode use for commuters. This section first presents an analysis on the overall change in mode use in section 5.1. Sections 5.2 and 5.3 present and discuss the detailed results for respectively the change in car use for commuting and in e-bike use for commuting.

5.1. Changes in mode use as a result of a pilot with e-bikes

The average share among the population (N = 82) of using each mode before and three months after the pilot has ended is shown in Fig. 6. Before the pilot the participants reported to use the car on 88% of

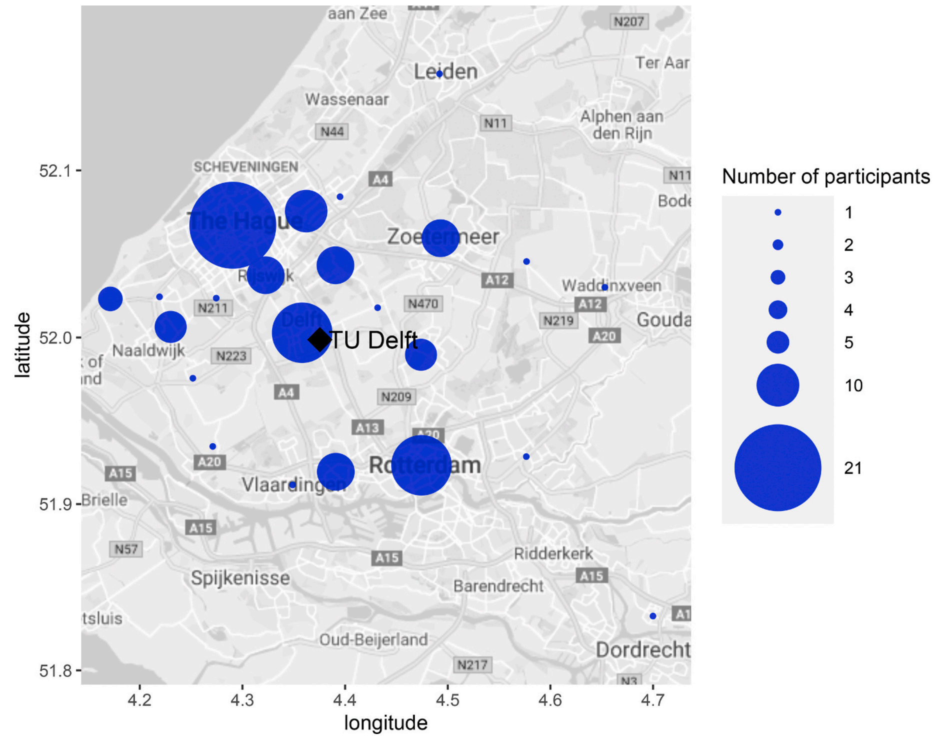

Fig. 4. Distance from home to campus (left) and home locations of participants (right).

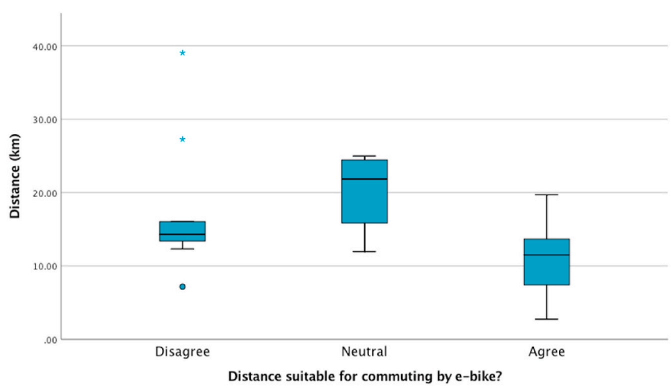

Fig. 5. Perceived suitability of commuting distance for e-bike versus actual commuting distance (km).

the days, whereas after the pilot this dropped to 63% (significant change, $p < 0.01$). The share of e-bike use has increased significantly from 2% to 18% ($p < 0.01$). Interestingly, the share of the bicycle has also significantly increased ($p < 0.01$) after the pilot, from 5% to 12%. It seems that the experience with the e-bike has triggered an increase in the commuting bicycle mode share. To continue cycling on an e-bike, the participants had to purchase one, as the e-bikes in the pilot had to be returned at the end of the pilot. In the Netherlands, most people already own a bicycle (Ton et al., 2019a). Consequently, it seems that a fair share of the participants wanted to continue cycling, but did not (want to) purchase an e-bike. Potentially, they had such a positive cycling experience, that they continued cycling without requiring the additional support of the e-bike. The differences in shares of moped, train, and bus/tram are not significant and represent only a small share of the commuting trips. This second finding also indicates that the pilot only increases the e-bike and cycling mode share, but not the share of other sustainable modes of transport.

Fig. 6 also shows that the car is not the only used mode by most participants before and after the pilot. Jointly, all modes used for commuting form the experienced mode choice set (Ton et al., 2020). Fig. 7 shows the experienced mode choice sets before and after the pilot, together with the changes in the mode choice sets. Please note, this figure does not show the frequency of using each mode over a week, only the composition of the choice set. The majority of the participant in this study was a car-only user before the pilot, which is to be expected due to the nature of the pilot. The results show that 56% of those car-only users does not change or expand their experienced mode choice set. The others have either expanded their experienced mode choice set (33%) or have changed fully to bicycle or e-bike (11%). The participants that were already multimodal for their commuter trips (30%), have mostly remained multimodal (60%). However, some of the multimodal commuters changed to become unimodal car users (16%). It seems that these participants had an unsatisfactory experience during the pilot and returned fully to the car.

5.2. Understanding changes in car use for commuting

The change in car use on an individual level is shown in Fig. 8. Around 39% of the participants used the car for all of their commuting days before the pilot, which remained the same three months after the pilot. Basically, testing the e-bike for a period of eight weeks did not convince these participants to change their behaviour. Six people switched completely from car to another mode of transport for their commuting trips. Bjørnarå et al. (2019) classified participants in their pilot as car user when more than 50% of the trips was made by car. They found a decrease in car users from 83% to 50% of the participants (−33 pp). In the TUD campus pilot, the share of car users decreased from 94% to 62%, which is a drop of 34 pp, thereby confirming the findings of Bjørnarå et al. (2019).

51% of the participants have decreased their car use for commuting. Table 3 shows the results of the CCCU binary logistic regression model. The results show a decent model fit with five variables in the model (i.e. Nagelkerke $R^2 = 0.51$). The odds of participants to decrease their car use is 3.04 times higher for participants that have said they would not

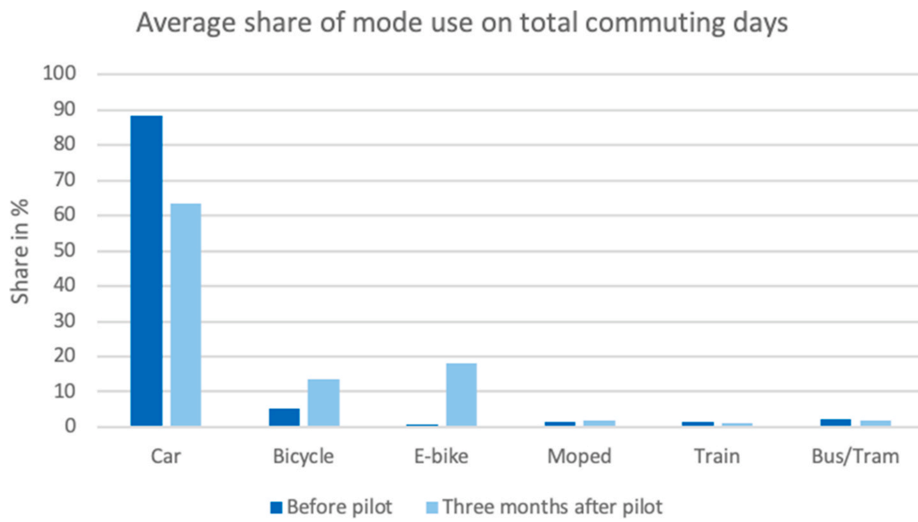

Fig. 6. Average share of mode use before and after pilot. Note that the share of walking was zero before and after the pilot.

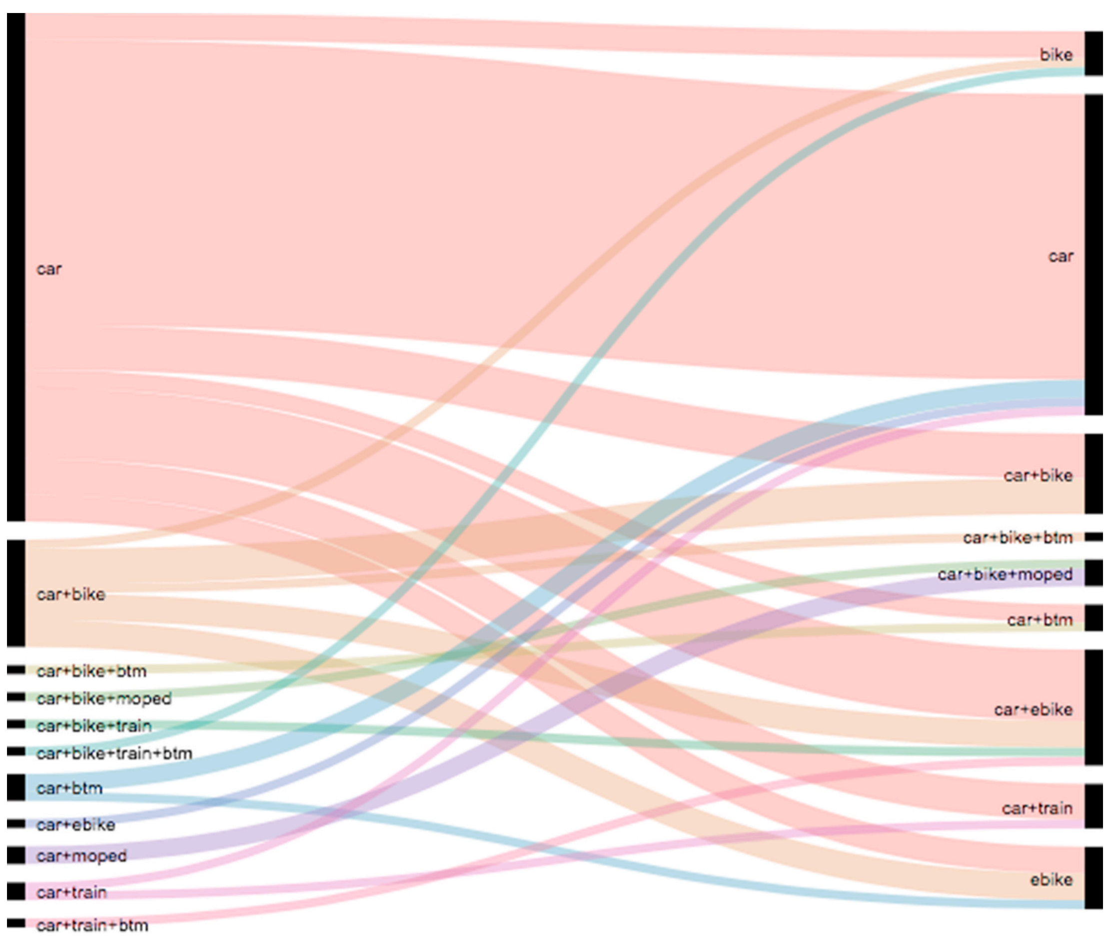

Fig. 7. Sankey-diagram showing the experienced commuter mode choice set before and three months after the pilot. The colours show what the mode set was before the pilot. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

consider changing their commuting mode use behaviour without the pilot compared to those who would consider this. This suggests that a pilot could be the last step in the process of changing behaviour. They want to test the alternative to be sure, but then act upon this experience. Consequently, a successful e-bike trial period provides the final nudge to change participant's mode choice behaviour. The odds of decreasing the car use share are 11.45 times higher for those who have purchased an e-bike after the pilot compared to those who did not purchase an e-bike. This is in line with the finding of Moser et al. (2018) that participants who purchased an e-bike after the trial had a lower habit association with car use.

If participants felt like the car was time saving, they would be less likely to decrease their car use compared to disagreeing on this statement (OR = 0.19). The parameter for neutral is not significantly

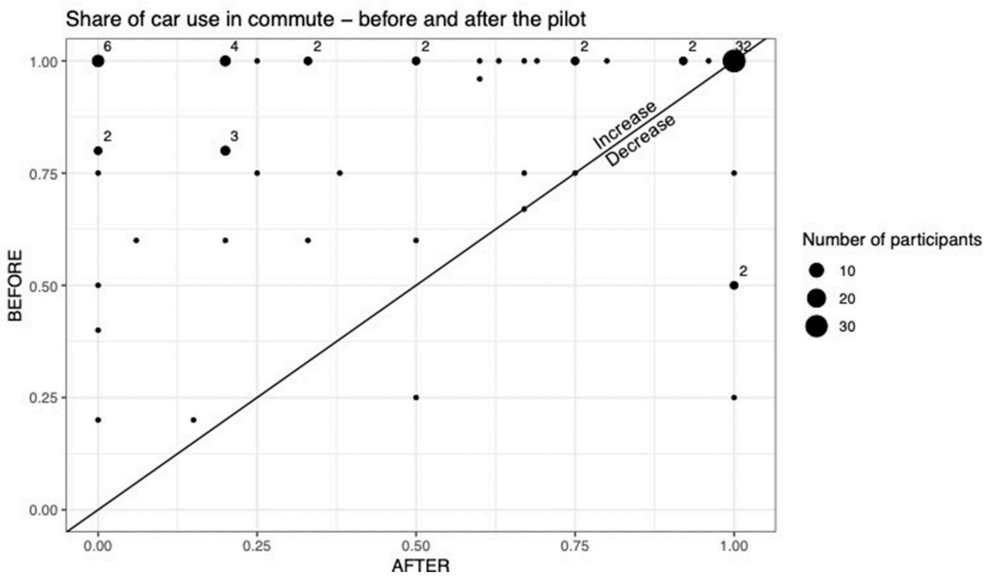

Fig. 8. Change in car use after testing the e-bike in the pilot.

Table 3
Binary logistic regression with dependent variable CCCU.

S	Variable	Level	B	S.E.	Sig.	Odds Ratio Exp (B)
–	Constant	–	−0.72	1.33	0.59	–
0	Consider changing behaviour without pilot	Yes	0			
		No	1.11	0.66	0.09	3.04
2	E-bike purchase after pilot	Yes	2.44	0.81	0.00	11.45
		No	0			–
2	Using the car is time saving	Agree	−1.68	1.02	0.10	0.19
		Neutral	−0.68	1.22	0.58	0.51
		Disagree	0			–
2	Using the e-bike is safe	Agree	2.25	0.94	0.02	9.50
		Neutral	0.14	0.84	0.87	1.15
		Disagree	0			–
2	Using the e-bike is good for my health	Agree	−2.44	1.20	0.07	0.11
		Disagree/ Neutral	0			–

Note: $R^2 = 0.38$ (Cox & Snel), $R^2 = 0.51$ (Nagelkerke), model $\chi^2 = 71.65$, N = 79.

different from zero, hence having a neutral opinion is similar to disagreeing towards this statement. However, the complete variable is significant, thus we include the parameters for all categorical levels in the model. When commuting, where you have to be at work or in class at a specific moment in time, time is valuable. This time-saving attitude therefore favours the car. Besides that, the odds for decreasing car use are 9.5 times higher for those who felt like using the e-bike was safe compared to those who thought otherwise. A neutral opinion towards the safety of the e-bike is again not significantly different from zero, hence neutral is similar to disagreeing to this statement. Again, because the complete variable is significant, all parameters are included in the model. When participants think that the e-bike is good for their health, they are less likely to decrease their car use, compared to when they believe this is not the case or are neutral to this. Here, we grouped the neutral and disagree answers, as there were only few and otherwise no significant effect could be found. A potential explanation for the difference between agree and neutral/disagree regarding health is that people who remained car users might view the e-bike as a very active mode for their commute, which also adds to their health. It shows that the people who decreased their car use do generally not use the e-bike for health reasons. A finding, using the same dataset, but with all participants, on the motivation for participating in the pilot showed that one of the strong motivators to participate was improving one's health (Ton et al., 2021). This finding suggests that intention to change behaviour because one feels it is good for their health, might work on the short-term, but does not have a lasting effect. It will result in people signing up for pilots or trials, but when they have to do it on their own without support in any shape or form, they cannot continue their 'healthy' behaviour.

The model includes only five variables that are significant. Many others were not found to be significantly associated with CCCU. We highlight the most striking insignificant factors below. First, sociodemographics (gender, age, student/employee) are not significantly related to decreasing car use. Hence, this pilot was not more successful for specific subgroups of the population. Second, the experience and intentions of using the e-bike during the trail did not significantly affect the change in behaviour on the longer term (three months after). We expected that positive experiences or the intention to continue using the e-bike would explain the decrease. Instead, no variables from the S_1 are significantly related to car use reduction. Finally, only some elements of attitude towards car and e-bike are found to be related to the car use reduction. Others, such as the e-bike being fun or comfortable are not related to car use decrease. The included attitudinal variables are more basic variables (needs) instead of extra benefits (being fun or comfortable). Hence, this suggests that the basics/needs are more relevant when changing behaviour and adopting new behaviours compared to the extra benefits.

5.3. Understanding changes in e-bike use for commuting

The change in e-bike use on an individual level is shown in Fig. 9. Interestingly, 61 participants (74%) did not increase their e-bike use after the pilot. According to the definition of Bjørnarå et al. (2019), a cyclist is a person that makes more than half of their trips by (e-)bicycle. In their pilot, they found an increase from 0% to 38.9% in cyclists. In our pilot the share of cyclists (both normal and e-bike) increases from 7% to 32%, which is less than the study of Bjørnarå et al. (2019). The pilot at the TUD campus focusses on car users, whereas the pilot of Bjørnarå et al. (2019) focused on people that cycle less than 15 min per week. In

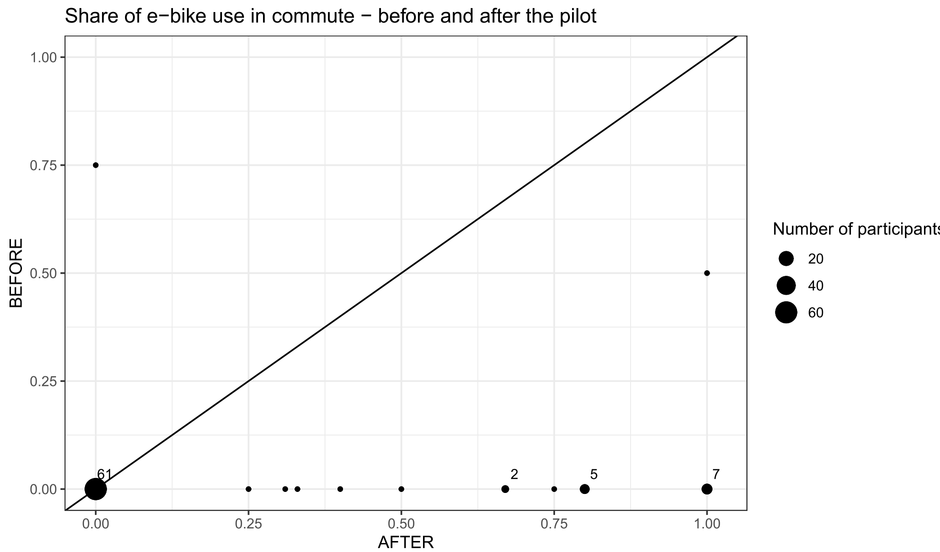

Fig. 9. Change in e-bike use after testing the e-bike in the pilot.

that case, participants already use a bicycle to travel to some activities. In the Netherlands, most people own a bicycle and use it (Ton et al., 2019a). Thus, we expect that people who would be easily persuaded to commute per bicycle, are already using it. That being said, most TUD participants did not use the bicycle for commuting purposes, but most likely do use it for other trips. In other words, due to the specific focus on commuting trips and the relatively long commute distances, we can expect differences to occur between Bjørnarå et al. (2019)'s findings.

Car use decrease and e-bike use increase are not perfectly correlated (as also the bicycle share increases, see Fig. 6). Therefore, the reasons for reducing car use might differ from the reasons for increasing e-bike use. As the latter, requires the purchase (or lease) of an e-bike and the former does not require anything specific. The purchase of an e-bike also turns out to be the only and dominant factor associated with increasing e-bike use. The estimated model ($R^2 = 0.46$ (Cox & Snel), $R^2 = 0.68$ (Nagelkerke), model $\chi^2 = 40.83$, $N = 81$) explains that having purchased an e-bike after the pilot results in 109.56 higher odds of increasing e-bike use compared to not purchasing one. Out of the 81 participants, 20 have purchased an e-bike. 17 of those have increased their e-bike use and three have not, the latter might use the e-bike for other trip purposes. Of the 61 participants that have not purchased an e-bike, only three have increased their e-bike use. Mostly likely, the latter have borrowed or leased an e-bike.

A total of 75.6% of the participants does not use the e-bike after the pilot, mostly because they do not possess an e-bike. Table 4 describes the most important reasons provided by these participants on why they chose to not purchase an e-bike. The costs of an e-bike are mentioned as the most important reason, most likely because an e-bike is quite an investment if purchased in one go. The second most important reason is that they do not know which e-bike to buy. This can be dealt with by providing good reviews and comparisons on price/quality ratio. From the open answers in the survey, we found that the e-bike being slow relates frequently to the fact that the e-bike only provides pedal support until 25 km/h. If you want to cycle faster, you have to do cycle unassisted. In those cases, a speed pedelec that supports until 45 km/h, might be an outcome. Thus, to increase the uptake of cycling, small trials with speed pedelecs might sway this group of participants. Some mentioned that commuting by car is easier. If a significant change towards cycling is desired, this means that the comfort of the car use or car parking should be reduced. This is, however, generally not a desired outcome as it diminishes the overall accessibility of the destination.

Table 4
Most frequently mentioned reasons for not purchasing an e-bike after the pilot ($N = 62$).

Most important reasons for not purchasing an e-bike	Frequency	Share in %
Too expensive to purchase in one go	38	61.3%
Don't know which e-bike to buy	11	17.7%
The e-bike is too slow	9	14.5%
Commuting by car is easier	9	14.5%
The weather is too bad	8	12.9%
Travel time by e-bike is too high	7	11.3%
Not enough safe parking spots for e-bike on campus	6	9.7%

The participants that did not increase their e-bike use after the pilot were also asked about their e-bike intentions towards the future. 20% mentions they do not want to start using the e-bike again. Surprisingly, 65% indicates that they want to start using the e-bike again for commuting 2–4 days a week and 8% even mentions they want to start using it every day. This mismatch between their behaviour three months after the pilot has ended and their future intentions could have to do with the leasing scheme introduced by the Dutch government in January 2020 (which was announced already in 2019) (Rijksoverheid, 2019). This scheme allows employees to lease an e-bike via their employer by means of a monthly fee, therefore taking away high investment costs. The presentation of this scheme might have induced participants to wait to actually purchase an e-bike.

6. Policy implications

As a result of this pilot, the behaviour of a significant share of the participants changed on the long-term. Consequently, this type of pilot can be considered a success with respect to changing the commuting habits of frequent car travellers. Next to this generic conclusion, our findings identify five lessons for policy making.

First, individuals who had a positive experience during the pilot and have a positive attitude towards e-bikes are more likely to also change their behaviour. This confirms once more that people's attitude towards a mode and people's travel behaviour are related. This lesson implies that e-bike pilots are especially effective when people are already inclined to accept the e-bike as a mode of transport, hence organizing e-bike trials using an opt-in sign up policy seems attracts individuals who are motivated to change on the long-term.

Second, those participants that have mentioned that they would not have changed their behaviour if they did not have the possibility to participate in a pilot were more likely to change their behaviour. Consequently, acknowledging that one might need to test another mode before actually making the purchase, signals that a participant has been looking into the e-bike for commuting purposes and requires assistance taking the final leap forward. Future pilot programs could ask questions to interested individuals on beforehand about the reasons for joining the program, to identify whether individuals have the potential to actually change behaviour.

Third, individuals that indicated that they would like to try the e-bike to improve their health were far less likely to adopt the e-bike as a lasting mode of transport. To ensure that individuals who join a pilot for health reasons are more inclined to change behaviour on the long term, more assistance at the end of the pilot featuring the health of the participant might improve the potential of the e-bike trials. Through additional support, the effectivity of e-bike pilots might be further increased.

Fourth, this study shows that socio-demographic characteristics did not have a significant effect on changeing behaviour. Hence, according to our sample from the Netherlands, there is no need for a pilot like this to target a specific group of individuals, such as only men or only young people. This is in line with other studies on cycling in the Netherlands, that found that cycling is for everyone (e.g. Ton et al., 2019a).

Fifth, the investment costs for an e-bike are relatively high and our findings indicate this is a large obstacle for participants to purchase an e-bike. Spreading the costs over multiple months, like a "lease e-bike", which is offered by the Dutch government since January 2020 (Rijksoverheid, 2019), might potentially take away people's hesitation due to the high initialization costs. A scheme that allows individuals to purchase an e-bike in several terms, could potentially increase the share of participants that change behaviour on the long-term.

7. Conclusions and recommendations for future research

This paper presents the findings of an analysis on the long-term impact of a pilot with e-bikes on the car use and e-bike use for commuting trips. A pilot with e-bikes was organised at TUD, where frequent car users (>3 days per week) were targeted to try the e-bike for free for a period of eight weeks. Their commuting behaviour was registered before and three months after the pilot, to evaluate the change in behaviour. Through three surveys (before, right after, and three months after the pilot) various aspects of their experiences and opinions were captured to help understand the changes in commuter mode use. By means of binary logistic regression models, we identify which factors are important in changing the mode use behaviour of frequent car commuters.

This research finds that car use share for commuting decreased from 88% before the pilot to 63% three months after the pilot. Some participants have fully replaced their car commute by an e-bike commute for all commuting days, but most participants have extended their experienced mode use set by adding the e-bike and/or regular bicycle. The most important variables that explain the decrease in car use frequency are the purchase of an e-bike, the perception of e-bike as being safe, and the necessity of the e-bike pilot for changing their mode choice behaviour. Perceiving the car as being 'time saving' and the e-bike as being 'healthy' are significantly related to not changing car use behaviour. At the same time, the share of e-bike use went up from 2% before the pilot to 18% three months after the pilot. The increase in e-bike use is explained mostly through the purchase of an e-bike. The most commonly mentioned reasons for not purchasing an e-bike are the cost of the e-bike, the large variety of e-bikes on offer (i.e. choice complexity), the limited top speed of the e-bike (too slow), and that commuting by car is easier. Besides that, this study determines that the distance of the commute does not play a role in the change of behaviour.

There are multiple alleys for future research. This study is the first to identify factors that are related to long-term changes in commuter mode choice behaviour after a pilot. Many studies only evaluate the pilot right after it has ended and do not include a follow-up survey to investigate long-term changes. We investigate the effects after three months. One might argue that this is not long enough to observe or witness durable changes. However, since we focus on commuting, which is considered rather habitual, we believe three months to be sufficient to witness lasting changes. To be sure about the durability of these changes, future research should evaluate the effects of such pilot also on a later stage, to ensure that seasonal effects have also been captured. Furthermore, the sample size in our study was limited. This prevented us from including the data as we collected it (five-point Likert scale) and might result with some variables being insignificant in our model, whereas a larger sample might find these associations. Also, this pilot was organised in the Netherlands, which is a cycling friendly country with a strong cycling culture. Even though our target group was car users, the environment is very inviting for cycling. Hence, the results might too optimistic, when transferred to other countries with different contexts. It is essential that the results of similar pilots are also evaluated featuring other countries and communities, such as health care, municipalities, and companies.

Author contributions

Danique Ton: conceptualization, data curation, formal analysis, investigation, methodology, visualization, writing – original draft; Dorine Duives: conceptualization, data curation, writing – review & editing.

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