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Towards Sweden's transport climate target by substituting cars with e-bikes

Understanding e-bike usage from a survey study

Master's thesis in Industrial Ecology

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Abstract

Sweden's transportation emissions, mostly attributed to passenger cars, are not falling rapidly enough to reach its transport climate target. Car kilometers should be reduced with 22% to reach this target. Cycling serves as an alternative for cars, but cycling shares in Sweden are not as high as in the Netherlands, Denmark or Germany. E-bikes might be able to substitute more car kilometers, as some of the constraints often cited for cycling (e.g. distance, effort and sweatiness and transportation of goods and children) can be overcome by e-bikes. The environmental potential of e-bikes is largely dependent on the context which determines which mode e-bikes are substituting. In this survey study, it was investigated which factors determine e-bike usage. This was done by asking current Swedish e-bikers about their three most recent trips, travel behavior, perceived advantages and benefits and individual characteristics. It was found that the occurrence of a 'life-event', a natural break-of-habit, could potentially be a strong motive to purchase an e-bike. More evidence of a possible learning and novelty effect was found. Commuting trips were also identified as a potential purchase motive, while a climate moral message could be an effective marketing strategy to sell e-bikes, but not necessarily to reduce car usage. Perceived advantages generally outweighted disadvantages and the risk of theft was classified as the main barrier for further e-bike adoption in Sweden. Rural-living Sweden showed large potential in terms of car substitution and thus potential environmental savings. Preferably, people that currently not cycle should be targeted, while multiple car owners showed elevated levels of covered distance. E-bikes were not hindered by hills in contrast to conventional bikes. Weather influences on e-bike usage were found to be low, but have likely been underestimated. Travel time was found to be the only significant variable determining the modal choice in the discrete choice model. Hence, investment costs might be more determinant for e-bike usage than price measures like congestion charge and parking fees. Moreover, time-reducing measures like direct cycling pathways for e-bikes could be effective to increase usage. Only 22% of the e-bike trips replaced car trips in this study which is low compared to earlier literature findings. However, a 16% reduction in car kilometers was calculated after purchasing an e-bike. This outcome is uncertain, but if these would be in the right order of magnitude, it would mean that e-bikes could be a major support in reducing car kilometers and accelerate the road to sustainable transportation.

Keywords: e-bikes, substitution, sustainable transportation, travel behavior, emissions, discrete choice model

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Contents

List of Figures

List of Tables

1 Introduction

1.1 Transport emissions

Sweden's emissions were 52.7 Mton CO_2 from all sources in 2018 [47]. Energy (including transport) was the largest contributing sector to Sweden's greenhouse gas emissions with 36.6 Mton CO_2-equivalent in this year, corresponding to 70% of the annual emissions [47]. The transportation sector alone contributed with 16.6 Mton (31%), of which passenger cars were responsible for 10.4 Mton CO_2-equivalent, roughly equivalent to about 20% of Sweden's total emissions [47]. The share of transport emissions is relatively large compared to the rest of the world (25%) due to low fossil-based electricity generation and heating [33]. Most passenger kilometers in Sweden are conducted by car (60%) [64]. From 2007, passenger car emissions have started to fall in Sweden due to improved energy efficiency, more renewable fuels and a reduced fuel consumption [47]. However, the rate that these emissions are falling, specifically in the transport sector, is too low. The transport climate goal of reducing 70% of the 2010 level by 2030, is predicted to only be reached by half [38]. To reach that goal fully, transport emissions should annual fall by 8%: these emissions remained mostly stable in recent years [3]. Hiselius and Rosqvist [29] calculated that the car kilometers per capita have to reduce with about 22% by 2030 assuming population growth. The recommendation that follows from Klimatpolitiskarådet [38] is that Sweden should strengthen regulations to decrease car dependence. Non-motorized transportation, in particular cycling, could be an alternative mode of transportation that can accelerate the road towards more sustainable transportation.

1.2 Share of cycling

The national transport research agency Trafikverket [66] stresses that the Swedish cycling culture is similar to Denmark, the Netherlands and Germany in which cycling is primarily a mode of transportation and secondly used for leisure. In Norway and the UK on the other hand, cycling is mainly seen as a leisure mode. Despite stating to have an utilitarian cycling culture, the share of cycling in the total trips and distance are relatively low. In Table 1.1, an overview of the share of cycling in these countries is provided. In 2019, about 13% of the total trips were made by bike corresponding to about 1.6% of the total travelled distance in Sweden [64]. It can be observed that Sweden has more similar cycling levels to Norway and the UK in terms of share of mileage instead of the countries mentioned by Trafikverket [66]. Other North-West European countries like Germany, Denmark and the Netherlands possess higher cycling shares in both trips and distance (except share of trips in Germany). Thus, despite stating to have an utilitarian cycling culture, the biking numbers are behind. Around 80% of all urban car trips in Sweden are 4 kilometer or less, indicating a potential for mode replacement by bicycle or walking [58]. The Swedish government stated that 25% of travel distance should be conducted by bike, foot or public transport in 2025 [45]. On a city level, Gothenburg aims to reach 12% of all trips to be conducted by bike in 2025 which was 6% in 2015 [59]. Promotion of cycling and electromobility have separately been targeted by the European Commission as a clean and efficient transport pathways towards sustainable urban mobility [15]. These targets on a city, country and continental level should push Sweden's cycling numbers in the coming year, although it is not specified how this exactly will be done.

Country	Share of bike km	Share of bike trips	Source
Netherlands	8%	28%	KiM [37]
Denmark	4%	17%	TOI [62]
Germany	3.5%	10.8%	MiD [44]
Sweden	1.6%	13%	Trafa [64]
Norway	1.5%	5%	DTU [14]
UK	1%	2%	DoT [13]

Table 1.1: Share of cycling in various North-West European countries.

1.3 E-bikes

One of these alternative, active modes of transportation are e-bikes. Car trips that are considered too long to be taken by conventional bike, could be replaced by e-bikes that are able to cover a longer distance due to the electrical support [58, 39, 41]. Moreover, e-bikes could induce additional cycling trips by overcoming or lowering burdens such as effort, sweating, uphill slopes, headwinds, start-ups and transportation of goods or children [58, 39, 41]. A lower effort could lead to attraction of more cyclists such as elderly and/or people with physical limitations [41]. Despite lowering the effort, physical activity on an e-bike is still regarded as 'moderately intense' [8]. When comparing with a car, an e-bike serves as a more economical transport mode [42]. Riding an e-bike is often considered as rewarding and fun, provides freedom to the riders and offers opportunities for social engagement [42, 68]. This could lead to enhanced freedom, independence and civil engagement of users [54]. Lastly, it is believed that e-bikes could not only lower greenhouse gas emissions, but also positively affect the transportation system in terms of safety, accessibility, congestion, physical and mental health, air pollution and noise [58, 30, 8, 7]. All these benefits make e-bikes an interesting mode to further look into.

1.3.1 E-bike sales

Sweden's e-bike sales have risen tremendously in recent years. The share of e-bike sales of the total bike sales reached 20% with more than 100,000 sold e-bikes in 2017/18 [66]. This sales peak was partially obtained due to a subsidy program that financed up to 10,000 SEK or 25% of the purchase price [58]. When the subsidy program ended in 2018, a sales drop to 86,000 units was observed in 2018/19, but the e-bike sales were back on a rise in 2019/20 [58]. The general trend remains positive despite ending the subsidy program. This suggests that e-bikes can more and more be considered as a serious mode of transportation in Sweden. The more wide-spread e-bikes become, the more substantial the effects on modal change become.

1.4 Environmental potential

In order to assess the environmental impact of e-bikes, it is essential to know the modal choice substitution. Replacement of trips with motorized vehicles like cars and public transportation will be more environmentally beneficial than replacement of a less emitting modes such as conventional bikes (c-bikes), walking or newly induced trips. Research on the substitution effect of e-bikes gives differentiating outcomes in various countries. Kroesen [39] concluded that the substitution effect is very context-dependent as research in car-oriented countries like the US and Australia showed high replacement of cars (60-80%), while bike-oriented the Netherlands and Denmark found car replacement shares of about 40-49%. E-bikes mainly substitute the mode that was previously dominant in the individual travel pattern which usually still remains dominant after partly being substituted by e-bike trips [10]. Hence, it was assumed that environmental impact is the greatest where car use is high [58]. Given the relatively low cycling and high car usage shares, and the notion that environmental gains are large in car-oriented places, carbon savings could possibly be large in Sweden.

1.5 Aim

There is a strong incentive for Sweden to reduce its transport emissions as climate goals are not expected to be reached. Cycling could serve as a sustainable mode to help reach these goals, but the share of cycling is currently low. E-bikes, whose sales have been rising, could fill a gap in the sustainable transportation mix being able to cover larger distances than a conventional bike. Moreover, previous studies showed that car-oriented countries have a larger environmental potential for e-bike adoption. These findings brought me to the point that I aim to improve the understanding and current usage of e-bikes as a way to increase Swedish cycling levels and lower car dependency. Enhanced understanding of e-bike usage patterns in Sweden could help estimating the potential environmental gains. Better understanding of e-bike usage could also help targeting specific groups or purposes for promotion of e-bikes and serve as a base for policies if the environmental effect would show potential. The current transportation mix makes Sweden an interesting case, while the positive, utilitarian cycling culture and hilly terrain could further enhance the e-bike potential.

Therefore, the aim of this thesis is twofold:
(1) To understand which factors influence e-bike usage in Sweden, and
(2) to explore the environmental benefit of e-bike adoption.

1.5.1 Research questions

In order to reach this aim, three research questions have been formulated:

- Which factors influence the decision to purchase an e-bike?
- Which modes are e-bike trips replacing for certain user groups?
- What could be the potential environmental benefit of e-bikes in Sweden?

1.5.2 Scope

The scope of the thesis was to identify and investigate the explanatory factors of e-bike usage such as purchase decision, purposes, motivations, burdens, mode replacement and user groups. Based on the findings regarding e-bike usage, the potential environmental savings, target groups for promotion and policy implications were discussed. This research focused on current e-bike users that take residence in Sweden. The duration of the study was about 5 months (January to May 2021) as part of the Master's thesis in Industrial Ecology at Chalmers University of Technology. The emphasis of this thesis laid at understanding e-bike usage in Sweden. However, not all topics are covered in the same extent: topics that were considered more relevant or determinant for e-bike usage were prioritized over topics that were considered less so. Moreover, more focus was put on the environmental aspects of sustainability compared to the economic and social dimension.

2
Method

In this Chapter, the methods used for both data collection and data analysis are described.

2.1 Data Collection

In order to understand what factors influence e-bike usage in Sweden, a set of tools were used: literature study, interviews and a survey. These tools are all used for data collection.

2.1.1 Literature review

Google Scholar was used as the main search engine with terms as ’e-bike’, ’e-bike usage’, ’electric bike’ and similar. In the literature review, European studies were favoured over non-European studies as the travel behavior and cycling culture in European countries was assumed to be more similar as Sweden than e.g. China and the US. E-bike sales are high in China and a relatively large amount of Chinese studies are performed, but fall largely outside of the scope of this study as most e-bikes in China are of a different type. The Chinese e-bikes do not require pedalling and would be classified as scooters in Europe [39]. Explorative US studies were used as a comparison, but US studies on travel behavior and substitution were generally avoided. Additionally, recent studies were favoured over elder studies as e-bikes are a developing market and hence information might get outdated soon, for instance, when comparing early adopters to late followers. Lastly, the intention was to create a mixed set of types of studies such as comparative, longitudinal, review, dialogual and bibliographical. However, most e-bike studies were comparative.

2.1.2 Interviews

Participants of the interviews were selected based on the personal network of the author. The aim of these interviews was to increase the understanding of the individual travel behavior, purchase decisions and motives of e-bike users and identify categories that could serve as basis for the survey. Analysis of the interview answers using the Constant Comparative Method allowed these categories to be found. The interviews took place online and were recorded, so that notes could be taken afterwards. The interviews continued until saturation in the answers was observed (N=6). The interview template was not strictly followed. Instead, additional questions on certain topics were asked to enhance understanding. The interview template was altered iteratively after each interview. All participants contributed on a voluntary base and were not financially compensated.

2.1.3 Survey

2.1.3.1 Sample

A convenience sample was used for data collection in the survey. The survey was spread amongst multiple channels. First, Facebook groups with e-bike riders in Sweden and conventional bike groups with enthusiastics were used to advertise the survey. Second, e-bike shops in Gothenburg were asked to spread the survey to their customers via a flyer with a QR-code. Lastly, the author and several others spread the same flyer by attaching it to e-bikes on the streets. In order to further increase the scope of the survey, the snowball effect was used in which respondents were asked to forward the survey to other e-bike users they knew. The survey was conducted in English under the assumption that most Swedish residents are fluent enough in English, while the author was not fluent in Swedish. The requirements to participate in the survey were to live in Sweden and ride an e-bike. The survey was send out in the end of February 2021 by Facebook groups, followed by QR-code flyers in e-bike shops and on the street the week after. The same Facebook groups were used again two weeks after the first post. In total, the survey remained open until April 2021 and N=105 was reached. Thereafter, mischievous answers were filtered out.

2.1.3.2 Survey design

The survey was split up in four parts: 1) travel behavior based on revealed preference, 2) additional travel behavior questions, 3) purchase decision and motives and 4) individual characteristics. A trip was defined in the survey as a journey back an forth to a certain destination. Secondary destinations along the way did not count as a separate trip. The main intention of the trip was described as 'purpose'. These purposes fell in four categories according to the official Swedish transportation statistics of Trafa [64]. These were 'commuting' to school or work or related trips, 'service & shopping' including grocery shopping, doctors appointments etc., 'leisure' which were trips conducted in spare time for the purpose of relaxation and 'others' which included visits to friends and family.

2.1.3.2.1 Recent trips The first set of questions about travel behavior was regarding the three most recently conducted trips. First, it was asked which mode of transport the respondent had used. Then, it was questioned what the purpose of the trips was, the distance of the trip and which mode of transportation would have been used if the participant would not have had access to an e-bike. An option to select 'the trip would otherwise not have been taken' was also included to include newly induced trips. Then, it was asked if the trip was conducted alone or with others. If the respondents did not filled in e-bike as a mode of transportation in any of the three trips, a question about when the last time they had used an e-bike was added.

2.1.3.2.2 Travel behavior Secondly, additional travel behavior questions were asked regarding the frequency of trips per purpose. Also, an open question about the average distance per trip for each purpose was asked. In this way, a trip distance range per purpose could be plotted. An indication of how much the travel behavior per mode was affected after purchasing an e-bike was also asked using a Likert scale from 1 'much less' to 5 'much more' for each of the transport modes.

2.1.3.2.3 Purchase decision The section regarding the purchase decision was split in two parts: first, the motivation or an external factor that induced the purchase of an e-bike and secondly, the general benefits and disadvantages of riding an e-bike. Answer categories on these questions were based on the outcomes of the CCM in the interviews. For the purchase decision motive, an option 'other' was added to stimulate respondent to come up with an answer outside the predefined answer options. For the advantages and disadvantages this option was not added as these factors were better covered in literature. In both sets of questions, it was possible to select multiple options. A set of three questions regarding symbolic benefits were asked using a Likert scale from 1 'Yes, for sure' to 5 'No, not at all' based on the study of Simsekoglu and Klöckner [57]. These imported questions were 'Do you think riding an e-bike says something positive about you?', 'Using an e-bike enables me to distinguish myself from others' and 'I can show who I am by using an e-bike'.

2.1.3.2.4 Individual characteristics Individual characteristics such as age, gender, level of urbanization, hilliness, usage period, weather factors, e-bike sharing and cycling history were asked. Moreover, questions about their previous cycling experiences and ownership of car and conventional bike were asked. Age was segmented into four answer options similar to Haustein and Møller [28] which differentiated *young adulthood* (19-35), *middle adulthood* (36-55), *late adulthood* (56-65) and *old adulthood* (65+). This segmentation was based on different typical life phases in career and family life. For gender, the option to 'other' was added besides male and female. There were five levels of urbanization differentiated, whose definitions were based on Swedish governmental reports. The highest level of urbanization was the *Storstad* with 200,000 citizens or more. The second level, or Tier, was the *Pendlingskommun* with are commuting communities near large cities. This was followed by Tier 3, a *Större Stad* of 50,000 to 200,000 citizens. Tier 4 was the *Tätort or mindre stad* with 15,000 to 50,000 citizens. The most rural category was Tier 5, the *Landsbyskommun* having less than 15,000 citizens. A Likert scale with 1 'It is really hilly were I live' until 5 'It is totally flat were I live' was used for hilliness. There were four groups of e-bike usage period ranging from less than 1 year to more than 5 years. A multiple choice question was used to question which weather factors negatively influenced e-bike usage. The answer options were snow, ice, rain, wind and high temperatures and nothing. E-bike sharing could be answered with 'yes, I share the e-bike with others' or 'no, I am the only user of my e-bike'. For cycling history, differentiation between restorative and resilient cyclists could be made according the study of Marincek and Rérat [41] by asking if the respondent cycled continuously prior to purchasing an e-bike. Car ownership was questioned on a household level with 'no car', 'one car' or 'two or more cars' were answer options, while conventional bike ownership was asked on an individual level with a yes or no question. The survey ended with a space for comments and feedback. An overview of the questions on individual characteristics and answer options can be found in Appendix B.

2.2 Data Analysis and Modeling

Once the data was acquired, several methods were used to analysis this data. The Constant Comparative Method was used to analyse the interviews, the Discrete Choice Method on the survey together with Tableau software and Analysis of Variance to spot statistical relevance. Thereafter, own calculations were performed to explore the environmental savings.

2.2.1 Constant Comparative Method

The Constant Comparative Method (CCM), which is part of the Grounded Theory, was used to examine qualitative data obtained from the interviews. This theory, which was first introduced by Glaser and Strauss, is commonly used by researchers to sort pieces of data into categories [26]. As the sorting process continues, the categories will become more explicit [26]. The CCM is build up on four stages: 1) comparing incidents applicable to each category, 2) integrating categories and their properties, 3) delimiting the theory and 4) writing the theory [25]. CCM can be used to develop new theories in a structured manner. In the interviews, the answers of different participants were compared and coded. Answers of the interviewees were added to an existing category, or a new category were established. Over time, more nuances could be added to the categories making them more focused. The CCM was used to develop categories for advantages, disadvantages, motives, purchase reasons and the used modes. In Table 2.1 the outcomes of analyzing the interviews with CCM can be found. A question category can be found on the top of the table, while the categorized answer possibilities can be found below. For purpose options, the four categories used by the official Swedish statistics of Trafa [64] were found. Additionally, the purpose of transporting children could be categorized as a separate purpose. However, it was decided to stick with the categories of Trafa [64] in the survey.

2.2.2 Discrete choice analysis

Discrete choice modelling or analysis is used to model behavior in experimental economics and mathematics with a focus on individual behavior. In the transportation field, it can be used to predict travel behavior. Two types of discrete choice models are *stated preference* and *revealed preference*. Stated preference modelling involves an experimental design and asks participants for a hypothetical scenario in which a choice between several alternatives has to be made. In a revealed preference study,

Table 2.1: Findings interviews using CCM.

Purposes	**Advantages**	**Disadvantages**
Commuting	Joy/fun	Infrastructure
Transport children	Outside feeling/fresh air	Carry loads
Groceries & shopping	Time savings	Less exercise
Leisure trips	Cost saving	Weather
Other errands	Less sweatiness	Theft
	Movement/exercise	Heavy weight
	Carry loads	
	Weather	

Motive/Inducement	**Purchase reasons**	**Main mode**
Change of job	Longer distances	Car
Move house	Reduced sweatiness	Conventional bike
Main vehicle broke	Shorter transport time	Public transport
Ageing	Transport children	Walking
Participation to trial	Reduced effort	E-bike
	Environmental	
	Cost savings	
	Fresh air	
	Avoid car	

the actual decisions that the participant took are asked. Stated preference modelling is thus prospective, whereas the revealed preference method is retrospective. In this study, it is chosen to use a revealed preference model. It is expected that more reliable results will be obtained when actual behavior is questioned rather than speculative behavior. Reason for this is that participants might respond in a socially desirable way. This option does however reduce the potential sample size as participants had to be e-bike users in order to participate, while a stated preference approach could have allowed potential e-bike riders to participate as well. The software Tableau was used to make graphs from the survey data. If a striking data point was found, the function 'Explain data' was used. This function proposes possible explanations for the diverging data point by searching for other data entries in which the data entries are statistically different. This allows researchers to help finding explanations for their data.

2.2.2.1 Revealed preference

The revealed preference theory is an influential consumer behavioral theory pioneered by Samuelson [55]. The method assumes that the preference of customers is revealed by their choices or habits. Although the widely believed theory of planned behavior (TPB) states that behavioral intentions are a key determinant of actual behavior, the role of habits is also found to be of influence [24]. Habits are especially thought to be a strong determinant of actual behavior in the most habitual type of trip: commuting [21, 60]. Considering this supposed habitual nature make the revealed preference method the preferred method to understand the travel behavior of e-bike users. Participants were asked about their last three trips by e-bike. By asking about three trips, the quantity of acquired data was tripled.

2.2.2.2 Discrete choice modeling

The software Stata was used to perform the DCM. A conditional logit model (McFadden's choice model) was the function that was utilized. This function used data on the choice, choice set and ID. The choice set was assumed not to be the same for every participant. Participants that had filled in to not own a conventional bike were modeled not to be able to choose conventional bike as a mode choice. The same was done for non-car owners. However, car-owners could rent or borrow a car leading to car choices for non-owners. These entries were included. A set of two alternative-specific independent variables were created being travel cost and travel time. These are commonly used variables in transport discrete choice models [52]. Travel cost was assumed to be 0 for walking and conventional cycling. The e-bike travel costs were based on the price to charge an e-bike. Travel costs for trips of 15 km or shorter by public transport were assumed to be 34 kronor, based on the tram and bus Zone A ticket of Västtraffik and 150 kronor for longer (train) tickets. The travel costs for car were based on an average petrol usage, parking prices and congestion charges in the large cities. The travel time was simply calculated by dividing the distance by the average speed of the used mode. The assumptions were 7 km/h for walking, 21 km/h for the cycling, 25 km/h for e-biking, 50 km/h for car and 25 km/h for short public transport trips (<15 km) and 50 km/h for longer public transport trips (>15 km). Lastly, a set of eleven case-specific independent variables was used being: usage period, travel party, urbanization, age, gender, hilliness, purpose, sharing, car ownership, c-bike ownership and cycling history. All data was obtained in the survey. As all data needed to be numerical to function within Stata, some adaptions had to be made. Binary codes were used for gender, sharing, car ownership, c-bike ownership and cycling history. The median of an answer interval was taken for usage period and age. A Likert scale from 1 to 5 was used for hilliness and urbanization. Purpose was coded from 1 to 4 ranging from more utilitarian (commuting) to less utilitarian (leisure) purposes.

2.2.2.3 Analysis of variance

The analysis of variance or ANOVA is commonly used in statistics to validate if two or more populations differ from each other. In this study, ANOVA was used to compare the distance between different mode choices, purposes and substituted modes. If different average distances were found between user groups, an ANOVA was also performed to validate the statistical difference.

2.2.3 Emission calculations

In order to explore the environmental potential of e-bikes in Sweden, outcomes from the survey were used to estimate the frequency of trips and the average trip distance by e-bike, specified per purpose. The revealed preference outcomes for substituted modes were taken to calculate which share of trips would have been made per transportation mode. Combining this with the frequency of trips per mode and the average trip distance per mode, the substituted distance per mode could be obtained. Several life cycle analysis studies on e-bike substitution were used to make assumptions on the emissions per kilometer for each transportation mode. By multiplying the difference in CO_2 emissions per kilometer between e-bike and a certain mode with the total annual distance for that mode, the avoided or added CO_2 per mode could be estimated. These were added to find the total avoided CO_2 emissions per year per person. These calculations can be found in Appendix A.

3

Literature Review

3.1 Purpose of e-bike trips

3.1.1 Other countries

The review article of Bourne et al. [7] concludes that e-bikes are more frequently used for utilitarian purposes like commuting and shopping than for non-utilitarian purposes such as leisure. However, it is also observed that leisure trips tend to be longer. Fyhri et al. [24] concluded that 72% of their respondents used the e-bike primarily for commuting in Norway. A study in the USA found that utilitarian purposes were responsible for 80% of the trips [42]. A national large-scale Dutch research showed that the main purpose of an e-bike trips is spare time in the Netherlands (33%), followed by shopping (21%), commuting (18%) and education (15%) [37]. Adding up the utilitarian purposes shopping, commuting and education gives 54% of the trips in that research. The share of distance is more determinant for environmental savings than the share of trips. Sun et al. [60] found that 39.3% of the e-bike kilometers could attributed to commuting, 25.2% to shopping and 26.5% to leisure in the Netherlands, meaning 64.5% of utilitarian kilometers. E-bike adoption in the Netherlands is relatively high, hence, there is more e-bike data available compared to e.g. Sweden. However, e-bike usage patterns of other countries might differ as a result of different cycling culture and conventional biking levels as shown in Section 1.2.

3.1.2 Sweden

E-biking promotion policies can be based on studies about to e-bike purposes [7]. Out of all trips in Sweden, about 55% is carried out for commuting, around 20% for leisure and around 10% for shopping in 2019 [65]. This means that the share of utilitarian trips (65%) is higher than in the Netherlands (54%). In terms of mileage, commuting corresponds to a 47% share, leisure to 34% and shopping remains around 10% [65]. Thus, leisure trips by e-bike in Sweden seem to be longer than commuting trips. Hiselius and Svensson [30] compared the urban and rural e-bike usage in Sweden by holding a web questionnaire and found that most users were using the e-bike for multiple purposes. Differences in frequency and share of users in a certain purpose between rural and urban areas were found to be insignificant. Commuting was found to be the most frequently used purpose in terms of days per week with 2.93-3.62 days/week, leisure was less frequently used (1.40-1.44 days/week). However, the average distance per purpose did: leisure trips were the longest (11.07-13.65 km), followed by commuting (9.20-9.23 km) and grocery trips were the shortest (1.75-2.00 km). Söderberg et al. [58] found that commuting (81%) and 'other errands' like visiting friends and family (77%) were the most frequently mentioned possible trip purposes in Sweden. This study provides additional proof that Swedish leisure trips are on average longer than commuting trips, and that commuting trips are more frequent. Moreover, commuting being most often mentioned could imply that it is considered as the main purpose of e-biking. Multiplying the frequency and distance leads to a weekly total distance of about two times as much commuting kilometers than leisure, which strengthens the hypothesis. For promotion strategies, it would be interesting to understand if commuting is not only the most dominant purpose in share of trips, but also a key determinant to purchase an e-bike.

3.2 E-bike purchasing decision

Understanding what drives people to purchase an e-bike is of key importance when aiming to promote e-bike usage. Several different perspectives and theories have been taken in literature to provide insight in this decision. A selection of them is presented in this section.

3.2.1 Habits

Travel behavior is in multiple studies explained as a habitual behavior, besides the role of intentions [41, 51, 24]. The decision to purchase an e-bike can be considered as a reconsideration of a habit which is often induced by a 'life-event' such as childbirth, a change in residency or workplace or increased health problems [41]. A life-event can be considered as a way to force people to re-evaluate and break with their habits. Breaking the habit was used as a starting point in several studies [46, 6, 63]. In the longitudinal experiment of Moser et al. [46], participants were given an e-bike on the condition to give up their car access for a period of 2 weeks. After one year, a persistent habitual change was observed for 10% of the participants that bought an e-bike, while non-buyers cycled more. In the experiment of Ton and Duives [63], participants who frequently commuted by car were selected and offered an e-bike for a 8-week period. Three months after the trial, the participants were questioned again. It was found that the car usage dropped from 88% to 63% of the commuting trips, while e-bike usage rose from 2% to 18%. Similarly, Bjørnarå et al. [6] concluded that car usage decreased and e-bike usage increased during their 9-month intervention study focused on young parents with different types of bikes. They found that e-bikes could raise cycling levels in the Norwegian winter which is generally considered as a large cycling barrier in Norway. A different approach was taken by Handy and Fitch [27] who encouraged commuters in the US to use an e-bike by setting up an e-bike sharing system. It appeared that substantially more respondents in a survey stated to be aware of e-bikes after the experiment, and that more people were considering an e-bike for commuting. Based on these studies, breaking or disruption of habits seem to be a promising idea, however, this break is mostly forced or unnaturally created in the trials. A life-event could be regarded as a more natural break of this habit. This study aims to enhance the knowledge on habit disruption by assessing how often life-events are mentioned as a reason to purchase an e-bike.

3.2.1.1 Commuting

The purpose of a trip could be a motive to purchase an e-bike. Plazier et al. [51] concluded that commuting was a prime motive to buy an e-bike for all 24 participants of their study in the Netherlands. This finding was both qualitatively and quantitatively obtained: participants mentioned commuting as a motive, and 63% of e-bike trips were commuting trips compared to a share of 34% of commuting trips in all trips. The high share of commuting in travelled e-bike kilometers earlier described strengthens this hypothesis. MacArthur et al. [40] asked which trip purpose was a motive to purchase an e-bike towards several user groups. Almost half of the respondents listed commuting as their main purpose motivation. Shopping and running errands was the main trip purpose for about a quarter of respondents, while recreation (leisure) scored 19%. Interestingly, it was also found that recreation was a stronger motive for people of 55 years and older (31% against 9% for younger than 55), whereas the opposite held for commuting (58% for younger than 55 and 30% for older than 55). The habitual nature of commuting makes it a logical motive to purchase an e-bike.

3.2.1.2 Learning effect

Most e-bike studies use trial programs and are comparative. However, a few longitudinal studies mention the effects of learning against the novelty of an e-bike. For instance, de Kruijf et al. [11] evaluated the e-bike usage for commuting in a trial program with monetary compensation in the Netherlands after 1 month and 6 months. It appeared that e-bike usage was higher after 6 months (73%) compared to 1 month (68%). Similarly, Fyhri and Fearnley [21] found that the longer riders had access to an e-bike, the stronger the effects were. They concluded that the learning effect was stronger than the novelty effect. In a later study by one of the authors, a similar conclusion was drawn [22]. These findings imply that after travel habits are disrupted, they can be replaced with new habits. Over time, these habits tend to grow stronger. This study will not be longitudinal due to time constraints. However, by asking about the usage period of the e-bike, it can be assessed if usage patterns between relatively old and new e-bike users exists. Based on these previously mentioned studies, it may be expected that e-bike owners possessing an e-bike for a longer time period are also more frequent users than recent purchasers. Besides assessing the frequency between different user groups, the covered distance could also be compared in this study.

3.2.2 Intentions

Intentions are recognized as another key determinant of actual travel behavior besides habits [24]. The Theory of Planned Behavior by Ajzen [1] acknowledges that subjective norms are a determinant of behavioral intention. Subjective norms in its turn consist of the opinions of significant others about engaging in a certain behavior. A study of Fyhri et al. [24] studied both habits and intentions amongst Norwegian e-bike interested people and found that those with intentions to drive less car and weaker cycling habits, were more willing to buy an e-bike. Another Norwegian study by Simsekoglu and Klöckner [57] focused on the perceived benefits by e-bike interested and non-interested persons in Norway. They concluded that perceived symbolic (positive self-image of e-bikes) and mobility benefits (reduced effort and able to cover longer distances) were the strongest predictors of e-bike purchase intentions. As a consequence, it could be beneficial to stress out the mobility benefits to potential buyers, but also create a positive image around e-bikes. Before doing so, it is worth to validate the Norwegian findings on a Swedish sample.

3.2.2.1 Climate morality

A specific intention to purchase an e-bike is to reduce or avoid car kilometers by replacement of a households' car with an e-bike [28]. The Danish study found that 37% of their respondents listed the replacement of car trips as a motive to purchase an e-bike. Studies in the USA and Australia found even higher percentages of around 60% for the same question [40, 34]. In the study of Johnson and Rose [34], it was the most commonly cited motive, while in the study of MacArthur et al. [40] car reduction intentions were also the strongest motivations amongst all groups except respondents with physical limitations. Sweden can be considered as less car-dependent than Australia and the USA, but more than Denmark. Thus, a share of participants motivated to reduce car trips between 37% and 60% may be expected. Andersson [3] turned around the question by asking which motivation would be the strongest to reduce car usage. By comparing different promotion messages for sustainable transport, it was found that climate morality was the strongest predictor of reducing car usage. Thus, climate morality can be viewed as an incentive to reduce car usage, resulting in more e-bike usage as an alternative sustainable mode in its turn.

3.2.2.2 Attitudes

One of the main conclusions of Ton and Duives [63] was that participants with a positive attitude towards e-bikes prior to the trial, were more likely to change their behavior. For these people, it seemed that a trial period could serve as a last nudge towards e-bike adoption. More so, respondents that indicated that they were would not have changed their behavior without a trial, were more often changing their behavior. Both of these findings show that attitudes towards e-bike and behavioral change do matter to actually achieve behavioral change. Ton and Duives [63] also studied the reasons why participants did *not* purchase an e-bike after the trial. The main mentioned reason were the investment costs, followed by the overwhelming amount of options, the limited speed and level of comfort of their car. Popovich et al. [53] early and influential e-bike study performed in California found that recommendations of close friends, relatives or respected community members were an important predictor in the decision to purchase an e-bike. A possible implication of this finding could be that trials, in which people get familiar with an e-bike, could possibly not only directly, but also indirectly stimulate e-bike purchases. Hence, e-bike trials could serve as an important simulator of e-bike adoption.

3.3 Advantages and Disadvantages

Once the e-bike is purchased, the actual travel behavior will be influenced by the perceived advantages and disadvantages to make use of the e-bike. An overview of the identified advantages and disadvantages by several studies can be found in Table 3.1 [7, 35, 57, 28, 58, 40]. These are segmented according to the categories of Wolf and Seebauer [70] who differentiated perceived usefulness, perceived ease of use, facilitating conditions, social norms, personal norms and attitude towards physical activity.

Advantages	**Categories**	**Disadvantages**
Longer distances Reduced travel time Cheaper Overcome hills	Perceived usefulness	Purchase price Theft
	Perceived ease of use	Errands with goods (Un)loading Battery weight
	Facilitating conditions	Maintenance Infrastructure Lack of parking options Lack of charging options Unsafe with cars/pedestrians Battery life
Ride with others	Social norms	Social stigma
Environmental reasons	Personal norms	
Fun/joy Fresh air Less sweatiness Reduced effort More exercise	Attitude towards physical activity	Reduced physical activity Weather

Table 3.1: Advantages and disadvantages identified in literature. Categories adopted from Wolf and Seebauer [70].

Some motivations and burdens of Table 3.1 might seem contradictory such as 'cheaper' and 'purchase price' or 'more exercise' and 'reduced physical activity'. This can be explained by the difference with the mode of transportation e-bikes are being compared with. For example, an e-bike can be cheaper per trip compared to a car, while the purchase price is high compared to a conventional bike. Similarly, a person can increase their physical activity compared to a previously used car (more bike kilometers), however, the effort per kilometer is lower than a conventional bike. Moreover, it is interesting to see that most motivations related to perceived usefulness and attitude towards physical activity are inherent to an e-bike, while most burdens can be overcome with modifications in the facilitating conditions or the perceived ease of use. For example, parking and charging options can relatively easy be increased by a city council, while e-bike manufacturers are constantly aiming to improve the battery life and weight. Even the social stigma on e-bikes, can be changed over time as more people can become e-bike users.

3.3.1 Key factors

The approach to identify and rank perceived advantages and disadvantages differs per study. The early, North American study of MacArthur et al. [40] was one of these studies. Increased speed and range, less effort and overcoming hills, health, cheaper, fun and environmental reasons all come out as advantages in a similar range (11-18%). Weight was the most commonly cited disadvantage (26%). Since e-bikes have developed in terms of weight since the time of the study, it is expected that weight is nowadays less perceived of a disadvantage. The Danish study of Haustein and Møller [28] used a Likert scale to compare the impact of several advantages with each other. Fun/joy was the strongest factor (4.3) followed by longer distances (4.1), less effort (4.1) and more exercise (4). Environmental reasons (3.7) and costs (3.8) were also positive influences. The burdens were not researched in this study. The review of Bourne et al. [7] found that most investigated studies mentioned fun/joy (21), longer distances (20), faster journeys (18), reduced sweatiness (15), ride with others (12), less effort (12) and overcome hills (12) as main advantages. In the same study, battery life (19), safety concerns (17), weight (17), theft concerns (15), cost (14) and weather (13) were the main observed disadvantages. Söderberg et al. [58] asked in a recent Swedish study to the three most prominent advantages and disadvantages about e-bikes. The outcomes were that convenience, exercise/health and environmental reasons were the main perceived advantages, while bad weather, errands with goods, battery weight and risk of theft were the main perceived disadvantages. The positives were generally outweighing the negatives in this study. It can be concluded that the key advantages and disadvantages vary, depending on the place, time and research question. The overview shown in Table 3.1 might not be complete and different emphases may be placed depending on the context. Hence, it will be relevant to research the advantages and disadvantages once more.

3.4 User groups

Knowledge about travel behavior of certain user groups can be advantageous to target environmentally promising groups. A certain user group can be described as environmentally promising when covering large distances by e-bike, possessing frequent usage, showing high shares of car or motorized substitution (especially in terms of mileage) and/or portraying a currently low e-bike adoption. Segmentation of e-bike users can be made based on different characteristics.

3.4.1 Age

Age is a frequently researched segmentation of e-bike users. In most countries, people aged over 65 have been the early adopters of e-bikes [35, 70]. These early adopters were generally using e-bikes for leisure trips and hardly replacing carbon-intensive modes [70]. However, the average e-bike user age is falling [30]. The KiM [37] observes a stronger increase in <65 year old users between 2013 and 2019 than >65 year old in the Netherlands. Engelmoer [19] and Dill and Rose [12] conclude that commuters and young people willing to transport heavier loads by trailers could be responsible for this trend. Melia et al. [43] observes two main user groups in the UK: older men and young, working, educated women. Older people have been found to be more motivated to buy an e-bike due to higher perceived benefits such as reduced effort [57]. However, this does not mean that their usage is also high. Contrarily, e-bike usage and cycling distances are found to decrease when age is increasing [7, 39]. In conclusion, younger users (<65 years) are arguably a group with more potential given their currently lower ownership, higher individual usage and higher car replacement.

3.4.2 Gender

Men seem to be dominating e-bike users in most countries, except for Denmark and the Netherlands [30]. These two countries are also known for having high levels of cycling in general, leading to more awareness of cyclists by car drivers [56]. This is one of the suggested reasons why road safety in Denmark and the Netherlands is reported as the most safe [56]. An explanation for the high levels of cycling women could be that enhanced road safety would help women overcome the burden to cycle. Stimulating women to cycle more is especially interesting as it was found that females show a stronger learning effect on the e-bike than men [21] and travelled more additional distance by e-bike [60]. Sweden is the second best performer on road safety, expressed in road fatalities per 100,000 population and cycling fatalities per billion travelled km per bike [56]. This implies that Sweden possess conditions which could be beneficial to stimulate women to increase their e-bike usage. These effects are enhanced as women are also showing a larger potential due to a greater learning effect and additional cycling kilometers.

3.4.3 Urbanization

Marincek and Rérat [41] mention a higher share of rural e-bike users in Switzerland compared to urban areas, while the Dutch KiM [37] concludes that e-bike adoption is more developed outside the most urbanized region Randstad. Not only are e-bikes already used more often in rural areas, the car substitution also seems to be higher in rural areas resulting in a larger environmental benefit. Bourne et al. [7] summarizes that e-bike trips replace 71%-86% car trips is rural areas against 42%-60% in urban areas. However, Hiselius and Svensson [30] counter that the effect of replacement of rural car trips is wiped out by a larger number of trips in absolute terms that is being replaced in urban areas. This would result in a negligible difference in net energy saving between urban and rural areas. The notion that more car trips are replaced in rural areas is explained by Sun et al. [60] stating that more rural trips fall in the desired e-bike range of 5 to 20 km. It can thus be interesting to validate Suns' e-bike distance range for Swedish e-bike users. Additionally, it could be relevant to investigate if any difference in usage patterns between more and less urbanized groups can be observed.

3.4.4 Cycling history

Marincek and Rérat [41] used a bibliographical approach to asses the adoption of e-bikes in the Swiss city Lausanne. Two different types of e-bike users were differentiated: resilient and restorative users. Restorative users started using a bicycle after an interrupted period of cycling, while resilient users wished to remain cyclists despite changes in personal or spatial contexts. The study focused on segmenting users in these two groups, but did not studied the difference in e-bike behavior between these groups. By including a survey question about the personal cycling history, it could be assessed if these groups indeed behaved different. Restorative users were beforehand expected to show a larger potential, since the amount of public transport and car trips is expected to be higher prior to e-bike purchase. Ownership of a conventional bike could also be seen as a measure for cycling history.

3.4.5 Car ownership

de Kruijf et al. [11] differentiated unimodal car commuters and multimodal commuters in an e-bike trial and found that after both 1 month and 6 month, similar levels of e-bike usage could be achieved for unimodal (64% and 68%) and multimodal (70% and 75%) users. This means that car usage was relatively higher for unimodal car commuters (-66% against -21%). This finding suggests that frequent car users convey a large reduction potential. Wolf and Seebauer [70] found that early adopter in Austria possessed a higher car ownership than the average Austrian sample. Thus, they concluded that an e-bike was more an additional mode than a substitute for cars. Kroesen [39] agreed by stating that although an e-bike can replace car trips, it does not replace car ownership. Hence, studies like Moser et al. [46], Fyhri et al. [24] targeted car owners as they expected that the environmental and behavioral change would be larger. Contrarily, Sun et al. [60] did found some evidence of a drop in car ownership after e-bike purchase from 92.5% to 86.9% six months after their trial. They expected a potentially further drop in car ownership over a longer time period. There seems to be no consensus yet about influence of car ownership on e-bike usage despite that several experimental studies are targeting car owners. Thus, it would be relevant to re-evaluate if car owners should indeed by targeted.

3.4.6 Attitude towards cycling

Attitude was considered a more important predictor of e-bike usage than age by Haustein and Møller [28]. Hence, a segmentation based on attitudes was made: enthusiastic, utilitarian and recreational users were identified [28]. Enthusiastic riders, known for their frequent usage and positive attitude towards cycling, report the highest increase in cycling and car replacement. Contrarily, recreational users were the least interesting group having a low car replacement share. Utilitarian riders were already cycling much prior to using an e-bike, but can still provide an environmental benefit due to increased trip distance. Hence, targeting of e-bike enthusiastics was suggested by Haustein and Møller [28]. The Canadian study of Willis et al. [69] made a distinction between cyclists based on there seasonal cycling behavior and examined their cycling satisfactory with a Likert scale survey question. Within the seasonal distinction, 'convenience-motivated' ('cycling is the fastest mode') and enthusiasts (exercise, environment, enjoyment) riders were separated. The cycling enthusiastics were found to drive significantly longer average distances. In general, more satisfactory cyclists were travelling longer distances. Slope, build environment and distance were found to be not related to satisfaction. The definitions of user groups segmented by attitude are not standardized and differ amongst studies. In this study, it was chosen to use the definitions of Haustein and Møller [28] due to its clarity.

3.4.7 E-bike sharing

Bike-sharing is mostly discussed as part of a sharing economy: bikes are shared rather than owned in these studies [52, 71]. These e-bike specific sharing studies are still rather novel and have rarely been studied [71]. The purpose of these e-bike sharing systems was sometimes to increase awareness [27]. This study does not aim to research the possibilities of a bike-sharing system, but rather aims to acquire more insight in sharing e-bikes whilst being an e-bike owner. For example, with family members, roommates or neighbours. This aspect came up during the interviews, when multiple participants stated that they were sharing their e-bike with their partner and/or children. This aspect is different than the shared-biking systems and not often studied.

3.4.8 Travel party

The influence of the travel party on e-bike usage has not been researched in detail to the best of the knowledge of the author. Travel party could be explained as the set of people that is travelling together from one destination to the next. It could be that travelling with others influences the modal choice. For example, if the other traveler does not have access to an e-bike, it might decrease the likelihood of choosing an e-bike. Alternatively could a second person (e.g. a child) be transported on the back of the e-bike, but that groups of three of more persons might switch to another modal choice such as car or public transport.

3.4.9 Summary

It can be summarized that various groups can be interesting to target based on different attributes which is done in Table 3.2. Young, rural living, enthusiastics, women and frequent car users are all seemingly appealing target groups. Moreover, as outcomes might be context-dependent it is relevant to validate if previously found outcomes also hold for the Swedish context.

Table 3.2: Summary of user group findings.

User group	Finding	Source
Age	Ownership >65 high, <65 usage is increasing	[35, 37]
	Low car replacement at old users	[70]
	Usage and distances decreasing with age	[7, 39]
Gender	Men generally more frequent users	[30]
	Safety could stimulate women	[56]
	Stronger learning effect women	[21]
	More additional km by women	[60]
Urbanization	Switzerland more e-bike users in rural areas	[41]
	More e-bike adoption outside of urban areas in NL	[37]
	Higher car replacement share in rural areas	[7]
	More e-bike trips in absolute terms in urban areas	[30]
Cycling history	Restorative users expected to have a larger motorized transport replacement	
Car ownership	Unimodal car commuters show larger car trip replacement than multimodal	[11]
	E-bikes do not replace car ownership	[39, 70]
	E-bike ownership led to a decrease in car ownership	[60]
Attitude	Enthusiastic riders show largest car replacement	[28]

3.5 Substitution effect

3.5.1 Mode replacement

Albeit the *share of car kilometers* being replaced by e-bike is more relevant to estimate the environmental gain, the *share of car trips* replaced by e-bike has more frequently been assessed. Recent review studies of Bourne et al. [7] and Castro et al. [10] found widely scattered shares of car (20%-86% and 16%-76%, respectively) and c-bike (23%-76% [7]) replacement. It is generally agreed that car and c-bikes are the most frequently replaced modes of transport by e-bike. Another seemingly consensual hypothesis is that car replacement is the highest is car-dominating places [39, 7, 60, 58]. Castro et al. [10] add that the main used mode is often the replaced mode, but is hardly fully replaced. This implies that the largest environmental potential for e-bikes can be found in car-dominating areas. Another meta-analysis of Bigazzi and Wong [4] on Chinese, European, North American and Australian studies summarized that cars, public transportation, cycling and walking are consistently measured for mode replacement, but the share of induced trips is often not included. There exists a trade-off between automotive and public transport replacement in which Chinese studies find to a large extent public transport replacement and others automotive replacement. The median car mode replacement was 24%. However, this percentage is probably low due to the inclusion of 50% Chinese studies in which mostly public transportation is displaced instead of automobiles. Moreover, it was concluded that more recent studies report significantly higher shares of motorized transportation and lower shares of cycling displacement suggesting a learning effect. Assessment of car, public transport, conventional bike and walking trip replacement is crucial to determine the environmental impact of e-bikes.

3.5.2 Car distance reduction

Eventually, road emissions can be lowered depending on the reduction in car distance. The study of Sun et al. [60] used 106 individuals who purchased an e-bike between 2013 and 2016 and studied how their travel behavior changed after the purchase. They found that the share of car kilometers of the total dropped with 16%, while the aggregate of e-bike and c-bike kilometers almost doubled (from 20% to 42% of the total km) in the Netherlands. A study by Cairns et al. [8] amongst 60-80 employees found a 20% reduction in car mileage during a 6-8 week trial period in Brighton. Brighton has lower car use than the UK, indicating that this reduction could potentially have been larger elsewhere in the United Kingdom. Similarly, Söderberg et al. [58] calculated a 21% drop in car kilometers, corresponding to 16.6 km per person per day, in a group of frequent car users that participated in a 5-week trial in Sweden. In Germany, Kämper et al. [36] reported that e-bikes replace for 45% car kilometers. For commuters, even 62% of the e-bike kilometers substituted a car in this study. Assuming 13,500 car km per German person per year and 2,500 e-bike kilometers per person per year, this would mean a car kilometer drop of about 8% per German e-bike user. Kroesen [39] used a statistical method utilising national transport data of the Netherlands. He found that an e-bike replaces about 5.8 car kilometer per day (28%) and 9.4 kilometer by public transport (64%). The studies about car distance reductions are however still insufficient to generalize its outcomes, especially since context is dependent, meaning that more studies are desirable. An overview of the findings is shown in Table 3.3.

Table 3.3: Overview of car distance reductions after e-bike purchase in literature.

Reduction car distance	Location	Source
16%	Netherlands	[60]
20%	Brighton	[8]
21%	Sweden	[58]
8%	Germany	[36]
28%	Netherlands	[39]

3.6 Sustainability

3.6.1 Environment

Road transport is responsible for a wide range of pollutants such as CO_2, NOx, particulate matter (PM) and volatile organic compounds. Besides, road transport causes other negative externalities such as noise, congestion and accidents. In this thesis, it was decided to focus on CO_2 as this is the main greenhouse gas. Moreover, the air pollutant PM is discussed as this is a serious air pollutant.

3.6.1.1 Carbon emissions

Despite the growing amount of research on e-bike usage in general, only a few studies calculate the actual carbon emission savings. The secondary aim of this thesis is to explore the potential environmental potential of e-bikes in Sweden. Hence, an overview of studies that did examine the environmental potential of e-bikes can be found in Table 3.4. An estimation of the potential environmental savings can be made based on the mode substitution, trip distance per mode and the average CO_2 emissions per kilometer per mode. These environmental savings are typically calculated in avoided CO_2 emissions per person per year. Fyhri et al. [23] calculated the yearly CO_2 savings for e-bike users in Oslo based on the difference in transport emissions between e-bike users and potential e-bike users. Assumptions were that cars in Oslo emit 200 g CO_2/km and public transport 35 g CO_2. The average emissions per travelled km for e-bike users were 11% lower than for non-users and citizens were expected to travel around 40.2 km per day, leading to a potential emission saving of 87 to 144 kg CO_2 per year. McQueen et al. [42] performed a study in Portland (USA) and calculated how much CO_2 could be saved based on the assumption that a share of 15% e-bike passenger miles travelled (PMT) could be achieved. This share of PMT would lead to a reduction of car miles from 84.7% to 74.8% according their model, resulting in a 12% reduction in greenhouse gases. This corresponds to 225 kg saved CO_2 per e-bike per year. The authors incorporated newly induced trips electricity generation differences per state in their model. The higher emission savings than the Norwegian study can be explained by a high car share and generally more polluting cars in the US and a relatively large (15%) e-bike PMT. An even larger annual emission saving per e-bike was found in a Swedish study performed by Hiselius and Svensson [30]. Here, a range between 272 and 394 kg of avoided CO_2 was obtained by first calculating the changes in transport mode, frequency and distance travelled per week and assuming 33.2 to 48 travel weeks per year. The greenhouse gas reduction would mean 14-20% of the individual Swedish transport emissions. Compared to the Norwegian study, relatively clean cars were assumed with 140 g CO_2 per kilometer. However, the car kilometers replaced were higher (~58 km per week). As several countries are stimulating the use of electric cars, it is also worth to note that the e-bike is emitting less than electric cars. Weiss et al. [67] compared the energy consumption of a wide range of electric vehicles and concluded that the weight of a vehicle is a decisive factor in energy consumption, more than for internal combustion engines. Therefore, e-bikes were accounted 90% less energy than electric cars leading to a potential CO_2 saving of 50±39 g per kilometer depending on the source of energy generation.

Table 3.4: Emission savings in literature.

Source	**Place**	**GHG**	**CO_2 savings**
Fyhri et al. [23]	Norway	11 %	87-144 kg/year
McQueen et al. [42]	Portland	12 %	225 kg/year
Hiselius and Svensson [30]	Sweden	14-20 %	272-394 kg/year

The large range in potential CO_2 savings is heavily dependent on assumptions regarding the car kilometers replaced, the average emissions per kilometer for each mode (especially car) and the travel distance per person. A higher share in e-bike kilometers travelled will result in transport emission reductions. The more car kilometers get replaced, the larger the environmental potential. In order to get an idea of the emissions per kilometer per mode, an overview is presented in Table 3.5. These are studies that quantified the CO_2 emissions per kilometer for several modes of transportation. These numbers are also dependent on the location and time. More recent studies are expected to use lower emissions per kilometer for car and public transport as the emissions per kilometer are supposed to decrease as a result of the use of more low-emission vehicles in the car fleet. E-bike emissions are also expected to decrease due to innovations. The location matters mainly for car and public transport emissions. Car emissions are dependent on the manufacturer and the type of car. For example, a higher share of SUVs would lead to a higher average car emissions due to an increased weight. Moreover, as the EU is pushing car manufacturers to lower emissions, European brands are generally expected to be less emitting than American brands [32]. Asian brands tend to possess the lowest emissions per kilometers due to a larger share of electrical vehicles in their fleet [32].

Table 3.5: Emissions found in literature. All entries are in kg CO_2 per kilometer.

	Car	Public transport	E-bike	C-bike
Kämper et al. [36]	177	81	18	10
Philips et al. [50]			22	16
McQueen et al. [42]	232	87	3	
Hiselius and Svensson [30]	140			
Fyhri et al. [24]	200	35		
Engelmoer [19]	260	100	30	20

3.6.1.2 Particulate matter

Particulate matter (PM) is a serious pollutant known for being harmful for human health responsible for many thousands premature deaths in Europe [18]. PM pollution is particularly apparent in urban areas as 48% and 74% of the urban European population gets exposed to PM_{10} and $PM_{2.5}$ levels that exceed the World Health Organization's air quality guidelines, respectively [18]. Road transport is one of the main reasons that PM values are too high, especially in urban areas [61]. Timmers and Achten [61] found that electric cars emit similar amounts of PM_{10} and $PM_{2.5}$ as internal combustion engine cars which is about 65-66 mg per vehicle kilometer for PM_{10} and 22-23 mg per vehicle kilometer $PM_{2.5}$. The PM emissions are mainly dependent on the weight of the vehicle. E-bikes weight on average about 20 kg, while medium size cars weight about 1600 kg. This means that the e-bike weights about 80 times less than an electric car. Since both vehicles are using similar battery technologies, it is expected that PM emissions of an e-bike will only be a small fraction of car PM emissions.

3.6.2 Economics

Subsidies are highly effective tools to lower the price of a new technology by creating learning effects [9]. By creating economies of scale, the price of a new technology, like e-bikes, is expected to drop in the coming years before the technology could penetrate the market. In this way, a breakthrough in the chicken and egg cost problem could be obtained after which the technology should economically be able to sustain itself [9]. E-bikes have been subsidized in Sweden with 10,000 SEK until 2018 [58]. Other e-bike subsidy programs on either a local, regional or national level were previously running in Austria, Belgium, France, Italy, the Netherlands and Spain [16]. These European e-bike usually cover around 20-33% of the purchase price [20]. It is unsure yet if the e-bikes will be able to economically sustain themselves in the future, but the quick sales increase after the subsidy program stopped in Sweden (described in Section 1.3.1) is a good sign. From the customer perspective, the economics may expected to be sustainable as an e-bike can be considered cheaper in both investment and running costs compared to a car. The energy costs of a car were for example estimated to be about up to 58 times as large as an e-bike [2]. However, when comparing with a conventional bike, both the investment costs and running costs of an e-bike are higher due to charging and maintenance. The commercial success of e-bikes could thus also depend on the if customers perceive an e-bike mainly as a c-bike or car substitute. E-bikes do not only have potential in passenger transport, but could also be used as cargo vehicle. Urban logistics are estimated to be responsible for a contribution of 8% to 18% of congestion and an occupancy of about 30% of the road space [49]. E-bikes could potentially take over part of the trips made by internal combustion vans as was done in the pilot project of Nocerino et al. [49]. In this study, two vans were replaced by four to six e-bikes at the Italian company GLS. The e-bikes reduced the emissions and contributed to a positive image. The total costs were estimated about the same as the vans on an annual base considering salaries, energy costs, congestion charge, depreciation, platform renting and fines. Hence, it was decided to keep the e-bikes after the pilot and the project was considered as economically sustainable.

3.6.3 Social

3.6.3.1 Health

E-bikes are considered as having a positive impact on health. Despite being a physically less intensive mode than conventional cycling, the physical activity level can still be considered as 'moderate intensity' when riding an e-bike [8, 7]. Moreover, e-bike trips tend to be of longer duration, longer distance, at higher slope, with heavier loads and at higher speed than regular bike trips which dampens the intensity effect [7, 8, 10, 41]. Castro et al. [10] made an attempted to quantify the health benefits of e-biking and concluded that it mostly depends on the previously take mode. Switching from c-biking led to an decrease of 200 Metabolic Equivalent Task (MET) units per week, but an increase of 550 MET per week switching from motorized vehicles and 800 MET per week from public transport was found. Bourne et al. [7] adds that physical activity is more frequent reduced for younger users than older user, but mostly improves physical activity for older e-bikers. For elderly people, the e-bike then often serves as a way to prolong cycling when physical abilities are diminishing [41, 35, 51]. Hence, the e-bike is especially recommended to those not physically active for health reasons [11]. This led to a social stigma -mainly in USA- that e-bikes were associated with elderly or obese people [40]. To summarize, there seems to be an academic consensus about the health benefits of e-bike being in general apparent, depending on the substituted mode and especially of interest for those physically less active. Hence, health aspects were not further studied in this thesis.

3.6.3.2 Safety

The safety aspects of e-bikes could be described as contradictionary. Relatively more conflicts between e-bikes and motorized vehicles than between c-bikes and motorized were reported [7]. The severity of these e-bike accidents is similar to c-bike accidents [10]. However, the perceived safety of e-bikers is similar to other modes [10]. The fact that e-bikes end up in more accidents currently, does not mean that e-bikes cannot be considered safe by itself. The relative novelty of e-bikes could also play a role in estimating the speed of an e-bike by a car driver or cycling infrastructure that has insufficiently adapted to the new needs yet. Considering these possible novelty effects, it could be argued that it could be more relevant to study safety aspects of e-bikes when e-bikes become more widespread. Thus, it was decided to not further study safety aspects in this thesis.

3.6.3.3 Physiological

The social aspect of cycling is considered positive, but it appeared to be difficult to catch these positive social sides of cycling in a quantitative study. Cycling is perceived as more satisfactory than other mode choice such as car and public transport and sometimes even walking [69]. Willis et al. [69] describes driving, especially in congestion, as highly stimulating sometimes leading to 'overarousal'. Public transport on the other hand provides very little stimuli and can therefore lead to 'underarousal'. Travelling by foot is often experienced as 'relaxing', but the most positive connotation has cycling which is frequently experienced as 'pleasant' or 'exciting'. Moreover, it has earlier been found that a switch from driving or public transport for commuting can lead to a boost of physiological well-being [68]. A dialogical study that in-depth interviewed 24 e-bikers in New Zealand continued on that notion to find reasons why e-cycling is experienced in this way [68]. Four reasons were suggested in this research for the pleasant and exciting cycling experience: 1) arrival time reliability, 2) enjoyable levels of sensory stimulation, 3) feel better due to moderate exercise and 4) opportunities for social interaction. The focus within the social aspects of cycling in literature is often about (perceived) safety and health as they are easier to quantify, but it is important to also include these other physiological, social and physical pleasures that cycling offers. Including these factors might lead to more comprehensive decision making.

3.7 Summary

Factors related to e-bike usage were identified and conceptualized in a conceptual model which is presented in Figure 3.1. These factors were discussed in the literature review. E-bike usage -being the aim of this study- is portrayed in the middle of the model. The factors on the left were found to be influential on e-bike usage in literature. The possible consequences of increased e-bike usage are portrayed on the right side. E-bike usage will lead to a substitution effect which in its turn could lead to more sustainable transportation. The explanatory factors also influence each other. It was found that commuting could be a motive to purchase an e-bike which is shown in the conceptual model. The e-bike purchasing decision could be influenced by perceived advantages, as Simsekoglu and Klöckner [57] showed that e-bike owners perceive advantages stronger than non e-bike owners. Certain user groups, such as men or older people, seem to be more inclined to purchase an e-bike which lead to the relation between user groups and purchase decision. The user group also affects how a person perceives advantages and disadvantages of e-bikes. For example, car users could perceive different advantages than regular bike users. Costs might be an advantage for a car user, while regular bike users might perceive travel time reduction as an advantage. The user groups also affect the distribution of trip purposes. Retired persons will be less likely to commute, for example.

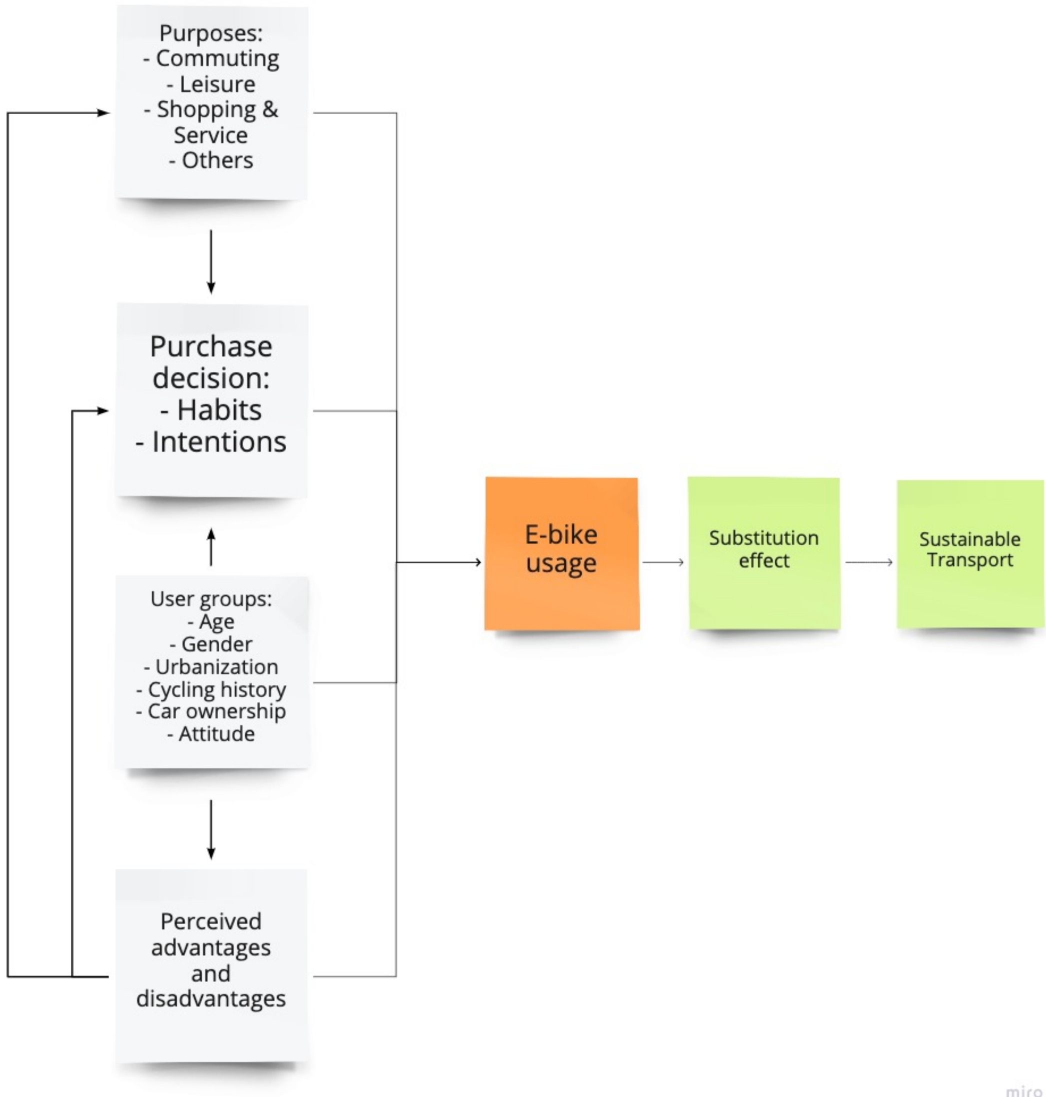


Figure 3.1: Conceptual model.

4
Analysis

The analysis consists of several parts. First, a descriptive analysis aimed to describe the sample and the trip based on observations from the survey. Second, a diagnostic analysis was performed which dives deeper in the patterns and causes of certain striking data. Then, a discrete choice analysis was done to identify relevant mode choice variable. Lastly, an environmental exploration is made based on the survey outcomes and literature findings.

4.1 Descriptive analysis

4.1.1 Sample characteristics

4.1.1.1 Age, gender and urbanization

In the sample (N=105), the middle adulthood group (36-55 years) was overrepresented, while oldest group (66+) was underrepresented compared to the general Swedish population as can be seen in Table 4.1. The youngest group (18-35 years) and the late adulthood (56-65) were fairly well represented. Females were underrepresented, while males were overrepresented in the sample. A few respondents did not identify themselves as either male or female, or preferred not to say. Most respondents lived in large cities. The largest group of respondents (52.7%) was based in a so-called *Storstad* (Stockholm, Gothenburg or Malmö). When adding up the population of the agglomerate areas of these cities, these three major cities account for about 25% of the Swedish population. Thus, the most urbanized areas are overrepresented in the sample. The third and fourth tier of urbanization, *större stad* and *mindre stad/tätort*, seem to be fairly well represented in the sample. This means that Tier 2 and 5, *pendlingskommun* and *landsbyskommun*, were underrepresented.

4.1.1.2 Car and c-bike ownership

More than half of the participants' households owned one or more cars (60.2%). The remaining 39.8% did not own a car in their households. Most of them, 31.6% did already not own a car prior to purchasing an e-bike. A small group answered to have sold their car after e-bike purchase (6.1%) or would have bought a car if they would not have had an e-bike (2%). In the qualitative part of the survey, a respondent that did not own a car mentioned to have access to a car if necessary. A question about car accessibility in the survey was lacking, but it is assumed that more respondents that did now own a car had access to a car. Reason for this is

Table 4.1: Sample characteristics. *Age groups as a share of 18+ population.

	Sample	**Sweden**
Age		
18-35	20.2%	25.5%*
36-55	60.6%	33.2%*
56-65	14.1%	15.1%*
66+	5.1%	26.0%*
Gender		
Female	33.3%	49.7%
Male	62.6%	50.3%
Urbanization		
Tier 1: Storstad	52.7%	25%
Tier 2: Pendlingskommun	6.8%	15%
Tier 3: Större stad	17.6%	18%
Tier 4: Mindre stad/tätort	12.2%	15%
Tier 5: Landsbygskommun	10.8%	27%

that multiple respondents that did not own a car did use a car in their three most recent trips. Owning an e-bike did not prevent riders to own a conventional bike as 74.5% listed to own a conventional bike as well. Some respondents (17.3%) got rid of their conventional bike after purchasing an e-bike, while 8.2% did not own a conventional bike prior to purchase an e-bike.

4.1.1.3 Usage period and hilliness

Respondents were asked to indicate for how long they have been using an e-bike and could choose between >1 year, 1-2 years, 3-4 years and >5 years. The respondents were fairly even distributed between these four groups with 18%, 33%, 23% and 26% respectively. Respondents lived in relatively hilly areas according to their own perception. Participants encountered hills during usual trips on an average score of 2.44 was obtained using the Likert method in which 1 was 'very hilly' and 5 was 'totally flat'. About 81% of the respondents perceived their place of living as medium to very hilly.

4.1.2 Trip characteristics

The most frequent trip purpose was commuting with 48% of all trips as shown in Figure 4.1a. Leisure accounted for 20% of the trips, while shopping and service was responsible for 26% of the trips. The remaining 5% was made by other purposes. In terms of distance, the share of commuting was larger (54%). The share of leisure trips is also slightly larger with 21%. Shopping and service trips were responsible for 18% of the e-bike distance. Commuting trips by e-bike were performed 3.3 times per week on average. Leisure place took on average place about 1.9 times per week and service & shopping 1.6 times per week.

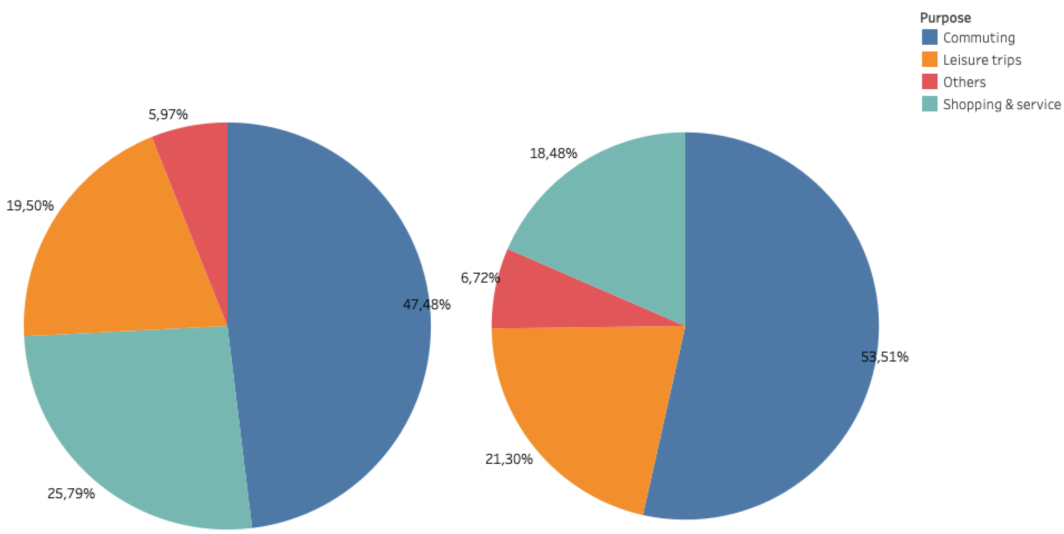


Figure 4.1: Purpose distribution based on: (a) share of trips and (b) share of distance.

The average trip distance per purpose is shown in Table 4.2 for both e-bike trips and general trips. The average trip length per purpose was found to be statistically different from each other as in summarized in Table 4.3. Particularly shopping and service trips were shorter than the other purposes. The general trip length in each category was longer than the e-bike trip length, but follows the same pattern. More so, the purposes were statistically different between each other as well. The average trip length for all trips irregardless of the mode was 10 kilometer; this was 9.5 kilometer for e-bike trips.

Table 4.2: Average trip distance per purpose.

	E-bike	**Total**
Commuting	10.6	11.2
Leisure	10.2	10.8
Shopping & Service	6.4	7.1
Others	9.1	11.1
Average	9.5	10.0

Table 4.3: ANOVA on trip length per purpose.

		SS	***df***	***MS***	***F***	***P-value***	***F crit***
E-bike	Between Groups	619	3	206	5.3400	0.0015	2.6509
	Within Groups	7539	195	39			
	Total	8158	198				
General	Between Groups	949	3	316	7.1542	0.0001	2.6339
	Within Groups	13619	308	44			
	Total	14568	311				

Figure 4.2 shows the trip distances per purpose. The answers are based on the non-revealed-choice questions in which participants could give an open answer based on their average trip for the mentioned purpose. It could be observed that the upper hinge and whisker for leisure trips are larger than commuting distances, despite a higher median for commuting trips. Commuting trips tend to take place in a smaller distance range from 6.6 to 22 kilometer. For shopping & service trips is this range lower: between 3 and 14 kilometer. Leisure trips mostly take place in the 4.5 to 25 kilometer range.

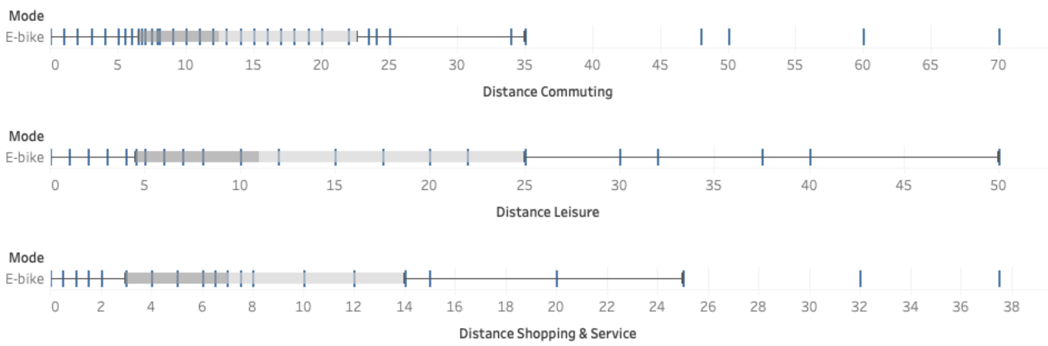


Figure 4.2: Boxplot of distances per purpose based on the additional questions.

The vast majority of trips from the revealed choice part were e-bike trips which can be found in Figure 4.3a. This share of e-bike trips was 64%. Car was the second most chosen mode of transportation (18%), followed by conventional bike (8%), walking (6%) and public transportation (3%). In terms of distance, shown in Figure 4.3b, the share of e-bike trips is smaller (60%). The share of cars is 25%, followed by c-bike (9%), public transport (4%) and walking (2%). A small share of 10% of the respondents did not used the e-bike in one of their three most recent trips. The majority of them, 8%, did not used the e-bike over a month.

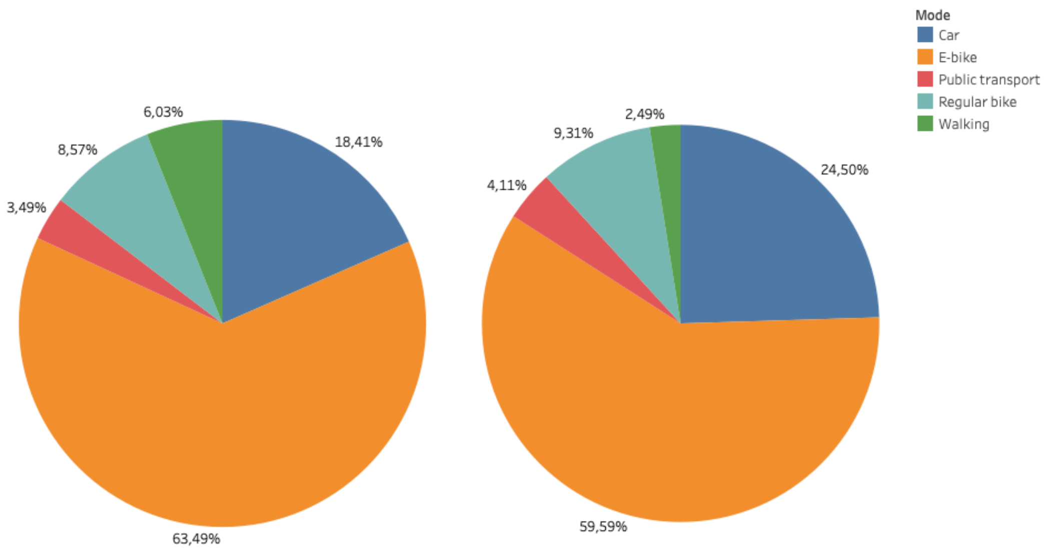


Figure 4.3: Mode distribution of (a) share of trips and (b) share of distance.

Figure 4.4 shows the mode substitution distribution of both share of trips (a) and share of distance (b). These are the modes that the e-bike trips from Figure 4.3 are replacing if people would not have had an e-bike. Generally, public transport, conventional cycling and car trips were replaced to a similar extent of about a quarter of the entries. The remaining part was divided between walking and induced trips. The pattern of modal substitution based on distance does not differ largely from the trip-based chart. Most noticeable difference is that the share of walking is reduced in the distance chart.

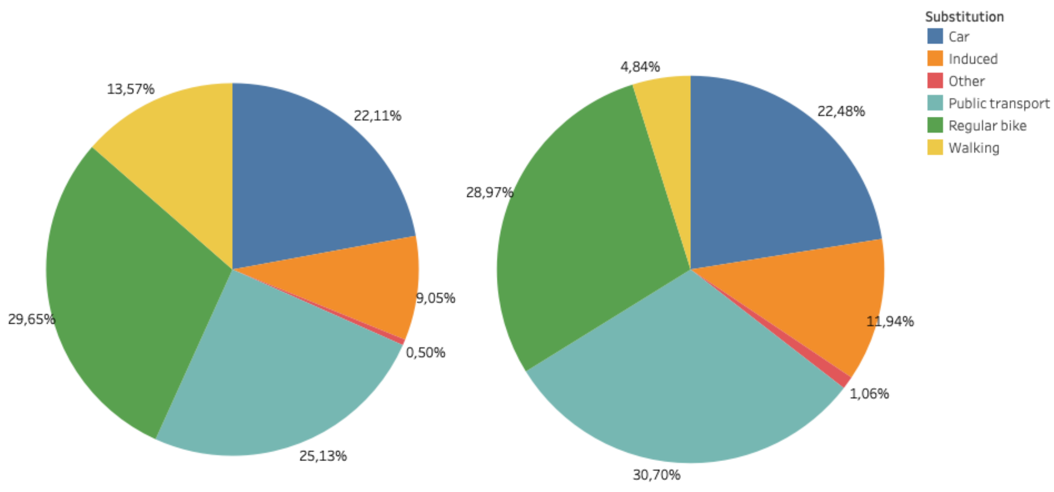


Figure 4.4: Mode substitution distribution as (a) share of trips and (b) share of distance.

Table 4.4 presents the average distance for each chosen mode and the substituted modes. Chosen car trips were the longest on average with 13.4 kilometers, while walking trips were the shortest with 4.3 kilometers. Conventional bike trips in the survey appeared to be on average longer than e-bike trips. The mode distances were found to be statistically different from each other as can be seen in Table 4.5. Walking trips are significantly shorter than the other substituted modes. The average distances of the substituted modes were lower than the actual modal averages in each case and followed the same pattern. Moreover, induced trips show a higher average distance than the other substituted modes. Table 4.5 shows that the the differences in average trip length between all substituted modes were statistically different, but that the three main replaced modes (car, public transport and conventional bike) were not statistically different.

Table 4.4: Average trip distance per mode.

	Mode Distance (km)	**Substituted mode** Distance (km)
Car	13.4	9.6
E-bike	9.5	
Public transport	11.9	11.5
C-bike	10.9	9.2
Walking	4.3	3.4
Induced		12.5

Table 4.5: ANOVA of mode differences, all substitution difference and the three main substitution differences.

		SS	***df***	***MS***	***F***	***P-value***	***F crit***
Modes	Between Groups	1439	4	360	8.4042	1.8927E-06	2.4007
All	Within Groups	13313	311	43			
	Total	14752	315				
Substitutions	Between Groups	1384	4	346	10.0240	2.1612E-07	2.4184
All	Within Groups	6662	193	35			
	Total	8046	197				
Substitutions	Between Groups	159	2	80	2.0666	1.30E-01	3.0564
Car, PT and c-bike	Within Groups	5783	150	39			
	Total	5942	152				

Figure 4.5 shows the distribution of substituted modes per purpose. Car replacements were mostly present in commuting and shopping & service, while very limited in leisure. Instead, leisure trips consisted of a relatively large share of induced trips: 32%. This is about three times as frequent as the overall sample. The category 'others' shows a fairly similar pattern as leisure, but is smaller in quantity. Public transport is proportionally large in commuting trips with 34% compared to 25% in general.

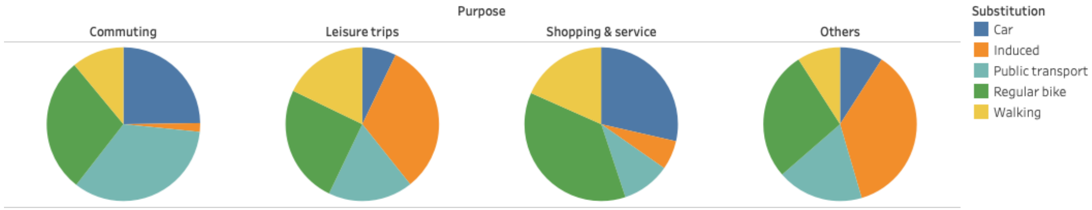


Figure 4.5: Division of modal choice separated by purpose.

4.2 Diagnostic analysis

4.2.1 Habits

Participants were segmented based on their e-bike usage period. It can be seen at top part of Figure 4.6a that the longer the participants used their e-bike, the longer the trips on average became, except for 1 to 2 year users. The distance difference between the usage period groups were statically different (Table 4.6). The 1 to 2 year users were also the least positive about e-bikes, while 3 to 4 year users were the most positively minded regarding e-bikes. These 3-4 year users were also the users that replaced a relatively high share of motorized trips as can be seen in Figure 4.6b. The other groups all showed a slight majority of non-motorized trip replacement. Figure 4.6c shows the e-bike frequency in average amount of trips per year usage segmented by usage period. The longest users (>5 years) used the e-bike most frequently with on average 465 times per year, while new users (<1 year) were the second most frequent users with 400 times per year.

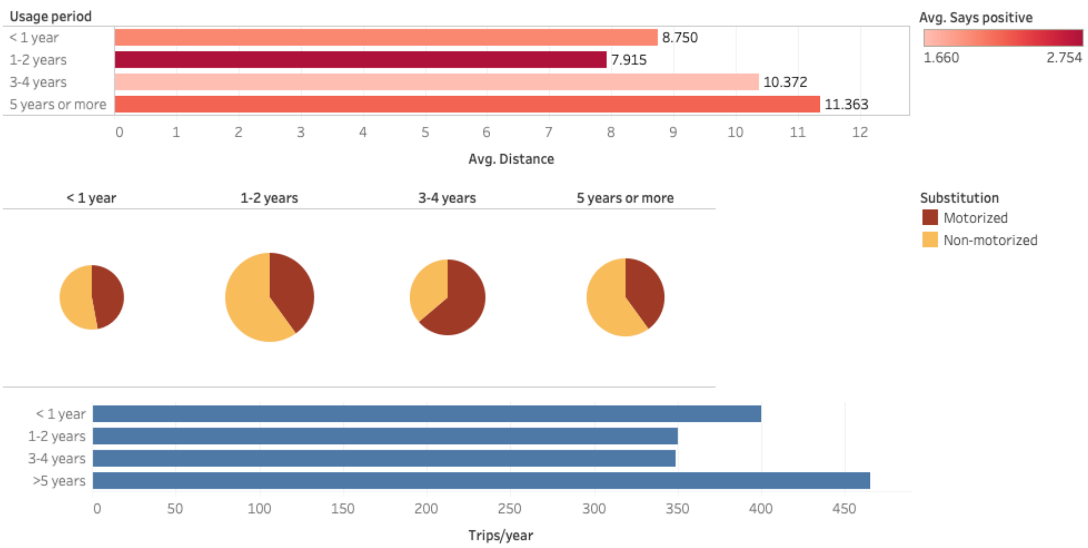


Figure 4.6: (a) Distance, (b) Modal Substitution, and (c) Frequency segmented by usage period.

4.2.2 Intentions

Figure 4.7 illustrates the distribution of answers on the questions 'Do you think riding an e-bike says something positive about you?', 'Using an e-bike enables me to distinguish myself from others' and 'I can show who I am by using an e-bike' which were abbreviated 'Says positive', 'Distinguish and 'Show yourself', respectively. The y-axis shows the amount of respondents that selected a certain Likert score. The pattern on the answers in the former question visibly differs from the latter two. Most respondents thought riding an e-bike said something positive about themselves, while the respondents generally did not find that they were able to distinguish themselves with an e-bike or to show who they are. The average Likert score of 2.35 for positively confirms the optical observation which is notably lower than the average Likert scores for 'distinguish yourself' and 'show who you are' with a scoring of 3.76 and 3.72, respectively.

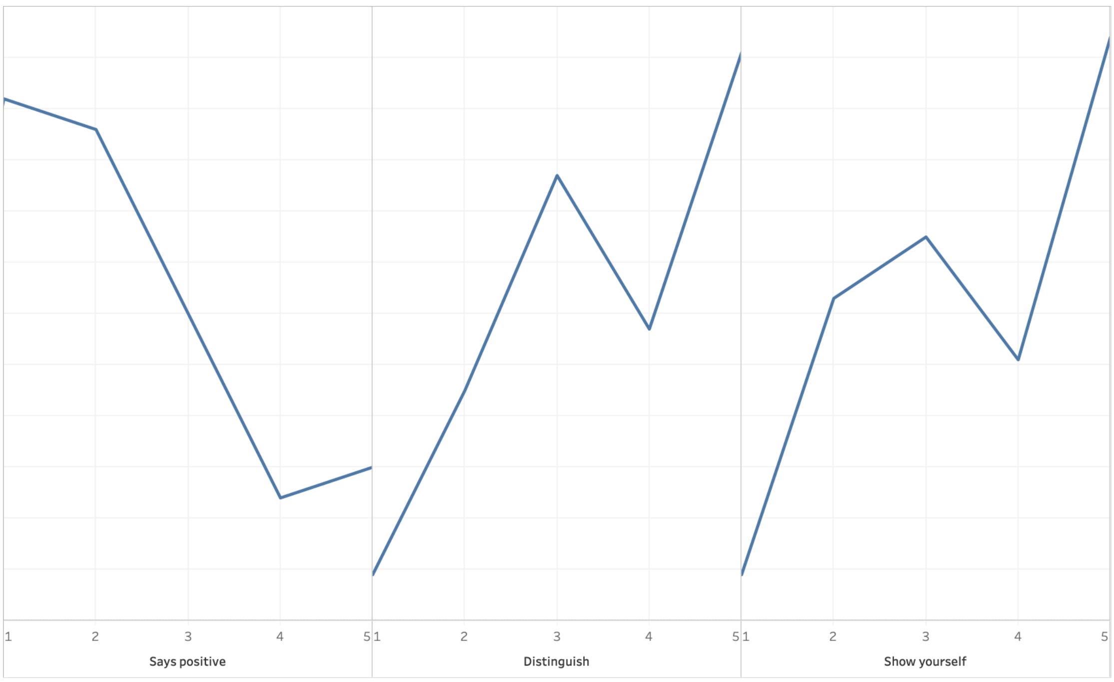


Figure 4.7: Attitude towards e-bike usage.

Respondents that mentioned 'avoid/reduce car use' as a motive to purchase an e-bike were compared with respondents that did not mention this motive in Figure 4.8a. It can be observed that people with the intention to reduce or avoid car use did *not* statistically substitute car trips more often than people that did not have that intention. In Figure 4.8b it can be seen that car reduction intentions did *not* lead to lower car usage compared to participants that did not have that intention. Participants with the intention to reduce car usage were responsible for 48% of all performed car trips and only 40% of all other trips. That means that people with car reduction intention were relatively more often choosing for car. However, this effect was not significant.

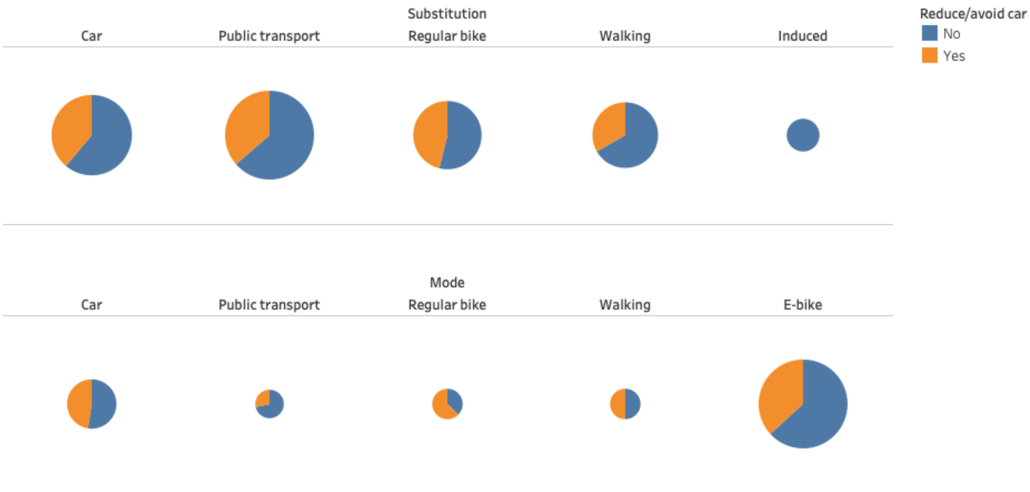


Figure 4.8: (a) Substituted mode and (b) Modal choice distributed by intention to reduce or avoid car usage.

4.2.3 Motives

The outcomes of the most frequently listed motives to purchase an e-bike can be found in Figure 4.9. The most often selected factor was 'avoid/reduce using a car' which was selected by 42% of the respondents. Often, respondents gave multiple factors that influenced the purchase decision. 'Finding a way to transport a child' (22%) and 'new job or change of workplace' (20%), physical condition got worse/-better (17%), 'Moving to a new house' (10%) and 'Partner bought an e-bike' (10%) were also mentioned by multiple participants. 'None of the above' reflects all light-blue answer options; the dark-blue options have been suggested by the respondents and were categorized afterwards. For example, 6 respondents wrote that cycling was their preferred mode of transport, especially to commute. This was the most frequently mentioned options outside the provided answers. Finally, alternative mentioned reasons were COVID-19 (2 times), low costs, the replacement of another broken vehicle, working with e-bikes and an interest in technology.

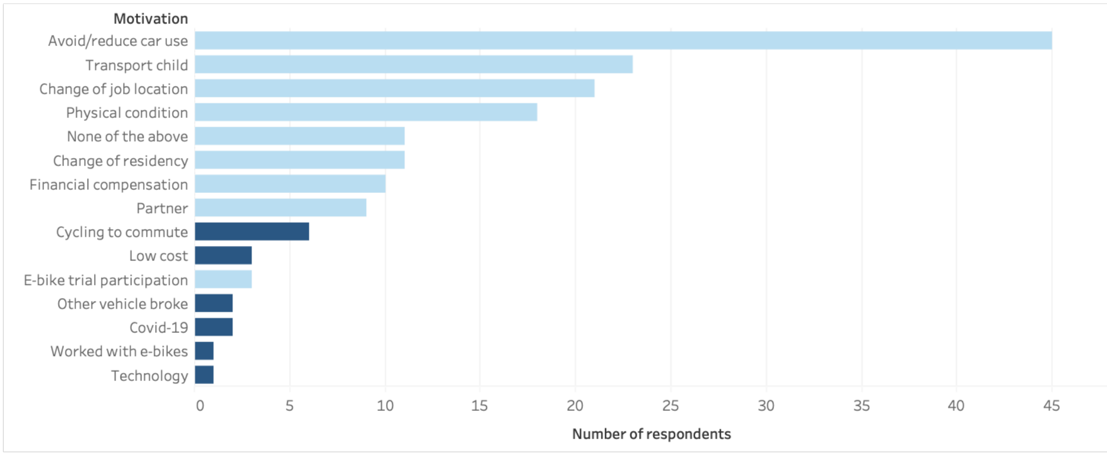


Figure 4.9: Motivations to purchase an e-bike.

4.2.4 Advantages and disadvantages

Multiple advantages were frequently mentioned by the participants as can be seen in Figure 4.10a. The ability to cover longer distances, fun to ride, fresh air, easier to counter hills, environmental reasons, reduced travel time and reduced sweatiness were all mentioned by more than half of the participants. 'Cheaper' was the least frequently mentioned advantage. The same approach as for the advantages was taken for the disadvantages. In this case, a different trend could be observed in Figure 4.10b. 'Risk of theft' was by far most frequently mentioned as being a disadvantage (71%). A poor biking infrastructure was the second most frequently mentioned disadvantage, but was less often mentioned than any advantage except costs. Safety and the disability to transport goods were the least mentioned disadvantages.

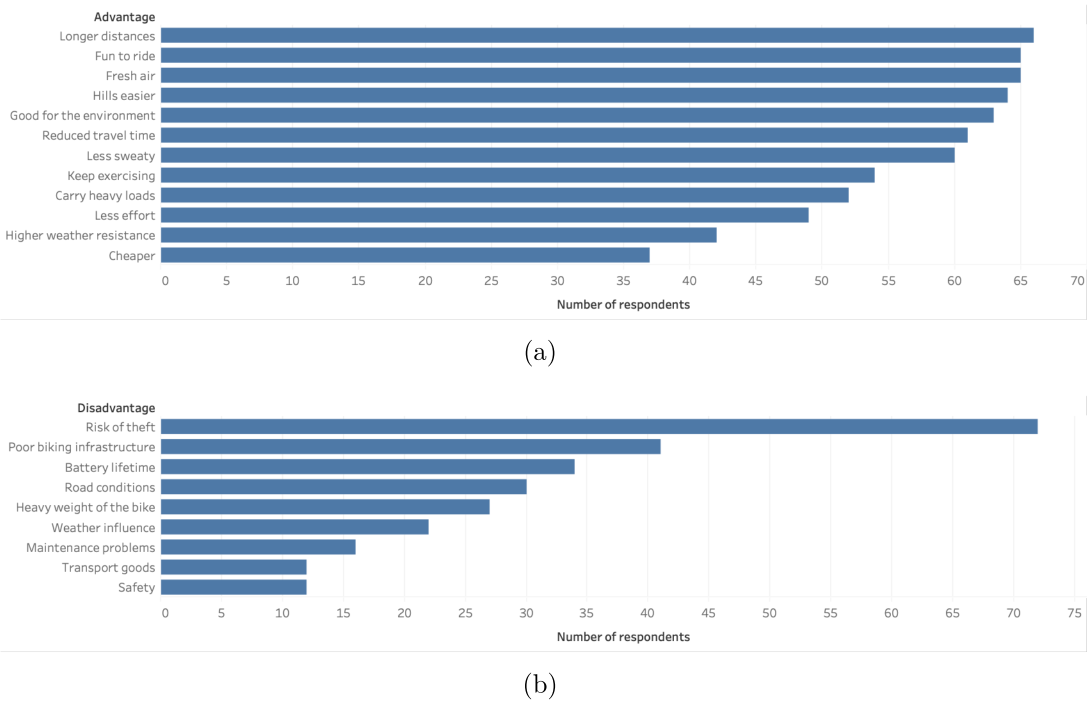


Figure 4.10: Perceived (a) advantages and (b) disadvantages of e-biking.

4.2.5 Age

In Figure 4.11, it can be found that the largest age group of respondents, 36-55 year old users, replaced as much motorized as non-motorized trips. The younger age group replaced slightly more motorized trips, while older groups substituted relatively more non-motorized trips. Alternatively, the elder the user group, the longer the average e-bike trip distance. This goes up from 7.5 kilometer for the youngest group to 11.9 kilometer in the eldest group. The ANOVA presented in Table 4.6 shows that the trip length differences between the age groups were just not statistically different from each other.

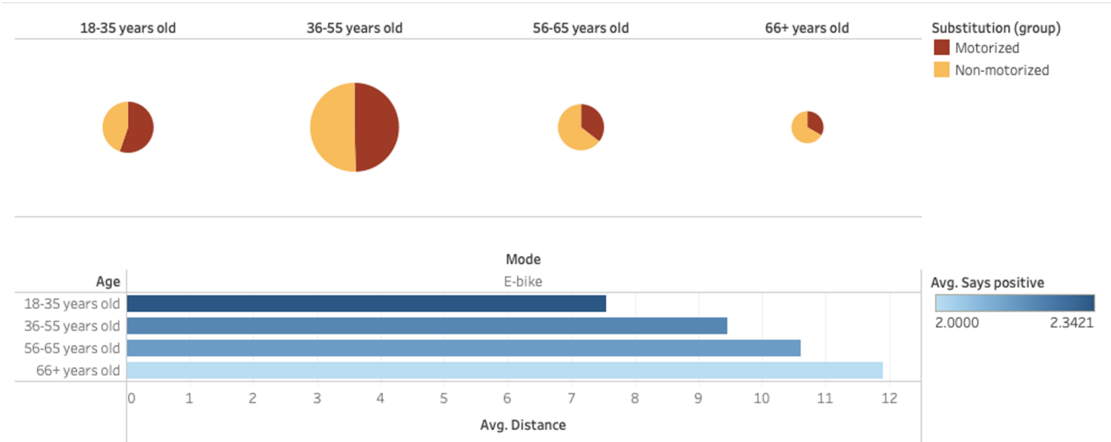


Figure 4.11: (a) Modal substitution and (b) Distance distribution by age groups.

Figure 4.12 concentrates on the eldest age group travelling the longest average e-bike distances: 66+ years old users. First, these elder users mainly used their e-bike for leisure trips and shopping & service rather than commuting with about 85% of the trips compared to less than 40% in the other age groups. Secondly, the oldest age groups were also more often longer users than in general. This especially holds for the longest users with 5 years or more e-bike ownership. The average usage period is 3.2 years overall in this study, but 5.6 years for the elders user group. The 66+ users were proportionally more impacted by weather events of any kind with 93% compared to 59% in other groups. The 66+ years old participants in this study exclusively lived in the large cities Stockholm, Gothenburg and Malmö denoted as Tier 1. Overall, they answered that their frequency of conducting leisure trips was higher than other groups. Mainly the answer option with the frequency of 'more than 5 times per week' sticks out. Lastly, walking was affected proportionally much in this group: 86% answered to walk less or much less since owning an e-bike compared to 36% of the other age groups.

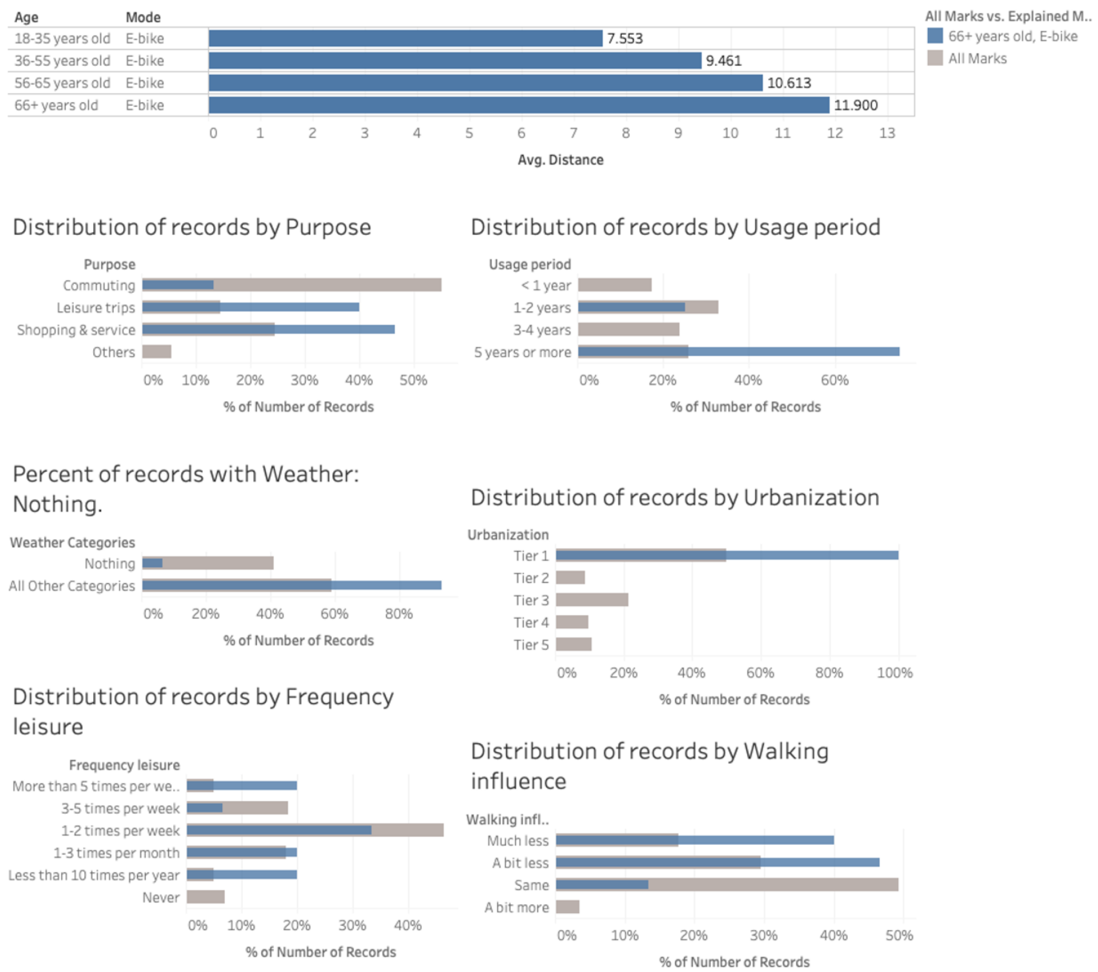


Figure 4.12: More detailed characteristics of the 66+ age group.

4.2.6 Gender

The usage differences between male and female e-bike users were small (Figure 4.13). Men made on average longer trips, however, not statistically different (see Table 4.6). Women tended to be more positive about e-biking than men. Approximately half of the substituted trips were motorized (car and public transport) for both genders.

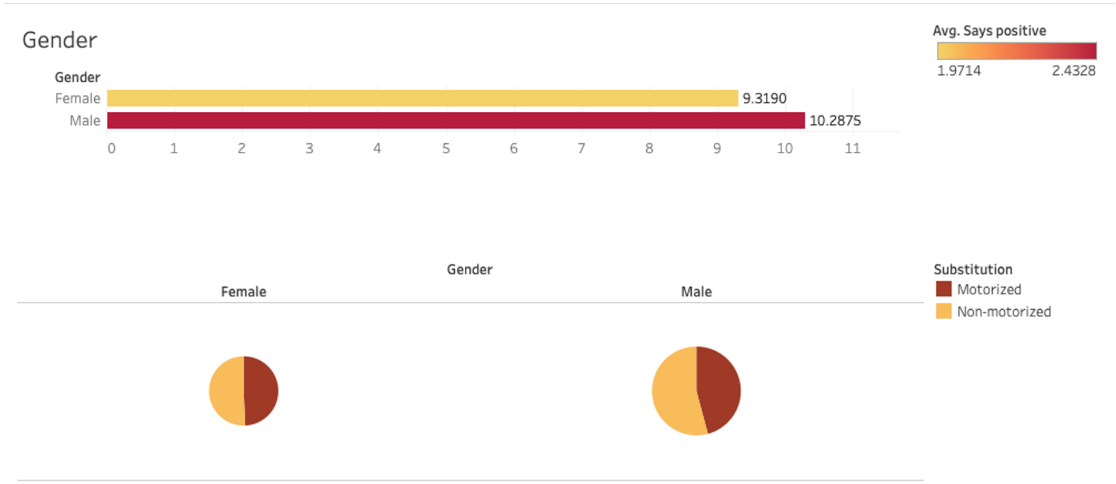


Figure 4.13: (a) Distance and (b) Modal substitution distributed by gender.

The differences in average e-bike trip distance between female and male users can further be explained by Figure 4.14. Here, it appeared that female participants were relatively more recent e-bike users than men as the share of the longest user groups (>5 years) was considerably smaller, while all other groups were proportionally larger. Additionally, female respondents more often indicated to be affected by weather events such as snow, ice, rain, wind and high temperatures than the general sample. This was the case in 83% of the female entries, while only 63% of men were bothered by weather events of any kind. Figure 4.14c also shows that women in this sample were commuting more frequently than men. About three quarters of the women commute 3 times a week or more compared to approximately half of the men. A proportionally lower amount of women mentioned to commute 'never' or less than 10 times per year than the total sample. When calculating the commuting trips per person based on these answers, it appeared that women take about 235 commuting trips per year, while there were on average 170 annual commuting trips performed by men. This corresponds to about 38% more commuting trips for women compared to the men.

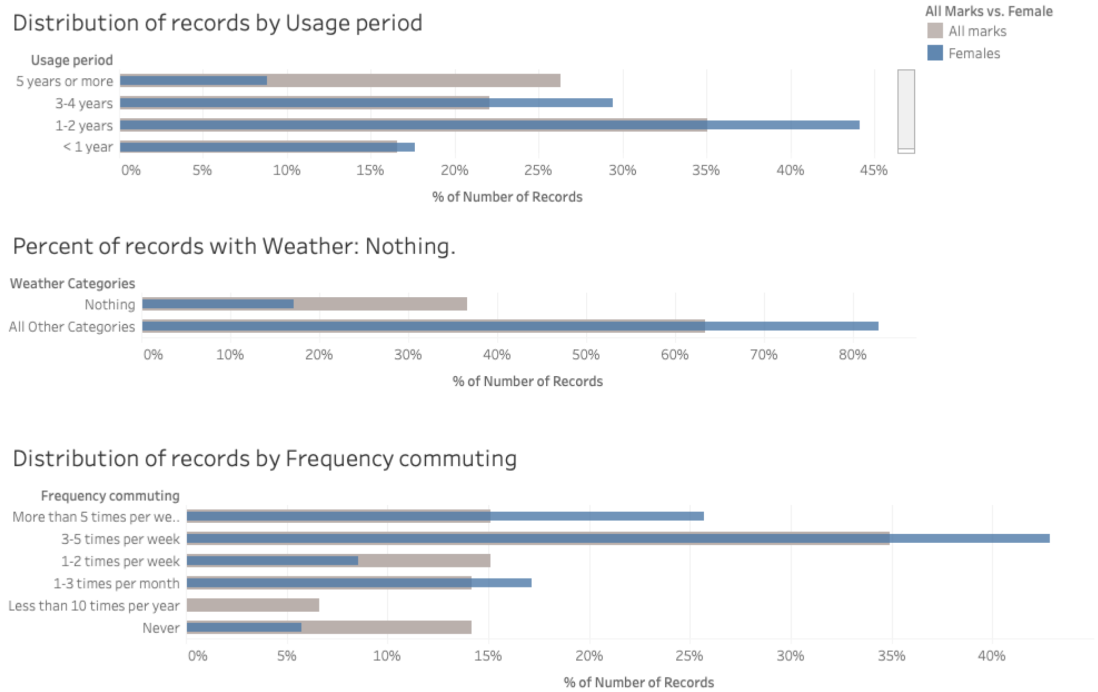


Figure 4.14: (a) Usage period, (b) Weather influence and (c) Commuting frequency of women compared to men.

4.2.7 Urbanization

The number of modal substitutions per level of urbanization can be seen in Figure 4.15. Conventional bike, public transport and car trips were to a similar extent being replaced in absolute terms. The darker the blue, the more urbanized the place of residence of the respondents was. Figure 4.15a shows that public transport is proportionally more replaced in urban areas, while cars were relatively more frequently being replaced in rural areas. It seems that there were also relatively more induced trips is rural areas. The average trip distance for e-bike trips per urbanization Tier can be found in Figure 4.15b. Tier 2, the *Pendlingskommun*, and Tier 4, towns of 15,000 to 50,000 citizens, portray the highest average trip distance. The five Tiers were statistically different from each other as was found in an one way ANOVA (Table 4.6). The modal substitution of Tier 5 respondents is significantly different from other urbanization groups as can be observed in Figure 4.15c. Car was replaced in 57% of the entries, while car was replaced in only 22% for other Tiers. Public transport was not substituted once by Tier 5 respondents. Moreover, walking is twice as often being replaced (28% versus 14%), while the regular bike was barely substituted in Tier 5 (5%).

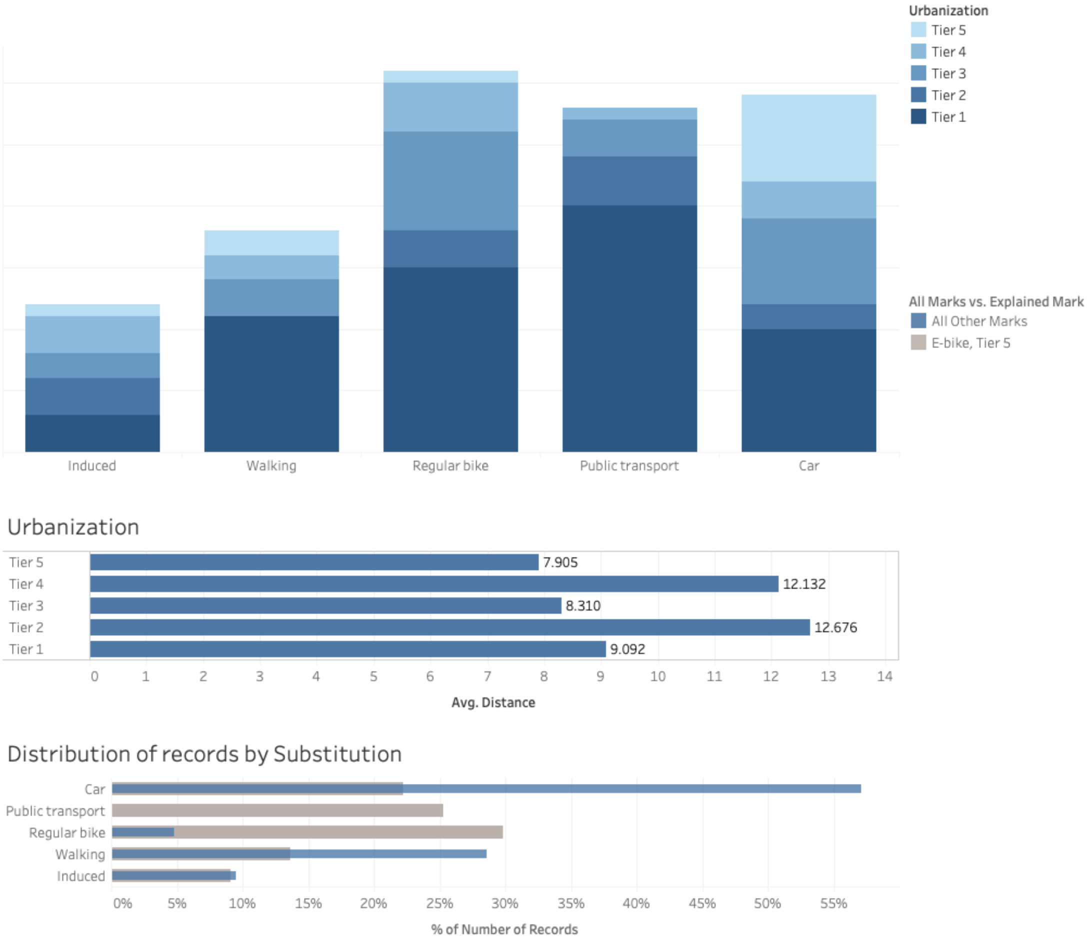


Figure 4.15: (a) Modal substitution and (b) Distance distributed by urbanization, and (c) Modal substitution of Tier 5.

4.2.8 Cycling history

Figure 4.16 displays on the left the cycling history of the respondents. Three groups were differentiated: new cyclists, restorative cyclists and resilient cyclists. Resilient users had been cycling before and kept cycling. Moreover, red denotes a motorized substitution and white a non-motorized substitution. Resilient drivers replaced mainly non-motorized trips. However, restorative cyclists portrayed a higher share of motorized replacement than non-motorized. New cyclists showed almost exclusively motorized replacement. On the bottom of Figure 4.16, the average e-bike trip distance is displayed. New cyclists possessed the shortest average trip distance. Restorative and resilient users had a similar average e-bike trip distance. Statistically, the groups were overlapping as was found in a one way ANOVA test in Table 4.6. The bottom part of Figure 4.16 shows that these new users were proportionally frequent belonging to the youngest age group of users and less to all other groups.

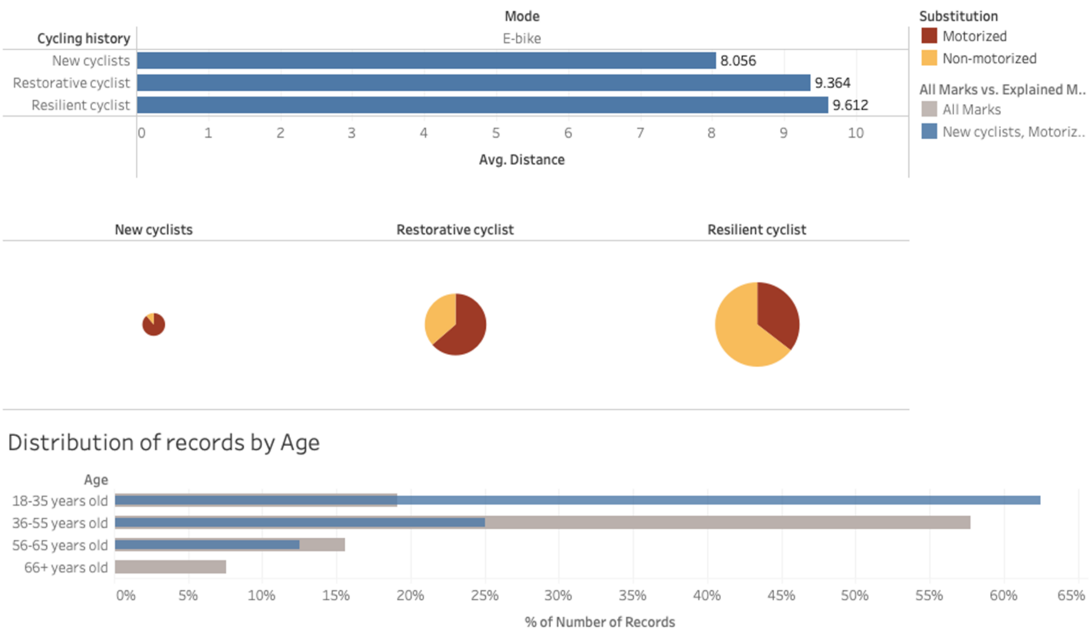


Figure 4.16: (a) Distance and (b) Modal substitution distributed by cycling history and (c) Age distribution of new cyclists.

Average e-bike trip distances differentiated by conventional bike ownership are presented in Figure 4.17. Owners of a conventional bike made on average 31% longer e-bike trips than non-conventional-bike owners. New cyclists made slightly longer trips than people that got rid of their conventional bike after purchasing an e-bike. An one-way ANOVA (Table 4.6 showed that the e-bike average trip distance divided by c-bike ownership was statistically different. C-bike owners substituted more non-motorized trips such as regular cycling than participants not owning a conventional bike, specifically compared to respondents that did not own a conventional bike prior to purchasing an e-bike.

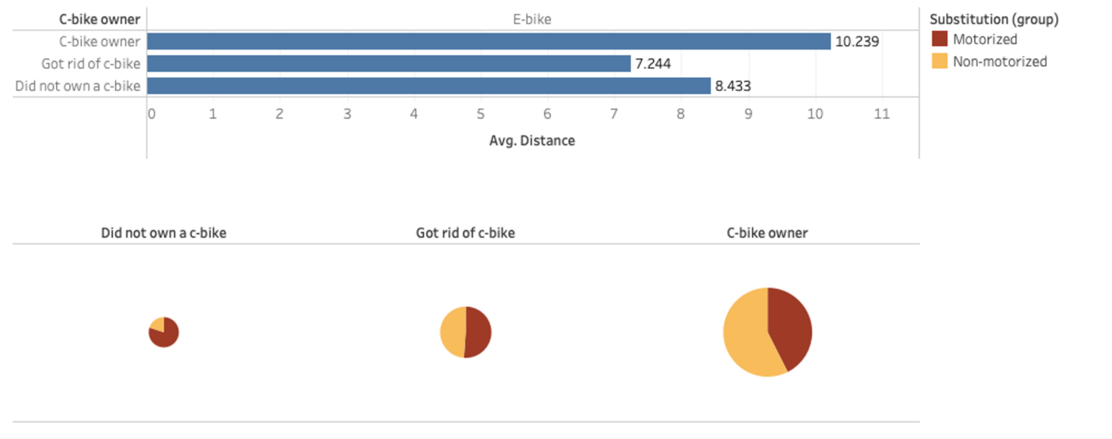


Figure 4.17: (a) Distance and (b) Modal substitution distributed by c-bike ownership.

4.2.9 Car ownership

Participants that owned multiple cars covered on average 78% longer e-bike trip distances than participants that owned no or only one car as can be seen in Figure 4.18. The first group conveyed an average of 15.1 kilometer per trip, while the latter groups drove 8.1 and 8.8 kilometer, respectively. The one way ANOVA summarized in Table 4.6 showed that the average trip distance between multiple car owners and users owning one or no cars was statistically different. When concentrating on the multiple car owners, it can be observed that this group consists of a proportionally large group of rural citizens (Tier 4 and 5) and a low urban representation (Tier 1). Weather events of all kinds bother this group particularly much: 83% of the groups mentioned to be affect by weather of any kind, compared to 59% of the remainder.

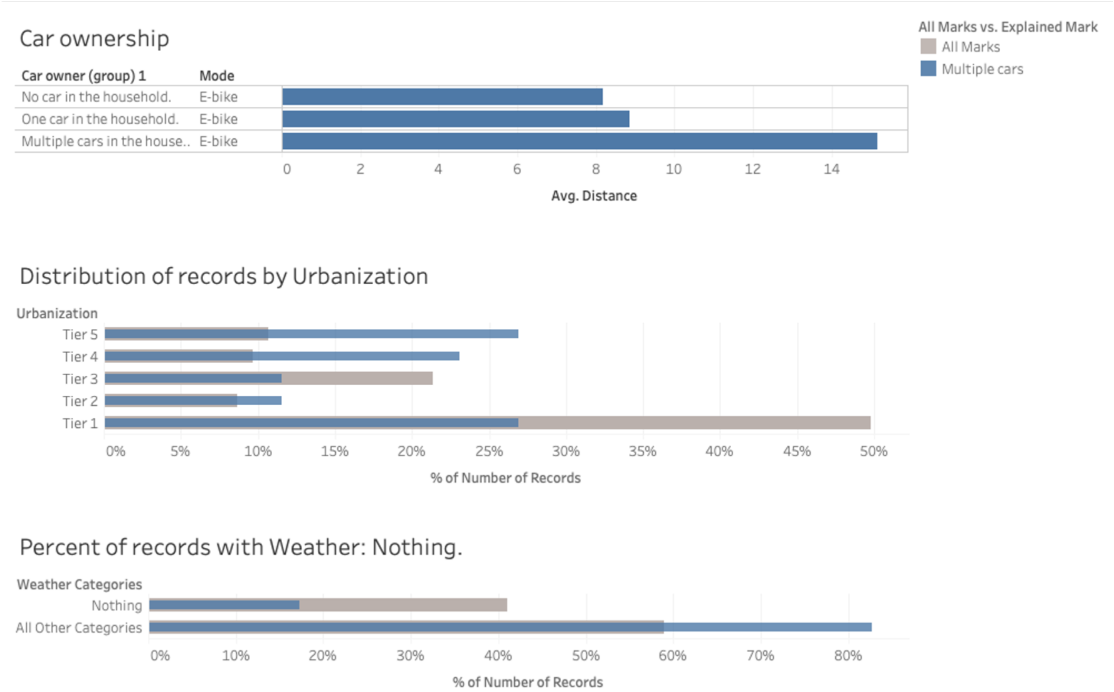


Figure 4.18: (a) Distance distributed by car ownership, and (b) Distribution of urbanization and (c) Weather influence of multiple car owners.

4.2.10 Hilliness

The average trip distance per level of hilliness is shown in Figure 4.19a. In this Figure, 1 denotes a very hilly area, where 5 refers to a flat area. It can be seen that the average trip distance of conventional bikes strongly increases (+145% between level 1 and 4) when the surroundings get more flat. This is not the case for e-bikes (-17% between level 1 and 5) and cars (-15% between level 1 and 5). If anything, opposing effect seems to be true: the more hilly, the longer the average e-bike and car trip distance. However, an one-way ANOVA presented in Table 4.6 showed that the average trip distance between c-bike groups divided by hilliness level was *not* statistically different. The average hilliness of conventional bike trips is 2.9, while the average hilliness of an e-bike trip 2.3 is which is considerably more hilly. In Figure 4.19b portrays the share of c-bike (green) and e-bike (orange) trips as part of the total cycling trips. The most level circle corresponds to level 1 (hilly) and the most right to level 5 (flat). It can be observed that the more hilly the area, the smaller the share of c-bike trips of the total bike trips. An exception is the most flat category where no c-bike trips were observed. There were too little respondents falling in this category.

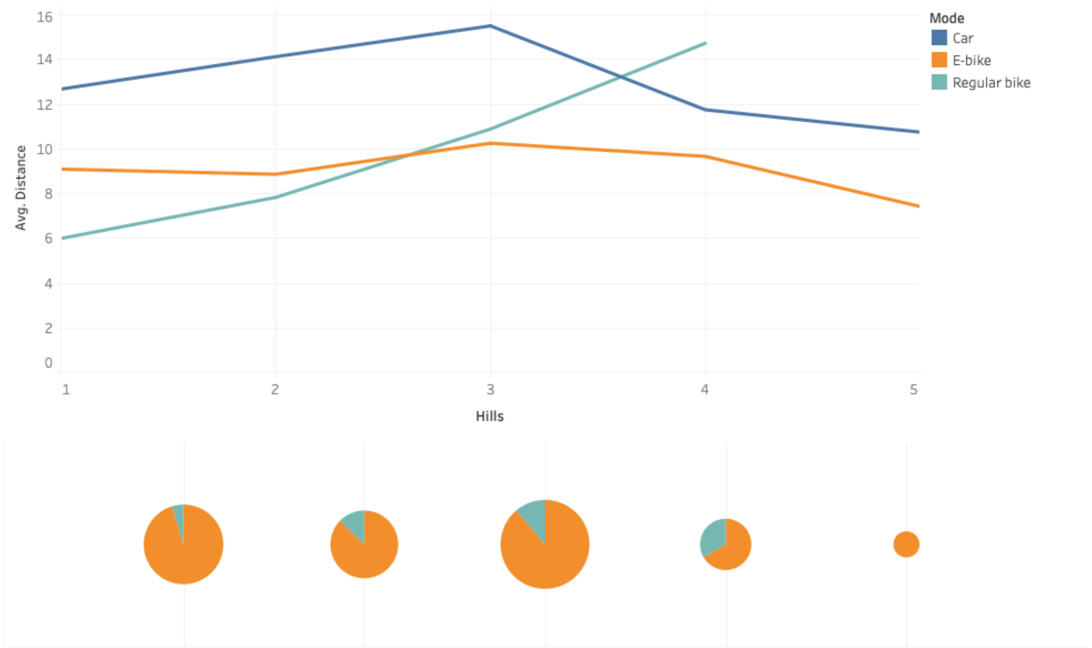


Figure 4.19: (a) Hilliness compared to average trip distance. (b) Share of c-bike and e-bike trips based on hilliness.

4.2.11 Weather factors

The answers on the question which weather factor is negatively influencing e-bike usage is shown in Figure 4.20. The larger the bubble, the more frequently this answer combination was given. Many respondents perceived no influence of weather events at all (39%). Ice or the combination snow and ice was also frequently mentioned. Individually, ice was the most mentioned weather event (51%); snow ranked second with 37%. Rain was mentioned by 20% of the respondents, often in combination with ice and snow. Wind was only a problem for 10% of the participants, usually in combination with another weather type. High temperatures were only mentioned by two respondents. The combinations snow & ice and snow, ice & rain were also frequently listed.

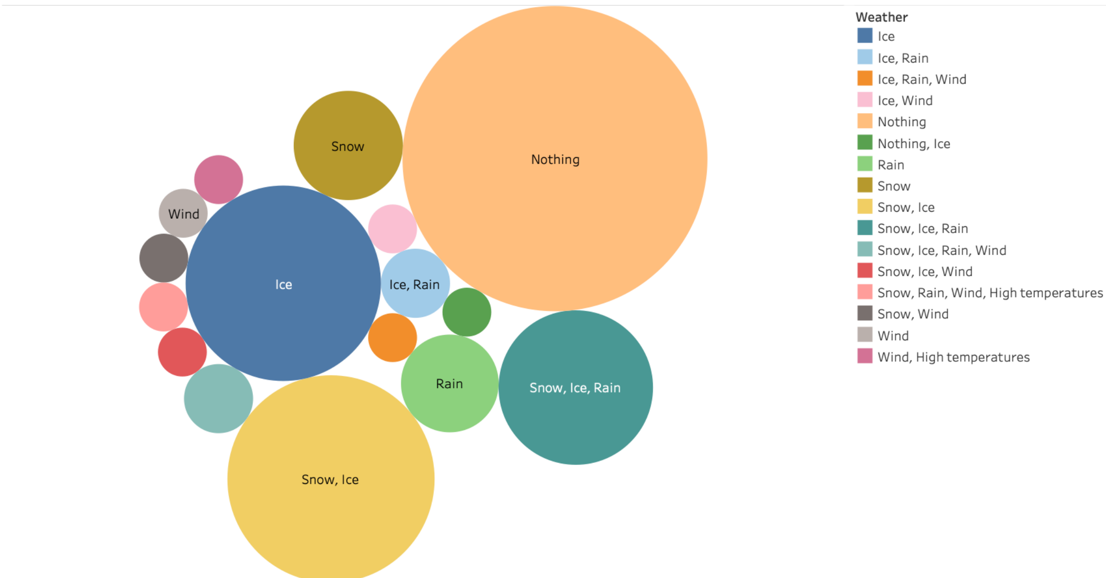


Figure 4.20: Weather factors negatively influencing e-biking.

Table 4.6: Overview of ANOVA results.

Segmentation		SS	df	MS	*F*	*P-value*	*F crit*
Age	Between groups	269	3	90	2.2231	0.0868	2.6507
	Within groups	7898	196	40			
	Total	8167	199				
Gender	Between groups	114	1	114	2.8303	0.0941	3.8903
	Within groups	7744	192	40			
	Total	7858	193				
Urbanization	Between groups	430	4	108	2.7145	0.0312	2.4187
	Within groups	7612	192	40			
	Total	8042	196				
Cycling history	Between groups	21	2	11	0.2570	0.7736	3.0418
	Within groups	8146	197	41			
	Total	8167	199				
C-bike ownership	Between groups	313	2	157	3.9280	0.0212	3.0418
	Within groups	7854	197	40			
	Total	8167	199				
Car ownership	Between groups	1214	2	607	17.0180	1.51E-07	3.0415
	Within groups	7064	198	36			
	Total	8278	200				
Hilliness	Between groups	98	4	25	0.5923	0.6686	2.4180
	Within groups	8069	195	41			
	Total	8167	199				

4.3 Discrete choice analysis

4.3.1 Models

Figure 4.21a shows a discrete choice model on the purpose of the trip. The most habitual type of trip, commuting, was denoted with the lowest score, while the least habitual, leisure, was given a 4 mark. The figure shows that the more habitual the trip, the higher the likelihood that one would travel by e-bike. E-bike reaches the highest share at commuting with 75% which decreases until 40% at leisure trips. Car choice increased from 16% at commuting trips to 26% at leisure trips. The share of walking also increases with less habitual trip until 14% at leisure. Figure 4.22b shows the DCM for the habits expressed by usage period. Longer e-bike users choose less frequent a car (14%) as new users (22%). This also holds for e-bikes themselves which decreases from 64% to 58% of the instances. Longer e-bike users are more inclined to walk with 22% for the 7 year long users. Age does have an effect on the modal choice distribution as can be observed in Figure 4.21c. Older people are more frequently choosing to use the e-bike (71% versus 58%), while younger people were more often selecting the car (21% versus 15%). More so, younger people are walking and using public transport more often, while older people were relatively more often using their conventional bike. Males were denoted with a 0 and females with a 1 in Figure 4.22d, the DCM of gender effects. Women choose more frequently for the e-bike according the DCM with 69%versus 62%, while men are more frequent car drivers with 21%. Women opt for car in 16% of the instances.

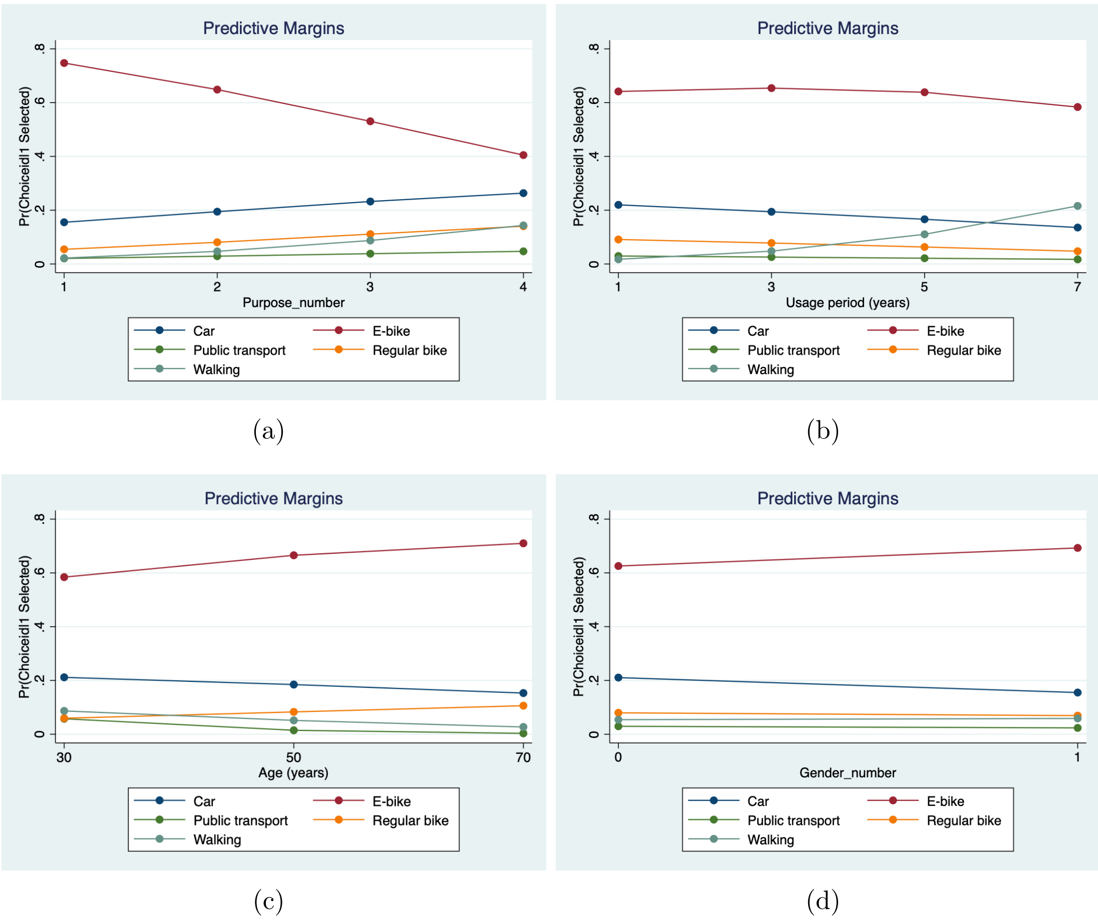
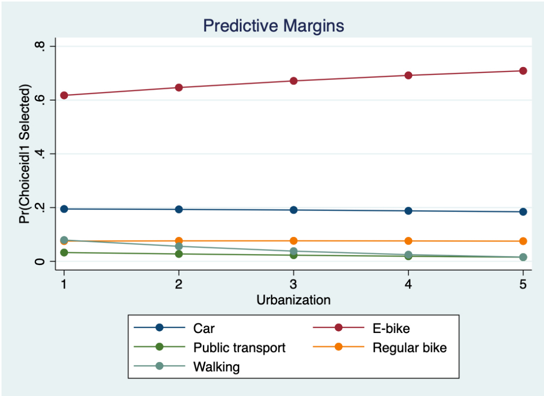
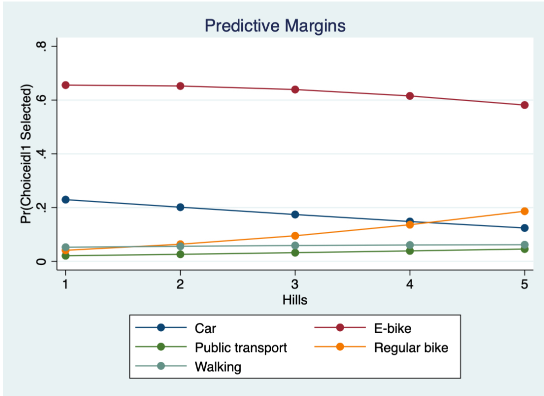


Figure 4.21: DCM of (a) Purpose (b) Habits (c) Age and (d) Gender

Figure 4.21a presents the DCM of urbanization. It can be found that the modal distribution is slightly influenced by the urbanization level of the participants. Lower urbanized areas, portray higher levels of e-bike choice (71%) than the most urban area (62%). Oppositely, cities show higher levels of walking with 8% compared to 2% in rural parts of Sweden. Figure 4.22b illustrates the DCM of hilliness on the travel mode choice. The most hilly area is denoted with 1 and the most flat with 5. The share of choosing for conventional bike increases in more flat areas from 4% to 19%. People choose car and e-bikes more often in hilly areas with 23% compared to 12% for cars and 66% versus 58% for e-bikes. Sharing your e-bike with others, mostly household members, is denoted with a 1 in Figure 4.22c, while keeping the e-bike for yourself corresponds to a 0. People sharing their e-bike choose it less frequent themselves (58% against 66%). More often than non-sharers, e-bike sharers choose a regular bike or car. Figure 4.21d shows the influence of the size of the travel group on the choice of transportation mode. Single persons would opt for an e-bike in 65% of the cases, but when three people are travelling together, only 57% would still do so. A similar pattern for conventional bike can be observed which decreases from 11% to 1%. The more people travel together, the higher the chances that car will become the travel mode choice. Car is chosen by 14% of individuals, but 41% if the travel party reaches three persons.



(a)



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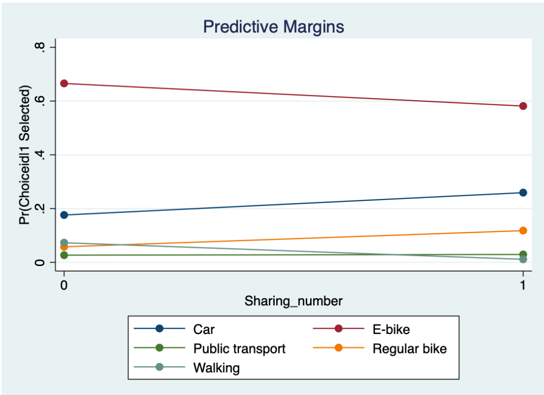
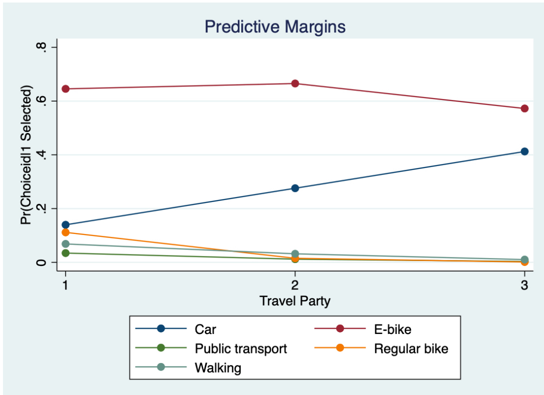


(c)



(d)

Figure 4.22: DCM of (a) Urbanization (b) Hilliness (c) Shared usage and (d) Travel Party

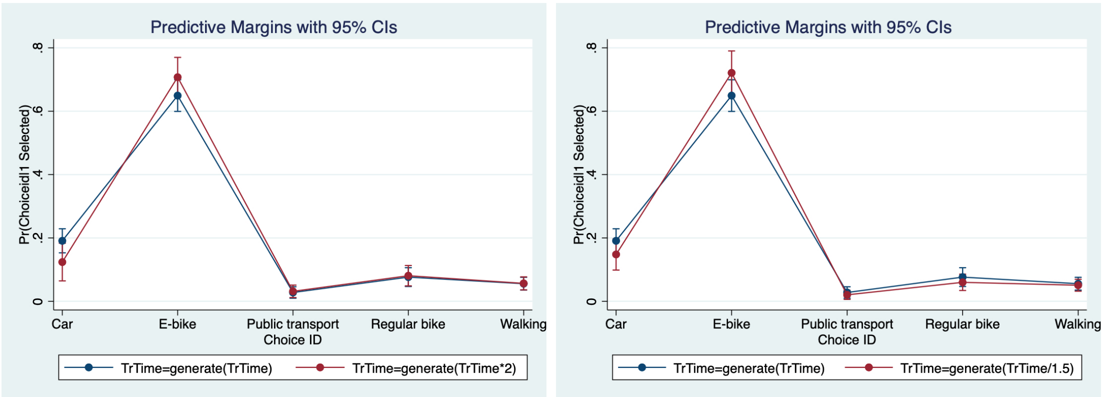
4.3.2 Variables

Travel time and travel cost were used in the DCM model as variable to model the transportation mode choices. It appeared that travel time was the most determinant variable of the two, while travel cost had little impact on the mode choice decision. This can be found in Table 4.7. The coefficient of travel time had a value of -3.15 while travel cost was close to 0 with 0.00017. Moreover, the travel time variable was significant and travel cost not. The 95% interval of travel cost was almost as much in negative as in positive values.

Table 4.7: Statistical relevance of the variables.

Choice	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
TrTime	-3.158192	1.477845	-2.14	0.033	-6.054715	-.2616687
TrCost	.0001745	.0106191	0.02	0.987	-.0206385	.0209876

The impact of travel time on the modal choice is further explored in Figure 4.23. Here, two scenarios regarding travel time are sketched. In the left graph, the consequences of a hypothetical scenario in which every car trips takes double as long (e.g. congestion) are shown. It can be seen that more people will shift from car to e-bike. The 7 percent-point reduction of car trips is almost exclusively flowing towards e-bike trips. Another scenario is portrayed on the right side in which every e-bike trip was running 1.5 times as fast as normal, simulating speed pedelecs or more direct roads. This would lead to a rise of e-bike choice from 65% to 72%. The increase would mostly come from car trips.



(a) (b)

Figure 4.23: DCM of (a) Car trips two times as slow (b) E-bike trips 1.5 times as fast.

It was tested what effect the trip purpose had on travel time. This was done to investigate if participants cared more about the travel time for commuting, leisure or service & shopping trips. It appeared there were different coefficient for these purposes. The strongest influence of travel time was for service & shopping trips with a coefficient of -8.91. Travel time mattered the least for leisure trips for which travel time appeared to be not a significant variable. Commuting trips were most similar to the average of all trips with a coefficient of -4.24. This value was significant. Travel costs was also not found to be significant in this scenario. An overview of these outcomes can be found in Table 4.8.

Table 4.8: Coefficient of travel time segmented by trip purpose.

Choice	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Commuting and Other	-4.2434	1.814809	-2.34	0.019	-7.800374	-.6864545
Leisure	-2.6391	1.628549	-1.62	0.105	-5.831083	.5527131
Service & Shopping	-8.9348	1.962729	-4.55	0.000	-12.78167	-5.087916
Travel Cost	-.00518	.0115038	-0.45	0.652	-.0277299	.0173641

4.4 Environmental exploration

4.4.1 Emissions

In this thesis, it was chosen to use the 140 g CO_2 per kilometer suggested by Hiselius and Svensson [30]. This is the lowest value found, meaning that the outcomes will be more conservative. Moreover, it can be reasoned that this number is also the most representative as the study was performed in Sweden. It was assumed that the US car fleet is in general more polluting as there are more SUVs and American brands on the market. The German fleet should be more comparable, but the study of Kämper et al. [36] was performed in 2016. The Norwegian study of Fyhri et al. [24] was also performed in 2016. For Norway, this is especially important since EVs started to penetrate the market after 2016. In 2019, more than half of the newly introduced cars were EVs [32]. For e-bikes, an average of the three lower found entries is taken as it is not known which estimation would be better. The entry of Engelmoer [19] was excluded as this study was performed almost 10 years ago and e-bike technology has evolved since then. The average gives 14 g CO_2 per kilometer for e-bikes. It was assumed that the Swedish public transportation system is lower emitting than the German in 2016 and the Portland system of 2020. The public transport emissions were expected to be more similar like the Norwegian. Hence, a somewhat lower value than the German and US entry, but higher than Norway of 50 g CO_2 per kilometer was taken. For conventional bikes, the lowest value of 10 g CO_2 per kilometer was taken as it should be lower than the 14 g CO_2 per kilometer taken for e-bikes. It was assumed that walking was zero emitting.

4.4.2 Substitutions

The survey responses led to a substitution distribution of 13% walking, 31% conventional bike, 25% public transport, 22% car, 9% induced and 1% other trips. These shares are used to calculate the average amount of trips per person per year per mode based on the assumptions stated above. When this number is multiplied with the average trip distance per mode, the total distance travelled per mode per person can be obtained. These are multiplied with the emissions per kilometer to calculate the emission savings or gains per mode. These are added up to find the total number of kg CO_2 saved per person per year. A summary of these calculations can be found in Table 4.9.

4.4.3 Potential emissions savings

Table 4.9 points out that the emission saving potential per person is about 174 kg CO_2 per year. This would correspond to 17% of the average emissions per person on passenger cars, 11% of the annual transport emissions per person or 5% of the Swedish general individual footprint. Additionally, it can be observed that the environmental hotspots are cars and public transportation. Cars are responsible for 82% of the emission reduction and public transport for 24%, the aggregated other emissions compensate for the additional 6%. A substitution from one of these two

Table 4.9: Emissions. Trips refers to trips per year per person, t.d. to average trip distance, distance to total distance per person and emis. to the emissions per person.

Mode	Share	Trips	T.d.	Distance	Emis.	
Walking	13%	52	4.2	217	3	kg CO2
Bike	31%	121	10.9	1323	5	kg CO2
Public transport	25%	98	11.9	1163	-42	kg CO2
Car	22%	86	13.4	1147	-144	kg CO2
Induced	9%	38	13.6	511	7	kg CO2
Other	1%	2	20	42	-4	kg CO2
Total					**-174**	**kg CO2**

modes affects the outcome more than a mode switch of any of the other modes. Even a replacement of conventional bike trips is low sensitive -despite having a similar trip length as cars and public transport- due to the relatively small difference in environmental impact with e-bikes.

4.4.4 Sensitivity analysis

The sensitivity of the car substitution can be illustrated by inserting alternating values for car substitution. For example, a decrease of the share of car trip replacement from 22% until 16% -the lowest found value in literature by Castro et al. [10]- would result in 141 g CO_2 per person per year. This would be a 12% car kilometer reduction and would correspond to a 14% passenger car emissions reduction, compared to the earlier found 17%. When inserting the 86% car substitution, the highest value found by Bourne et al. [7], a 582 g CO_2 annual reduction would be the outcome of the calculation. This most optimistic value would lead to a 57% passenger car emission reduction.

5 Discussion

5.1 Sample

A possible explanation for the low engagement of the oldest age group is that the usage of technologies like Facebook and a QR codes might have made a higher barrier this group than younger people. Additionally, the choice of English as the survey language might have strengthen that effect assuming that younger generations typically speak better English as a second language in Sweden. It could also be that people aged 66 or more are using e-bikes to a relatively lower extent than younger age groups. However, this does seem unlikely give the opposite trend in other European countries where older people are more frequent e-bike users. Although exact numbers are missing, it is believed that Swedish e-bikers tend to be more often male. Previous Swedish e-bike studies had male overrepresentations in their convenience samples [58, 31]. This study also had a higher share of male respondents. Another explanation could be that men are more likely to respond on a survey, or that men were overrepresented in these Facebook groups as well. A probable cause for the overrepresented Tier 1 cities is that Gothenburg has been the main target for promotion by QR code. Additionally, specific group Facebook for cyclists in Gothenburg and Linköping were used. It is not known if smaller communities had a lower response rate, or that there were also less e-bike riders in these areas. About half of the respondents (49%) used the e-bike for 3 years or longer. This means that approximately half of the participants purchased an e-bike after the subsidy program stopped in 2018.

5.2 Purpose

About 47% of recent e-bike trips appeared to be commuting trips, while shopping & service and leisure were responsible for approximately 26% and 20% of the trips, respectively. As 55% of all trips in Sweden are commuting trips, it seems that e-bikes in this sample were slightly less used for commuting compared to other transportation modes [65]. In some studies like Plazier et al. [51], it was concluded that commuting was a main motive for e-bike riders. The outcome of this study, could be explained by the impact of the COVID-19 pandemic that arguably affects commuting more than other purposes as the recommendation in Sweden was to work from home during the time the survey took place. Some participants also mentioned in the comment section of the survey and in the interviews that this factor played a role. Utilitarian purposes (commuting and shopping & service) were responsible for 73% of the trips and 72% of the distance. The share of utilitarian trips in this study is higher than the Dutch study of Sun et al. [60], but lower than the American study of McQueen et al. [42]. Moreover, it is slightly higher for both trips and distance when compared to the findings of Söderberg et al. [58] in Sweden. Hence, it seems that the participants of this study were relatively utilitarian users. Also, the effect of COVID-19 on commuting were possibly limited with a 7 percentage point reduction in trips and a 7 percentage point increase regarding share of kilometers compared to Söderberg et al. [58]. This would be an argument against a severe impact of COVID-19 on commuting trips. An interesting comparison can be made with the study of Söderberg et al. [58] which was performed in the same context (Sweden) and only one year earlier. In this study, leisure trips were found to be the longest, followed by commuting trips. However, in this study, commuting trips were slightly longer and leisure trips shorter. Commuting trips were in this study 1.4 kilometer longer, while leisure trips were 0.9-3.4 kilometer shorter. The frequency of commuting trips in this study fell in the frequency range of Söderberg et al. [58]. Leisure trips were slightly more frequently conducted in this study despite the low share of older users who made relatively often leisure trips. When multiplying the frequency and distance of commuting trips, an average of 1800 kilometers for solely commuting could be reached. For leisure, about 1000 kilometers were calculated. This implies that the covered distance of commuting trips would in general be (much) larger than leisure. If commuting trips were indeed longer than originally thought, it could mean that commuting, would reach an even larger environmental impact. The DCM did show that people who were undertaking a more utilitarian type of trip had a higher likelihood of choosing an e-bike (75%). This strengthens the hypothesis that utilitarian trips like commuting can enhance e-bike usage. Moreover, it strengthens the explanation that people undertook less commuting trips during the study period in general, irregardless of the transportation mode. Concluding, there were mixed outcomes for the influence of COVID-19 on e-bike commuting and further research (after the pandemic) might provide more understanding of this relation.

5.3 Purchase decision

5.3.1 Habits

Breaking with a habit, in an unforced manner, by a life-event was frequently listed as a motive to purchase an e-bike in the qualitative study of Marincek and Rérat [41]. Several answer options in this thesis were categorized as a life-event such as change of residency, change of workplace, a growing child, a declining or improving physical condition, a partner using an e-bike and COVID-19. Together, these factors added up to 78%. This means that most respondents listed at least one of these life-events as a (secondary) motive to purchase an e-bike. Albeit the impact of life-events have been discussed before, a quantification of the impact of such events is novel to the field, in which breaking the habit is usually referring to an e-bike trial period. It is recommended to test in future studies if the impact of these life-events is indeed this large. If so, targeting people going through these life-events could appear to be an effective promotion strategy. This does not mean that e-bike trials are ineffective.

It is still believed that these experiments will enhance e-bike adoption in a direct and indirect way.

5.3.1.1 Commuting

Another strategy to further optimize carbon savings would be to target people that nowadays commute by car and live within a range of about 5-22 km from work. This range is based on the distance range for commuting found in this study and the results of the study of Sun et al. [60] who found a 5-20 kilometer range. As commuting is a strongly habitual trip, the burden for behavioral change might be higher for this purpose, but the environmental reward could be high. The e-bike could be purchased specifically for this reason which could also turn out to be a cheaper travel option. Motives that were added by respondents provide interesting insights. These motives were probably more often mentioned if they would have been listed as an answer option beforehand. 'Cycling is the best way to commute' or words along those lines were mentioned by six respondents. This was the largest amount for an beforehand unidentified motive indicating that commuting might indeed be a purchase motive. Plazier et al. [51] and MacArthur et al. [40] also found that commuting was a strong motive for e-biking. Once the e-bike is purchased, extensive usage can be expected based on the results. About 70% of the participants used their e-bike in their three most recent trips. Only 12% of the respondents did not used their e-bike in the last two days. This confirms the statements of Kroesen [39] who observed extensive e-bike usage after purchase. It is therefore recommended to further study commuting as a motive to purchase an e-bike.

5.3.1.2 Learning effect

Fyhri and Fearnley [21], de Kruijf et al. [11], Fyhri and Sundfør [22] discussed the learning effect and the novelty effect and argued that the learning effect was larger than the novelty effect. In this thesis, cautious evidence of both a learning effect and a novelty effect could be observed. Reason for this statement is that the average e-bike trip distance was the lowest for medium-long users (1-2 year). Novel users (< 1 year) were on average conduction longer trips, but more experienced users (3+ years) were on average conducting the longest trips. Moreover, user groups that were making longer trips were on average also feeling more positive about their e-bike usage. The average trip distance and positivity of the riders are indications for a novelty effect, followed by a 'dip' after 1 to 2 years, after which a learning effect occurs. An argument against a novelty effect came from the DCM in which it was found that longer e-bike users were less frequently choosing for the e-bike. Walking trips increase with usage period which could also be an explanation for the longer average distances. In terms of modal substitution, it appeared that 3-4 year long e-bikers were replacing the most motorized trips indicating a larger environmental potential. It could also be seen as a form of a learning effect. However, the effect dampens after 5 years of usage. E-bike usage was the most frequent for the longest users, followed by the newest users. This is a clear sign of both a learning and a novelty effect. de Kruijf et al. [11] also found the learning effect based on frequency, but his timespan was only 6 months which could be considered as novelty effect within the segmentation of this thesis. Hence, indications of a cautious learning effect in terms of covered distances, positivity, modal substitution and frequency could be observed, and a novelty effect for distance and frequency.

5.3.2 Intentions

The Likert scores for symbolic values could imply that the respondents thought an e-bike was something positive, but that it was not important enough to make them distinguish themselves or show who they are. Simsekoglu and Klöckner [57] tested if there was a statically correlation between the symbolic effects and the decision to purchase an e-bike between a group of e-bike users and non-e-bike users. In this study, only e-bike users have been part of the study, meaning that a comparison between these groups was not possible. Thus, it could still be that e-bike users perceive the symbolic effects stronger than non e-bike users. However, e-bikers do not seem to perceive the symbolic effect strongly by itself. It was unexpected that the findings regarding symbolic values of this study were seemingly divergent from the Norwegian study, since Norwegians and Swedes were expected to be culturally similar. A possible explanation could be the wording of the question. Although three of the four sentences from the Norwegian study were literally copied, it is not known if these were originally stated in Norwegian, while English (and not Swedish) was used in this study. The absence of using the mother-language of most respondents might have decreased the likelihood to respond with a strongly personal statement.

5.3.2.1 Climate morality

Climate morality could be considered as a strong motive to purchase an e-bike for respondents of this study as 40 % mentioned 'avoid/reduce using car' as a reason to purchase an e-bike. Thereby, it as was more than twice as often mentioned as the second most listed motive. The number is comparable to an earlier Danish paper of Haustein and Møller [28] which found 37% on a similar question, but lower than the American and Australian study of MacArthur et al. [40], Johnson and Rose [34]. Additionally, 60% of the participants in this study thought that it was an advantage that the e-bike is good for the environment. This is an indication that promotion conveying a climate moral message -reduce car usage- could potentially be effective for the sales of e-bikes. However, the findings of this study should be understood within a possible pro-cycling bias as the respondents were recruited by Facebook groups about (e-)cycling. A counterargument could be provided by the comparison between participants that intended to reduce or avoid car usage with people without mentioning that intention. Both the modal choice and modal substitution showed a slight favour of car usage amongst people with intentions to lower it. It could be that these participants were driving car more often in the past and reached now similar levels of car usage as their peers. However, the substitution results do not confirm this. Despite that the intention to reduce car usage could be beneficial for e-bike purchases, does it not mean that car usage will actually be lowered.

5.4 Advantages and disadvantages

It is somewhat difficult to compare the main advantages and disadvantages of e-biking found in this study with literature findings as the approach was different in each study [40, 28, 7, 58]. However, by analysing the key advantages and disadvantages regardless of the method, a comparison can be made. The variety of advantages that were listed by the respondents are largely in line with previous literature findings. Personal norms such as environmental concerns seem to be stronger represented in this study compared to other studies which can be explained by the possible cycling-enthusiastic bias of the sample. Other explanations could be that people taking residency in Sweden are more environmental aware or that environmental concerns became more internalized in society over the years. Hiselius and Svenssona [31] found that 58% of their Swedish respondents in 2014 agreed to be environmentally conscious. This indicates that environmental reasons remained more or less stable in recent years in Sweden given a similar share in this study. The attitude towards physical activity played also a strong role with fun, fresh air and reduced sweatiness being main perceived advantages. In previous studies, perceived usefulness was often rated higher than physical factors. It could be that Swedes are less pragmatic and more prone to physical arguments which might be an interesting take for a future marketing campaign. A low share (less than <25%) of the respondents perceived facilitating conditions as a disadvantage. This could be understood as a sign that e-bikes have surpassed the first stages of technological innovation and starts to behave like a more mature product. Facilitating conditions (except infrastructure) and the perceived ease of use have improved over recent years. Theft could considered as a large concern. Theft came out of the survey as the most frequently mentioned disadvantage (by far) and was also multiple mentioned in the interviews as a burden to increase e-bike usage. One participant told that she solely used her e-bike to commute as she considered all other travel destination to be unsafe. Hiselius and Svensson [30] found that the risk of theft was the fourth largest disadvantage in Sweden. As theft is not frequently indicated as problem in other countries, it could be that this is a typical Swedish issue. Hence, it can be stated that in order to promote e-bikes in Sweden, the risk of theft should be substantially lowered. A recommendation with respect for safety is to look at solutions that are used in other countries. Since respondents were able to select as many options as they preferred, the findings could indicate that disadvantages were outweighted by all listed advantages, except for the risk of theft. Consequently, this could mean that most of the respondents were satisfied with their e-bike.

5.5 User groups

5.5.1 Age

The analysis showed that older age groups covered on average longer trip distances than young age groups. This finding was however not statistically significant and contrary to the findings of Kroesen [39], Bourne et al. [7]. The DCM also showed that elder user choose slightly more for e-bikes compared to younger users. Contrarily, it was also found that elder age groups substituted relatively more non-motorized transportation than younger age groups. These findings make it not obvious to state which age group should be prioritized in terms of environmental potential as these effects might cancel each other out and are uncertain. If older people would be targeted, more kilometers might be undertaken by e-bike, but there is a higher likelihood that they would have been performed by foot, conventional bike or be induced and vice versa. A closer look on the oldest age group shows that the study only captured users in the large cities which means that the numbers for this age group should be taken even more cautiously. However, as rural users show on average longer e-bike distances than urban users, it could be that the average e-bike distance for the eldest group would be even larger if the sample would have been more geographically representative. Elder users were also longer users of an e-bike, strengthening the observation of Wolf and Seebauer [70] that older people were the early adopters in e-cycling, possibly also in Sweden. Leisure trips were undertaken proportionally often, which seem to have been mainly conducted by foot otherwise. Additionally, these trip were heavily weather-dependent. These are all signs that the environmental gain in this group is not large. Nonetheless could elder people help normalize e-bikes as a mode of transportation. Last, based on this study, it is not obvious if and which age group should be targeted in Sweden.

5.5.2 Gender

No significant differences between male and female e-bike riders could be observed in terms of average trip distance or modal substitution. Men did made on average longer trips, while women used e-bikes slightly more often. Male e-bike users also opted more often for car compared to female users. Men where overrepresented in the sample which implies that e-bike users could still be predominantly male in Sweden. Signs of strong gender effects described by Sun et al. [60] in the Netherlands and Fyhri and Fearnley [21] in Norway could however not be observed. It seems that men were early adopters in Sweden as the average usage period of women was lower. There was not a clear sign that women are 'catching up' as the newest group of users (<1 years) was about as large for men as women. It is difficult to compare the learning effect between women and men like done by Fyhri et al. [24], because the share of females in this user group is simply too small. Women appeared to be commuting significantly more often than men in this study. This finding was not earlier mentioned in literature to the best of knowledge of the author. Due to the habitual nature of commuting, the supposed lower e-bike adoption amongst Swedish women and a possible stronger learning effect, females might still show more e-bike potential in Sweden. Hence, it is recommended for later studies to look further into this finding.

5.5.3 Urbanization

More interesting were the findings regarding urbanity. It was found that car trips were proportionally more substituted in more rural areas, while public transport was predominantly replaced in urban areas. This makes sense given the absence of proper public transport facilities in the most rural parts of Sweden and the measures to reduce car travels in cities such as low emission zones and congestion charges. It does imply that the potential environmental savings would be larger for rural citizens than for urban residents. This is especially interesting given the overrepresentation of urban respondents indicating that e-bikes might currently be more widespread in urbanized parts of Sweden. The participants from *Landsbygskommuns*, communities with less than 15,000 citizens, showed a particularity high car replacement of 57% indicating the potential in rural areas. A possible explanation for this is the larger commuting distances that these communities might have. In Switzerland and the Netherlands, e-bike adoption is especially high on the countryside already [54, 37]. All in all, Swedish e-bike distributors could focus more on rural customers instead of targeting urban customers. However, more research into this finding is recommended given that these differences were not statistically significant.

5.5.4 Cycling history

The distinction between between restorative and resilient e-bikers made by Marincek and Rérat [41] was used to research behavioural differences. Moreover, the category new cyclists was added as a separate group. Novel to this study was that a first attempt to quantify differences between these groups was made. It was found that the newer the e-bike rider to cycling, the more motorized trips it substitutes as expected. As new cyclists and restorative did not cycle before, it is only a small fraction of walking and induced trips that are replaced by e-bikes, while resilient e-bikers substitute a large portion of conventional bike trips. Hence, this outcome provides indications for larger environmental potential at people that are not cycling at the moment of purchasing an e-bike. This potential is slightly dampened by the finding that new cyclist drove on average shorter distances than resilient or restorative e-bike riders. This could be explained by the less positive attitude towards e-biking. It might be that these new cyclists are not using their e-bike long enough to undergo a learning effect. An hypothesis could be that these new users have a greater or longer learning effect as they first have to get to get used to cycling in general which might be a larger step than from cycling to e-cycling. Interestingly, these new cyclists appeared to be relatively often young citizens between 18 and 35 years old. This not only provides more proof that the younger age groups are indeed getting more familiar with e-bikes, but also stresses that young people, even without riding a conventional bike, could still be an interesting target group. Conventional bike owners probably show higher average e-bike distances as they can use their c-bike on shorter trips, leaving the e-bike for the longer trips. C-bike owners proportionally substituted more non-motorized trips as these are c-bike trips. People that did not own a c-bike yet, are the generally the new cyclists that substitute more motorized trips. The size of this group in the sample was small, but might be an interesting group to further analyse in other studies as naturally more motorized transport will be replaced in this group.

5.5.5 Car ownership

People who owned multiple cars in their household drove on average e-bike trips of almost 80% longer distance. Multiple car owners also tended to be more often taking residence in a rural area. In rural areas, the distances from one location to the other tend to be longer. Hence, owning a car is more useful which could explain the high car ownership. It could also explain that if the e-bike is taken, larger distances will be covered. It is expected that in rural areas, more direct roads are available with less interruption by, for example, traffic lights. This makes it possible to cover longer distances with the same amount of time and effort. The notion that this group is more bothered by weather events could also have to do with the longer distances and high car ownership. If a household owns more cars, there is a higher chance that one of these cars is available to use in case of bad weather. The longer distances make it more problematic to get through bad weather, while snow and ice might be treated worse in rural areas. The findings suggest that rural e-bike users are more likely to use their e-bike more as an addition to their car(s). This does not mean that the potential to substitute cars is low, but rather the opposite: longer trip distances suggest a large environmental potential.

5.5.6 Attitude towards cycling

The attitude of the rider, separating enthusiastic, recreational and utilitarian types, was discussed by Haustein and Møller [28]. Based on the approaching method of this thesis using Facebook groups with (e-)bike enthusiastic people, it can be assumed that the respondents in this sample were mainly enthusiastic and utilitarian. Recreational users were generally elder, retired people which were underrepresented in this study. Enthusiastic cyclists were described as having a positive attitude and by frequent usage which could also be observed in this sample. Utilitarian cyclists used the e-bike much for utilitarian purposes corresponding to this sample. It was concluded by Haustein and Møller [28] that enthusiastic and utilitarian persons would show larger environmental reduction potential as they would replace more car trips. However, this study finds a relatively low share of car replacement compared to previous studies, even when the share of recreational riders was low.

5.6 External factors

5.6.1 Hilliness

The trip distance of a conventional bike trips was influenced by the hilliness of the area. The more hilly, the shorter the c-bike trip. That was not the case for e-bike trips: the average e-bike trip distance slightly increased in more hilly surroundings. However, the absence of a statistical difference in c-bike trip distance does make the statement less strong. There were more indications of a more negative influence of hilliness on c-biking than e-bike. E-bike trips were on average conducted in more hilly terrain. Moreover, more hilly terrain led to proportionally more e-bike trips compared to c-bike trips. The DCM also showed that c-biking was particularly sensitive for hills, while the share of e-bike choice decreased less in more hilly areas. Thus, these findings can still provide additional evidence on the claim that e-bikes are better able to overcome hills. About 60% of the participants indeed confirmed that one of the perceived advantages was that e-bikes are made it easier to get over hills. Sweden is a relatively hilly country, in cities, but also in rural areas in the North and West of the country. Thus, the ability to overcome hills can increase the potential amount of users. Especially frequent car drivers who do not use a conventional bike due to the topography, could be targeted. They might consider cycling with electric assistance.

5.6.2 Weather

Weather factors do have an influence on the daily e-bike usage for a majority of about 60% of the respondents. Out of them, ice and secondly snow were the main weather barriers for e-bikers. Even though Sweden has a colder climate than most parts of Europe, snow and ice are not frequent weather events in the Southern part of Sweden. This part, the area between Gothenburg, Stockholm and Skåne, is also the part were the vast majority of the citizens is habituated. Snow and ice are present maximum a few weeks in this area, meaning that e-biking would mostly not be hindered by these weather events in Sweden. Rain was listed by almost a fifth of the respondents. Rain is a more common weather event that could reduce e-bike usage on a daily base, but the severity of the rainfall was not questioned. It could be that e-bike riders were mainly bothered by severe rainfall and not by regular rainfall. Either way, it seems that e-bike is a more robust mode of transportation through weather events compared to a conventional bike. This statement is strengthened by the finding that almost 40% mentioned that the ability to withstand more weather types was perceived as an advantage of e-bikes. It could be that the impact of weather effects is underestimated in this study. There were specific user groups such as elderly, women and rural-living users that were found to be more affected by weather events than the main sample. These groups were all underrepresented which would mean that the negative effect of weather effects is probably greater.

5.6.3 E-bike sharing

Sharing of e-bikes with others did influence the mode choice as people that shared their e-bike choose the e-bike slightly less frequent themselves. It could be that this is because their e-bike is not always available. However, this does not have to mean that these e-bikes were also used less. The contrary could be the case as the e-bike usage of these others was not taken into account in this survey. Future studies could research the effects of sharing an e-bike within a household more thoroughly. This has not been done so far, while a substantial part (22%) of the respondents indicated that they were sharing their e-bike. This was also mentioned in one of the interviews. The interviewee mentioned that she not only shared her e-bike with her family members, but also replaced car trips to transport children with an e-bike. It would be interesting to see with whom, how frequent and for which purposes e-bikes are shared. Hence, it is recommended for future studies to look into this.

5.6.4 Travel party

The travel party also played a role in e-bike choice, as solo riders more frequently choose for e-bike. Car usage increased at larger groups of travellers. These findings can be logically explained by the notion that the majority people do not have an e-bike yet. When travelling alone, or with one other traveller, the e-bike is preferred. But in larger groups, there is a higher chance that others do not own an e-bike and will not be able to join a shared trip. In such a case, car provides the answer. This difference could be smaller in the future if e-bike adoption will substantially increase. Literature does not often mention the travel party of e-biking yet, but it could be interesting to gain understanding in the travel party. For example, if children are transported on the back of the e-bike frequently, or to which extend travelling with c-bikers is limiting e-bike usage.

5.7 Travel cost and time

Travel time came out as the only significant variable influencing modal choice decision. Travel cost was found to be an irrelevant criteria to base the modal choice decision for the participants of this study. It was unexpected that travel cost had such a small impact, as a previous study of Politis et al. [52] about e-bike-sharing systems concluded that travel time and costs both played a role. Several possible explanations are suggested:

- The income of the participant was not asked in this survey, but it could have been high as purchasing an e-bike requires a significant investment. If the average income would indeed have been high, this could led to more ignorance about travel costs.
- In this study the focus was at short, daily trips such as commuting, shopping & services or leisure, while holidays were not identified. It could be that travel costs were important for longer trips like holidays, but these were not undertaken. Additionally, long trips were discouraged in the period the interviews were taken as a result of the COVID-19 pandemic.
- E-bike was often selected as the modal choice for most of the trips (70%). Hence, it could be stated that e-bike owners use their e-bike by default. This could result in that more expensive modes like car or public transport are not been taken often anyway. This could imply that if it would be necessary to take one of those modes due to a longer distance and/or faster travel, cost will not play a role as travel costs were in general low already. In other words, the sunk costs are already present in the purchase of the e-bike itself, stimulating extensive use of the vehicle. Moreover, costs already played a much smaller role than travel time in Politis et al. [52] study. This is also the main difference with a bike-sharing system in which the e-bike user is not the owner of the e-bike which leads to more running costs and no investment costs. A participant also mentioned in one of the interviews that he did not own a car. However, on about three special occasions a year, he would rent a car. For these instances, costs did not play a role in the decision making as the car was the only option

for these trips. This statement would be in line with the hypothesis that the role of travel costs might be small after purchasing the e-bike.

An interesting take for future studies could be to further test the importance of investments costs of the e-bike versus the travel costs. In this study, it seems that investment costs play a more decisive role. It was found by Ton and Duives [63] that investment costs were a main barrier for e-bike adoption in the Netherlands. The relation between these two types of costs is especially interesting given the possible consequences for policy making. If investments costs indeed appear to be more decisive than travel costs, then, e-bike subsidies that were granted in the past might actually be more effective than a congestion charge, parking fee or a similar policy measure that raises the travel costs of cars. Additionally, the importance of travel time would also mean that it could be beneficial to improve the cycling infrastructure. Nowadays, cycle pathways in Sweden are not always direct and often disrupted which is causing longer travel time. Such improvements could thus reduce travel time for bikes and e-bikes and thus higher the modal e-bike choice.

5.7.1 Validation

Multiple hypotheses were tested in Stata to check if travel costs would be statistical significant for certain groups. In one attempt, a segmentation was made based on age (<36 years old, 36-55 years old and >55 years old). This was done as age was expected to be a possible proxy for income of the participants. It was tested if older (richer) people would show a particular low correlation with travel costs. It was found that neither of these segments showed a statistical significance on travel costs, implying that travel costs were not a decisive factor for any age group. It could still be that income would be a significant factor, but information on income of the participants was lacking. Similarly, the hypothesis that the trip purpose might affect the travel costs was checked. The hypothesis was that the travel costs of commuting could be more decisive for mode choice than a less frequent purpose such as leisure. Again, no segmented trip purpose did result in a significant effect of travel costs. Trip purpose segmentation did give variation in outcomes when related to travel time. Especially for service & shopping trips, travel time appeared to be a relevant variable. On the other hand, travel time did not play a significant role for leisure trips. These outcomes can be explained intuitively with the reason that leisure trips were made to relax. Hence, enough time will be taken to conduct these trips so that stress can be avoided. Travel time is determining shopping & service mode choice, because these trips are of a utilitarian nature which could mean that time-efficiency will play a larger role. Environmental costs were also calculated for each trip based on the distance and emissions per kilometer for each mode. It was tested if environmental costs could have an effect on the mode choice decision of the participants as they stated to be environmentally aware and bike-enthusiastic. The environmental costs also did not appeared to be a significant factor in the mode choice decision. Reason could be that environmental costs are more of an externality whose personal, short-term impact is not taken into account in the everyday decision making process. However, it could still be that environmental concerns do play a role in the purchase of e-bike.

5.8 Substitution

Car substitution was in line with previous studies mentioned in the Literature Review [8, 58, 36, 60, 39]. These studies found car mileage reduction between 8 and 28%, while this study found a 16% reduction. However, a relatively low car replacement share of 22% was found in this study. This is on the very low side of the ranges observed in the review studies of Bourne et al. [7], Castro et al. [10] who found 20-86% and 16-76% car replacement respectively. The low car replacement share was especially unexpected given the supposed car-dependency of Sweden in combination with the notion that the main used mode is commonly the main replaced mode. Multiple reasons are suggested for this outcome:

- As a result of the COVID-19 restrictions, less commuting trips were being replaced who tended to be more frequently performed by car. However, the COVID-19 impact on commuting has been discussed in Section 5.2 as well.
- There were signs for a pro-environmentally biased sample described in Section 5.5.6. This group might not have used a car anyway as they might be more resistant towards cars.
- The sample had an overrepresentation of urban residents. Urbanized citizens were relatively more frequently substituting public transport instead of cars. The high share of public transport replacement puts additional strength on this hypothesis. Tier 5, the *Landsbyskommun*, was underrepresented in the study. This group substituted car trips more than twice as much as the general sample with 57% of the cases. A higher car replacement share may be expected in a more representative sample based on this finding.
- Induced trips were taken into account in this study in contrast to most other studies. Even though the share of induced trips is 9%, this will still reduce the share of car replacement.

5.9 Sustainability

5.9.1 Environmental

Compared to the studies discussed in the Literature Review, the environmental impact in line with earlier findings, but on the low side. The environmental savings were expected to be lower than the study of Hiselius and Svensson [30], but higher than Fyhri et al. [23] and similar to McQueen et al. [42]. This low environmental impact is a consequence of the low share of car substitution which is the most determinant factor in assessing the CO_2 emissions. If all annual emissions from passenger cars in Sweden would be divided equally amongst its citizens, the use of an e-bike would result in an 17% decrease of an individual car emissions. Similarly, an e-bike would mean a 11% reduction of transport emissions and 5% total emission reduction. A sensitivity analysis with the lowest and highest found car replacement shares led to a 14% and 57% reduction of individual car emissions. This shows that the outcomes of this environmental exploration are indeed conservative. Although the most optimistic scenario is not realistic for Sweden, the calculation shows that the environmental potential of e-bikes might be substantially higher than initially calculated 17%. The range of these numbers also denote that these are highly uncertain given the assumptions on modal emissions, the biased, small sample and the COVID measures at the time the study was performed. As Sweden is not heading towards meeting its climate goals, especially in the transport sector, this study could be used as an indication that e-bikes could indeed be used as an alternative mode of transport for cars in order to accelerate emission reductions. This study calculated the carbon saving based on the percentage of e-bike trips that were substituting car trips. A longitudinal approach like done by Söderberg et al. [58] was not conducted in which the amount of car trips prior to purchasing an e-bike was taken into account. However, similar results in terms of carbon savings were obtained. The carbon emission reduction could potentially be larger if congestion would be taken into account. As e-bikes take up less road space than cars, less congestion may be expected. A lower level of congestion could lead to shorter travel times for car trips. Reduced car travel time in its turn could lead to lower carbon emissions from passenger cars. The effects of congestion were however not quantified in this thesis. Substitution of car kilometers with e-bike kilometers will probably reduce PM pollution. This is especially relevant for urban areas where PM concentrations are more often higher. However, lower car substitution shares were found in urban areas compared to rural areas. Hence, the effects on PM reduction and human health improvement will be dampened.

5.9.2 Economic and social

The economic sustainability of e-bikes for customers was mainly discussed in Section 5.7. It was concluded that investment costs might lead to sunk costs and that these costs could be affecting e-bike usage more than travel costs. E-bikes in Sweden are still not considered as a fully mature product despite that facilitating conditions are improving and the product is not only used in a niche anymore. Currently, 20% of the bike sales are e-bikes. The main question if this share can further rise without subsidies. In multiple European countries, a similar situation is existing in which e-bike sales are about 10-30% of the bike sales [48]. The COVID pandemic further boosted the e-bike sales in e.g. Germany, while the EU Commission announced a 13€ billion cycling package for infrastructure and e-bike access as part of their COVID-19 recovery fund [17, 5]. Hence, there are signs that e-bike market penetration in Europe is about to start which could normalize e-bikes and make it economically sustainable by creating economies of scale. Social sustainability aspects such road safety and health were not further studied in this thesis. The physiological aspects such as arrival time reliability, enjoyment, a better feeling due to activity and social interactions were not further researched as well.

5.10 Limitations

5.10.1 Sample

The main limitation of this study is that the results are not representative for the Swedish population as a convenience sample was used based on Facebook groups with e-bike enthusiastics. On top of that, the snowball approach was used to spread the survey further leading to a potentially even larger positive bias towards e-bikes. The study never intended to be representative. The use of literature and interviews allowed the study to be more than quantitative and makes cautious generalizations allowable. This especially holds for the environmental exploration which should be viewed as a conservative scenario. The sample size of the study was rather small due to budget and time constraints. As this is a master's thesis, it could not be afforded to hire a representative panel of respondents, for example. The time constraint of half a year made a longitudinal study out of reach. This thesis only covered real e-bike owners whose travel behavior should give a more accurate representation of the actual behavior than potential e-bike users in a trial.

5.10.2 Self-report bias

Although self-reporting are the standard in e-bike literature, a potential weakness of the study is the self-reporting bias that the participants might have leading to socially desirable answers [28]. Self-reporting might also lead to over- or under-representation of the actual travel behavior. This especially holds when estimating the travelled distance. A way to solve this bias is by using GPS technologies. Unfortunately was the use of these technologies not possible due to budgetary and time constraints. Related to a self-report bias is a memory bias. The effects of this bias have been limited by asking only about the last three trips by e-bike and not going further back.

5.10.3 COVID-19

The study was conducted in the early spring of 2021, after one year of the COVID-19 pandemic and in the middle of a third wave. Although the measures in Sweden have been relatively mild compared to other European countries, were there still restrictions and working from home became more common. This adds to the uncertainty of extrapolation of results and might lead to underrepresentation of the share of commuting of the total trips. However, it was decided not to take up COVID-19 questions in the survey as this would have been a too large factor which would have altered the aim of the study. An earlier, Swedish study of Söderberg et al. [58] noted that 56% of their participants said to use the e-bike less due to the pandemic. A survey held in the UK found a 20% decrease in e-bike usage during the lockdown in which the use of all modes fell [43]. It was shown that this especially holds for commuting, since working from home has become more standard. Moreover, it is also not known to which extent the influence of COVID will be temporary or persistent. One could think of a scenario in which a 5-day workweek from the office will not be the standard anymore. This uncertainty led to the choice that this study focused on the present rather than a speculative future. If anything, the results of this thesis might have been an underestimation of the carbon savings as modal substitution of cars could have been larger without the pandemic.

5.10.4 Survey design

The phrasing of the mode substitution question matters. In this study, participants were asked for the *alternative mode* in 'What mode of transportation would you have taken if you did not have access to an e-bike?' which is a partially hypothetical approach since the respondent did had access to an e-bike. Alternatively, one could have asked for *previous mode* in a question like 'What mode of transportation would you have taken for the same trip before to having access to an e-bike?' which would refer to the mode prior to e-bike adoption. This difference is further explained in the paper of Bigazzi and Wong [4]. An example of a consequence of the phrase choice is that a participant mentioned that he would probably had owned a car if he would not have had an e-bike, however, in the survey it is not obvious if 'car' should be selected as alternative mode as it is not available in reality. Mode substitution could also lead to a change of destination and distance [4]. Especially distances for leisure and shopping trips could be dependent on mode. It is difficult to take this effect into account in terms of emission savings. When car has been substituted, it may be expected that the emission potential could be higher as car trips will generally be longer than e-bike trips. Another factor that is difficult to take into account in the vehicle occupation. Car emissions could turn out to be lower if the emissions would be divided by the amount of occupants in the car. The savings compared to an e-bike would in that case be smaller. On the other hand, the reduced effort by electric support also increases the likelihood to transport a second person on an e-bike compared to a regular bike.

6 Conclusion

This study aimed to understand the factors that influence e-bike usage in Sweden. Reason for this was that e-bikes could provide an alternative way of travelling which could contribute to reduce car-dependency and car kilometers. Sweden's car-dependency should be reduced as passenger travel emissions are not falling fast enough to reach the transport climate goal of 70% CO_2 emission reduction by 2030. The *purpose* of a trip, the *purchase decision*, perceived *benefits and disadvantages* were all considered as factors influencing e-bike usage. Besides, different user behavior could be differentiated when the sample was segmented into *urbanization*, *cycling history* and *car ownership*, while *gender* and *age* differences were not clearly observed. Other, external factors such as *hilliness* and *weather* appeared to have an effect on e-bike use as well. Climate morality was found to be a potential strong motive which especially suitable for marketing purposes for purchase, but less strong for actual car use reductions. *Travel party* and *e-bike sharing* were found to be potentially interesting but underreported factors and would require more research for better understanding. The main e-bike trip purpose amongst the participants of this study was commuting, followed by leisure and shopping and service. The main modes that were replaced were conventional bike, public transport and car who were all responsible for about a quarter of the trips. Car substitution is the most determinable factor in achieving environmental and health benefits, but was considerably lower than similar European e-bike studies. Reasons for this might be the small and biased sample, the influence of the COVID-19 pandemic and/or the inclusion of induced trips. Travel time was found to be the only significant variable determining the modal choice decision once owning an e-bike. Travel cost was not found to be significant which could be explained by e-bike being the default transport mode resulting in generally low travel costs. Although further research is necessary, it might be that investment costs are a larger boundary to increase e-bike levels than travel cost. Also, improved cycling infrastructure such as more direct cycling paths which would lower the travel time, could boost e-bike modal choice. Consequently, the purchase decision could be playing a key role in adoption and whose effects might currently be underestimated and underreported. In this study, it was assumed that the purchase decision of an e-bike is based on habits and intentions. Current research is often focused on 'breaking the habit' by e-bike trials in which car usage should be lowered. These trials should continue, but research in 'natural', unforced breaking-the-habit studies in the form of investigating the role of 'life-events' such as a change of workplace or residence and a deteriorating physical condition should be promoted too. Future research could expand their focus into this area. A wide variety of benefits was perceived by the respondents which consisted of enjoyment, the ability to cover larger distance, fresh air, reduced sweatiness and environmental concerns in line with previous studies in other contexts. More so, advantages seemed to outweigh disadvantages for current e-bike users of this study. However, one particular disadvantage, the risk of theft, stuck out as the main barrier for further e-bike adoption in Sweden. This appeared in both the quantitative and qualitative part of the study. Additionally, it seems that the perceived risk of theft is also higher than in other countries. The most obvious user groups to target were found to be rural-based citizens and people that are currently not cycling. These groups replaced more motorized trips compared to other groups. Multiple car owners appeared to ride on average longer trips and could thus also be interesting. Indications of both a novelty and learning effect could be observed in terms of trip distance and frequency. The outcomes for age groups were mixed as elder users conducted longer trips, but replaced less motorized transport. The oldest user groups appeared to be replacing mainly leisure trips, otherwise mostly conduced by foot. These outcomes were not significant and contrary to earlier findings. Hence, no age target group is recommended in this study. Hilliness appeared to be no burden for e-cycling, while it did reduce the frequency, modal choice and average distance of conventional bike trips. This makes e-bikes especially interesting for citizens living in more hilly areas who are also more likely not to cycle at the moment. Weather factors were found to have a low to moderate impact on the e-bike use. Snow and ice were considered as the main weather barriers. However, it could be that the weather impact is underestimated in this study as women, elder people and rural-based respondents appeared to be more weather-dependent and underrepresented. Respondents generally found that using an e-bike said something positive about themselves, but did not think that they were able to distinguish or show themselves with an e-bike. This indicates that the effect of symbolic factors was limited for Swedish e-bike users. Sharing an e-bike with others was a novel element to be included in an e-bike study. Slight behavioral differences between non-sharing users and sharing users were found, but more research would be required in this area to draw conclusions. Car kilometers were calculated to decrease with 16% which would support the goal to reduce car kilometers with 22% until 2030 to a large extent. It was calculated that the purchase and use of an e-bike could lead to carbon savings of about 17% of an individual's passenger car emissions. This might seems as a relatively small share, but could be increased up to 57% per e-bike user in the most optimistic scenario with a high share of car substitution. E-bike adoption could be a useful, additional contributor for Sweden to meet their transport climate goal.

Several policy recommendations were mentioned in this section. A list of these discussed policy implications is presented here:

- Target frequent or unimodal car commuters living around 5-22 kilometers from work.
- A promotion conveying a climate moral message such as reduce car usage could potentially be effective for e-bike sales.
- Find solutions to reduce to risk of theft.
- Target rural living residents.

- Target people that are currently not cycling.
- Hilly areas could be targeted.
- E-bike subsidies might be more effective than congestion charging or parking fees in order to stimulate e-bike use.
- Cycling time reducing measures such as direct cycling pathways could enhance e-bike use.

Moreover, some findings were regarded novel and/or were considered to require further research and are listed here:

- Continue with projects that focus on ’breaking the habit’.
- Improve and further quantify the findings regarding the impact of ’life-events’ on the e-bike purchase decision.
- Improve the understanding of gender effects on e-bike use.
- Study with whom and how frequent e-bikes are shared between household members or others.
- Study the influence of the travel party on e-bike usage
- Research the impact of e-bike subsidies and policy measures discouraging car use on e-bike use.
- Study the influence of the COVID-19 pandemic on e-bike adoption and commuting specifically.
- Study the substitution effect with a larger and more representative sample, preferably with a longitudinal approach.

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A

Appendix A

Table A.1: Assumed average emissions per transportation mode.

Mode of transport	**Emissions**	
Walking	0	g CO_2/km
Bike	10	g CO_2/km
E-bike	14	g CO_2/km
Public transport	50	g CO_2/km
Car	140	g CO_2/km
Other	100	g CO_2/km

Table A.2: Calculation share of trips based on substitution answers in the survey.

Substitution mode	Trip 1	Trip 2	Trip 3	Total
Walking	7	11	7	13%
Bike	19	20	19	31%
Public transport	17	18	12	25%
Car	19	12	10	22%
Induced	6	5	7	9%
Other	1			1%
Total	69	66	55	190

Table A.3: Average trip distance for each mode. * is based on the substituted mode distance, ** is based on the mode distance.

Substitution mode	Trip distance (km)*	Trip distance (km)**
Walking	3.4	4.2
Bike	9.2	10.9
Public transport	11.5	11.9
Car	9.6	13.4
Induced	12.5	13.6
Other	20.0	20.0

B

Appendix B

Table B.1: Survey questions on individual characteristics and answer options. Part 1.

Category	Answer options	
Age	19-35	Young adulthood
	36-55	Middle adulthood
	56-65	Late adulthood
	66+	Old adulthood
Gender	Female	
	Male	
	Other	
Urbanization	Storstad	Tier 1
	Pendlingskommun	Tier 2
	Större stad	Tier 3
	Tätort/Mindre stad	Tier 4
	Landsbyskommun	Tier 5
Hilliness	Likert scale	
E-bike usage	<1 year	
	2-3 years	
	3-4 years	
	>5 years	

Table B.2: Survey questions on individual characteristics and answer options. Part 2.

Category	**Answer options**
Weather	Multiple choice
Sharing	Yes No
Cycling history	Cycled continuously Stopped cycling for a while I haven't cycled before
Car ownership	No car No car, e-bike instead Sold car after e-bike One car More cars
C-bike ownership	Yes No, I did not have one No, I got rid of it

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