Acknowledgements

This master's thesis is the culmination of a surprisingly lengthy process. My survey distribution was delayed, and work had to be postponed.

I would like to thank the respondent reporting an annual driving distance of ten million kilometers. This corresponds to roughly 250 laps around the earth, i.e. one lap each day if weekends are spent resting to overcome the fatigue such a feat may cause. However impressive, I would encourage this respondent at least to consider reducing her speed through densely populated areas, given that her average driving speed (assuming no sleep or two drivers, an unlimited amount of fuel and a continuous road around the earth[1]) would be about 1,700 km/h.

Moreover, if included in the dataset, this single observation makes women – on average – drive almost four times further (and most likely faster) than men.

On a more serious note, I would like to thank Eirik Romstad for his supervision and valuable feedback, Arild Angelsen for the idea, Heidi Tønnesson for her remarkable patience with my steadily increasing stress and wining [sic], and Tord Ståle Nyborg Storbækken for his supportive nature concerning food and drink. A more general thank you goes to the people with whom I have been as lucky as to share study quarters at Sørhellinga.

Any terrible errors, silly mistakes or funny typos are the products of the author's slippery fingers and as such his responsibility alone.

Best regards and happy reading,

Erik Nygaard

Ås, December 13th, 2015.

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[1] Considering some of the assumptions economists get away with, these seem relatively straightforward.

Abstract

The number of electric vehicles (EV) registered in Norway is increasing rapidly because of generous policy benefits. In light of the rapid EV adoption, this thesis examines the extent to which the EVs substitute the use of conventional vehicles (CV), public transportation, manual transportation and non-transportation. It also explores the perceived importance of the various policy attributes among EV owners, and among people with either some or no intention to acquire an EV in the future.

Survey methods were used to collect data for the assessments. Of the 1,810 people invited to participate in an online survey, 529 responded.

To analyse the data, Wilcoxon rank-sum and signed-rank tests were used in addition to ordinary least square regressions and Heckman selection models.

In the sample, EVs are found to replace about 40% of CV use, but increase overall car transportation. Substitution effects on public and manual transportation are minor, and only significant for commuting. The implications of these findings are mixed. While CV to EV substitution yield environmental benefits, increased car transportation might worsen issues related to higher traffic volumes.

EV owners and survey participants with purchase intentions ranked the importance of different policy attributes equally high in the sample. Both groups reported that the economic EV benefits are most important in making EVs attractive to them. Among respondents without intention to become EV owners, the most important reason for their lack of interest is the limited battery capacity of EVs. Solving range issues could therefore be an effective measure to increase this group's EV adoption.

It is clear that the strong incentives favouring EVs have led to high adoption rates. However, the increase in car travel and limited CV replacement in the sample highlights the importance of considering externalities in policy design. Because of the externalities, adding EVs to the car fleet is less environmentally friendly than it appears. This, in turn, has negative consequences for the efficiency of the EV policy package.

Sammendrag

Antallet elektriske biler (elbiler) registrert i Norge øker raskt på grunn av generøse støtteordninger. I lys av dette tar denne masteroppgaven for seg i hvilken grad elbiler erstatter bruk av konvensjonelle biler (CV), offentlig transport, manuell transport og ikke-transport. Oppgaven undersøker også betydningen av de ulike støtteordningene blant elbileiere, og blant personer enten med eller uten intensjon om å kjøpe elbil i fremtiden.

En online spørreundersøkelse ble brukt til å samle data til analysene. 529 av 1810 inviterte personer besvarte undersøkelsen.

For å analysere dataene ble Wilcoxon rank-sum og signed-rank-tester brukt, i tillegg til regresjon ved minste kvadraters metode og Heckman utvalgsmodeller.

Resultatene indikerer at elbilene i utvalget erstatter omtrent 40% av CV-bruken, men at de også øker den totale biltransporten til elbileierne. Elbiler erstatter kun i liten grad offentlig og manuell transport, og signifikante effekter ble kun funnet i forbindelse med pendling. Implikasjonene av funnene er blandede. Det gir miljømessige fordeler at elbiler erstatter konvensjonelle biler, men økt total biltransport kan forverre problemer knyttet til økt biltrafikk.

Elbileierne og respondentene med intensjoner om å kjøpe elbil rangerte viktigheten av de ulike elementene i elbilfordelene likt. Begge gruppene svarte at de økonomiske fordelene er viktige for å gjøre elbiler attraktive for dem. Blant respondentene uten intensjon om å kjøpe elbil er begrenset batterikapasitet den viktigste årsaken til den manglende interessen. Å løse utfordringer knyttet til rekkevidde kan derfor være et effektivt tiltak for å øke elbilinteressen i denne gruppen.

Det er liten tvil om at støtteordningene for elbil har ført til høye salgstall. Økningen i total biltransport og den begrensede CV-substitusjonen i utvalget indikerer likevel viktigheten av å vurdere eksternaliteter i politikkutformingen. Disse eksternalitetene gjør elbiler mindre miljøvennlige enn antatt, noe som har negative konsekvenser for effektiviteten til støtteordningene.

Table of contents

1   Introduction

Road transportation accounts for close to 20% of the climate gas emissions on Norwegian territories (SSB 2015b). Moreover, pollutants from combustion engines such as particulate matter and hydrocarbons have negative effects on human health. One of the proposed solutions to these issues is to replace the internal combustion engine vehicle (CV) with one that runs on electricity (EV). Since EVs do not burn fuel as they travel, their release of local pollutants is limited to road dust. In addition, given a low carbon electricity mix, they carry climate benefits compared to their fossil-fuelled counterparts (Nordelöf et al. 2014). Unfortunately, however, EVs also have some disadvantages, most notable that they are expensive, and offer low range. In addition, the supporting infrastructure is limited. The net effect is limited competitiveness in the personal car market.

To make EVs more competitive, the Norwegian government has gradually introduced a range of policy measures to reduce owners' costs and increase ease of use. The aim is substantial EV market penetration[2]. To achieve this, EVs are exempt from a range of taxes and fees, are allowed to use public transport lanes[3], and are given free access to toll roads and some free ferries. Moreover, EVs have access to designated free parking spots and public charging stations at several favourable locations.

The policy seems to work in accordance with government intentions. By October 2013, Norway had the world's highest number of EVs per capita and the highest EV share of new road vehicles (Figenbaum and Kolbenstvedt 2013). The number of EVs has kept growing rapidly, and by September 2015, it passed 66,000, as shown in *figure 1.1.*
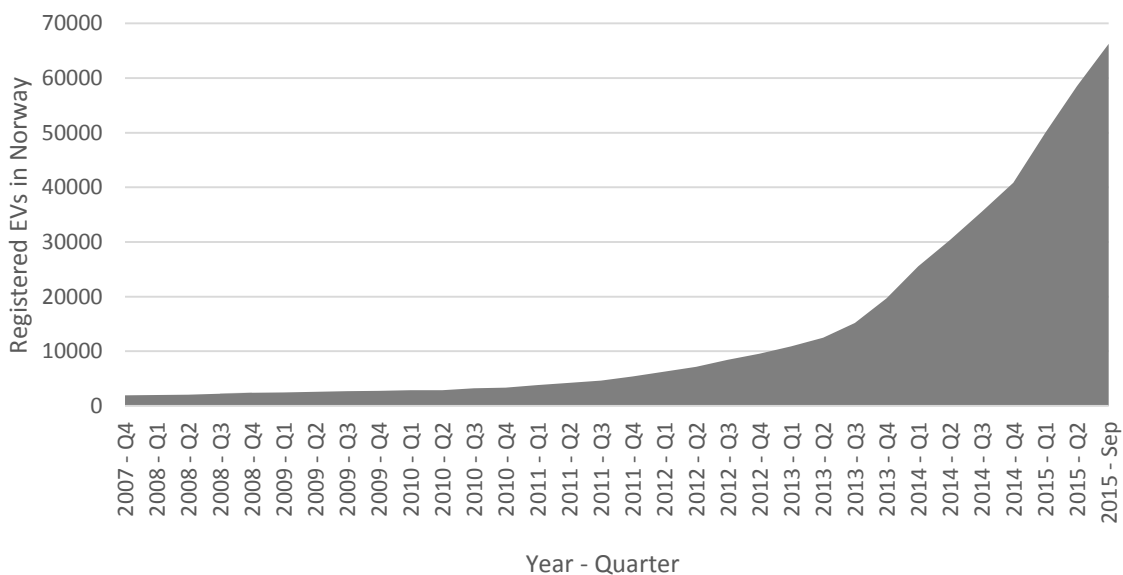
Figure 1.1 - Number of registered electric vehicles in Norway from late 2007 to late 2015 (Grønn Bil 2015). Data is quarterly except in the last period, as data was not yet available.

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[2] The long-run policy objective is technological and infrastructural development. Learning and network effects may lead to increased range and quick chargers in plenty. When or if these effects make EVs market competitive, the supportive measures will be superfluous and phased out. Assessing long-run effects lies outside the scope of this thesis.

[3] With some exceptions, for example outside Oslo (Norwegian Public Roads Administration 2015).

1.1 Research questions

Unfortunately, it is not obvious that the number of EVs is a good measure of policy success. The effectiveness and efficiency of the supportive scheme rely on two critical assumptions: That EVs substitute CVs in use, and that EVs do not increase overall car transportation at the expense of public transportation, manual transportation or non-transportation. This thesis' main objective is to explore the extent to which these assumptions hold.

Two separate subchapters explore the development of the research questions: *1.1.1 - Substitution effects* handles substitution from CV and public or manual transportation to EVs. Increased overall car transportation may also indicate that people increase their total transportation, and substitution of non-transportation is therefore discussed as well.

Subchapter *1.1.2 - Attitudes* explores attitudes towards EV attributes and the EV policy package.

1.1.1 Substitution effects

A key requirement for the EV-policy package to be effective and efficient is that EVs substitute CVs. There are various reasons why this may not be the case. Figenbaum and Kolbenstvedt (2013) find that 91-93% of EV owners belong to households with more than one car. Considering the population average of 45% two-car households (Hjorthol et al. 2014), it seems likely that an EV often is bought as an additional car. This would be reasonable, given that tax and fee exemptions lower costs, thus increasing incentives to procure an additional vehicle. Low electricity prices, meanwhile, decrease the incentive to leave the car stationary once bought. At the same time, it is reasonable to assume that the number of vehicles in a household constrains car travel to some extent. Additional cars make it possible for multiple household members to drive simultaneously, and people may hang on to existing CVs for this exact reason. Moreover, CVs are likely preferred for long journeys because of the EVs' limited battery capacity and hence short range. These effects therefore make full CV to EV substitution improbable.

Moreover, policy makers should worry that EVs substitute public and manual transportation, and that EVs may reduce incentives to avoid unnecessary transportation. A shift from public or manual transportation to EVs would result in an increased amount of road traffic, thus increased congestion, more road dust and higher risk of accidents.

Substitution of both manual and public transportation could take place because of an EV's convenience and low operational cost as compared to a CV. Electricity is cheap, and free toll roads and attractive parking spots are obvious benefits for urban travel. Bus lanes let the EV slip past congestions, and schedule independence gives it an additional edge on public transportation. In addition, EV owners may experience a *"green glow"* from owning an environmentally friendly vehicle. This green glow could mean that drivers use their car more often because they associate EV driving with environmentally friendly behaviour. The same line of argumentation further implies that EVs may increase driving that EV owners previously considered unnecessary. It makes intuitive sense that lower operational costs may trigger additional driving if unnecessary driving is defined as "*costs of transportation exceed the benefits of transportation*".

These arguments lead to research question *(1)*:

> 1) *To what extent do electric vehicles substitute the use of conventional vehicles, public transportation, manual transportation and non-transportation?*

1.1.2 Attitudes

Assessing which policy attributes are most and least important to EV buyers lets policy makers adjust their instruments for increased effectiveness. Under- or overfunded features could be adjusted, while irrelevant, but expensive features could be weeded out. A record of attitudes towards the characteristics of EVs and the EV policy package could help identify which issues policy should and should not address. By identifying target groups and issues, authorities can allocate resources where they are most effective.

Research question *(2)* and sub-question *(2.1)* are therefore:

> 2) *How important are the different attributes of the policy package for purchase and use of electric vehicles?*

> 2.1) *Do EV owners rate the attributes differently than people who do not own EVs?*

1.2 Outline of the thesis

The rest of this thesis is organised in the following sections: Chapter 2 provides a review of literature, chapter 3 describes the data collection process, chapter 4 describes the statistical methods used to analyse the data, chapter 5 presents the results, chapter 6 discusses the results and provide context for the findings, and chapter 7 concludes. The references are listed in chapter 8.

2   Literature review

The literature review is divided into two subchapters: *2.1 Substitution effects* and *2.2 Attitudes.* The first examines substitution effects, while the latter examines attitudes towards the attributes of EVs and the EV policy package. Chapters *2.1* and *2.2* relate to the first and second research question respectively.

It is worth noting that the market penetration of EVs in Norway has increased significantly after the turn of the century, and especially over the last three years. The differences between EV owners and other car owners are decreasing, as EV owners are no longer necessarily early adopters (Figenbaum et al. 2014). There has also been significant technological progress, resulting in for example longer range per battery charge. This should have reduced range anxiety, and allowed use patterns to change and evolve. The findings of earlier studies on EVs are therefore likely to be somewhat outdated.

2.1   Substitution effects

Although many studies and reports explore different aspects of EV adoption, few scholars have directly assessed substitution effects between EVs and other modes of transportation. Because of this void in the literature, many of the included assessments are not peer reviewed, and often limited in their use of statistics.

Green Car Institute (2003) examined the use of neighbourhood electric vehicles (NEV) – small EVs allowed on roads with a speed limit of 45 mph or below. Through a phone survey to 260 randomly selected NEV owners in California, they found that NEVs were replacing two thirds of short trips that were previously taken by CV.

ECON Analyse (2006) distributed a survey to all EV owners in Norway to examine their travel habits. Excluding businesses, 703 of the 986 EV owners that received the survey answered – a response rate of 71 per cent, which is quite high. ECON Analyse (2006) asked EV owners how they would have travelled if they no longer had the EV. The results suggest that EVs substitute CVs in the sample, as 91% report that they would either "often" (79%) or "sometimes" (12%) have used the CV instead of the EV. The results also suggest that EV owners reduce their use of public transportation, as 23% answered "often" and 25% answered "sometimes" for that mode of transportation. For cycling and walking, respondents chose "often" in 8% of the cases and "sometimes" in 15%, thus indicating substitution, although not severe. The ECON report finds that annual EV travel distances are long for being additional cars in 91% of the cases.

Halvorsen (2009) conducted a survey to uncover behavioural differences between EV owners and the general car owner population in Oslo, Trondheim and Bergen. Pre and post EV purchase behaviours were also compared. The sample included a group of 600 EV owners and a population control of 600 people who had a driver's license, but did not own an EV. She found that people reduced their use of public transport for commuting to work significantly after acquiring an EV. Before the purchase, they took 23% of their trips to work by public transport, but this figure decreased to 6% after they bought the EV. Moreover, car transportation to work increased from 65% to 83% of trips taken in the same sample. In addition, EV owners used less public transport and the car more often for commuting than the control group. Overall, the EV group walked, cycled and travelled by public transport significantly less than non-EV owners.

These findings suggest that EVs substitute public transportation and increase overall transportation by car, and that EV owners substitute both non-transportation and manual modes of transportation for EV use.

Rolim et al. (2012) mapped the driving habits of eleven drivers who used both a CV and an EV. Their study used initial interviews supported by driving journals over the course of five months. In their sample, the subjects used the EV daily as a substitute for the CV, especially for commuting and short trips. This finding is in accordance with **Rolim et al. (2014)** where a similar approach was used in a sample of 25 drivers. Rolim et al. (2012) did not specifically measure to what extent substitution took place, but 36% of the drivers said that the EV changed their driving habits. 36% of those who changed their habits – i.e. 13% of the total – said that they had increased their overall amount of trips by car.

Franke et al. (2012) used data from 40 EV users to assess their mobility patterns. Data was recorded before the users received the EV (T_0), and after they had used it for three months (T_1). The 40 participants kept driving journals to gather the data. They compared the use of different modes of transportation from 30 of the participants with panel data for the Berlin population, as well as assessing habitual changes between T_0 and T_1. Compared to the Berlin population, the participants used the car more and other means of transportation less than average, both before and after receiving an EV. Moreover, they found that the participants reduced the amount of trips taken by CV, foot, bike and public transportation after receiving the EV. The participants also increased their overall use of car transportation. *Table 2.1* summarizes their findings.

Table 2.1 - **Percentage use of different means of transportation in baseline measurement (T0), measurement after three months (T1) and Berlin population (Franke et al. 2012).**

	T0	T1	Berlin population
Foot	9.0 %	5.4 %	28.6 %
Bike	8.3 %	1.7 %	12.6 %
Public transport	12.2 %	1.8 %	26.5 %
CV	70.5 %	21.3 %	32.3 %
EV	N/A	70.0 %	N/A

Klöckner et al. (2013) conducted two online surveys of Norwegians who recently bought either a CV or an EV. The first survey asked about the purchase, while the second asked about use. They distributed surveys to a sample including all households that bought either a CV in November and December 2011 or an EV in all of 2011. They oversampled EV buyers to ensure a decent group size. The study found that EVs are most commonly bought as additional cars (i.e. that a previously owned CV is kept), and that the EV is used for a large share of the total transportation after procurement. EV owners only drive less than CV owners do if the EV is the only vehicle in the household. They also found that EV owners use the car more for everyday transportation, e.g. for trips to work, shopping or leisure activities. These findings imply that while EVs substitute CVs to some extent, they may also substitute non-transport and other modes of transportation.

Hjorthol (2013) undertook a meta-study to examine a range of aspects related to EVs. The resulting report summarizes multiple Norwegian and foreign journal articles and reports. The meta-study indicates that trips taken by EVs often replace trips taken by CVs, but also tend to substitute the use of public transport and often increase overall transportation by car. In some cases, Hjorthol (2013) states, most of the EV users used public transport before they acquired the EV: "*Some studies show that EV drivers are, for the most part, former public transport commuters.*"

Figenbaum and Kolbenstvedt (2013) used data from 19 surveys on EVs from 1993 to and including 2013. The surveys included both reports and conference presentations, and most of them were differently designed and formulated. By summarizing and comparing the studies' findings, Figenbaum and Kolbenstvedt (2013) concluded that EVs chiefly substitute CVs (65-83%), but also public and manual transport to a limited extent (10-20%). They were, however, careful not to infer causation between EV ownership and reduced use of public and manual transportation, arguing that the length and means of a typical substituted public transportation trip is unknown. Moreover, they point out that it is not clear what the counterfactual of owning an EV is. The EV owner may have been in need of a second vehicle regardless of technology, and might have bought an additional CV if the EV was unavailable. Therefore, they argue, public and manual transportation substitution may not be directly caused by EV ownership.

Figenbaum et al. (2014) highlighted the need for more and updated research on EVs, including substitution effects between different modes of transportation. They therefore distributed two internet surveys via e-mail. One went out to all members of the Norwegian Electric Vehicle Association (NEVA) to represent the EV owner population, and the other to 10,000 randomly drawn members of the Norwegian Automobile Federation (NAF). The latter group was a control for the general car owner population. They got 1,721 responses from the EV-group and 2,241 from the control. To study effects in urban areas, they identified a sub-group in the dataset of those residing in the Oslo-Kongsberg region.

Their study examined change in total annual mileage, general change in use of other modes of transportation and commuting specific change in use of transportation. They used the number of kilometres specified in the car insurance policy to approximate the number of annual kilometres travelled per household*.* After acquiring an EV, the total annual mileage increased in 18% of the households and decreased in 6%. The rest reported no change to their insurance. In the Oslo-Kongsberg region, which should be most geographically comparable to this thesis' study area, they found that 28% of the EV respondents drove more than they did before they bought the EV, while 7% drove less. The use of public transportation was reduced in 24% of the cases, while 4% increased their use. The EV did not seem to have much impact on manual modes of transportation, as 7% reduced their cycling and walking, while 5% increased theirs. For EV commuting, 80% reported to have replaced CV travel. Another 11% reported to have previously used public transport, while about 4% used the EV to replace manual modes of transportation.

Their findings suggest that EV ownership increases car travel in a household and reduces the use of public transport, but mainly substitutes CV transport. The impacts on cycling and walking seems negligible. They emphasize, however, that it is conceivable that the EV is a response to changed transport needs rather than the cause of changes to transportation habits. Nevertheless, they find it probable that EVs contribute to increased car use and to increased overall transportation because of their low marginal costs in use.

Grøndahl (2015) summarizes findings from the Norwegian Electric Vehicle Association's (NEVA) yearly member survey. The 2015 survey had 7,780 participants. NEVA asked how their members would have travelled in the absence of EVs. The most common response was CV (86%) in addition to a few answering public transport (8%) and even fewer answering cycling and walking (3%). Moreover, 28% of the respondents reported that the EV replaced *all* of their CV driving, while 54%

said they used the CV *a lot less*. Nine percent answered *less* CV use, while the last 10% said their habits were unchanged or had changed only slightly. Their findings imply that EVs largely, although not completely, substitute CVs. They also suggest substitution from public transport and manual transport, but to a limited extent[4].

2.1.1 Summary

While effects vary between studies, they mostly conclude that EVs replace CVs at least to some extent. There is also evidence that EVs tend to increase overall car transportation, and that they substitute public and manual transportation.

2.2 Attitudes

A number of studies have explored how important a range of EV and EV policy attributes are to potential EV buyers both in Norway and abroad. This review summarizes main findings from recent studies.

ECON Analyse (2006) found that the policy package as a whole was critical in triggering EV sales. Their respondents most frequently stated free toll roads, low annual fee, a reasonable purchase price and free public parking as important for their decision to buy an EV. In addition, access to public transport lanes and environmental considerations both ranked highly. The respondents found the main challenges to be driving range, charging time and technological risk related to e.g. resale value or the price of new batteries.

It is worth noting that this study is from 2006, and therefore is unlikely to represent todays EV owners. It may however give valuable input on how perceptions and preferences have changed over time.

Halvorsen (2009) identified access to public transport lanes, environmental considerations and low operating costs as most important among EV owners. In a control group of randomly sampled car owners, charging stations, range and low operation costs were most important.

Accenture (2011) surveyed 7,003 people in 13 different countries. They found that reduced EV tax, free parking and discounted toll roads were the incentives their respondents considered most important. Charging possibilities at home, battery capacity, low purchase price and low operation costs were also important features.

Thiel et al. (2012) found that reduced purchase price and improved range were the most influential factors in the decision to buy an EV. They asked drivers in France, Germany, Italy, Poland, Spain and the UK, and, on average, got 600 answers from each of the countries.

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[4] It should be noted that the participants in the study do not necessarily represent the typical EV owner. As members of the Norwegian Electric Vehicle Association, the participants have expressed an explicit interest in EVs. They could therefore be expected to go further to use their EVs for everyday purposes, as well as being more aware of the negative effects of substitution from public and manual transportation than the average user.

Figenbaum and Kolbenstvedt (2013) found that the economic benefits of the EV, such as cheap fuel and free toll roads, are most important to buyers. The respondents also mention the purchase price of the EV and the price of replacement batteries. Environmental considerations and access to public transport lanes are also regarded as important benefits of the EV.

Figenbaum et al. (2014) found that EV owners put most emphasis on economic factors like cheap fuel and free toll roads, and that the car matches the owner's needs and that it is environmentally friendly. Free ferries, access to public transport lanes and free public parking were important to some respondents, but varied with place of residence.

Grøndahl (2015) summarizes findings from the Norwegian Electric Vehicle Association's yearly member survey. The participating members ranked the absence of a one-time purchase fee as the most important EV benefit. Thereafter came no value added tax, free toll roads, cheap fuel and a low annual fee. When asked about the single most important reason for their personal EV purchase, 59% answered *to save money*, while 24% answered *environmental considerations*. Some also mentioned a high degree of personal technological interest, and logistical preferences that matched well with the EV's properties.

NAF (2015) ran an online survey recruiting more than 50,000 respondents by self-selection. Their report concluded that free toll-roads, a low annual fee, no value added taxes, free parking and no one-time purchase fee were the most important EV incentives. Due to the methodological shortcomings of the study, however, its results are not given much weight in this thesis.

2.2.1   Summary

The literature review, and especially the most recent studies, indicate that economic incentives are important drivers in making EVs attractive. In addition to the economic incentives, survey participants often mention environmental considerations and access to public transport lanes.

3 Data collection

3.1 Transportation habit survey

An internet survey was used to gather the data needed to answer the research questions. The Questback Essentials platform was used for both design and data collection. The respondents received an e-mail with a brief description of the survey and a link for them to follow in order to answer. To reduce possible biases, the survey was presented as a transportation habit study rather than as a mean to assess aspects of the electric vehicle policy package. Since the supportive measures for electric vehicles are heavily debated, it is reasonable to assume that knowledge of the study's purpose could have biased responses.

All respondents were required to provide an e-mail address at the beginning of the survey. Questback hid these e-mail addresses to keep the respondents anonymous. An e-mail was required to avoid the unlikely case of "ballot stuffing", i.e. that respondents complete the survey multiple times to bias the data in favour of their own preferences. A more important benefit of the e-mail requirement, however, was to enable anonymous interaction with the respondents. If questions were submitted in the comment section at the end of the survey, relevant feedback could be given through the Questback e-mail system for clarification[5].

Before the survey was distributed to the respondents, academic expertise on survey design at the School of Economics and Business at the Norwegian University of Life Sciences (NMBU) provided valuable input on layout and contents. A group of students then tested the survey to detect and correct problems.

As an incentive to answer, the invitation e-mail offered those who completed the survey participation in a lottery for a gift certificate of 500 NOK. The gift certificate could be used at a location of the winners choosing from Gavekorttorget.no. Deutskens et al. (2004) found that survey response rates increased significantly when price raffles were offered.

3.1.1 Questionnaire design

The survey consisted of 51 questions in total. The setup allowed routing of the participants based on their answers in order to spare them irrelevant questions. As a result, not every question in the survey has the same number of respondents. A list of the survey questions is included in chapter 11.1

The answer format included both closed-ended and open-ended questions. An open-ended format was used to measure annual RVT for the respondents' vehicles, weekly RVT for spare time activities, commuting distance and commuting time. A closed-ended format was used to measure how a respondent commutes to work and undertakes trips longer than 150 km. Control variables, such as gender, age, education, and number of vehicles owned, was collected with both closed-ended and open-ended formats.

To assess the importance of a range of EV and EV policy attributes, the respondents were asked to rank their opinions using a six-point Likert scale. Depending on the question, the range was either from *no importance* to *vital importance* or from *definitely not* to *definitely*. A scale without a middle

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[5] As it turned out, the only need for the function was to answer one respondent's question regarding privacy issues related to the compulsory e-mail requirement.

point was chosen to avoid the potential issue that respondents who are uncertain about or reluctant to reveal their preferences tend to choose the middle point as an "easy way out" (Yang and Hinkle 2012). In addition to the six points, a *do not know*-alternative was included. This was done to avoid forcing respondents to choose a position without having the necessary knowledge or opinion on the issue. The inclusion of a *do not know*-alternative has been found to substantially reduce the share of respondents that, despite their limited knowledge about a topic, indicate a strict opinion (Foddy 1993).

As preferences vary substantially, however, it was impossible to make an exhaustive list of attributes to measure the perception of EVs. The included attributes were therefore selected based on common choices in literature, as well as the current policy package. To capture alternatives potentially left out, respondents were given the option to provide additional information in an open-ended follow-up question.

Although cross-sectional[6], the survey was designed to capture the EV owners' behaviour both before and after their EV purchase. Respondents were asked to think back and report their past behaviour. The approach allows measuring change in behaviour through comparison of pre and post EV purchase data. An issue with this approach, however, is that it relies on the respondents' ability to recall their past behaviour. Because past habits are no longer directly observable to the respondents, they are unlikely to remember exactly how they behaved. To avoid this problem, the survey could have been repeated annually to record a longitudinal data set. Unfortunately, this was not a feasible approach given the time constraint of the thesis. Moreover, it would be challenging to draw a sample in which a significant number of respondents would become EV owners during the study period.

3.1.2 Sample

While it would be preferable to collect a population representative dataset, this task lies outside the limitations of this thesis. Ideally, respondents would have been randomly drawn from the Norwegian Central Register of Motor Vehicles. Since the registries do not include
e-mail addresses, however, the survey would have had to be distributed by mail or phone. Both approaches would be too labour intensive and expensive to be feasible within the thesis' budget and time constraints.

The survey was distributed to the 1,700 employees of NMBU, as well as 110 parents of children attending Spydeberg handball club. In total, the survey was distributed to 1,810 people.

In an effort to expand the EV owner group, multiple organisations were contacted and asked if they could distribute the survey among their members. For various reasons, they were unable to help. Self-selection into the survey through internet fora and social media was considered, but abandoned. While it is likely that the approach would have brought in a higher number of EV respondents, it would introduce self-selection bias in the dataset. It is reasonable to assume that those who choose to participate in the survey would be those with the greatest interest in transportation habits. This effect could be heavily magnified in certain cases, such as e.g. recruitment through the Norwegian Electric Vehicle Association's online forum. An EV owner who chooses membership in an EV association, further chooses to participate in a forum dedicated to EVs and then chooses to

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[6] A cross-sectional analysis implies that each study object – in this case respondent – is observed only at one point in time (Wooldridge 2012b).

participate in the survey is likely to differ from the average EV owner. This should hold true with respect to both transportation habits and opinions on EV policy.

3.1.3 Response rate, attrition and summary overview

Of the 1,810 people invited, 529 completed the survey. This corresponds to an overall response rate of 29.2 %. The response rate was slightly higher in the handball club-sample (34.5 %) than at NMBU (28.8 %). 347 of the respondents chose to participate in the raffle for the gift card. The winner was drawn using an atmospheric noise true random number generator (random.org).

Eighty-nine respondents started, but did not finish the survey. Minutes after the survey was made available, however, it was discovered that the routing did not work properly if the first question was accidentally left unanswered. Moreover, some respondents reported issues with the function designed to move them back and forth through the questionnaire. Consequently, some respondents fell out of the survey involuntarily. After adding a bold informational text about the importance of answering the first question, the dropout rate subsided almost entirely. Of the 89 dropouts, 67 occurred before the routing problem was discovered. Since technical issues caused most of the dropouts, the relatively high rate is unlikely to have caused problems with attrition bias in the data.

Of the 529 respondents, 473 report to own at least one vehicle, while 56 own no vehicles. The average number of cars owned by car owners is 1.37. *Table 3.1* summarizes respondent characteristics with respect to number and types of vehicles owned.

Table 3.1 - Car owner characteristics of the respondents. Number of respondents for each category and percentage of total number of respondents.

Respondents who own:		
At least one vehicle	473	89.4 %
One or more CVs	451	85.3 %
One or more HEVs	26	4.9 %
One or more EVs	37	7.0 %
No vehicles	56	10.6 %
One vehicle	323	61.1 %
Two vehicles	128	24.2 %
Three vehicles	21	4.0 %
Four vehicles	1	0.2 %
Total	529	100 %

Table 3.2 provides an overview of the sex distribution among the survey participants. There is a slight female majority with 275 versus 237 male respondents. Seventeen respondents did not report their sex. The sample average age is 46.2 years, with an average of 43.8 and 49.1 years for females and males respectively.

**Table 3.2 - Number and percentage of male and female respondents.**

Sex	Number	Percentage
Female	275	52.0 %
Male	237	44.8 %
Unknown	17	3.2 %

About half of the respondents live in either Ås or Oslo (51%), while the vast majority work in either Ås or Oslo (87%). This is unsurprising, given that the sample is spatially limited either by respondents' commuting distance and work relation to NMBU, or by the traveling distance to the handball club located in Spydeberg. *Figure 3.1* maps the respondents based on their residential postcodes. Correspondently, *figure 3.2* maps their workplaces. The black shares of the bars represent EV owners, while the grey shares represent the rest.
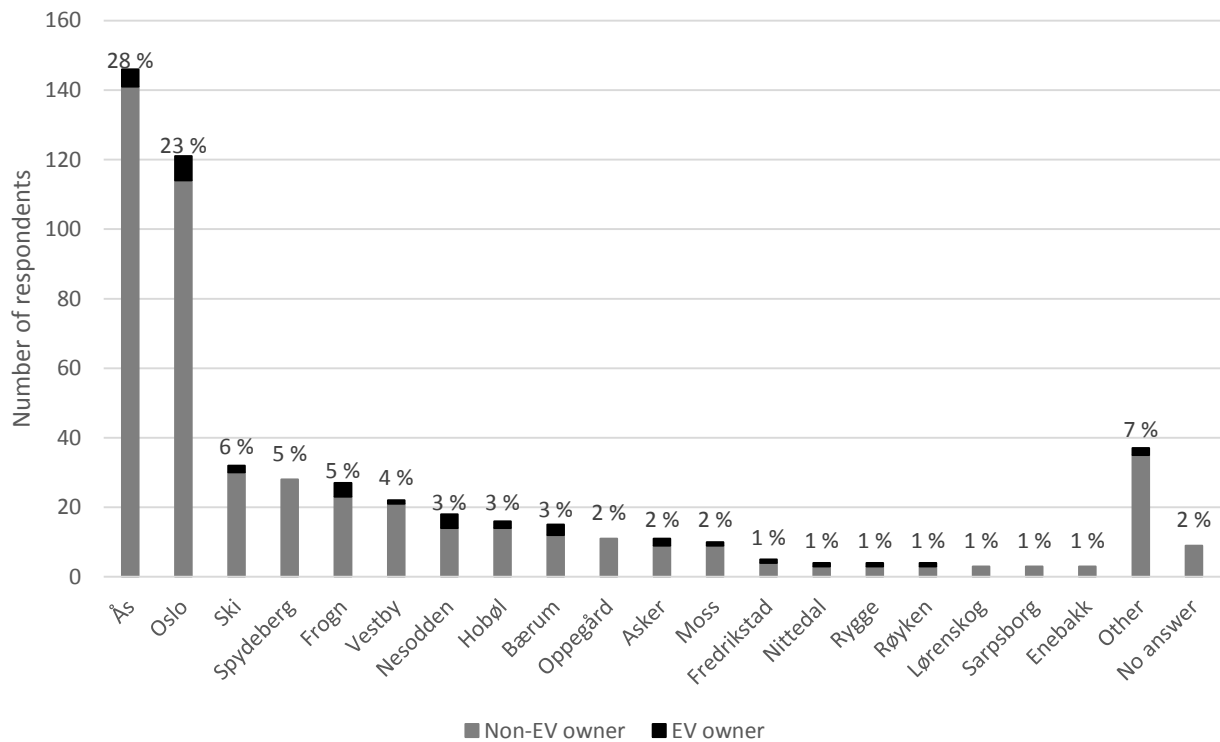
Figure 3.1 - Number of respondents and percentage of total respondents residing in each represented municipality. Municipalities with two or fewer respondents are aggregated in "Other" and include Sandnes, Skedsmo, Hurum, Hvaler, Våler, Kongsberg, Krødsherad, Lenvik, Lunner, Marker, Nannestad, Nedre Eiker, Nes, Rakkestad, Re, Ringerike, Ringsaker, Rælingen, Råde, Sande, Skiptvet, Askim, Båtsfjord, Gjesdal, Gran, Halden, Hamar, Stavanger, Sør-Odal, Tjøme, Østre Toten and Ullensaker.
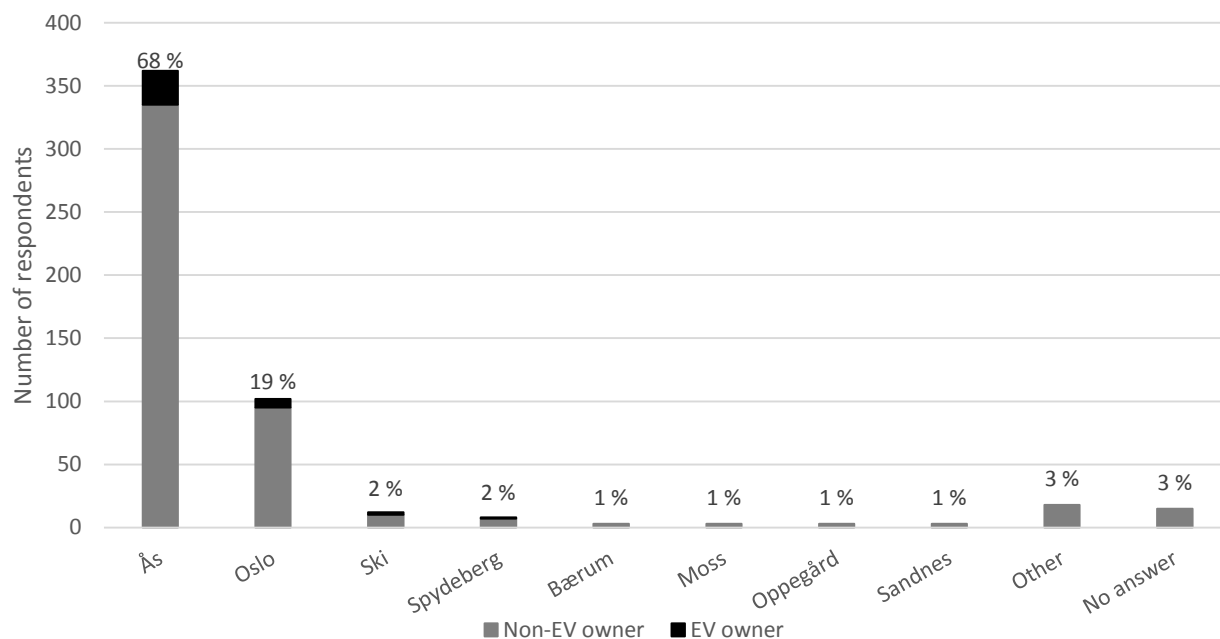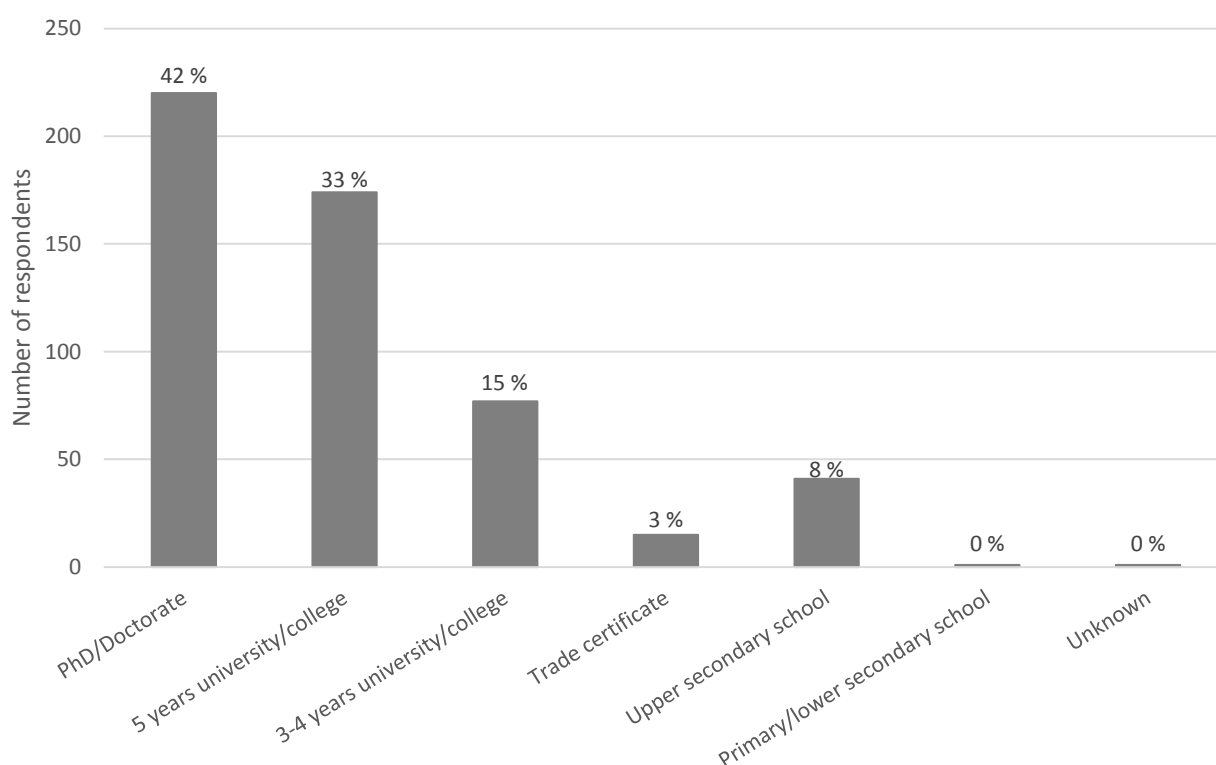
Figure 3.2 - Number of respondents and percentage of total respondents working in each represented municipality. Municipalities with two or fewer respondents are aggregated in "Other" and include Aremark, Asker, Askim, Bergen, Båtsfjord, Eidsberg, Enebakk, Frogn, Hamar, Hobøl, Lenvik, Meløy, Nesodden, Skedsmo, Trøgstad and Vestby.

The data sample consists largely of university employees, and it is therefore unsurprising that most respondents are highly educated. *Figure 3.3* shows the number and share of respondents within each educational level.

Figure 3.3 - Number and percentage share of respondents within each educational level.

Theoretically, the survey data could be weighted to better represent the education level of the population. However, individuals with below national average education are hardly represented among the survey participants. A generalization to population level based on these few individuals' preferences would thus result in inconsistent results. As an example, there is only one respondent in the survey data with primary/lower secondary school (7-10 years) as her highest completed education, as compared to a population proportionate share of 26.9 % (SSB 2014). Similarly, only 7.7 % of the respondents report upper secondary school as their highest completed education, as compared to a population expectation of 40 % based on the sex ratio among the survey participants and education statistics from SSB (2014).

The income distribution among the respondents is shown in intervals of 100,000 NOK in *figure 3.4.* Assuming respondents, on average, earn the median value of their respective income intervals, the mean gross income in the survey sample is 570,000 NOK. This is somewhat higher than the Norwegian 2014 average of 503,800 NOK (SSB 2015a). Wilcoxon rank-sum tests[7] indicate no significant differences between EV owners and other car owners, neither with respect to income, nor with respect to education. Those who own no vehicles, however, have significantly lower incomes than those who do.
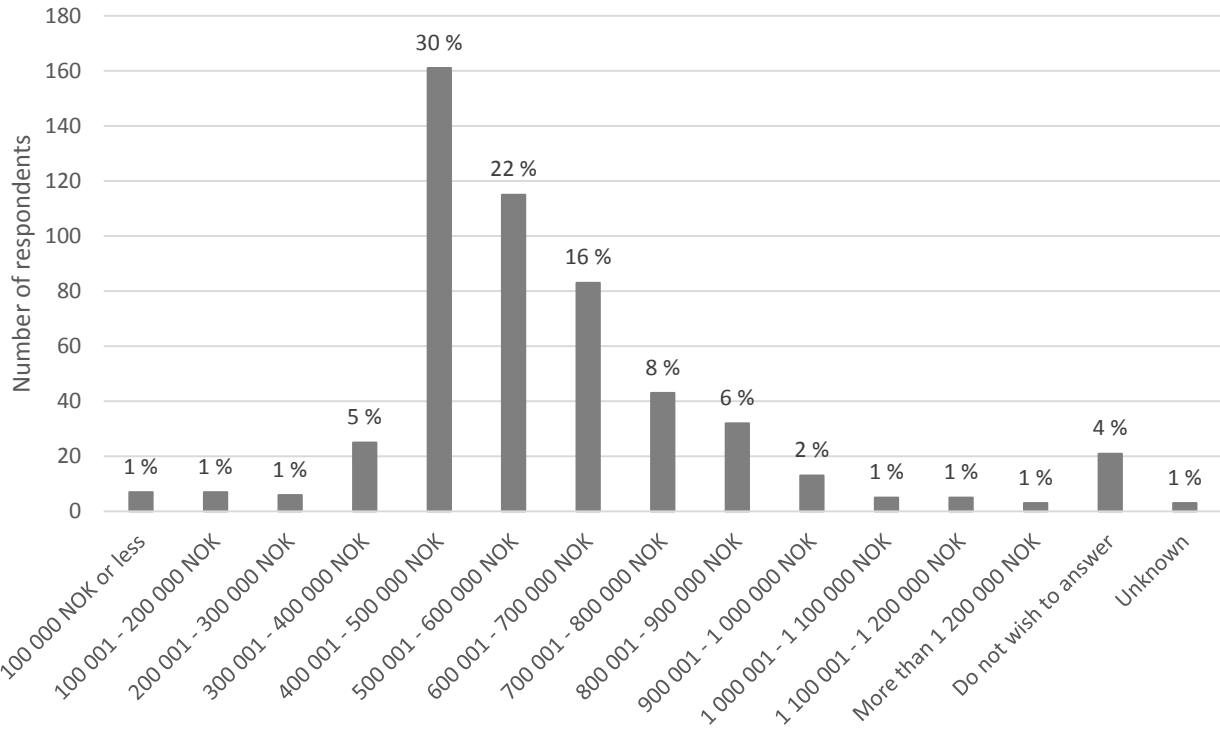
Figure 3.4 - Annual gross income in Norwegian kroner (NOK). Number and share of respondents in each interval.

The comments-section at the end of the survey yielded a mix of positive and negative feedback, helpful suggestions and clarifying comments. Some respondents found one or more questions hard to answer. This was partly due to some answers being hard to estimate exactly, and in some occurrences difficulties understanding the question correctly. Consequently, some respondents

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[7] See chapter 4 for explanation.

either skipped a question, gave their best guess or answered a value that would be easy to find and remove. Skipping of questions was relatively rare and does not seem to correlate with any particular respondent characteristic. It is therefore unlikely that the issue has biased the dataset in any significant manner. It is worth noting however, that respondents report that they have been unable precisely to estimate the number of kilometers traveled.

Because of the survey's "camouflage" as a study of transportation habits, some respondents felt topics or alternatives lacking from the survey. While many of the respondent-suggested topics could have been interesting objects of study under different circumstances, they would have been mostly irrelevant to the research questions of this thesis.

3.1.4 Potential data issues

As mentioned, there is some guesswork involved in estimating quantitative answers about transportation habits. The reason for this is that people are unable to remember and describe their habits perfectly. This could stem from lack of memory or lack of incentive to remember exact numbers of trips or kilometers traveled with a given vehicle. If a respondent for example is asked the percentage of work trips taken with public transportation, he is more likely to give a rough and round estimate of 10 % than an accurate 7 %. This should explain why answers to open questions in the survey tend to congregate around round numbers. Further, some respondents may be more aware of their habits than others are, meaning the accuracy in the estimates may vary across respondents.

These issues lead to measurement errors in the data set. This has different implications for a regression depending on if it is the dependent or the independent variables that are measured with errors. Measurement errors in the dependent variable need not have noteworthy negative impact on the estimation. An inflated variance and potentially biased constant term are normally the only issues, unless the measurement errors are correlated with the independent variables. This problem cannot be abated except by collecting better data. Measurement errors in the independent variables, however, tend to cause attenuation bias. Attenuation bias implies that effects will be underestimated. The inconsistencies in the estimates will increase with the number of independent variables with measurement errors, as well as the size of the errors and their correlation with the true value of the independent variables (Wooldridge 2012b).

Measurement errors are not expected to be a problem in this thesis, since the independent variables are easily observed and measured compared to the dependent variable. See chapter 4 for a thorough discussion.

3.1.5 Data cleansing

Some observations were coded as missing from the dataset due to comments provided by the respondents. Examples include a respondent who answered 10,000,000 yearly kilometers to stand out enough to be removed and some highly implausible answers such as 15 yearly or 3,000 weekly kilometers per vehicle.

4 Methods

This chapter reviews the econometric methods used to assess the substitution effects of electric vehicles, and the perceptions of EVs and the EV policy package. Although a visual or summary approach to data analysis may indicate differences between groups, econometrics are needed to assess whether these perceived differences are statistically significant. The analyses are performed using the statistical software Stata.

4.1 Wilcoxon rank-sum/Mann-Whitney two-sample statistic test

The Wilcoxon rank-sum test is a non-parametric test used to test whether the median value is equal between two independent samples. It was independently developed by multiple statisticians, but is commonly named after Wilcoxon (1945) and Mann and Whitney (1947)[8]. The test does not rely on assumptions about the statistical distribution of the samples, and provides a more efficient alternative to the parametric t-test in cases when the normality assumption does not hold (Hettmansperger and McKean 2010); it can be as much as four times as powerful as the t-test under such circumstances (Sawilowsky 2005).

The test works by combining all observations from the two samples to be compared. The observations are then ranked depending on their value. The smaller the value of the observation, the lower the rank. A rank of one will be assigned to the smallest value, a rank of two to the second smallest and so on. If there is no difference between samples, the expectation is that observations from the two samples are randomly distributed within the rank order. If there is a difference between the samples, the observations from one sample will tend to have more observations in one end of the rank order than in the other end. The ranks are then allocated to their respective samples and the ranks summed for each. The observed ranks are compared to the expected distribution of ranks given random assignment, and the probability of randomly observing the observed rank-sums is calculated. The test statistic can be expressed by *equation 1* (reproduced from Corder and Foreman (2009)):

1) $U_i = n_1 \, n_2 + \frac{n_i(n_i+1)}{2} - \sum R_i$

where

U_i is the test statistic for the sample of interest.
n_i is the number of observations in the sample of interest.
n_1 is the number of observations in the first sample.
n_2 is the number of observations in the second sample.
$\sum R_i$ is the sum of ranks from the sample of interest.

To calculate the statistical significance of the test statistic, a z-score is computed through normal approximation and then compared to critical z-values. Reproduced from Corder and Foreman (2009), *equations 2* through *4* are used to derive the z-score:

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[8] See Berry et al. (2012) for a thorough review of its history.

2) $\bar{x}_U = \frac{n_1 n_2}{2}$

where

$\bar{x}_U$ is the mean rank of the sample.

3) $s_U = \sqrt{\frac{n_1 n_2 \, (n_1 + n_2 + 1)}{12}}$

where

s_U is the standard deviation of the ranks.

4) $z^* = \frac{U_i - \bar{x}_U}{s_U}$

A significant z-score implies that the hypothesis of equality between samples is rejected.

In this thesis, the test is used e.g. to examine whether there are groupwise differences between EV owners and other car owners.

4.2   Wilcoxon matched-pairs signed-rank test

The Wilcoxon matched-pairs signed-rank test is a non-parametric test for the equality of paired data (Wilcoxon 1945). Like the Wilcoxon rank-sum test, Wilcoxon's rank-based statistic for paired data does not require the sample to follow a normal distribution, and is therefore preferable to parametric methods in cases when the normality assumption does not hold. Further, the signed-rank test does not lose much efficiency to the paired t-test even under normality (Hettmansperger and McKean 2010).

The test is used to test whether there are differences between multiple pairs of data. An example is a variable that is measured both before and after a treatment of multiple individuals. If the treatment was effective, the variable should have changed post-treatment. The Wilcoxon statistic can be used to assess whether or not this is the case, by testing the null-hypothesis that the median difference between pre-treatment and post-treatment values is equal to zero (Harris and Hardin 2013). A rejection of this hypothesis implies the rejection of the hypothesis of no effect of the treatment.

To perform the test, the pre-treatment values are subtracted from their paired post-treatment values. The absolute values of the differences are then ranked. The positive and negative differences are separated and their ranks are summed independently. This yields one rank sum for the negative differences ($\sum R_-$) and one for the positive differences ($\sum R_+$). The Wilcoxon T-statistic is whichever of the two sums is the smallest. In small samples, the T-value can be compared to a table of critical values, but in large samples a z-score needs to be calculated using normal approximation as for the Wilcoxon rank-sum (Corder and Foreman 2009).

Reproduced from Corder and Foreman (2009), the z-score can be calculated using *equations 5* through *7*:

5) $\bar{x}_T = \frac{n(n+1)}{4}$

where

$\bar{x}_T$ is the mean rank of the sample.

6) $s_T = \sqrt{\frac{n(n+1)(2n+1)}{24}}$

where

s_U is the standard deviation of the ranks.

7) $z^* = \frac{T-\bar{x}_T}{s_T}$

A significant z-score implies that the hypothesis of zero median difference between post- and pre-treatment values is rejected.

In this thesis, the test is used for example to examine whether or not the use of public transportation changes when a respondent acquires an EV. The test examines whether the pre-ownership use of public transportation equals the post-ownership use of public transportation, i.e. whether or not there has been a change in use.

4.3 Ordinary Least Squares (OLS) – Multiple Linear Regression (MLR)

OLS regression models are specified and run to investigate the effects of EVs on the respondents' car transportation in general and CV transportation in particular.

Multiple linear regression implies using a range of *independent variables* simultaneously to explain a *dependent variable*, thus evaluating the effect of each independent variable on the dependent variable while holding all other variables constant (*ceteris paribus*). OLS fits a linear relationship between the dependent variable and a function of the explanatory (independent) variables with the data by minimizing the squared differences between observed and predicted values, i.e. the squared distances from the actual data points to the fitted line (Wooldridge 2012b).

The general multiple regression model estimated by OLS can be expressed by *equation 8*:

8) $y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + u$

where y is the dependent variable, β_0 is the intercept of the equation, β_1 through β_k are the parameters indicating effects of independent variables X_1 through X_k, and u is the error term of the equation. To capture non-linear effects in the OLS framework, variables can be transformed for example by using logarithmic values or polynomials. The error term captures the variation in y that is not captured by the independent variables (Wooldridge 2012b).

4.3.1 Model assumptions

Adapted from Wooldridge (2012b).

1) The model is linear in the parameters.

2) Randomly drawn sample of observations from the population, i.e. no correlation between values of a variable.

3) The expected value of the error term is zero given any value of the independent variables:
   a. $E(u|x_1, x_2, x_3, \ldots, x_k) = 0$

4) No perfect collinearity, i.e. no independent variables are constant and no exact linear relationships between independent variables.

5) The variance of the error term is equal across all observations, i.e. homoscedasticity.
   a. $var(u|x_1, x_2, x_3, \ldots, x_k) = \sigma^2$

6) The population error term is independent of the independent variables in the model, and is normally distributed with zero mean and constant variance.

4.3.2 Model specification

The first regression model is specified to investigate factors that affect total car transportation. The dependent variable *totalcar* represents kilometres travelled annually in all cars (EVs, CVs and HEVs) owned by the respondent. The model specification is shown in *equation 9*:

9) $totalcar = \beta_0 + \beta_1 evnum + \beta_2 cvnum + \beta_3 hevnum + \beta_4 envorg + \beta_5 diffcommtime + \beta_6 income + \beta_7 age + \beta_8 hhlicence + u$

The second regression model is specified to investigate factors that affect car transportation, excluded EVs. The dependent variable *nonelectric* represents kilometres travelled annually in all cars that are not fully electric (CVs and HEVs). The model specification is shown in *equation 10*:

10) $nonelectric = \beta_0 + \beta_1 evnum + \beta_2 cvnum + \beta_3 hevnum + \beta_4 envorg + \beta_5 diffcommtime + \beta_6 income + \beta_7 age + \beta_8 hhlicence + u$

The independent variables are the same in both models:

- *evnum* is the number of EVs owned by a respondent.

- *cvnum* is the number of CVs owned by a respondent.

- *hevnum* is the number of HEVs owned by a respondent.

- *envorg* is a dichotomous variable equal to 1 if a respondent has membership in an environmental organisation, and 0 if not. The variable is included to control for high environmental commitment, potentially decreasing the propensity to travel by car.

- *diffcommtime* is the time saving in minutes by commuting with car rather than public transport. The variable is included since the car should be more competitive against public transportation with an increasing time saving, thus potentially increasing car transportation. The variable is calculated as:

$$diffcommtime = \ minutes\ spent\ with\ public\ transport - minutes\ spent\ with\ car$$

- *income* is a respondent's gross income in 2014 measured as a rank from 1-14. Each rank represents a 100,000 NOK interval.

- *age* is a respondent's age in years.

- *hhlicense* is the number of people in a respondent's household who possess a driver's license for passenger cars. A high number of drivers in the household should increase the potential frequency of car use, thus potentially increasing car transportation.

- *u* is the random and unobservable error term.

To test whether the assumption of homoscedasticity holds, a Breusch-Pagan test for constant variance was performed. The test rejected the hypothesis of homoscedasticity at the 0.01 confidence level. Hence, Huber-White heteroscedasticity robust standard errors are used in the regressions[9]. The test results are found in *table 11.4*.

4.4 Heckman selection model

Adapted from Wooldridge (2012b).

A positive amount of car travel can only be observed if a respondent is in possession of at least one car. Since having a car is not a randomly assigned feature, the probability of being a part of the censored sample is not equal for all respondents. This implies that the dependent variables of the OLS regressions are censored by incidental truncation. The decision to buy a car may be related to for example the respondent's income or environmental stance. Hence, respondents with certain characteristics may have higher chances to be included in the sample, thus introducing selection bias. To remedy the issue, a Heckman two-step correction model is specified for each dependent variable.

The first stage of the Heckman two-stage correction model is a probit regression in which all available observations are used to estimate each respondent's probability of inclusion in the censored sample. The second stage is an OLS regression where the results of the probit model are taken into account.

The first stage is given in *equation 11*:

11) $P(s = 1|z) = \Phi(z\gamma)$

where $s = 1$ if the censored variable y is observable, and 0 if it is not, z is a range of variables thought to influence s, Φ is the cumulative distribution function of the standard normal distribution and γ represents the parameter estimates for each variable; $z\gamma$ is shorthand for $\gamma_0 + \gamma_1 z_1 + \cdots + \gamma_m z_m$.

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[9] The interested reader may find a thorough treatment of Huber-White standard errors and the Breusch-Pagan test for constant variance in e.g. Wooldridge (2012a).

The probit model is estimated, and $\hat{\gamma}$ obtained. The values of $\hat{\gamma}$ are used to compute the inverse Mills ratio $\hat{\lambda}$ to be included in the second stage.

The second stage is given in *equation 12*:

$$12)\ E(y|z, s = 1) = x\beta + \rho\lambda(z\gamma)$$

where it is shown that the expectation for y given that y is observable and z is $x\beta$ plus a term dependent on the inverse Mills ratio. $x\beta$ is shorthand for $\beta_0 + \beta_1 X_1 + \cdots + \beta_k X_k$. $\rho = 0$ if the error terms of the two stages are uncorrelated, i.e. that there is no selection bias. If $\rho = 0$, the second stage equation becomes the normal OLS equation without bias correction.

The dependent variable of the first stage equation indicate whether the respondent own at least one car by taking the value of 1 if the respondent is a car owner, and 0 if not. The independent variables selected for the first stage equation are determinants of car ownership used to calculate the probability of sample inclusion, i.e. whether the dependent variable is equal to 1.

The independent variables in the selection equation are the respondent's *income, age* and *sex*, as well as the number of people in the respondent's household who possess a driver's license for passenger cars, *hhlicnum.*

The second stage variables are the same as in the OLS regressions.

Bootstrapped standard errors with 1,500 replications are used to correct for heteroscedasticity. A high number of replications was chosen to increase the likelihood that the bootstrapped errors converge to their true values (Guan 2003).

4.5 Potential issues

4.5.1 Omitted variables
Omitted variable bias may arise if the regression model is underspecified, i.e. that an explanatory variable that should have been included in the model is left out. Bias arises if that variable has an effect on the dependent variable *and* is correlated with at least one of the explanatory variables. The effect of the omitted variable will in any case be captured by the error term of the regression. This is unproblematic for coefficient interpretation of other explanatory variables if the omitted variable is uncorrelated with the other explanatory variables in the regression, but will give rise to inconsistent estimators if not (Wooldridge 2012b). Moreover, omitted variables increase the unexplained variance in the estimated model, which in turn lowers overall model reliability.

It is possible that one or more variables that explain car transportation have been omitted from the models. These are not necessarily correlated with the explanatory variables that are included, however, and need not cause inconsistent estimators. If they do, however, it would be problematic to control. An example could be differences in cultural propensity for car or public transportation use that may stem from e.g. different levels of peer pressure related to social status or environmental awareness. Such variables are inherently hard to measure and control. A potential approach might have been to use instrumental variable regression, but, alas, gathering additional data for the instruments lies beyond the scope of the thesis.

To test whether any of the potential independent variables gathered in the survey should have been included in the regression models, auxiliary regressions were run on the residuals to obtain Lagrangian Multiplier (LM) statistics. The hypothesis of no effect of the variables could not be rejected. These findings were confirmed by F-tests for joint significance of the omitted variables.

Consequently, omitted variables are assumed not to cause significant issues in the models. It could be relevant, however, to replicate the study with instrumental variables in the future if potential confounders are discovered.

4.5.2 Measurement errors

As mentioned in chapter 3, measurement errors are unavoidable in a questionnaire setting, especially when respondents are asked to recall past behaviour. Fortunately, however, the nature of the measurement errors in this dataset need not have any major negative impact on the regression analysis. The following briefly explains why this is a reasonable conjecture.

Measurement errors have different impacts on the regression analysis depending on whether it exists in the dependent variables or in the independent variables. Measurement error in the dependent variable of a regression implies that an additional error term, e_0, is added to the model:

$$13) \quad y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + u + e_0$$

Unless respondents on average consistently over- or underestimate the dependent variable, e_0 has zero mean and the estimators will be unbiased and consistent. Even if the assumption of zero mean does not hold, the consequence is but a biased constant term β_0. Should this happen it is unproblematic for this thesis' purpose, as the intercept is of no particular interest. An unavoidable, but rather unproblematic issue, however, is that the variance of the estimators will be inflated, thus somewhat increasing the odds of type II errors (Wooldridge 2012b).

Measurement errors in the independent variables have different and more severe consequences. This will not be given thorough treatment[10], as it can be argued that such errors are unlikely.

The reason for this is that the respondents can easily estimate the independent variables used in the regressions. The number of cars owned, *evnum, cvnum* and *hevnum,* should be obvious to the respondent. This also holds true for membership in an environmental organisation, *envorg*. The commuting time measurements, which are the basis for the *diffcommtime* variable, are perhaps slightly harder to get right, but any person who travels to work on a daily basis should have a sound idea about how long it takes by different means of transportation. Further, people are likely to be highly aware of their *income*, and the *age* variable should be exceptionally hard to get wrong. Finally, people are likely to have good information about their housemates' traits, thus providing accurate estimates of the *hhlicnum* variable.

Therefore, measurement errors are assumed to have little to no negative impact on the validity of the analyses.

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[10] See e.g. Wooldridge (2012c) for a review.

5 Results

Subchapter 5.1 of this chapter presents the results of the substitution effects analyses, while subchapter 5.2 presents the results of the attitude analyses.

5.1 Substitution effects

5.1.1 Overall car transportation

Substitution of non-transportation, public transportation and manual transportation.

5.1.1.1 *Wilcoxon matched-pairs rank-sum for pre vs. post EV purchase behaviour.*

To test the hypothesis that Eownership increases overall travel by car, a Wilcoxon matched-pairs signed-rank test was performed in the EV group on annual overall transportation by car before and after the EV was acquired. The signed-rank test was preferred to the paired t-test due to the non-normality of the differences between before and after distances, as assessed by a Shapiro-Wilk test. The Shapiro-Wilk output is found in *table 11.3.* The annual cumulative number of kilometres driven by all cars owned by the respondent was used to measure car transportation.

Table 5.1 reports the results of a Wilcoxon matched-pairs signed-rank test for the median annual cumulative number of kilometres driven by car. The hypothesis that the median annual cumulative driving distance is equal before and after EV acquisition is rejected at the 0.01-confidence level. The difference between before and after median distances driven is 7,250 kilometres, indicating an increase of 40.3 % in median overall car transportation.

Table 5.1 - Wilcoxon matched-pairs signed-rank test for equality of median annual cumulative kilometres driven by car.

H0: Overall car use post EV = Overall car use pre EV							
Median post	*Median pre*	*Sign*	*N*	*Sum ranks*	*Expected sum ranks*	*Z-value*	*P-value*
25,250 km	18,000 km	Positive	20	346.5	178.5	4.065	0.000
		Negative	1	10.5	178.5		
		Zero	6	21	21		
		Total	*27*	*378*	*378*		

5.1.1.2 *OLS regression*

To analyse the impact of EV ownership, as well as other impact factors, on annual total car use, an OLS regression model was specified and run. A Breusch-Pagan test rejected the hypothesis of homoscedasticity at the 0.01 significance level. The Huber-White heteroscedasticity-consistent standard errors are therefore used in the regression. The test output can be found in *table 11.4.*

The results of the OLS regression are reported in *table 5.2.*

Table 5.2 - OLS regression for annual driving distance per respondent using all cars the respondent owns. Huber-White robust standard errors. Equation: $totalcar = \beta_0 + \beta_1 evnum + \beta_2 cvnum + \beta_3 hevnum + \beta_4 envorg + \beta_5 diffcommtime + \beta_6 income + \beta_7 age + \beta_8 hhlicence + u$

Variable	Coefficient	Robust std. error	t	P>|t|	[95% confidence interval]	
Number of EVs	8 658	2 665	3.25	0.001	3 418	13 899
Number of CVs	17 177	2 118	8.11	0.000	13 011	21 343
Number of HEVs	24 051	4 181	5.75	0.000	15 829	32 273
Environmental organisation	-1 716	1 270	-1.35	0.177	-4 214	781
Diff. in commuting time, PT-CV	124	26	4.77	0.000	73	175
Income	525	418	1.26	0.210	-298	1 348
Age	-130	58	-2.24	0.026	-245	-16
Household driver's license holders	59	1 089	0.05	0.957	-2 082	2 200
N	363					
R^2	0.421					

The hypothesis of no effect of the number of EVs a respondent own on annual kilometres driven by car is rejected at the 0.01 confidence level. On average, the model indicates that ownership of one EV increases the annual distance driven by car by about 8,600 kilometres ceteris paribus.

The hypotheses of no effect of the number of CVs and HEVs a respondent own are both rejected at the 0.01 confidence level. Ceteris paribus, an additional CV is expected to increase the annual driven distance by almost 17,200 kilometres, while a HEV is expected to increase the distance by about 24,000 kilometres.

Further, the hypothesis that the difference in commuting time between public transport and personal car has no effect on the annual distance driven by car is rejected at the 0.01 confidence level. For each additional minute public transport loses to the car, the annual driven distance is expected to increase by 124 kilometres ceteris paribus.

Moreover, the hypothesis that the respondents' age has no effect on the annual driven distance is rejected at the 0.05 confidence level. A respondent is expected to drive 130 kilometres less for each additional year of age, ceteris paribus.

No significant effect is found of the respondents' income, membership in an environmental organization or the number of driver's license holders in the respondent's household.

5.1.1.3 Heckman selection model
Since the annual distance a respondent travels by car can only be positive if he or she owns a car, the sample in the OLS regression is censored and could therefore have selection bias issues. A Heckman two-step selection model is run to correct for this and to serve as a robustness check. Bootstrapped standard errors with 1,500 repetitions are employed to account for heteroscedasticity in the data.

Table 5.3 summarizes the Heckman two-step selection model results. The model was run multiple times to verify the consistency of the sampled bootstrap standard errors.

Table 5.3 - Heckman two-step selection model regression for annual driving distance per respondent using all cars the respondent owns. Bootstrapped standard errors with 1,500 repetitions. Equation: $totalcar = \beta_0 + \beta_1 evnum + \beta_2 cvnum + \beta_3 hevnum + \beta_4 envorg + \beta_5 diffcommtime + \beta_6 income + \beta_7 age + \beta_8 hhlicence + u + \rho\lambda(z\gamma)$

Variable	Coefficient	Bootstr. std. error	t	P>|t|	[95% confidence interval]	
Number of EVs	8 644	2 637	3.28	0.001	3 475	13 812
Number of CVs	17 176	2 141	8.02	0.000	12 981	21 372
Number of HEVs	23 884	4 646	5.14	0.000	14 779	32 990
Environmental organisation	-1 574	1 321	-1.19	0.233	-4 164	1 015
Diff. in commuting time, PT-CV	123	28	4.46	0.000	69	178
Income	789	815	0.97	0.333	-809	2 387
Age	-96	114	-0.84	0.402	-320	128
Household driver's license holders	742	2 183	0.34	0.734	-3 537	5 021
Income	0.113	0.073	1.550	0.121	-0.030	0.255
Age	0.012	0.009	1.340	0.182	-0.006	0.029
Sex	0.223	0.189	1.180	0.237	-0.147	0.593
Household driver's license holders	0.302	0.167	1.810	0.071	-0.026	0.629
Mills' lambda	8 141	20 393	0.40	0.69	-31 829	48 111
N (total obs.)	406					
N (censored obs.)	53					
N (uncensored obs.)	353					

The selection equation suggests that the number of household members with a driver's license increases a respondent's sample inclusion probability at the 0.1 confidence level. The non-significant value of Mills' lambda, however, implies that the hypothesis of no correlation between the error terms of the equations cannot be rejected. The results are thus practically equal to the OLS regression with only minor coefficient adjustments.

The main equation rejects the hypothesis of no effect of the number of EVs a respondent own on annual kilometres driven by car at the 0.01 confidence level. On average, the model indicates that ownership of one EV increases the annual distance driven by car by about 8,600 kilometres ceteris paribus.

The hypotheses of no effect of the number of CVs and HEVs a respondent own on kilometres driven are both rejected at the 0.01 confidence level. Ceteris paribus, an additional CV is expected to increase the driven distance by almost 17,200 kilometres per year, while a HEV is expected to increase the distance by almost 24,900 kilometres per year.

Furthermore, the hypothesis that the difference in commuting time between public transport and personal car has no effect on the annual distance driven by car is rejected at the 0.01 confidence level. For each additional minute public transport loses to the car, the annual driven distance is expected to increase by 123 kilometres per year ceteris paribus.

No significant effects are found of the respondents' age, income, membership in an environmental organization or the number of driver's license holders in the respondent's household.

5.1.2   Overall CV transportation

5.1.2.1   *Wilcoxon matched-pairs rank-sum for pre vs. post EV purchase behaviour.*
The hypothesis that EVs replace CVs in use was tested with a Wilcoxon matched-pairs signed-rank test. In the EV group, the test compared the annual distance travelled by CV before and after the EV

purchase. The signed-rank test was preferred to the paired t-test since a Shapiro-Wilk test indicated high probability of non-normality of the differences between before and after distances. The Shapiro-Wilk output is found in *table 11.3.*

The Wilcoxon matched-pairs signed-rank test results are shown in *table 5.4.* The test rejects the hypothesis of equal median annual CV driving distance before and after EV acquisition at the 0.01-confidence level. The reduction in median annual CV use is 8,000 kilometres, i.e. a reduction of 44.4%.

Table 5.4 - Wilcoxon matched-pairs signed-rank test for equality of median annual cumulative kilometres driven by CV.

H$_0$: CV use post EV = CV use pre EV							
Median post	*Median pre*	*Sign*	*N*	*Sum ranks*	*Expected sum ranks*	*Z-value*	*P-value*
		Positive	1	6	186		
		Negative	23	366	186		
10,000 km	18,000 km	Zero	3	6	6	-4.333	0.000
		Total	*27*	*378*	*378*		

5.1.2.2   *OLS regression*

As for annual total car use, the impact of EV ownership and other factors on annual total CV and HEV specific car use was investigated in an OLS regression model. A Breusch-Pagan rejects the hypothesis of homoscedasticity at the 0.01 significance level. The Huber-White heteroscedasticity-consistent standard errors are therefore used in the regression. The test output can be found in *table 11.4.*

The results of the OLS regression are reported in *table 5.5.*

Table 5.5 - OLS regression for annual driving distance per respondent using all CVs and HEVs the respondent owns. Huber-White robust standard errors. Equation: $nonelectric = \beta_0 + \beta_1 evnum + \beta_2 cvnum + \beta_3 hevnum + \beta_4 envorg + \beta_5 diffcommtime + \beta_6 income + \beta_7 age + \beta_8 hhlicence + u$

Variable	Coefficient	Robust std. error	t	P>|t|	[95% confidence interval]	
Number of EVs	-8 497	2 256	-3.77	0.000	-12 933	-4 060
Number of CVs	16 794	2 140	7.85	0.000	12 586	21 003
Number of HEVs	19 517	4 929	3.96	0.000	9 824	29 210
Environmental organisation	-2 211	1 293	-1.71	0.088	-4 754	332
Diff. in commuting time, PT-CV	114	26	4.42	0.000	63	164
Income	559	416	1.34	0.180	-259	1 378
Age	-127	58	-2.18	0.030	-241	-12
Household driver's license holders	329	1 091	0.30	0.763	-1 817	2 475
N	363					
R²	0.424					

The hypothesis of no effect of the number of EVs a respondent own on annual kilometres driven by CV/HEV is rejected at the 0.01 confidence level. On average, ownership of one EV decreases the annual CV/HEV driving distance by almost 8,500 kilometres ceteris paribus.

The hypotheses of no effect of the number of CVs and HEVs a respondent own on CV/HEV kilometres driven are both rejected at the 0.01 confidence level. Ceteris paribus, an additional CV is expected to increase the annual driven distance by CV/HEV by almost 16,800 kilometres, while a HEV is expected to increase the distance by about 19,500 kilometres.

Moreover, the hypothesis that the difference in commuting time between public transport and personal car has no effect on the annual distance driven by CV/HEV is rejected at the 0.01 confidence level. For each minute lost to the car by using public transport, the annual driven distance is expected to increase by 114 kilometres ceteris paribus.

Additionally, the hypothesis of no effect of the respondents' age on the annual driven distance by CV/HEV is rejected at the 0.05 confidence level. A respondent is expected to drive 127 kilometres less per year for each additional year of age, ceteris paribus.

No significant effects are found of a respondents' income, membership in an environmental organization or the number of driver's license holders in the respondent's household.

5.1.2.3 Heckman selection model

A Heckman two-step selection model is run for CV use for the same reasons as for overall car use. Bootstrapped standard errors with 1,500 repetitions are employed to account for heteroscedasticity in the data.

Table 5.6 summarizes the Heckman two-step selection model results. The model was run multiple times to verify the consistency of the sampled bootstrap standard errors.

Table 5.6 - Heckman two-step selection model regression for annual driving distance per respondent using all CVs and HEVs the respondent owns. Bootstrapped standard errors with 1,500 repetitions. Equation: $nonelectric = \beta_0 + \beta_1 evnum + \beta_2 cvnum + \beta_3 hevnum + \beta_4 envorg + \beta_5 diffcommtime + \beta_6 income + \beta_7 age + \beta_8 hhlicence + u + \rho\lambda(z\gamma)$

Variable	Coefficient	Bootstr. std. error	t	P>|t|	[95% confidence interval]	
Number of EVs	-8 577	2 330	-3.68	0.000	-13 143	-4 011
Number of CVs	16 753	2 190	7.65	0.000	12 460	21 046
Number of HEVs	19 366	5 430	3.57	0.000	8 724	30 007
Environmental organisation	-2 135	1 290	-1.66	0.098	-4 662	393
Diff. in commuting time, PT-CV	113	26	4.27	0.000	61	165
Income	693	809	0.86	0.391	-892	2 278
Age	-109	107	-1.02	0.307	-319	100
Household driver's license holders	652	2 162	0.30	0.763	-3 586	4 890
Income	0.113	0.069	1.630	0.102	-0.022	0.248
Age	0.012	0.009	1.320	0.185	-0.006	0.029
Sex	0.223	0.191	1.170	0.244	-0.152	0.598
Household driver's license holders	0.302	0.175	1.720	0.085	-0.041	0.645
Mills' lambda	3 871	19 047	0.20	0.84	-33 461	41 203
N (total obs.)	406					
N (censored obs.)	53					
N (uncensored obs.)	353					

The selection equation suggests that the number of household members with a driver's license increases a respondent's sample inclusion probability at the 0.1 confidence level. As for total car use, however, the non-significant value of Mills' lambda implies that the hypothesis of no correlation between the error terms of the equations cannot be rejected. Hence, the results are practically equal to the OLS regression with only minor coefficient adjustments.

The main equation rejects the hypothesis that the number of EVs a respondent owns has no effect on annual kilometres driven by CV/HEV at the 0.01 confidence level. On average, the model indicates

that ownership of one EV decreases the annual distance driven by CV/HEV by almost 8,600 kilometres ceteris paribus.

The hypotheses of no effect of the number of CVs and HEVs owned by the respondent on kilometres driven by CV/HEV are both rejected at the 0.01 confidence level. Ceteris paribus, an additional CV is expected to increase the annual distance by almost 16,800 kilometres, while a HEV is expected to increase the distance by almost 19,400 kilometres.

Furthermore, the hypothesis that the difference in commuting time between public transport and personal car has no effect on the annual distance driven by CV/HEV is rejected at the 0.01 confidence level. For each additional minute public transport loses to the car, the annual driven distance is expected to increase by 113 kilometres ceteris paribus.

No significant effects are found of the respondents' age, income, membership in an environmental organization or the number of driver's license holders in the respondent's household.

5.1.3 CVs, public transportation and manual transportation: To work, for journeys >150 km and for everyday activities

This chapter further investigates whether EV owners have changed their total car transportation and their use of CV, public transportation and manual transportation after they bought the EV. The hypotheses are tested with Wilcoxon matched-pairs signed-rank tests.

5.1.3.1 Work

The hypothesis that EV owners have changed their overall car use and their use of CVs, public transportation and manual transportation for commuting after they acquired the EV was tested using Wilcoxon matched-pairs signed-rank tests. *Table 5.7* presents the results.

Table 5.7 - Wilcoxon matched-pairs signed-rank tests for changes in use of transportation mode for commuting to work post vs. pre EV purchase (percentage share of journeys). PT = public transportation.

Ho: Overall car use post EV = Overall car use pre EV							
Median post	*Median pre*	*Sign*	*N*	*Sum ranks*	*Expected sum ranks*	*Z-value*	*P-value*
97 %	95 %	Positive	12	366	225	2.403	0.016
		Negative	3	84	225		
		Zero	22	253	253		
		Total	37	703	703		
Ho: CV use post EV = CV use pre EV							
Median post	*Median pre*	*Sign*	*N*	*Sum ranks*	*Expected sum ranks*	*Z-value*	*P-value*
10 %	95 %	Positive	1	15.5	348.5	-5.028	0.000
		Negative	33	681.5	348.5		
		Zero	3	6	6		
		Total	37	703	703		
Ho: PT use post EV = PT use pre EV							
Median post	*Median pre*	*Sign*	*N*	*Sum ranks*	*Expected sum ranks*	*Z-value*	*P-value*
0 %	0 %	Positive	2	58	176	-2.213	0.027
		Negative	9	294	176		
		Zero	26	351	351		
		Total	37	703	703		
Ho: Cycling/walking post EV = Cycling/walking pre EV							
Median post	*Median pre*	*Sign*	*N*	*Sum ranks*	*Expected sum ranks*	*Z-value*	*P-value*
0 %	0 %	Positive	0	0	87.5	-2.234	0.026
		Negative	5	175	87.5		
		Zero	32	528	528		
		Total	37	703	703		

The Wilcoxon signed-rank test rejects the hypothesis that a car was used for an equal share of work related journeys before and after the EV was bought. The test indicates a significant increase in car use for commuting.

The tests further indicate that EV owners have significantly reduced their use of CVs, public transportation and manual transportation for work related journeys after buying their EVs.

5.1.3.2   Leisure journeys longer than 150 km

The hypothesis that EV owners have changed their overall use of cars, CVs and public transportation for longer leisure journeys after they acquired the EV was tested using Wilcoxon matched-pairs signed-rank tests. *Table 5.8* presents the results.

Table 5.8 - Wilcoxon matched-pairs signed-rank tests for changes in use of transportation mode for leisure journeys longer than 150 km post vs. pre EV purchase (percentage share of journeys). PT = public transportation.

H0: Overall car use post EV = Overall car use pre EV							
Median post	*Median pre*	*Sign*	*N*	*Sum ranks*	*Expected sum ranks*	*Z-value*	*P-value*
90 %	90 %	Positive	1	32	67	-1.044	0.296
		Negative	3	102	67		
		Zero	31	496	496		
		Total	*35*	*630*	*630*		
H0: CV use post EV = CV use pre EV							
Median post	*Median pre*	*Sign*	*N*	*Sum ranks*	*Expected sum ranks*	*Z-value*	*P-value*
90 %	90 %	Positive	0	0	188.5	-3.576	0.000
		Negative	13	377	188.5		
		Zero	22	253	253		
		Total	*35*	*630*	*630*		
H0: PT use post EV = PT use pre EV							
Median post	*Median pre*	*Sign*	*N*	*Sum ranks*	*Expected sum ranks*	*Z-value*	*P-value*
10 %	10 %	Positive	3	102	51	1.732	0.083
		Negative	0	0	51		
		Zero	32	528	528		
		Total	*35*	*630*	*630*		

While the tests indicate no significant changes in overall car use or use of public transportation for leisure journeys longer than 150 km, the hypothesis of equal CV use before and after the EV purchase is rejected at the 0.01 confidence level.

5.1.3.3 *Everyday activities*

The hypothesis that EV owners have changed their overall use of car, CVs, public transportation and manual transportation for everyday activities such as shopping and recreation after they acquired the EV was tested using Wilcoxon matched-pairs signed-rank tests. *Table 5.9* shows the results*.*

Table 5.9 - Wilcoxon matched-pairs signed-rank tests for changes in use of transportation mode for everyday activities post vs. pre EV purchase (kilometres per week). PT = public transportation.

H0: Overall car use post EV = Overall car use pre EV							
Median post	*Median pre*	*Sign*	*N*	*Sum ranks*	*Expected sum ranks*	*Z-value*	*P-value*
110 km	60 km	Positive	10	221.5	121	2.729	0.006
		Negative	1	20.5	121		
		Zero	16	136	136		
		Total	*27*	*378*	*378*		
H0: CV use post EV = CV use pre EV							
Median post	*Median pre*	*Sign*	*N*	*Sum ranks*	*Expected sum ranks*	*Z-value*	*P-value*
12.5 km	60 km	Positive	2	21	187.5	-4.006	0.000
		Negative	23	354	187.5		
		Zero	2	3	3		
		Total	*27*	*378*	*378*		
H0: PT use post EV = PT use pre EV							
Median post	*Median pre*	*Sign*	*N*	*Sum ranks*	*Expected sum ranks*	*Z-value*	*P-value*
0 km	0 km	Positive	1	25	60	-1.302	0.193
		Negative	4	95	60		
		Zero	21	231	231		
		Total	*26*	*351*	*351*		
H0: Cycling/walking post EV = Cycling/walking pre EV							
Median post	*Median pre*	*Sign*	*N*	*Sum ranks*	*Expected sum ranks*	*Z-value*	*P-value*
6 km	8 km	Positive	2	52	65	-0.447	0.655
		Negative	3	78	65		
		Zero	23	276	276		
		Total	*28*	*406*	*406*		

For everyday activities, the hypotheses of equal overall car and CV use before and after EV purchase are rejected at the 0.01 confidence level. The tests indicate an increase in overall car use, and a reduction in CV use. The tests do not indicate significant changes in use of public or manual transportation.

5.2 Attitude analyses

Table 5.10 reports how important a range of issues was to the respondents when deciding to get rid of an electric car they used to own. The question was only relevant to seven respondents, hence no comparative analysis versus other respondent groups.

The respondents most often report *inadequate battery capacity* as important. The second most often reported alternative was that the EV was an *old car in need of replacement*. One respondent also reported that it was of vital importance that the *vehicle was no longer needed*.

Table 5.10 – "Rate the most important reasons why you got rid of your electric car." Asked to respondents who once had, but no longer have, an electric vehicle.

Degree of importance	Inadequate battery capacity	High operation costs	Lapse of need for the vehicle	Old car - needed replacement	Lack of infrastructure	Inadequate support schemes	Change of workplace
No importance 1	14 %	71 %	71 %	57 %	71 %	86 %	100 %
2	0 %	29 %	14 %	0 %	0 %	0 %	0 %
3	29 %	0 %	0 %	0 %	14 %	14 %	0 %
4	0 %	0 %	0 %	0 %	14 %	0 %	0 %
5	0 %	0 %	0 %	14 %	0 %	0 %	0 %
Vital importance 6	57 %	0 %	14 %	29 %	0 %	0 %	0 %
Do not know	0 %	0 %	0 %	0 %	0 %	0 %	0 %
N	7	7	7	7	7	7	7

Table 5.11 summarizes reasons to have little or no interest in buying an EV within the next 12 months. Those who do not currently own an EV and indicated some degree of unlikelihood that they will buy one were asked.

No need for additional vehicles is most frequently reported as important, with 83 % of the respondents giving a score higher than 3. *Inadequate battery capacity* is the second most frequent choice, at 58 % higher than 3. *Lack of infrastructure*, *high procurement cost* and *charging time* follow, with 34 %, 34% and 32 % higher than 3 respectively. With a few exceptions, the remaining alternatives were not attributed much importance. *High operation costs* and *inadequate support schemes* are the categories most rarely indicated as important.

Table 5.11 – "Rate the main reasons why you do not have and/or will not buy an electric car within the next 12 months." The question was asked to those who do not own an EV and have indicated some degree of unlikelihood in: "How likely is it that you will buy an electric car within the next 12 months?"

Degree of importance	Inadequate battery capacity	Charging time	High operation costs	High procurement cost	No need for additional vehicles
No importance 1	23 %	31 %	48 %	33 %	9 %
2	6 %	11 %	16 %	13 %	2 %
3	7 %	13 %	8 %	10 %	4 %
4	11 %	11 %	4 %	11 %	7 %
5	17 %	12 %	2 %	12 %	12 %
Vital importance 6	30 %	9 %	1 %	11 %	64 %
Do not know	6 %	13 %	21 %	11 %	2 %
Importance > 3	58 %	32 %	7 %	34 %	83 %
N	392	384	376	379	407
Degree of importance	Lack of infrastructure	Inadequate support schemes	Long distance to workplace	Unattractive car models	Unknown/new technology
No importance 1	31 %	52 %	64 %	55 %	55 %
2	8 %	14 %	9 %	11 %	11 %
3	15 %	9 %	6 %	10 %	12 %
4	12 %	3 %	5 %	7 %	10 %
5	9 %	1 %	5 %	6 %	3 %
Vital importance 6	12 %	2 %	7 %	5 %	2 %
Do not know	12 %	17 %	4 %	7 %	6 %
Importance > 3	34 %	7 %	16 %	18 %	15 %
N	386	381	383	382	383

Table 5.12 summarizes reasons to find an EV appealing between two groups: Current and previous EV owners (top half) and those who have expressed interest in acquiring an EV, but do not currently own one (bottom half). Both groups were asked the same question with the same alternatives.

Wilcoxon rank-sum tests could not reject the hypothesis of equal answers between the groups.

Table 5.13 lists the factors ranked according to the share of respondents who have given the factor an importance score higher than 3. *Beneficial fuel cost* and *environmental considerations* hold the highest ranks in both groups - both overall and of the factors not attributable to supportive measures. The third ranking factor in the EV owner group is *reduce transport costs to workplace*, while *need car for short trips* ranks third in the non-EV group.

Of the factors attributable to supportive measures, the three most commonly chosen are the same between groups: *Favourable purchase price, free passage of tollbooths* and *low annual road use fee.* The purchase price holds the highest rank in both groups, while f*ree passage of tollbooths* is ranked higher than *low annual road use fee* in the EV owner group, and vice versa in the non-EV group. The importance and ranking of the remaining factors are found in *table 5.12* and *table 5.13*.

Table 5.12 - "How important are these factors to you in making an electric car appealing?" The top half of the table represents those who own or have previously owned an EV. The bottom half represents those who do not have an EV, but have indicated some degree of likelihood in: "How likely is it that you will buy an electric car within the next 12 months?" The percentages are the share of each group who answered a particular value. The "Ranksum p-value"-row reports the p-values of Wilcoxon rank-sum tests for the equality of answers between the two groups.

Current and previous EV owners / Level of importance	Access to public transport lane	Free passage of toll booths	Free parking	Free ferry	Beneficial fuel cost	Favorable purchase price	Low annual road use fee	Environmental considerations	Low noise	Change of workplace	Avoid change of transportation to workplace	Reduce transport costs to workplace	Reduce travel time to workplace	Need car for short trips
No importance 1	33%	2%	14%	50%	5%	9%	5%	9%	11%	70%	52%	14%	52%	39%
2	26%	7%	9%	16%	0%	5%	16%	9%	11%	5%	5%	2%	5%	11%
3	2%	20%	27%	11%	7%	9%	16%	2%	32%	0%	7%	7%	2%	7%
4	12%	14%	9%	11%	9%	14%	14%	14%	25%	2%	7%	23%	5%	2%
5	12%	34%	32%	7%	30%	34%	34%	16%	9%	7%	7%	23%	5%	20%
Vital importance 6	16%	23%	9%	5%	48%	25%	14%	48%	11%	11%	20%	32%	30%	18%
Do not know	0%	0%	0%	0%	2%	2%	2%	2%	0%	2%	2%	0%	2%	2%
N	43	44	44	44	44	43	44	44	44	43	44	44	44	44
Other interested respondents / Level of importance	**Access to public transport lane**	**Free passage of toll booths**	**Free parking**	**Free ferry**	**Beneficial fuel cost**	**Favorable purchase price**	**Low annual road use fee**	**Environmental considerations**	**Low noise**	**Change of workplace**	**Avoid change of transportation to workplace**	**Reduce transport costs to workplace**	**Reduce travel time to workplace**	**Need car for short trips**
No importance 1	33%	4%	9%	37%	4%	6%	6%	0%	7%	54%	44%	19%	46%	19%
2	24%	11%	15%	20%	2%	2%	4%	6%	20%	15%	9%	4%	13%	13%
3	13%	22%	26%	19%	4%	6%	9%	6%	20%	9%	13%	19%	15%	7%
4	15%	24%	15%	9%	13%	24%	19%	7%	15%	7%	4%	9%	11%	24%
5	11%	24%	28%	11%	39%	39%	44%	26%	15%	2%	15%	24%	7%	22%
Vital importance 6	5%	15%	9%	4%	41%	20%	20%	56%	19%	2%	7%	22%	9%	15%
Do not know	0%	0%	0%	2%	0%	6%	0%	0%	0%	13%	9%	4%	0%	0%
N	55	54	55	55	55	55	55	54	52	55	55	54	55	54
Ranksum p-value:	0.78	0.98	0.65	0.81	0.17	0.59	0.46	0.23	0.75	0.45	0.83	0.94	0.79	0.65

Table 5.13 - Ranked share of respondents who have indicated an importance of 4-6 in the EV owner and regular car owner group (non-EV) respectively.

EV		Non-EV	
Variable	**Importance > 3**	**Variable**	**Importance > 3**
Beneficial fuel cost	86 %	*Beneficial fuel cost*	93 %
Environmental considerations	77 %	*Environmental considerations*	89 %
Reduce transport costs to workplace	77 %	*Favorable purchase price*	83 %
Favorable purchase price	73 %	*Low annual road use fee*	83 %
Free passage of toll booths	70 %	*Free passage of toll booths*	63 %
Low annual road use fee	61 %	*Need car for short trips*	61 %
Free parking	50 %	*Reduce transport costs to workplace*	56 %
Low noise	45 %	*Free parking*	52 %
Need car for short trips	41 %	*Low noise*	48 %
Access to public transport lane	40 %	*Access to public transport lane*	31 %
Reduce travel time to workplace	39 %	*Reduce travel time to workplace*	28 %
Avoid change of transportation to workplace	34 %	*Avoid change of transportation to workplace*	26 %
Free ferry	23 %	*Free ferry*	24 %
Change of workplace	20 %	*Change of workplace*	11 %

Table 5.14 summarizes the car owners' tollbooth passing frequency grouped on whether or not they own an EV. The Wilcoxon rank-sum test in *table 5.15* rejects the hypothesis of equal frequencies between groups. The EV owners pass a tollbooth significantly more often than other car owners do.

Table 5.14 - "Approximately, how often do you pass a tollbooth?" EV owners versus other car owners (non-EV).

Frequency	Non-EV	EV
Multiple times a day	9 %	30 %
Daily	16 %	16 %
About twice a week	19 %	16 %
About weekly	18 %	11 %
About every fortnight	20 %	19 %
Less frequently	17 %	5 %
Never	0 %	3 %
N	429	37

Table 5.15 - Wilcoxon rank-sum test for equal tollbooth passing frequency among EV owners and other car owners (non-EV). Lower median value indicates higher frequency.

		H_0: Tollbooth passing frequency equal between groups					
Median EV	*Median non-EV*	*Group*	*N*	*Sum ranks*	*Expected sum ranks*	*Z-value*	*P-value*
3	4	Non-EV	429	102 388	100 172	2.864	0.004
		EV	37	6 423	8 640		
		Total	*466*	*108 811*	*108 811*		

Table 5.16 shows that 89 % of EV owners report that it is at least somewhat likely that they will replace their current EV with another EV in the future. While none of the respondents explicitly stated replacement unlikely, 11 % answered that they do not know what they will do.

Table 5.16 - "Will you replace your current electric car with another electric car in the future?" Question asked to EV owners only.

Will definitely replace	43 %
Very likely	41 %
Somewhat likely	5 %
Somewhat unlikely	0 %
Very unlikely	0 %
Will definitely not replace	0 %
Do not know	11 %
N	37

6 Discussion

The discussion chapter reviews the results of the analyses, and provides context for the findings. Chapter 6.1 reviews substitution effects related to research question 1, while chapter 6.2 addresses attitudes related to research question 2 and 2.1. The research questions are:

1) *To what extent do electric vehicles substitute the use of conventional vehicles, public transportation, manual transportation and non-transportation?*

2) *How important are the different attributes of the policy package for purchase and use of electric vehicles?*

   2.1) *Do EV owners rate the attributes differently than people who do not own EVs?*

Chapter 6.3 discusses strengths and weaknesses in the thesis, and chapter 6.4 suggests further research based upon this analysis.

6.1 Substitution effects

6.1.1 EVs replace CVs in use

Both the Wilcoxon signed-rank tests and the OLS and Heckman regression models indicate that EVs replace CVs in use. Nevertheless, neither method indicates full substitution. In the sample, owning an EV reduces annual CV travel about 40%*.*

The signed-rank tests for specific activities suggest that EVs mainly substitute CVs for commuting and everyday activities. For commuting, the median CV use fell from 95% to 10% of the trips after the EV purchase, and 89% of the respondents decreased their CV use to some extent. For everyday activities, the median CV use shrunk from 60 kilometres to 12.5 kilometres per week, and 85% said they had decreased their CV use for such trips. For longer journeys, 37% said they used the CV less after acquiring an EV, despite no change in the median CV use. The limited battery capacity should explain the comparatively small effect for such trips.

The finding that EVs only partly substitute CVs is unsurprising, given that respondents own both vehicle technologies at the same time. Owning both, but using only one would be an irrational expense, since the respondents would have been better off by selling cars they did not use. Although an unsurprising finding, the implication of a low substitution rate is important: There is correspondingly small environmental benefits per monetary unit spent on EV subsidies. The findings on EV substitution of CVs are in line with the literature reviewed in chapter 2.

6.1.2 EVs increase overall transportation

The Wilcoxon signed-rank tests and the OLS and Heckman regression models indicate that EVs increase car transportation, both in general and for specific activities. These findings are in line with recent literature reviewed in chapter 2.

The implication of increased overall car transportation is that EVs substitute public, manual or non-transportation in use. The tests for changes in transportation preferences for commuting, longer journeys and everyday activities indicate that EV substitution of public and manual transport is limited. This suggests that increased overall car transportation mainly replaces non-transport. As noted in chapter 1, increased car transportation results in higher traffic loads. This could in turn

mean more accidents, more congestion, more road dust, and more noise[11]. Increased congestion, especially where EVs are allowed in public transport lanes, could worsen and extend of rush hours.

As Figenbaum et al. (2014) pointed out, however, care should be taken when interpreting increased car transportation among EV owners. Although the tests show that EV owners travel further by car after their EV purchase and that an additional EV increases annual car transportation versus other car owners, the EV does not necessarily cause the differences. EV owners may be predisposed to travel further, or the decision to buy an EV might stem from an increased need for car travel.

If the increased use is a result of changing needs for car travel, the actual substitution depends on what the EV owners had done if not buying the EV. The options include buying a CV, using public or manual transportation, or to reduce transportation needs, for example by moving or changing workplace. In line with Figenbaum et al. (2014), however, it is arguable that EVs have advantages that explain increased use beyond changes to and differences in transportation needs. As argued in chapter 1, EVs have lower marginal costs in use than CVs have. Hence, economic incentives to reduce personal car transport are lower with an EV than a CV once bought. In addition, incentives such as free parking and access to public transport lanes make EVs convenient to use. These factors should lower the threshold for using the car, and explain why EV owners use their cars in situations when they previously would have avoided travel altogether.

Moreover, an EV owner - consciously or subconsciously - may rationalize increased driving with the EV's low environmental impact. This is in line with Klöckner et al. (2013), who concluded that EV owners may feel that they have already *"done their share"* by buying an environmentally friendly vehicle, and therefore feel less compelled to reduce their driving. As Klöckner et al. (2013) point out, this fits well with studies on recycling, e.g. Thøgersen (1999), who find that "*Performing an environmentally friendly behaviour, such as recycling, seem to have a negative impact (spillover effect) on the feeling of obligation to do other things."*

6.1.3 EVs replace public transport and manual transport in use

The tests conducted on the data sample indicate minor, but statistically significant EV substitution effects on public and manual transportation for commuting. Although some respondents decreased their use of public and manual transportation, the median use did not change. 70% and 86% respectively held on to their public and manual transportation habits when they became EV owners. Moreover, the tests indicated no significant EV substitution of public and manual transport for everyday activities or long journeys.

The implication is that EVs only to a limited extent substitute public and manual transportation, and when substitution takes place it is mainly for trips to and from work. The modest size of this effect should be relieving to policy makers. Increased car use at the expense of public and manual transport would be a counter-productive result of the EV subsidies. In light of the strong link between car use and timesaving versus public transport, increasing the frequency and convenience of public transport could help offset this effect.

The findings are in line with recent literature reviewed in chapter 2, although some studies suggest more severe effects than found in this thesis.

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[11] At speeds over 50 km/h, the tire noise equals or exceeds the engine noise (Sandberg and Ejsmont 2000), referred in Holtsmark and Skonhoft (2014). Therefore, unless going slowly, EVs and CVs make roughly the same amount of noise.

6.1.4 Summary

In the sample, EVs reduce CV use by about 40%, but increase overall car transportation. Effects on public and manual transportation are minor, and only significant for commuting. The implications of these findings are mixed. While CV to EV substitution yield environmental benefits, increased car transportation may worsen issues related to higher traffic volumes. Moreover, replacement of public and manual transportation would have negative implications for EV policy effectiveness. The finding that such effects are limited should therefore be relieving to policy makers.

Although the results fit well with the literature review, it should be noted that the sample of respondents is closely linked to NMBU. Caution is therefore advised in extrapolating findings to the national level.

6.2 Attitude analyses

In the data sample, EV owners and other respondents who are interested in buying EVs agree that economic benefits are decisive in making EVs appealing. This finding fits well with the literature review in chapter 2, as well as the observation that EV owners pass a tollbooth significantly more often than other drivers do[12]. Moreover, both groups put great emphasis on environmental considerations. While this finding fits well with the literature review, it contrasts observed behaviour in the sample: EV ownership increases overall car transportation and EVs substitute CV use only by about 40%. Although environmental considerations may be important in theory, the discrepancy between stated preferences and observed behaviour suggests that economic benefits dominate environmental considerations in practice.

The two policy related attributes that rank lowest are free ferries and access to public transport lanes. "Free ferries" is not surprising given that the sample is from a region where ferry travel is quite rare. Respondents have given free ferries little importance in the studies reviewed in chapter 2 as well, and this is intuitive given the spatial limitations of ferry transport. Access to public transport lanes, however, has been important to the participants in earlier studies, and its low ranking in this thesis is therefore unexpected. It might be that preferences have changed over time, or that increased congestion in the public transport lanes has weakened this benefit. It might also be that public transport lanes are not particularly relevant to the majority of the respondents in this sample.

Further, it is interesting to note that only 7% of those not interested in buying EVs find the policy package inadequate. Their main objection to buying an EV is the limited battery capacity. This suggests that investments in battery technology research could be effective in getting this group to trade their CVs for EVs, and perhaps more so than strengthening the current policy scheme would be.

6.2.1 Summary

In the sample, there are no significant attitude differences between EV owners and other respondents interested in buying EVs; both groups rank the economic EV benefits highly. Respondents also state that environmental considerations are important. There is, however, a discrepancy between stated preferences and observed behaviour. Although car owners rank environmental considerations highly in the survey, they increase overall car transportation and reduce their CV use by only 40% when they buy an EV. Among respondents without intention to

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[12] Note that it also could be that people in urban areas, where tollbooths are common, are more likely to acquire EVs in the first place, thus passing them more often.

become EV owners, the most important reason for their lack of interest is the limited battery capacity of EVs. Solving range issues could therefore be an effective measure to increase this group's EV adoption.

6.3 Strengths and weaknesses

This thesis represents the first econometric study specifically assessing EV substitution effects related to the Norwegian EV policy package. Its main strengths compared to earlier studies is that it controls for more variables than just the EV, and that it uses multiple methods to assess substitution effects.

The rank-sum tests used to measure change in EV owners' behaviour as they acquire EVs open for additional questions related to how well the regression models capture change in attitudes for new EV owners. The regression models in this thesis include control variables, such as income, age and the number of driver's license holders in the household. However, how well they capture changes in attitudes remains uncertain. The included control variables allow the effects of owning an EV to be measured more purely than in earlier studies. However, controlling for changing attitudes would probably have further improved the measurements. Such issues were hard to identify before undertaking the study, and I did therefore not have this aspect in mind when I designed the survey. This means that the regression models were unable to capture this as well as they could have, given what I have learned from my analysis.

Although the Heckman selection model did not indicate significant bias in becoming a car owner within the sample, controlling for it makes the results more robust. Besides, using the Heckman approach would be relevant in a replication of the study.

Unfortunately, the sample could not be randomly drawn among all Norwegian car owners. As mentioned in chapter 3, the majority of the respondents were employees at NMBU. Because of this, many of the respondents in the sample were highly educated with above average incomes. Although the regression models controlled for socioeconomic factors, people with low incomes were scarcely represented. This made it difficult to control properly for these factors. Moreover, the EV group was quite small. The chance of unrepresentative samples increases with decreasing sample size, as it becomes more probable that all respondents are non-typical by chance[13]. The results do however fit well with the literature review. This observation indicates that effects found in this thesis are unlikely to be spurious, and that the EV owner group is similar to EV owners outside the sample.

Lastly, the relatively high number of tests increases the chance that some are significant due to spurious correlations. Since the results fit well with the literature review and the reasoning behind the hypotheses, it is reasonable to conclude that this risk is low.

6.4 Further research

Although internally valid, the sample's close relation to NMBU weakens the study's external validity. Moreover, the relatively low number of EV owners represented increases the risk of non-representative observations. A large, random sample replication of the study could counter these issues and give room for interesting retests of the hypotheses. To replicate the study on a broader sample would be a sound approach to science, and could serve to either strengthen or reject findings at the national level. Such a study would yield a good foundation for policy recommendations. Survey

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[13] For the interested reader, Kahneman (2011) explains this well.

participants could be randomly selected from the Norwegian Central Register of Motor Vehicles to ensure a representative sample. To get a sufficiently large EV group, the draw frequency could be adjusted to inflate the share of EV owners in the sample, as done by Klöckner et al. (2013). Given availability, an optional approach to respondent-reported driving distances could be using insurance data.

Moreover, as mentioned in chapter 4 and 6.3, gathering data on additional control variables, possibly for use in instrumental variable regressions, could be relevant to address potential endogeneity, and to control for attitude changes or unmeasurable variables. These adjustments could further improve the validity of the models.

In a larger sample, it could also be relevant to take a closer look at those who have sold their EVs. This approach could give input on which aspects of EV ownership people find challenging, and allow policy makers to adjust accordingly.

7 Conclusions

The research questions of this thesis are:

1) *To what extent do electric vehicles substitute the use of conventional vehicles, public transportation, manual transportation and non-transportation?*

2) *How important are the different attributes of the policy package for purchase and use of electric vehicles?*

    2.1) *Do EV owners rate the attributes differently than people who do not own EVs?*

In this sample, EVs partially substitute CVs, but increase overall car transport. While it is, given a reasonably clean electricity mix, good for the environment that EVs reduce CV use, the implication of increased overall car transportation is a higher traffic load.

Further, EVs substitute public and manual transport for trips to and from work in the sample, but only to a limited extent. Although a few respondents have decreased their use of public and manual transportation, the vast majority have not changed behaviour. No significant substitution is found for long journeys and everyday activities.

As shown in the attitude analyses, both EV owners and people interested in becoming EV owners consider the EVs' economic benefits important in making them appealing. There are no significant differences between the two groups' ranking of EV attributes. Among those less interested in EVs, limited battery capacity is the main concern. This finding suggests that solving range issues would lower the need for other strong incentives to maintain or increase EV adoption.

It is clear that the strong incentives favouring EVs have led to high adoption rates. However, the increase in car travel and limited CV replacement in the sample highlights the importance of considering externalities in policy design. Because of the externalities, adding EVs to the car fleet is a less environmentally friendly act than it appears. This, in turn, has negative consequences for the efficiency of the policy package.

If only long-term objectives, such as technology learning and infrastructure development, matter to policy makers, the implications of these analyses might be of limited interest. If short-term objectives are important too, however, increased car transportation and incomplete CV substitution should encourage rethinking of the current supportive scheme. Tuning the policy package to increase efficiency would yield both environmental and economic benefits. Because of this sample's close relation to NMBU, the study should be replicated in a broader sample. This would allow for more solid policy inferences. The inclusion of carefully formulated questions to capture how attitudes change when people become EV owners would further strengthen the results.

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9 List of figures

10 List of tables

11 Appendix

11.1 Questions asked in the survey

1) Please tick how many vehicles you own of each of the following types: *(0-4+)*
   a. Petrol/diesel
   b. Electric
   c. Hybrid

2) Do you have access to an electric car at the workplace?
   a. Yes
   b. No
   c. Do not know

3) Have you previously owned an electric car?
   a. Yes
   b. No

4) Rate the most important reasons why you got rid of your electric car. *(1-6 and do not know)*
   a. Inadequate battery capacity
   b. High operating costs
   c. Lapse of need for the vehicle
   d. Old car – needed replacement
   e. Lack of infrastructure (fast public chargers etc.)
   f. Inadequate support schemes
   g. Change of workplace

5) Are there reasons why you got rid of the electric car that did not appear in the previous question?

6) How likely is it that you will buy an electric car within the next 12 months?
   a. Will definitely buy
   b. Very likely
   c. Somewhat likely
   d. Somewhat unlikely
   e. Very unlikely
   f. Will definitely not buy
   g. Do not know

7) Rate the main reasons why you do not have and/or will not buy an electric car within the next 12 months. *(1-6 and do not know)*
   a. Inadequate battery capacity
   b. Charging time
   c. High operating costs
   d. High procurement costs
   e. No need for additional vehicles
   f. Lack of infrastructure (fast public chargers etc.)
   g. Inadequate support schemes
   h. Long distance to workplace
   i. Unattractive car models
   j. Unknown/new technology

8) Are there reasons why you do not have and/or will not buy an electric car that did not appear in the previous question?

9) Is your current electric car the first electric car you have owned?
   a. Yes
   b. No

10) Which year did you buy your first electric car?

11) Which year did you buy your current electric car?

12) Will you replace your current electric car with another electric car in the future?
   a. Will definitely replace
   b. Very likely
   c. Somewhat likely
   d. Somewhat unlikely
   e. Very unlikely
   f. Will definitely not replace
   g. Do not know

13) Rate the most important reasons why you will not acquire a new electric car in the future.
   (1-6 and do not know)
   a. Inadequate battery capacity
   b. Charging time
   c. High operating costs
   d. High procurement costs
   e. No longer need the vehicle
   f. Lack of infrastructure (fast public chargers etc.)
   g. Inadequate support schemes
   h. Change of workplace

14) Are there reasons why you will not acquire a new electric car in the future that did not appear in the previous question?

15) How important are these factors to you in making an electric car appealing? *(1-6 and do not know)*
   a. Access to public transport lane
   b. Free passage of toll booths
   c. Free parking
   d. Free ferry
   e. Beneficial fuel cost
   f. Favorable purchase price
   g. Low annual road use fee
   h. Environmental considerations
   i. Low noise
   j. Change of workplace
   k. Avoid changing mode of transportation en route to workplace
   l. Reducing transport costs to workplace
   m. Reduce travel time to workplace
   n. Need car for short trips

16) Are there other factors that make an electric car appealing to you, but did not appear in the previous question?

17) How important do you find it to consider these factors when buying an electric car? *(1-6 and do not know)*
    a. Operating costs
    b. Infrastructure (fast public chargers etc.)
    c. Range/battery capacity
    d. Battery charging time
    e. Battery lifetime

18) What is the approximate annual mileage of the electric car (kilometers)?

19) Did you own a car with a combustion engine or a hybrid car before you bought the electric car?
    a. Yes
    b. No

20) What is the approximate annual mileage of the combustion engine/hybrid car (kilometers)?

21) What was the approximate annual mileage of the combustion engine/hybrid car BEFORE you bought the electric car (kilometers)?

22) Approximately, how often do you pass a tollbooth?
    a. Multiple times a day
    b. Daily
    c. About twice a week
    d. About weekly
    e. About every fortnight
    f. Less frequently
    g. Never

23) Do you have the same workplace as before purchasing an electric car?
    a. Yes
    b. No

24) Approximately what share of your total work journey do you undertake with each mode of transportation? *(10% increments)*
    a. Combustion engine/hybrid car
    b. Electric vehicle *(only shown to EV owners)*
    c. Public transport
    d. Cycling/walking

25) Approximately, how long is your work journey if you are travelling by car (one way, kilometers)?

26) Approximately, how long was your work journey BEFORE you bought the electric car if you were travelling by car (one way, kilometers)?

27) Approximately, how much time does your work journey take if you are travelling by car (one way, minutes)?

28) Approximately, how much time did your work journey take BEFORE you bought the electric car if you were travelling by car (one way, minutes)?

29) Approximately, how much time does your work journey take if you are travelling by public transport (one way, minutes)?

30) Approximately, how much time did your work journey take BEFORE you bought the electric car if you were travelling by public transport (one way, minutes)?

31) Are there public transport lanes along your way to work?
    a. Yes
    b. No

32) Think of a typical working year for you. What approximate share of the journeys were undertaken using the following modes of transportation? *(1% increments)*
    a. Electric car
    b. Combustion engine/hybrid car
    c. Public transport
    d. Cycling/walking

33) Of your leisure journeys longer than 150 kilometers, what approximate share of them were undertaken using the following modes of transportation in 2014? *(10% increments)*
    a. Combustion engine/hybrid car
    b. Electric car
    c. Public transport

34) Of your leisure journeys longer than 150 kilometers, what approximate share of them were undertaken using the following modes of transportation in the last year that you did not own an electric car? *(10% increments)*
    a. Combustion engine/hybrid car
    b. Public transport

35) Approximately how many kilometers do you usually travel each week with the following modes of transportation when going for shopping trips, recreational activities and similar journeys?
    a. Combustion engine/hybrid car
    b. Electric car
    c. Public transport
    d. Cycling/walking

36) Approximately how many kilometers did you usually travel each week with the following modes of transportation when going for shopping trips, recreational activities and similar journeys BEFORE you bought the electric car?
    a. Combustion engine/hybrid car
    b. Public transport
    c. Cycling/walking

37) How many passenger cars does your household have at its disposal? Give the number for each of the following: *(0-5)*
    a. Electric car
    b. Combustion engine car
    c. Hybrid car

38) Which carmaker has produced your electric car?

39) How many members do your household have?

40) How many of your household members (yourself included) have a driving license for passenger cars?

41) Sex
   a. Male
   b. Female

42) Birth year (select from dropdown menu below)

43) What is your highest completed level of education?
   a. Primary/lower secondary school (7-10 years)
   b. Upper secondary school
   c. Trade certificate
   d. 3-4 years of university/college education (bachelor/cand.mag.)
   e. 5 years of university/college education or professional education (dentist, lawyer, veterinarian etc.)
   f. PhD/Doctorate
   g. Unsure/do not know

44) To what occupational group do you belong?
   a. Student
   b. Employee
   c. Self-employed
   d. Retired
   e. Disabled/social security
   f. Unemployed
   g. Other

45) What was your approximate gross income in 2014? Your gross income is your income before tax deduction.
   a. 100 000 NOK or less
   b. 100 001 - 200 000 NOK
   c. 200 001 - 300 000 NOK
   d. 300 001 - 400 000 NOK
   e. 400 001 - 500 000 NOK
   f. 500 001 - 600 000 NOK
   g. 600 001 - 700 000 NOK
   h. 700 001 - 800 000 NOK
   i. 800 001 - 900 000 NOK
   j. 900 001 - 1 000 000 NOK
   k. 1 000 001 - 1 100 000 NOK
   l. 1 100 001 - 1 200 000 NOK
   m. More than 1 200 000 NOK
   n. Do not wish to answer

46) What was your household's approximate combined gross income in 2014? This is the total income of all household members (including yourself) before tax deduction.
   a. 100 000 NOK or less
   b. 100 001 - 200 000 NOK
   c. 200 001 - 300 000 NOK
   d. 300 001 - 400 000 NOK
   e. 400 001 - 500 000 NOK
   f. 500 001 - 600 000 NOK
   g. 600 001 - 700 000 NOK
   h. 700 001 - 800 000 NOK
   i. 800 001 - 900 000 NOK
   j. 900 001 - 1 000 000 NOK
   k. 1 000 001 - 1 100 000 NOK
   l. 1 100 001 - 1 200 000 NOK
   m. 1 200 001 - 1 300 000 NOK
   n. 1 300 001 - 1 400 000 NOK
   o. 1 400 001 - 1 500 000 NOK
   p. 1 500 001 - 1 600 000 NOK
   q. 1 600 001 - 1 700 000 NOK
   r. 1 700 001 - 1 800 000 NOK
   s. 1 800 001 - 1 900 000 NOK
   t. 1 900 001 - 2 000 000 NOK
   u. More than 2 000 000 NOK
   v. Do not wish to answer

47) Are you a member of an environmental organization?
   a. Yes
   b. No
   c. Unsure/do not know

48) Postcode

49) Postcode to workplace/campus

50) Postcode to workplace/campus BEFORE you bought the electric car

51) Do you have any comments on the survey?

11.2 Correlation matrix for OLS and Heckman regression variables

Table 11.1 - Correlations between the variables in the OLS and Heckman regression models run in the thesis. PT = public transportation.

	Total car transport	CV and HEV transport	Number of EVs	Number of CVs	Number of HEVs	Environmental organisation	Diff. commtime PT vs. car	Income	Age	Household driver's licenses	Sex
Total car transport	1										
CV and HEV transport	0.9467	1									
Number of EVs	0.0822	-0.2017	1								
Number of CVs	0.5266	0.5652	-0.1568	1							
Number of HEVs	0.1691	0.1013	0.0967	-0.1110	1						
Environmental organisation	-0.0798	-0.0931	0.0049	-0.0635	0.0585	1					
Diff. commtime PT vs. car	0.3079	0.2735	0.0404	0.0903	0.0500	-0.0447	1				
Income	0.0934	0.0902	0.0241	0.0966	0.0197	0.0858	-0.0205	1			
Age	0.0163	0.0004	0.0547	0.1268	0.0735	0.1236	-0.0336	0.3444	1		
Household driver's licenses	0.2094	0.2267	-0.0403	0.3838	-0.0288	0.0011	0.0343	0.0859	0.0793	1	
Sex	0.0212	0.0164	0.0426	0.1017	0.0065	0.1464	0.0002	0.2420	0.2041	0.0135	1

11.3 Summary statistics

Table 11.2 - Summary statistics. • indicates an EV owner specific variable. PT = public transportation.

	Variable	N	Mean	Std. dev.	Min.	Max.
	Number of EVs	519	0.06	0.25	0	2
	Number of CVs	519	1.10	0.66	0	4
	Number of HEVs	519	0.05	0.22	0	1
	Household driver's license holders	519	1.84	0.70	0	6
•	Annual kilometres, sum all EVs owned	30	16 167	8 150	1 000	35 000
•	Annual kilometres, sum all CVs owned	30	10 517	6 075	1 000	25 000
•	Annual kilometres, sum all CVs owned before EV bought	27	19 741	8 985	2 000	40 000
•	Annual kilometres, sum all CVs and EVs owned	30	28 417	12 802	10 000	60 000
	Annual kilometres, sum all CVs and HEVs owned	404	23 850	17 242	1 000	105 000
	Commuting distance	504	21	22	0	160
•	Diff. in commuting time, PT - CV	28	36	29	-31	95
	Diff. in commuting time, PT - CV	368	30	32	-61	220
	Age	512	46	12	20	84
	Environmental organisation membership	510	0.23	0.42	0	1
	Income	516	6.48	2.36	1	14
	Sex	502	0.46	0.50	0	1

11.4 Tests

Table 11.3 - Shapiro-Wilk tests for normal data. Overall and CV/HEV specific car transportation. H_0: Normally distributed data.

Variable	Obs	Z-value	P-value
Overall car transportation	27	2.497	0.00626
CV/HEV transportation	27	1.888	0.02954

Table 11.4 - Breusch-Pagan tests for heteroscedasticity. Overall and CV/HEV specific car transportation. H_0: Constant variance.

Regression	Chi sq.	P-value
Overall car transportation	138.65	0.000
CV/HEV transportation	143.06	0.000