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Towards a sustainable use of electric vehicles

Final report

Györző Gidofalvi, Ehsan Saqib, Anastasios Skoufas, Iqbal Surahman, Jia Guo, Joram Langbroek, Joel Franklin, Yusak Susilio

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Preface

This report titled *Towards a sustainable use of electric vehicles* presents the results of a research project which is one of six funded projects in the 2017 call: “Sustainable and Efficient Transport in Society”. The research results aim to increase knowledge of how the planning of the transport system can contribute to achieving climate and environmental goals.

The project has been funded with the Swedish Environmental Protection Agency’s environmental research grant to support the Swedish Environmental Protection Agency’s and the Swedish Agency for Marine and Water Management’s knowledge needs.

The authors of this report are Györö Gidofalvi, Ehsan Saqib, Anastasios Skoufas Iqbal Surahman, Jia Guo, Joram Langbroek, Joel Franklin, and Yusak Susilio at the KTH Royal Institute of Technology.

The authors are responsible for the content of the report.

Stockholm, July 2022

Maria Ohlman
Head of the Sustainability Department

Förord

Denna rapport med titeln *Towards a sustainable use of electric vehicles* presenterar resultaten av ett forskningsprojekt som är ett av sex beviljade projekt inom utlysningen ”Hållbar och effektiv transport i samhället”, från 2017. Forskningsresultaten syftar till att öka kunskapen om hur planeringen av transportsystemet kan bidra till att uppnå klimat- och miljömålen.

Projektet har finansierats med medel från Naturvårdsverkets miljöforskningsanslag till stöd för Naturvårdsverkets och Havs- och vattenmyndighetens kunskapsbehov.

Denna rapport är författad av Gyözö Gidofalvi, Ehsan Saqib, Anastasios Skoufas Iqbal Surahman, Jia Guo, Joram Langbroek, Joel Franklin, och Yusak Susilio på Kungliga Tekniska Högskola KTH.

Författarna ansvarar för rapportens innehåll.

Stockholm, juli 2022

Maria Ohlman
Chef för Hållbarhetsavdelningen

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1. Summary

A large-scale transition towards electric vehicles would have large environmental benefits regarding energy-efficiency and reduced air pollution in urban areas. Nevertheless, the uptake of electric vehicles is still at a low level. The upfront investment cost and the limited range of electric vehicles are important hindering factors for electric vehicle adoption. On the other hand, the use of electric vehicles is relatively cheap. This is mainly due to the fact that electricity is cheaper per kilometer than petrol or diesel, as well as due to the fact that electric vehicles are more energy efficient.

Currently, policy measures are focused on electric vehicle adoption, and in many countries around the world, policy incentives are provided. However, with the low marginal cost of electric vehicle use and battery developments resulting in higher range, there is a risk for increased car travels, which would have negative environmental effects and might increase congestion. In this project, this risk for increased car use is investigated: the conditions under which increased car use is likely to occur and the influence of policy measures and the provision of charging infrastructure are explored using an interdisciplinary approach. Stated adaptation experiments are used to investigate the behavioral alterations of car users when changing to an electric vehicle. In particular, to combat the negative externalities in increased car uses after EV adoption, the study has designed three incentives that aim to reduce private car trips into the already congested city centers. The incentives were a combination of 1) free EV parking and charging outside of the congestion area (of Stockholm) and an additional reduced-fare 2) public transport- or 3) e-scooter. To test the effectiveness of the incentives, the study has designed a stated adaptation experiment and a custom web map based survey tool that most importantly allowed the respondents to record desired locations for their incentives, thereby providing an indication of public charging infrastructure demand and "entrance parking" (infartsparkering).

400 of the 7000 contacted registered EV users have answered the survey. The so collected data was analyzed using both descriptive statistics and statistical travel behavior modelling. While based on the small sample size the modelling results should be treated with caution, the modelling results can be interpreted as follows:

- The incentives are more effective in deterring female, young (18–24), or part-time employed respondents from driving into the city centers than their male, older, or full-time employed counterparts.
- The offer of free parking and charging can "attract" respondents who are currently not parking in the congestion zone or have a difficult time finding parking spot in the congestion zone. Conversely, those who already have confidence in parking opportunities are harder to sway toward leaving the car outside the city center.
- Respondents who are regular public transport users (i.e., are holders of a monthly public transport pass) are easier to attract with an offer of a reduced-fare public transport.

- Independent of their public transportation enjoyment level, respondents who have higher perceived safety in public transportation are more likely of choosing an offer of a reduced-fare public transport compared to those who have lower perceived safety levels.
- Respondents who “strongly” enjoy the use of e-scooters and e-bicycles are more likely to take an offer a reduced fare for this mode of transport since this incentive increases their opportunities to use these “enjoyed” modes.

While an initially planned detailed stakeholder analysis could not be carried out during the project period, based on the above results the study outlined several methodologies for stakeholder analysis and policy roadmap creation. Moreover, the above knowledge gained from the travel behavior modelling work is believed to be useful input for ongoing and future policy work towards sustainable electric vehicle use.

2. Sammanfattning

En storskalig övergång till elbilar skulle innebära stor miljönytta med hänsyn till minskad luftförorening i stadsområden och ökad energi-effektivitet. Elbilens marknadsandel är dock fortfarande låg. Inköpskostnaden och den begränsade räckvidden är viktiga hinder för storskalig elbilsacceptans. Å andra sidan är elbilsanvändning relativt billig. Det är huvudsakligen på grund av att el är billigare per kilometer än bensin eller diesel. Därutöver är elbilar energieffektivare.

De flesta nuvarande policyåtgärder är fokuserade på elbilsacceptans, och i många länder i världen används incitament för att göra elbilen attraktivare. Den låga marginalkostnaden för elbilsanvändning och utvecklingen i batteriteknologi som leder till högre räckvidd orsakar en risk för ökade bilresor, vilket skulle innebära negativa miljöeffekter och ökad trängsel. I detta projekt utforskas risken för ökade bilresor: under vilka omständigheter är det sannolikt att bilresorna ökar och vilken roll spelar policyåtgärder och utvecklingen av laddningsinfrastruktur? Dessa frågeställningar utforskas med hjälp av tvärvetenskapliga metoder. Stated adaptation experiment används för att undersöka ändringar i resvanor för bilister som byter till elbil. I synnerhet, för att bekämpa de negativa externa effekterna av ökad bilanvändning efter användarens elbilar inskaffande, har studien utformat tre incitament som syftar till att minska privatbilsresor till de redan överbelastade stadskärnorna. Incitamenten var en kombination av 1) gratis elbilsparkering och laddning utanför trängselområdet (i Stockholm) och ytterligare ett reducerat pris 2) kollektivtrafik eller 3) e-skoter resa. För att testa effektiviteten av incitamenten har studien utformat ett stated adaptation experiment och ett anpassat webbkartabaserat undersökningsverktyg som framför allt gjorde det möjligt för respondenterna att registrera önskade platser för sina incitament, och därigenom ge en indikation på efterfrågan på offentlig laddningsinfrastruktur och infartsparkering.

400 av de 7 000 kontaktade registrerade elbilsanvändare har svarat på enkäten. Den så insamlade informationen analyserades med både deskriptiva statistik och statistisk resebeteendemodellering. Även om modelleringsresultaten bör behandlas med försiktighet baserat på den lilla urvalsstorleken, kan modelleringsresultaten tolkas enligt följande:

- Incitamenten är mer effektiva för att avskräcka kvinnliga, unga (18–24) eller deltidsanställda respondenter från att köra in i stadskärnorna än deras manliga, äldre eller heltidsanställda motsvarigheter.
- Erbjudandet om gratis parkering och laddning kan ”attrahera” respondenter som för närvarande inte parkerar i trängselzonen eller har svårt att hitta parkeringsplatser i trängselzonen. Omvänt är de som redan har förtroende för parkeringsmöjligheter svårare att svaja mot att lämna bilen utanför stadskärnan.
- Respondenter som är vanliga kollektivtrafikanvändare (d.v.s. innehar ett månatligt kollektivtrafikkort (SL-kort)) är lättare att attrahera med ett erbjudande om en rabatterad kollektivtrafik.

- Oberoende av deras njutningsnivå för kollektivtrafiken, är de respondenter som upplevt högre säkerhet i kollektivtrafiken mer benägna att välja ett erbjudande om en rabatterad kollektivtrafik jämfört med de som har lägre upplevd säkerhetsnivå.
- Respondenter som ”starkt” tycker om användningen av e-skotrar och e-cyklar är mer benägna att ta emot ett erbjudande om ett reducerat pris för detta transportsätt eftersom detta incitament ökar deras möjligheter att använda dessa ”njutbara” transportsätt.

Även om en initialt planerad detaljerad analys av intressenter inte kunde genomföras under projektperioden, baserat på ovanstående resultat skisserade studien flera metoder för intressentanalys och skapande av policyfärdplaner. Dessutom anses ovanstående kunskap från arbetet med modellering av resbeteendet vara användbar input för pågående och framtida policyarbete för hållbar användning av elfordon.

3. Introduction

Currently, only a small part of the car users in Sweden has switched to an electric vehicle (EV), even though this number is growing over time (Elbilsstatistik, 2017). Major hindering factors are high upfront investment costs and range limitations. However, with battery costs decreasing, more and more charging infrastructure being provided and electric vehicles with a higher battery range entering the market, these range limitations are likely to become less of a hinder. Due to the fact that electric vehicle use has a much lower marginal cost than the use of conventional, internal combustion engine vehicles (ICEVs), because electricity is considerably cheaper per kilometer than fossil fuels (e.g., Hagman et al., 2016), there may be tendencies for people switching to an EV to also increase their car use. Increased car use would have a direct negative environmental implication as it entails a re-bound effect. Besides that, there are risks for increased congestion in urban areas, which is likely to have negative indirect environmental implications, especially in a situation where a subset of the vehicles has an electric drivetrain.

Policy measures aiming to stimulate electric vehicle adoption and use are generally focused on acquiring an electric vehicle. Examples are upfront subsidies, parking benefits, congestion charge exemptions, free use of ferries or the right to make use of bus lanes (Figenbaum, 2016). These policy incentives show that there is much less attention for future use patterns of electric vehicle. It is believed that the applied policy package has an influence on the chances for electric vehicle adoption to be accompanied by increased car use. For example, a policy incentive such as the provision of free parking in central urban areas increases the popularity of electric vehicles, but it also stimulates car use because it makes the use of the (electric) car cheaper, while the cost of alternative transport modes does not change. Over time, these policy incentives aiming to stimulate electric vehicle adoption are likely to fade out with increasing penetration of EVs, but current policy measures will help to shape habitual travel behavior of electric vehicle users that might last long into the future. Policy measures concerning public charging networks will have a permanent importance for e-mobility and are also likely to influence travel behavior.

Some studies have been done concerning the question whether electric vehicle adoption entails increased car use. In Langbroek et al. (2017a), an observational study has been described in which the travel patterns of electric vehicle users have been compared with the travel patterns of non-electric vehicle users. The results of this study show that EV-users use the car for a larger percentage of their total daily travel distance. Moreover, they tend to make more trips. In a subsequent stated adaptation experiment among the same car users, the results also show that under the condition that the EV-user has an abundance of range, there are a non-negligible number of additional car trips being reported (Langbroek et al., 2018). Part of these trips consists of new trips that have not been made before. Another part consists of trips where the travel mode has been changed from public transport or active modes towards the private car.

In Sweden, an ambition has been communicated to create a fossil fuel free vehicle fleet, as part of the transport political goals that have been formulated. Focusing on this goal in isolation would imply that measures should be taken in order to facilitate car users to use electric vehicles instead of internal combustion engine vehicles. However, focusing on this goal in isolation would imply that no measures are taken to decrease car use. To the contrary, due to the lower marginal costs of electric vehicle use, car use is likely to increase.

More research is needed to increase insight into the likely effects of electric vehicle adoption on car use in general, and specifically the effects of different policy packages aiming to stimulate electric vehicle adoption. Langbroek et al. (2016) have found that use-based policy incentives such as the use of bus lanes and discounts on parking have a rather substantial positive effect on electric vehicle adoption. However, these types of policy incentives do not target the high upfront investment costs of electric vehicles, but rather decrease the already comparatively low marginal costs of EV-use.

Figure 1 shows a conceptual model indicating the connections between electric vehicle adoption, electric vehicle use patterns and their two counteracting factors. Range limitations has a negative effect on electric vehicle adoption and use. However, the low marginal cost of electric vehicle use is assumed to have a positive effect on electric vehicle use. Policy measures aimed at increasing electric vehicle adoption also influence electric vehicle use, especially if the policy measures influence the marginal cost of electric vehicle use. The effects on sustainability depend on the adoption of electric vehicles, but also on whether the new travel patterns of electric vehicle users entail rebound effects (more car use) or reinforcing effects (less car use).

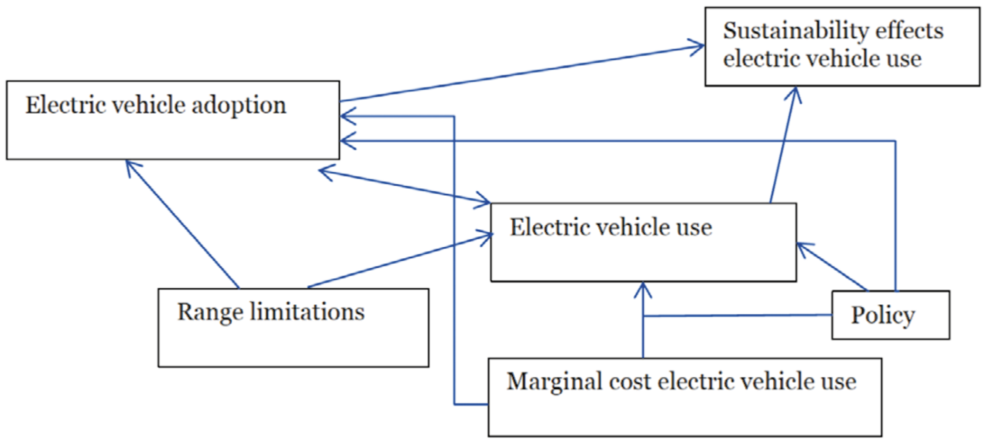


Figure 1. Conceptual model of relationships between EV adoption, use patterns, and their counteracting factors.

The aim of this study is to explore the influence of electric vehicle adoption on future car use. The following research questions will be addressed:

1. Under which conditions are car users adopting an electric vehicle likely to increase their car use?
2. Which (packages of) policy incentives aiming to stimulate electric vehicle adoption have a positive influence on car use?
3. What is the influence of the location of public electric vehicle charging networks on car use?
4. What is the influence of socio-cognitive aspects such as environmental awareness on increase car use after electric vehicle adoption?
5. Which are the relevant stakeholders in the process towards a large-scale electric vehicle adoption and how can this "supply-side" contribute to a sustainable use of electric vehicles, given these stakeholders' goals, expectations, legal and financial conditions?

The results of this study provide insight into the degree in which electric vehicle users are likely to increase their car use, as well as the effects of different policy measures on future car use. Based on these results, a roadmap for the introduction of a more sustainable development of e-mobility in Sweden is prepared and evaluated with the relevant stakeholders.

4. Methods

4.1 Research methodology plan and deviations

4.1.1 Theories about the research subject

The theories about the research subject as it was presented in the original project proposal were as follows. Electric vehicles have characteristics that are likely to have an influence on travel behavior. EVs currently available have a limited range compared to the range of internal combustion engine vehicles (ICEVs). Moreover, after depletion of the battery, the battery of EVs needs to be charged. There are several charging options, such as fast chargers, semi-fast chargers, and home chargers. However, these charging options are not available everywhere. Therefore, EV charging may be a limiting factor for electric vehicle use.

Research (e.g., Pearre et al., 2011) has shown that an available range of 150 kilometers is sufficient for the everyday travel patterns of the majority of the car drivers, under the condition that the vehicle can be charged overnight. However, some car drivers have an extraordinarily heavy car use pattern. Moreover, many car drivers sometimes surpass this available range when making long-distance trips. With developments in battery technology, the costs of batteries are likely to decrease into the future. This decrease can be used to make it cheaper to buy electric vehicles or to improve the available range of electric vehicles. For example, currently Tesla produces EVs with a range of about 500 kilometers, but Tesla is a rather expensive EV. It is expected that other car brands will be able to produce long-range EVs in the foreseeable future at a much lower purchasing cost.

Thus, in everyday life, the available range of EVs is already sufficient for a large part of the car trips being made. In the future, this range will become sufficient for an even larger percentage of car trips. Moreover, in countries with relatively cheap electricity such as Sweden, the marginal (or operational) cost of electric vehicle use is expected to be lower than the marginal cost of conventional car use. For example, Hagman et al. (2016) found out that EVs are up to a factor five cheaper per kilometer. This lower operational cost can compensate for higher investment costs that currently have to be made when purchasing an electric vehicle. However, lower marginal costs can result in increased car use, both because of the lower absolute costs and because of the lower costs compared to the costs of alternative transport modes such as public transport.

In case of a large-scale deployment of electric vehicles, it is expected that EV users will decrease their car use for long-distance trips, thereby switching to alternative transport modes or making other behavioral alterations. Increasing battery range and the development of a dense network of fast chargers will moderate this development. On the other hand, it is likely that EV users will increase their car use on short-distance trips. An increase of short-distance trips, especially in congested areas, is likely to increase congestion. Moreover, despite the absence of tailpipe emissions, electric vehicles use much energy. Therefore, there is a risk for re-bound effects to occur. However, more insight is needed into the degree car use is likely to increase due to a transition from conventional vehicles towards electric vehicles. Secondly, more insight is needed in the role policy measures can play in reinforcing or mitigating the "natural" effects of this transition on travel behavior. From economic theory, it is to be expected that policy measures such as preferential parking policies (free parking or parking at premium locations) for electric vehicles results in more car use. It is also expected that policy measures consisting of preferential access to part of the infrastructure (e.g., bus lanes) are likely to result in increased car use, because these policy measures further decrease the marginal cost of car use. Another policy measure that is likely to result in increased car use is the provision of charging infrastructure in a central urban area. Nevertheless, it is unclear to which degree these effects occur in the context of car users' daily travel patterns, under which conditions these are most likely to occur and how policy measures can be designed that are likely to have a positive effect on electric vehicle adoption but a negative or no effect on subsequent car use.

4.1.2 Planed research methodology

The paragraphs below present the research methodology as it was planned at the time of the project proposal.

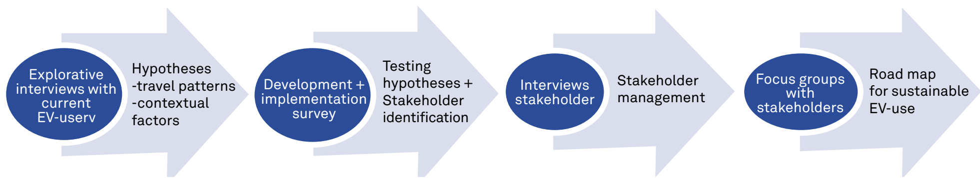
> *"In this study, a mixed method approach will be used. Qualitative research methods (in-depth interview studies) will be used in the first, explorative phase, of this project. Based on the results of these interview studies, a quantitative approach (stated adaptation experiments) will be used aiming to test a set of hypotheses that will be developed after the explorative phase. Based on the results of the qualitative and quantitative research, an intervention methodology will be designed, together with the relevant stakeholders, in order to make a roadmap for the development of sustainable electric vehicle deployment in Sweden.*
>
> *In the first stage of this project, current electric vehicle users in Greater Stockholm will be asked to participate in in-depth interviews. The topic of this interview study is travel behavior in EV-households and in the first place, use will be made of respondents to an earlier study about electric vehicle adoption that have indicated being willing to participate in interview studies. The aim of this explorative stage is to get more insight into the reasoning behind travel behavior patterns of EV-households.*
>
> *In the second stage of this project, a survey will be conducted among car drivers in different regions in Sweden. Most respondents should live in urban areas, but it is useful to also include a part of the respondents living in the countryside. The data will be collected with the help of a survey company, which must make sure that a representative sample regarding socio-economic characteristics such as age, gender and income will be collected.*
>
> *The survey will consist of four parts: in the first part, socio-cognitive questions are asked in order to make an assessment of the respondent's attitudes towards sustainability and electric mobility. In the second part, behavioral questions, amongst them a one-day travel diary will be asked in order to make a travel behavior profile of the respondents. In the third part, a set of stated adaptation experiments will be designed in order to investigate the influence of different policy measures or packages of policy measures on electric vehicle use. Stated*

adaptation experiments are a specific type of stated preference experiments, where the participants react to stimuli given by the researcher and potentially change their initial behavior (e.g., Janssens et al., 2009). In the last part, socio-economic questions will be asked that can be used to investigate potential confounding factors influencing car use.

In the third stage of this project, the main stakeholders that play a key role in the developments of electric vehicle adoption and use will be investigated. In the first part of this stage, private and public stakeholders related to electric vehicles will be identified and will be interviewed in order to get insight into their attitudes towards electric vehicles, the major problems, risks, costs, and issues concerning electro mobility, the opportunities that may arise or the goals for the future. In-depth interviews will be used with a semi-structured format enabling interviewees to feel more relaxed and reveal more information.

After the end of this first part and based on information and data to be collected through in-depth interviews with private and public stakeholders, focus group meetings will be organized, where all the stakeholders will be invited to participate in a round table discussion. The stakeholders will have the opportunity to interact with each other, share their views, concerns and thoughts on electric vehicles and create opportunities or synergies for further collaboration on that area. The outcome of this process will be a roadmap of future sustainable electric vehicle use, based on the different stakeholders' goals, expectations, legal and financial conditions.

The following figure gives an overview of the planned methodology and the different steps in this process."



4.1.3 Deviations

The project was planned to be a continuation of a part of a project that has been financed by the Swedish Energy Agency, called Bruka Elbil (Project no. 37054-1). In the Bruka Elbil project, that resulted in several academic publications (e.g., Langbroek et al., 2016; Langbroek et al., 2017a; Langbroek et al., 2017b), the process towards electric vehicle adoption was studied, as well as the influence of policy incentives on electric vehicle adoption. Moreover, in the Bruka Elbil project it was studied whether EV-users have different travel patterns as non-EV users. Both a revealed preference and a stated preference approach were used.

As a natural continuation, the qualitative and quantitative research aiming to investigate future travel patterns of electric vehicle users in the present project was planned to be mainly carried out by Joram Langbroek as a postdoc study in collaboration a senior PhD student in transport science working with the stakeholder and the policy roadmap. Unfortunately, both the lead researcher, Joram Langbroek and the senior PhD student have discontinued their academic employment and further engagement in the project. While equivalently qualified postdocs for the two respective research tasks were recruited through a lengthy process, difficulties in the knowledge transfer between the original researchers and the newly recruited postdocs, limited the newly hired postdocs ability to “own” the project, which hindered project progress and ultimately has also led to the early termination of employment of the postdocs. The remainder of the project has been led and staffed by the project leader, Győző Gidofalvi, whose most relevant technical and research background is in smartphone-based travel surveys and spatial analysis. This has naturally also shifted the focus of the project towards these areas while keeping as much of the project aims possible. More specifically, this implied three deviations from the project plan. First, more weight was placed in designing systems that can support the collection of the desired information for the survey study. Second, the iterative engagement of the stakeholders in forming of the incentives in the tested scenarios based on the stakeholders’ objectives and limitations, has been replaced by soliciting the expert opinion of researchers in the field (Associate Professor Joel Franklin and Professor Yusak Susilio) and designing feasible incentives and scenarios for the stated adaptation experiments, the results of which have been post-mortem discussed in stakeholder interviews at the later parts of the project. Finally, due to the temporal shift in parts of the project methodology less emphasis could be placed on deriving a “*roadmap of future sustainable electric vehicle use, based on the different stakeholders’ goals, expectations, legal and financial conditions*”. The following sections describe the carried-out project methodology in three main parts.

4.2 Explorative interview study

A transition towards electric vehicle use is connected to positive environmental effects. In most studies so far, it is believed that travel behavior will remain unchanged after changing to an electric vehicle. However, travel behavior changes might cause side-effects reinforcing or diminishing these positive effects.

The goal of this part of the is to gain a qualitative insight into these changes and their possible side-effects. Thus, between October and December 2018, in an in-depth interview study, 14 experienced electric vehicle users (>4 years of experience) were asked to reflect about their travel and charging behavior. Topics covered in the interviews were as follows:

- Background information: type of EV(s) of the user / household, number of cars in the household, and the mileage for each car.
- Travel behavior: changes in the user’ / household’s travel behavior and the nature of the changes
- Charging behavior: where and when the user charges, whether there has been changes over time in the user’s behavior, and user’s knowledge about cost of charging
- Household interactions in case of multi-car households
- Range anxiety
- EV and the environment

The interviews were transcribed. Samples of the transcribed interviews, in an anonymized format, are provided in this report in Section 5.1.

4.3 Survey study

The goal of this part of the study is to develop a survey which allow us to explore the influences of potential policies on sustainable EV-use. To this extent, an internet-based stated adaptation survey is designed to collect data about how different policy packages could influence EV uses' daily travel behavior change.

Stated adaptation experiment is a special form of the stated preference experiment, taken ones' behavior as references, respondents can indicate their stated responses to the hypothetical scenarios (Arentze, et al., 2004). Over the last decades, the number of studies based on such stated adaptation approach has been gradually increasing. For example, conducted the stated adaptation experiment, Nijland et al. (2009) investigated individuals' response to a reduction in available time for a planned activity in a number of hypothetical situations. Taken the stated adaptation approach, Dogterom et al. (2018) described the likelihood of changing car use and the number of kilometers driven in response to two distance-based tradable driving credits scenarios. Similarly, based on the stated adaptation approach, Langbroek et al. (2018) investigated changes of travel patterns because of range limitations or the opposite, abundant range. As an extension of Langbroek's work, more hypothetical scenarios are provided.

Often in such stated adaptation surveys, respondents are free to state which behavioral response he or she can imagine when faced with such situation. While this freedom provides a chance to collect rich textual information about behavioral response, the quantitative analysis (e.g., descriptive statistics, geospatial analysis, statistical modelling), in particular, the linking of (aspects of) the scenario to the response (i.e., travel behavior change) and the respondent's socio-demographics attributes and attitude towards the scenario becomes next to impossible. To remedy this situation, this part of the study has developed a new methodology and tool to design stated adaptation travel surveys that allows this type of quantitative analysis.

The sections below explain how, based on the explorative interview results, stated adaptation experiments and a corresponding web survey tool have been iteratively designed, how the tool was used to collect data from respondents, and how the survey data has been analyzed.

4.3.1 Initial design of stated adaptation experiments

The following is a coherent but not comprehensive description of the initial design of the stated adaptation experiments; full details are reported in (Guo et al., 2019). Based on the explorative interview results in Section 4.2 and the theories about the research subject in Section 4.1.1, the initially proposed survey consisted of three parts which are described as follow. The first part is designed to collect the respondent's socio-demographic characteristics and attitudes towards their EV-ride experiences. The second part is designed to collect the respondents' travel behavior data through a one-day travel diary. The third part is designed to collect as a stated adaptation experiment the influences of different policy measures or packages of policy measures on the sustainable EV-use.

PART 1: SOCIO-DEMOGRAPHIC CHARACTERISTICS AND EV RIDE EXPERIENCES

The first part consists of questions about socio-demographic attributes such as age, gender, marriage status, employment status, annual income, living and working area, transit pass ownership, and number of cars. In addition, in order to investigate EV users' travel behaviors changes by potential policy incentives, it is important to consider individuals' perception of their current EV ride experiences. The related survey questions are:

- How much is your average miles driven by cars per day?
- Do you think it is easy to find the charging facilities?
- Are you sensitive to the charging fee?
- Do you think it is easy to find a parking space?
- Are you sensitive to the parking fee?

PART 2: HABITUAL TRAVEL BEHAVIOR

The second part includes collecting individuals' habitual travel behavior. Respondents are asked to report their daily activity profiles, including the trip purpose, trip location, departure time, arrival time, address of origin, address of destination, and travel mode. Because the profiles depend on the current activity pattern of the respondents, they need to be generated during the survey completion process. Therefore, a survey platform is developed by in-house by the research group, which allows adding constraints to the questionnaire to avoid respondents writing unrealistic answers.

PART 3: STATED ADAPTATION SURVEY

In the third part, includes a stated adaptation experiment in which respondents are asked how they may change their daily activity travel behaviors in response to hypothetical scenarios. To understand the policy impact on behavior, change of EV users, several hypothetical scenarios were selected. Moreover, in order to provide respondents with more realistic choice situations, rather than creating an experimental design that is the same for all respondents, scenarios are selected based on the ride experiences of EV users. Personalized scenarios are provided to the respondents. As a result, respondents are familiar with the scenarios consistency with the real travel experiences and are much easier for respondents to imagine the scenarios provided.

Scenarios

In order to provide realistic hypothetical profiles to specific respondents, scenarios are formulated and distributed into five sections, differentiated according to the average miles driven by cars per day, attitudes towards the parking and charging fee, and attitudes towards the accessibility to the parking space and charging facilities, respectively.

1. Kilometer budget scenarios

Electric vehicles have finite battery capacity. Range limitations might limit the usability of EVs for long-distance trips (Franke and Krems, 2013). In order to investigate different types of behavioral alterations under different kilometer budgets, four potential kilometer budgets (-50%, 50%, 100%, and 150% difference) were set based on the total travel distance during the trip-diary day. Instead of randomly assigned these scenarios to the respondents, relatively strict controls were maintained in the scenarios selecting process. If the respondents having made short travel distance, the kilometer budget scenarios will not be provided to them. For example, if the respondents have only 2 km travel distance during the travel diary day, it might be too cumbersome to ask their behavioral adaptation under the scenario with a 3 km kilometer budget. Moreover, the relatively strict controls also served as the keeping the kilometer budget in a reasonable range. The kilometer budget range in this study is between 10 km and 500 km. The purpose of the minimum threshold is to avoid situations where the range in the different scenarios is too similar, while the maximum threshold is to ensure the hypothetical scenarios meets the top range of currently available EVs (Langbroek, et al., 2018).

2. Charging location scenarios

Charging infrastructure is critical to the development of EV system (Egbue and Long, 2012). In case of large-scale deployment of EVs, it is expected that EV users may decrease the long-distance trips due to the lack of publicly available compatible charging stations. Increasing the development of a compatible EV charging network will moderate this development. Moreover, mismatch of the charging demands and infrastructures could lead to under-utilized charging system and waste public resources. Thus, it is important to find the optimal positions for public charging facilities to satisfy all users' demands.

To release the burden and provide realistic hypothetical scenarios to the respondents, the rules of the personalized scenarios selection process are two-tier. Tier 1 covers questions on the satisfaction of the provision of charging infrastructure, which are asked in the first part of the survey as '*Do you think it is easy to find the charging facilities?*'. For respondents who thought the accessibility of the charging system is high enough, the charging location scenarios will not be given to them. Tier 2 depends on users' habitual travel behaviors. Respondents are introduced the potential charging location scenarios based on the travel locations they reported during the travel diary day. Thus, if the respondents have travel in the central city during the travel diary day and thought it is relatively hard find charging facilities, potential scenario as '*Public charging stations in central urban areas are easy to find*'.

Additionally, the purpose of this study is to explore how potential policies incentive on sustainable EV-use. In case where public charging facilities accessibility near the public transportation (PT) hub is good, it is hypothesized that EV users would more likely to charge their EVs around the PT hub, and change to the public transportation modes. Thus, scenario as '*Assume public charging stations near the PT hub are easy to find*' is given to the respondents.

3. Free charging scenarios

Finding not only the nearest charging station but free is one of the most important issues for an EV journey. Thus, in addition to increase the accessibility of the charging facilities, charging prices may affect users' travel behaviors as well. As a result, in this experiment, scenarios related to free charging are generated. Similarly, to facilitate the respondents participating in this stated adaptation experiment, the rules of the scenarios' selection process are two tiers as well. Firstly, it is asked whether respondents are sensitive to the charging fee. Charging free scenarios will not be exposed to the charging fee insensitive respondents. Secondly, the charging free policy packages are associated with the locations of the charging facilities. Hypothetical scenarios are provided according to the travel locations of the respondents.

4. Dedicated parking spaces scenarios

It is expected that different parking policies are likely to influence car use and travel behaviors. In addition, by instituting dedicated parking space at premium locations it is possible to favor or discourage users parking in certain areas. In case of a large-scale deployment of EVs, it is assumed that dedicated parking space at certain locations for EVs would provide incentive on sustainable EV-use and contribute to the sustainable transport system. For example, increase the accessibility of parking space to metro/bus station in the central city may lead EV users transfer to public transport modes and consequently relieve the congestion in the central city. Before given scenarios to the respondents, firstly, respondents are asked if they think it is easy to find a parking space. Parking location related scenarios will not be given to the respondents who think it is easy to find vacant spaces in the Stockholm city. Then, parking location related scenarios are selected based on travel locations respondents reported during the travel diary day.

5. Free parking scenarios

Besides instituting dedicated parking space at premium locations, the preferential parking policies measure is a very important factor in influencing the parking demand. To save money from the travel activities, cost-sensitive car drivers would be more likely to search for a free parking spot. In addition, spatial distribution of the free parking services would influence the parking location choices of drivers and consequently affect travel behaviors. Accordingly, hypothetical free parking scenarios are associated with the spatial distribution. Firstly, respondents are asked to evaluate their sensitivity of the parking price. After that, scenarios are shown to the respondents based on their trip locations reported in the travel diary day.

Adaptation

After introducing the personalized scenarios, respondents are asked whether they would change their travel behavior under the scenario they provided. Four main behavioral adaptations could be chosen by the respondents as a reaction to the hypothetical scenarios, include changing the travel mode of one or more trips; changing the travel location of one or more trips; changing the travel time of one or more trips; and cancelling one or more trips. The respondents are free to select any alteration or make a combination of different options. It is possible for respondents to change the travel mode for one trip and change the travel time for another trip. Moreover, no change option is provided in case of respondents do not want to make any changes. Respondents' adaptation behaviors are recorded based on the travel diary they reported in PART 2.

4.3.2 Initial stated adaptation web survey tool

As stated earlier, the overall objective is to collect information about 1) what specific travel changes EV users will make to their travels to meet the constraints of scenarios and 2) what extent these travel changes are influenced by the incentives that are provided in the scenarios. To the best knowledge of the authors, today there is no readily available system that can collect this information. In particular, the existing systems are not able to implicitly *link* a given stated travel change with a specific current trip of the user. Moreover, the existing systems are not able to *verify* how the stated travel changes of the user *abide the constraints* of the scenario and neither do they easily *quantify* to what extent the travel changes of the user *utilize the incentives of the scenario*. To provide this functionality, the following subsections describe the design of a prototype system including its conceptual model for travel diaries and stated adaptation experiments, its motivated representation of space and travel movements and its mechanics for linking stated travel changes (adaptations) to current trips and monitoring the fulfillment and utilization of scenario constraints and incentives.

CONCEPTUAL MODEL

The conceptual model of travel diaries and stated adaptation experiments is a simplified but extended version of the data model that is presented by Prelipcean et al. (2018). The conceptual model consists of *entities* that are described by their *attributes* and *relationships* among them**.** It consists of the *user* entity that is associated with a number of demographic and transport related attributes that define the economic, social and travel context of the user which are gathered through the survey questions that are presented in Section 2.2.1. The *travel diary* of a user consists of one or more of *trips* each of which is defined by attributes: *start time, end time, origin place, destination place, main travel mode,* and *purpose*. Each trip is further subdivided into one or more *trip legs* each of which is defined by attributes: *start time, end time, origin place, destination place,* and *travel mode*.

A *stated adaptation experiment* consists of a *scenario* and *travel changes/ stated adaptations* that user can make. Travel changes can refer to a trip or any of its attributes and parts, i.e., the origin / destination place, start / end time, (main) travel mode or purpose of a trip or any of its trip legs. In particular, the user can change attributes of a trip / trip leg and delete or add a trip or trip leg as long as entries of the travel diary remains internally consistent. A scenario is described by a set of *constraints* and a set of *incentives*. While one can envision a number of legitimate scenario constraints and incentives, due to the hard mobility limitations and anxiety caused by the capacity of- and the cost and possibility of charging of EV batteries, the most relevant constraints relate to travel distances and places of destinations. In particular, one distance-based scenario constraints might be imposed by the maximum range of the EV battery and a corresponding scenario incentive could be the availability of (free) charging at certain places likes public transport hubs. A user's travel diary, trip or any of its trip legs or any changes in it can *violate* a scenario constraint. A travel choice in a user's travel diary or any particular stated adaptation of these choices (e.g., park and charge at a public transport hub) can *utilize* a given scenario incentive. Moreover, the utilization of certain incentives can *affect* the constraints of a scenario, e.g., charging an EV parked at a public transport hub for some time will effectively increase the remaining range of the EV. The following subsections explain how these distance-based scenario constraints and placed based scenario incentives are monitored through a simple but effective representation of space and travel movements.

REPRESENTATION OF SPACE AND TRAVEL MOVEMENTS

In order to make the travel diary- and stated adaptation entries- and the specification and monitoring of scenario constraints and incentives as simple as possible, the proposed system models space in terms of lexical place or region names. Users are familiar with place names and can easily associate geographical location / extent and scenario-related semantics with places. Hence, space is partitioned into a well-known set of city districts / parts that are identified by their names, e.g., Gamla Stan (old town of Stockholm, Sweden), Kista (predominant technology center of Stockholm) etc., and certain scenario-specific places, like for example public transport hubs, are distinguished. While this lexical encoding of space has its drawback in terms of spatial precision, the advantages that is provided by 1) the inherent fuzziness of the place identified and the intuitive scenario-specific meanings that users can associate with them and 2) the simplified user entries and system implementation is believed to outweigh the drawbacks. In particular, Susilo at al. (2016) have shown that a survey tool that simplifies the data entry of users is important to maintain high response rates and that the design of an easy-to-use system that records and allows the editing of precise location information (primarily due to the difficulties in guaranteeing the spatial and temporal consistency of the data) is far from trivial.

Similar to and in line with the simplistic design choice of space representation, the representation of travel movements is also simplified. In particular, motivated by the fact that travelers can recall travel time more accurately than travel distances (Rietveld, 2002), each travel mode is associated with an average speed S_m and assuming a linear movement between the origin place *OP* and destination place *DP* between the start time *ST* and end time *ET* of a trip or trip leg, the assumed distance between *OP* and *DP* is modelled as $dist(OP, DP, m) = S_m / (ET - ST)$. The variations in travel speeds due to peak hour traffic conditions can be accounting for by applying a congestion factor to the average speed of the travel modes during peak hours. The variation in travel speeds on roads due to the speed limits of different road classes can be modelled by applying an inter-place speed increase factor based on the assumption that there usually exist road classes that allow faster travels between different places while travels within a place mostly have to use road classes that are allow slower travels. One can potentially, also determine the speed increase factor based on average travel times between regions that can be calculated using a trip planning services offered by providers like Google. The same service can also be used to adjust the linear movement assumption.

MONITORING OF SCENARIO CONSTRAINTS AND INCENTIVE UTILIZATIONS

The following three subsections, through three examples, illustrate in turn how 1) the internal spatial and temporal consistency of a trip diary, trips and trip legs-, 2) the fulfillment of scenario constraints- and 3) the utilization of scenario incentives are monitored.

Internal spatial and temporal consistency monitoring

For a travel diary to be consistent, trip legs of each trip and the trips within the diary have to be spatially and temporally contiguous, i.e., subsequent destination-origin spatial entries have to agree and, at the very least, subsequent end-start time entries have to monotonically increase. Violations of such internal spatial and temporal consistency constraints are illustrated (via the highlight and monitoring messages) in a sample travel diary of a fictive user in Figure 2.

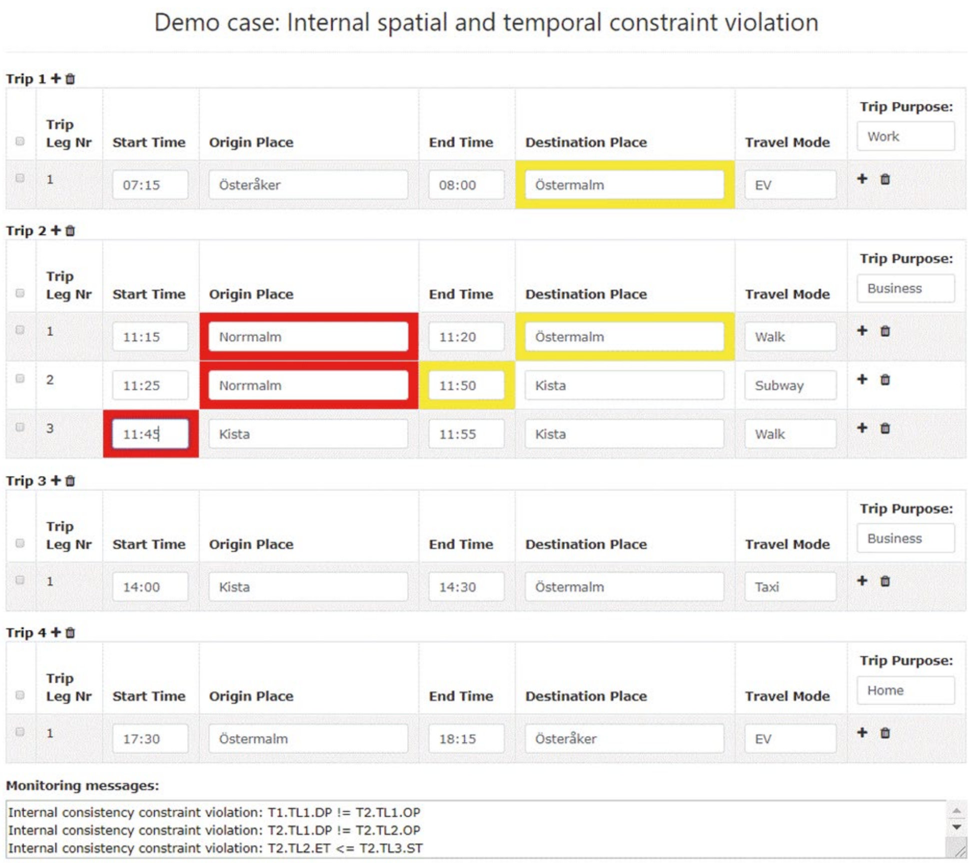


Figure 2. Illustration of internal spatial and temporal consistency monitoring and constraint violations (see red violation highlights and monitoring messages).

Scenario constraint fulfillment monitoring

As described earlier, scenarios in stated adaptation experiments also have constraints. A particular type of scenario constraint is based on the distance covered using a particular travel mode during a trip leg, within a trip or across the trips of the travel diary. More specifically, as explained in Section 4.3.1, some scenarios limit the range of EV mode between charging sessions. To monitor how and when such a distance-based constraint is fulfilled or violated, the travel movement model is applied to each trip leg of a trip that uses EV as a travel mode. The cumulative sum of the estimated distances of such trip legs is maintained and any trip leg for which the cumulative sum value exceeds the maximum range constraint is marked as a violation of the distance-based scenario constraint. A violation of such a distance-based scenario constraint is illustrated in the sample travel diary of the fictive user in Figure 3 for a scenario where the maximum range of EV is set to 50 km.

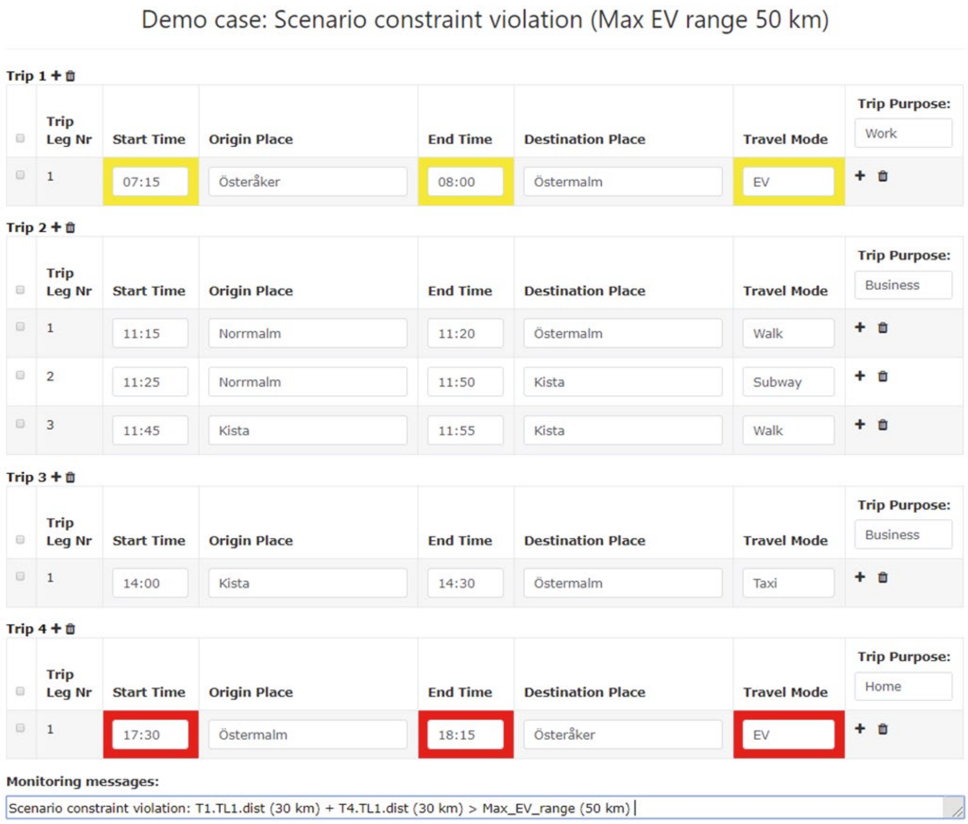


Figure 3. Illustration of distance-based scenario constraint fulfillment monitoring and constraint violation (see red violation highlights and monitoring message).

Scenario incentive utilization monitoring

To explore how different policies incentive on sustainable EV-use, the user is provided with a number of incentives. One potentially effective incentive for this involves the provision of the desirable services (i.e., dedicated / reduced cost / free parking or charging) at certain places, e.g., public transport hub(s) in a certain place / district. The previously introduced lexical representation of space can naturally caret for describing this scenario incentive by appending the name of the incentive to a name of a place as the example in Figure 4 shows this for the place "Täby PT hub" and the incentive "free charging". Yet another type of incentives, motivate users by counterbalancing the limitations of a particular mode. For example, the incentive of providing access to charging facilities (for a price or for free) eases the range limitation of EVs. The user can overcome specific limitations that the distance-based scenario constraints impose by adaptations that explicitly select the utilization of the incentive (see trip *T1* in Figure 3 vs trip *T1* in Figure 4). In the given example, based on the 10-hour long charging time that is calculated based on the end and start times of the consecutive uses of the EV, trip *T4* is feasible to perform under the scenario constraints (i.e., 50 km EV range) through the utilization of the scenario incentive (i.e., free charging at PT hubs).

Figure 4. Illustration of space and time-based scenario incentive utilization monitoring (see green scenario incentive utilization highlights and monitoring message).

An initial prototype of the stated adaptation web survey tool has been developed as a responsive, single-page, full-stack JavaScript web application using modern web development components and technologies including native client-side technologies (HTML, CSS, and JavaScript), client-side libraries (Bootstrap, AngularJS), server-side business logic (NodeJS) and data access (MongoDB and JSON documents). The prototype implementing stated adaptation experiments in Section 4.3.1 was internally tested by members of the project group and volunteer students from the master's program of Transport and Geoinformation Technology at the Department of Urban Planning and Environment at KTH.

4.3.3 Final design of stated adaptation experiments

The tests of the prototype web survey tool, including the stated adaptation experiments, revealed that even for users with highly relevant technical and theoretical background the experiments and the tool was too complex. In particular, while the tool was able to monitor the above-described constraints of the scenarios, the test subjects had difficulty to express valid travel adaptations to the scenarios which triggered too many violations that required tedious corrections by the test subjects. In particular, test subjects had difficulty estimating distances in their travel diaries which created many distance-based violations in the kilometer budget scenarios.

To some extent, even maintaining the internal spatial and temporal consistency of the activity travel diaries under the charging scenarios (especially the charging scenario in terms of charging times and the availability of the EV at a later time of the day) was proved to be difficult for the test users.

After consultations with experts in travel behavior modelling (Professor Yusak Susilio) and transport policies (Associate Professor Joel Franklin), the problematic scenarios were dropped or simplified and stated adaptation experiment has been redesigned. The structure of the incentives and the questions related to them in the so revised and final stated adaptation survey is shown in Figure 5.

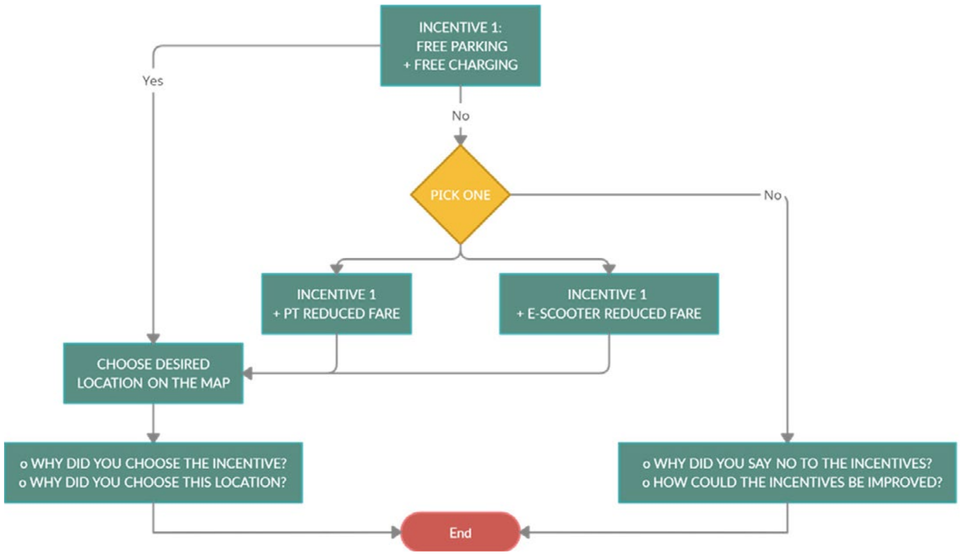


Figure 5. Structure of the incentives and the questions related to them in the final stated adaptation survey.

To make the stated adaptation survey relevant for the respondents and to maximize the information collected about EV ownerships and travel behavior, prior to the stated adaptation part of the survey, based on the travel diary entries of the respondent and an additional scenario-specific question '*Do you travel sometimes in the congestion tax area?', the scenario-based stated adaptation is* conditionally offered the respondent according to Table 1.

Table 1: Cases for conditional incentive offering and stated adaptation survey.

Case	Trip origin	Trip destination	Decision on incentive offering
Case 1	Outside congestion tax area	Inside congestion tax area	Offer incentives
Case 2	Outside congestion tax area	Outside congestion tax area	Screening question: ***Do you travel sometimes in the congestion tax area?*** yes -> Offer incentives no -> No incentives offered
Case 3	Inside congestion tax area	Inside congestion tax area	No incentives offered
Case 4	Inside congestion tax area	Outside congestion tax area	No incentives offered

4.3.4 Final stated adaptation web survey tool

In addition to implementing in the tool the logic of the above-described revision of he stated adaptation experiments (Section 4.3.4), several user interaction components and features were added to the final stated adaptation web survey tool to improve the user experience.

In order to capture the user travel diary, an innovative web map-based system was introduced. The web map-based travel diary makes it easy for the users to add their trips. Users can also easily navigate the map and select any region from where they start their travel and select the area where they ended the trip. In order to make the user location anonymous, the selection is made at the region level instead of a pinpoint location. Different colors for travel mode and different icons for travel purposes are being introduced to show different trips of the user. Through this approach the user is able to view his whole travel diary on a single web map view. The system also synchronizes the map with the trips table so the user can easily read map data in a table format and make changes to it that reflect directly on the map.

The web map was also introduced in the stated adaptation section. To capture the intended spatial constraint of the incentive of the scenario, the user is not allowed to choose a parking and charging location inside the congestion tax area. First the congestion tax area boundary is shown on the map to guide the user. Using the web map the user can easily choose an appropriate location for subsidized charging and parking. The map approach enables the use of spatial analysis.

Finally, to enable that a user can anonymously fill the survey across multiple across multiple devices without looking their partial work, the system has implemented user sessions via randomly generated authentication codes that act as a pseudo identifier for the user.

4.3.5 Survey data collection

A research survey consultancy has been precured to conduct survey with the help of the stated adaptation web survey tool. The consultant has sent out the survey via SMS to 7 000 EV users in the Stockholm region who have registered in the market research database of Cint (https://www.cint.com/). As an incentive to complete the survey, the contacted EV users were offered the possibility to win a one-year season card for the Stockholm public transport (SL card) valued at 6800 SEK. During the period of 2022–04–13 and 2022–04–31 around 700 (10%) people attempted- and 400 (6%) completed the survey.

The use of the consultant and the stated adaptation web survey tool design (i.e., the generalization of locations to regions and the randomized authentication codes) ensured that the data collection was fully GDPR compliant, including an informed user consent collection. In particular, the consultant did not have access to the survey results about the travel behavior, while the research team with the access to the travel behavior entries in the collection system could not link a randomized authentication code to the real-world identity or contact information of a user (that only the consultant possessed).

4.3.6 Survey data analysis

DESCRIPTIVE STATISTICS

As a first step of the survey data analysis, some descriptive statistics are estimated in order to shed some light to the different parts of the survey. The calculated descriptive statistics generally concern:

- Socioeconomic aspects (gender, age, income, educational level, employment status)
- Current EV access and usage (type of access, frequency of use, frequent charging spots, ownership status, main reason of usage)
- Incentives popularity and their improvement
- Perception of the respondents of other transport modes (public transport, e-scooters/e-bikes) in terms of enjoyment and safety feeling

The above-mentioned analysis axes can provide information about the sample, their relation to EV use as well as other transport modes.

STATISTICAL TRAVEL BEHAVIOR MODELLING

In the hypothetical survey questions, respondents choose whether to accept successively attractive alternatives to driving their EV into the city center. Once an alternative is accepted, the questions cease. This provides material to construct a discrete choice environment where a respondent chooses among several possible alternatives to driving the EV into the city center. In fact, we do not observe any explicit choice among all alternatives, but if we accept that the respondent will always prefer an ostensibly "preferable" alternative (e.g., two alternatives that differ only in the presence or absence of an extra incentive), then we can consider the expressed choices comprehensive.

In practice, then, the proposed decision modelling framework integrates the basic choice incentive between the free parking and charging and the selection of no incentive. Moreover, the model captures the additional incentives offered to the respondents who took no incentive. The additional incentives concern PT reduced fare and e-scooter reduced fare. and they only apply to the respondents who did not select incentive 1 at the first stage. The final choices, according to the sequence that incentives are offered, are the following:

- Incentive 1: Free parking and charging
- Incentive 2: Incentive 1 + PT reduced fare
- Incentive 3: Incentive 1 + e-scooters reduced fare
- No incentive at all

Due to the similarity of adjacent alternatives above, and as shown in Figure 5, there are grounds to suspect that some alternatives share correlated error components. This might be the case because under this incentive offering sequence, the incentive 2 or 3 will only be offered only when the respondents reject the Incentive 1. Thus, to capture this possibility in the modelling process, both a "flat" multinomial logit model and a nested logit model were investigated. The flat logit model can be seen in Figure 6, meanwhile the nested logit model can be seen in Figure 7.

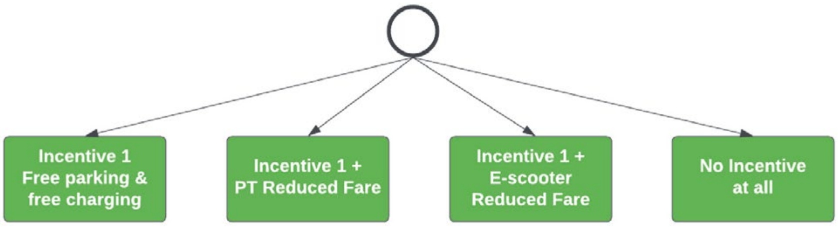


Figure 6: Structure of the flat logit model

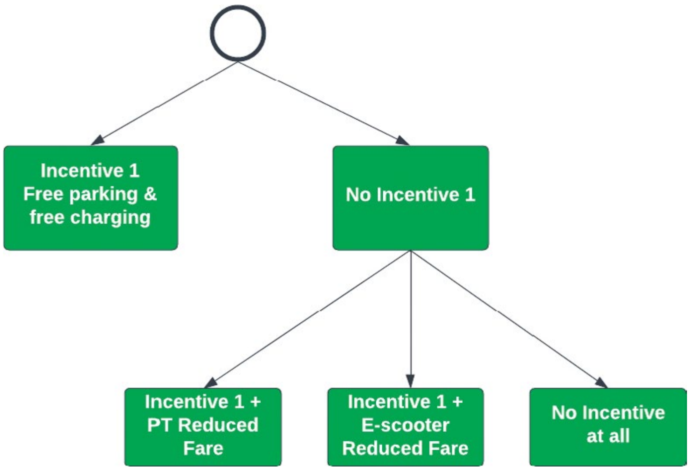


Figure 7. Structure of the nested-logit model

The tool used for the model development was the Python programming language, specifically the Biogeme maximum likelihood estimation library for estimating model parameters.

The survey data provide information about the preferred incentive that respondents select, their broader travel choices, and a variety of characteristics of the respondent. In building the model, the preferred incentive was treated as the dependent variable and the other information as explanatory variables.

The modeling steps were as follow:

1. **Data preprocessing**: Before the development of the model, data were preprocessed and thus the final dataframe that it was used for the modeling purpose was structured. Data preprocessing was accomplished through the following steps: Using the *authentication code* as a common attribute, the data from 3 separate excel files were merged as follows:
    - From Part 1 (Sociodemographic characteristics and EV ride experiences) all the columns were encoded and concerned in the final dataframe.
    - From Part 2 (Habitual travel behavior) trip purpose and travel mode were selected for the final dataframe.
    - From Part 3 (Stated adaptation survey) the incentive choice was selected since incentives are the dependent variables of the estimated utility functions.
    - Last, the distance attribute was estimated, based on the Euclidean distance between origins and destinations that respondents reported in Part 2.

    Then, data were filtered, only rows with incentive selection were concerned; this ended up with 330 responses

2. **Estimation of correlation coefficients among the variables**: Each incentive and the factors behind it are explored mathematically to find the possible correlations and relevant variables, also known as the "estimation of the correlation matrix". The estimation of the correlation coefficients between the dependent variable of the model (selected incentive) and the potential independent variables was the first step before the development of the nested logit model. Towards this direction, all variables were encoded. The selected incentive (*choice*) variable was encoded as follows:
   - 0 – No selected incentive
   - 1 – Selection of incentive 1 (free parking and charging)
   - 2 – Selection of incentive 2 (Incentive 1 + PT reduced fare)
   - 3 – Selection of incentive 3 (Incentive 1 + e-scooter reduced fare)

   Since the nature (nominal, ordinal, scale) and the number of the potential independent variables is high (40 variables), variables were grouped according to their nature. Therefore, the appropriate statistical tests were applied for the different combinations by using the SPSS v.27 software. It should be noted that the *choice* variable is a nominal variable with more than 2 categories. The alpha level (α) was set to .05. The tests that were performed based on the different variables' combinations are the following:
   - nominal x nominal (Chi-square)
   - nominal x ordinal (Kruskall-Wallis H / "One-way ANOVA on the ranks")
   - nominal x scale (t-test)
3. **Development of utility functions**: Each incentive is then defined by a utility function that consists of an intercept (α), parameters to each variable (β), and the value of explanatory variables (*x*). The general equation of the utility function is defined in (1) and the analytical form of the function is described in (2) based on the standard textbook of Ortuzar and Willumsen on Modelling Transportation.

$$U_{jq} = V_{jq} + \varepsilon_{jq} \ (1)$$

$$U_{INCENTIVE\ i} = a_i + \beta_{1i} * x_{1i} + \ldots + \beta_{ni} * x_{ni} + \varepsilon_{jq} \ (2)$$

4. **Parameters' estimation**: Each explanatory variable is weighted by a parameter that is estimated using Biogeme Library and fitted to a nested-logit model according to the logit model equation below which calculates the probability of the incentive being chosen.

$$P_{iq} = \frac{\exp(\beta\ V_{iq})}{\sum_{Aj\ \varepsilon\ A(q)} \exp(\beta\ V_{jq})} \ (3)$$

5. **Validation and statistical analysis:** The quality of the model is analyzed by using appropriate, standard quality of fit metrics. The aim of the developed model is to answer the following research questions:
   - How effective are the incentives?
   - How does the provision of the incentives affect the travel behavior of the respondents?
   - How is the modal split affected by the different incentives?

GEOVISUALIZATION AND GEOSPATIAL ANALYSIS

The survey also includes a set of data related to the spatial aspect of the respondents and their travel behavior. For example, respondents had the chance to indicate their desired location for charging spots and areas where they will be offered free parking. The visualization of the relevant data can give enlightening insight to the stakeholders regarding the future placement of charging spots in the greater Stockholm area as well as it will provide insights for the creation of a new parking policy. This policy will concern the needs of EV users and the facilitation of the proposed incentive. Additionally, the visualization of the travel diaries (e.g., choropleth map) by using GIS software can give information regarding the spatial distribution of the origin-destination points. The travel diaries can be disaggregated concerning the used transport modes, the trip purpose (commute to work, home, school, visit family/friends, work related trip, drop off/pick up someone, sports/leisure, shopping) or the travel mode (conventional car, EV, taxi, bicycle, public transport, passenger, e-bike, e-scooter, walk). Therefore, interesting results can emerge related to the travel habits of Stockholm's population. Last, is interesting to explore the relationship between the characteristics of the respondents with the space. For instance, an investigation of the current spatial characteristics of EV ownership as well as the change of them after the integration of the incentives can give relevant insight.

4.4 Roadmap for sustainable use of electric vehicles

With the design and results of the survey study at hand, the third major part of the planed research methodology included the identification of scenario- and incentive relevant stakeholders and the characterization of their constraints and objective including synergies and conflicts between them via stakeholder interviews, to derive a strategy roadmap for a sustainable future deployment of electric vehicles.

4.4.1 Identification of stakeholders

Based on the scenario incentives the following stakeholders have been identified at three levels for the large-scale transition towards electric vehicles:

Table 2: Scenario-relevant stakeholders for large-scale transition towards electric vehicles

Level	Stakeholders
Governance/policy	Environment and Health Administration Traffic administration Real Estate Administration Swedish Energy Agency
Municipal	City of Stockholm Housing companies/associations
Operational	Stockholm Parkering AB Public transport organization: Stockholm Lokaltrafik SL Electric grid operators: E.ON, Fortum, Vattenfall

4.4.2 Interview questions

Three-part interviews with a representative of each of the identified stakeholders were scheduled and conducted as follows.

First, the following set of questions were asked to identify the situation of the stakeholder:

- How is a rebound effect dealt with currently?
- What are the current strategies taken when plans are made for transport, EV charging, EV ownership?
- What incentives and strategies are feasible?

Next, based on the situation of the stakeholder, the feasible incentives and strategies were related to the scenario incentives of the survey as a way of validation.

As the final part of the interview, based on the travel adaptation modelling results and the feasibility of the incentives, discussions were led about the possible system-level impact of (packages of) policy incentives with the stakeholder.

5. Results

The following subsections report on the results of the relevant parts of the methodology.

5.1 Explorative interview study

In general, the interview results show that the hypothesis of stable travel behavior after electric vehicle adoption does not seem to hold. Two-third of the respondents increased car travelling as an effect of electric vehicle adoption. The main reasons given were the low marginal cost and the fact that internal combustion engine vehicles are most polluting for short distances with a cold engine. As one of the interviewees put it: “it is just so environmentally friendly cheap”. Consequently, a large-scale deployment of electric vehicles is likely to contribute to rebound effects causing increased energy use and increased congestion. By increasing the marginal cost of car use, this tendency to drive more might be tempered with.

The interview results also show that the availability of charging infrastructure also influence the travel patterns. In particular, it can lead to changes in destination choice and mode choice, indicating that the provision of charging infrastructure could potentially be a good instrument to shift user behavior towards more sustainable EV use. Notably however, home charging was dominant among the interviewed users.

Finally, the interviews also revealed that the role and influence of an electric car in the household can be result in a more sustainable travel behavior of the household. In particular, in multicar households, the electric vehicle appears to be the preferred vehicle rather than the “second car”. Moreover, several interviewees indicated that they had purchased a second electric vehicle afterwards.

5.1.1 Sample interview fragments

The paragraphs below show an indicative samples of interview responses that are mainly related to travel behavior change where the possible negative and positive side-effects are highlighted indicated with red and green font, respectively.

SAMPLE 1

Interviewee 1: ”Hmm, I might drive a bit more.

When I had a petrol car, I could skip some trips because I didn’t feel like using so much petrol and damage the environment. When the engine was cold, I thought I could just as well take the bus, go by bike, or do something else.

But right now, it became like: it doesn’t cost me anything it doesn’t damage the environment. It has become a little increase of the number of trips, short trips.

Because it is so environmentally friendly cheap.”

SAMPLE 2

Interviewee 2: “Maybe for short trips, such as going to Täby Centrum, I feel less resistance to take the car.

I think that I could drive 10 % more since switching to an electric car.

Examples when I use the car now is when I do shopping, want to go for hiking, take care of my grandchildren or go to the city.”

“There are also trips where I decreased my car use. I usually went by car to the Concert House, but now I drive to a parking next to a metro station, where I can charge my car for free, and take the metro to the city instead.”

SAMPLE 3

Interviewee 3: “I haven’t changed my travel patterns. However, my wife looks at economy in a different way. With the petrol car we got the feeling that, from the moment you start the car, the money is pouring out. Now it is free to drive. Family, let’s go for a ride.”

”My wife drives to the supermarket now, before she used to take public transport more often. She stopped taking the bus. She also often brings and gets my son, even though actually it is unnecessary. Before she used to be stingy with that.”

5.2 Survey study

5.2.1 Final stated adaptation web survey tool

While the final stated adaptation web survey tool is not theoretical knowledge or empirical result of the study, it is arguably a valuable result of the project. To allow the exploitation of this result, the source code of the tool will be published at the end of the project as a Github code repository, for other researchers in the field to be configured to collect data in similar stated adaptation experiments. The paragraphs below describe the detailed components and features of the final tool.

TOOL OVERVIEW AND FEATURES

The final tool is designed as an innovative system to collect information regarding user travel diaries, demographics, mobility characteristics and stated adaptions. The user provides information in respective sections.
Major features of our system are as follows:

- **Multiple language support:** The system supports both English and Swedish languages. User can switch to any one of them from the top navigation bar.
- **Automatic and manual saving:** The system saves the user data on each step automatically, but it also allows the user to save it manually using the save button.
- **Progress capturing:** The system captures the users progress throughout the survey. It helps the user to know how much survey he has completed and how much is left.
- **Anonymous survey:** The system does not collect any information that will lead to a particular individual.

- **User friendly user interface:** The system user interface and user interaction both are very user friendly. User can easily navigate through our system and can keep track of its progress.
- **User feedbacks:** The system also ask the users to provide feedback regarding the survey.

In details, functioning and operation of the system are described in subsequent sections.

SIGN IN

The system allows the user to fill out the survey once they authenticate themselves using the provided authentication code. Each authentication code is valid per user and once survey is being completed against it. The authentication code cannot be used again for another survey. The user can also auto login if the authentication code is provided as part of a URL link which directly takes user inside the survey screen.

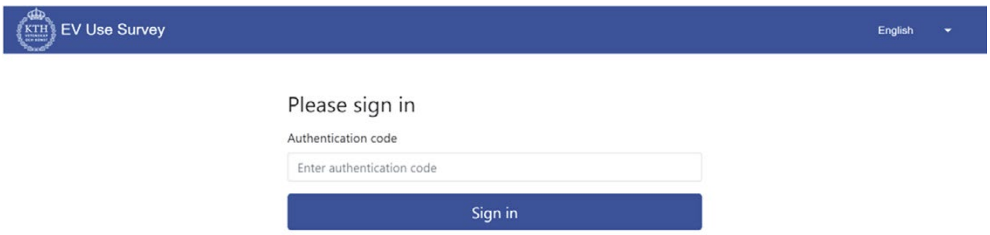


Figure 8: Login screen

BEFORE STARTING SURVEY - SECTION 0: SCREENING QUESTION

Once system authenticates the user it asks the user the following question (Figure 9): How often do you use your EV (commute to work included)?
Then the user is provided with multiple options that are shown in Figure 9. On selection of 'never' option, system simply logs out the user. In case of any of the other options the system starts with the first section of the survey.

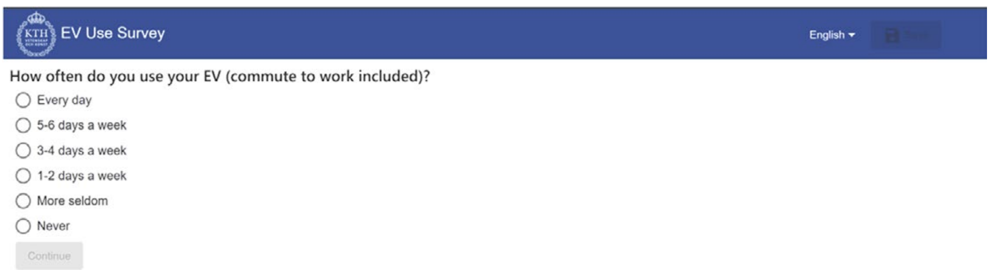


Figure 9. Initial screening question

THE SURVEY

The survey consists of four sections. Each section holds their respective information related form. The user must fill out all the four sections to complete the survey. Each section completion moves the progress bar up. The four sections are as follows:

1. Mobility characteristics
2. One day travel diary
3. Stated adaptation
4. Demographics

SECTION 1: MOBILITY CHARACTERISTICS

The first step in the survey is related to user 'mobility characteristics'. The system asks different questions (examples shows on Figure 10) in this section and the user has to answers all of them to move forward**.**

A total of 14 questions are asked in the section. Each answer will move up the completion progress bar by 2%. Once all the questions in this section are answered the 'next' button is enabled by the system to allow the user to go to next section. A confirmation message is also displayed by the system before going to next section.

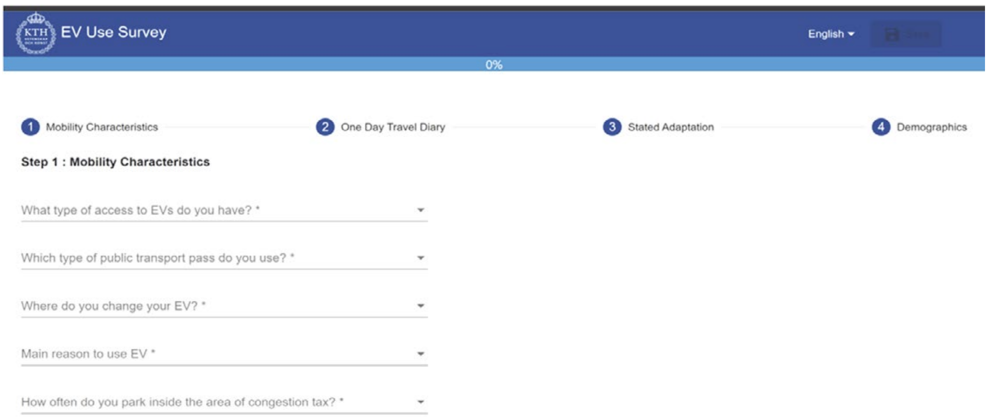


Figure 10. Mobility characteristics questions

SECTION 2: ONE DAY TRAVEL DIARY

In this step the user is asked questions related to the travel diary. The system provides a map interface to the users, which is used to add the travel diaries. The map on Figure 11 shows synchronized details as the user fills out the form. Map contains legend button that displays all 'travel modes' and 'travel purposes' colors and icons.

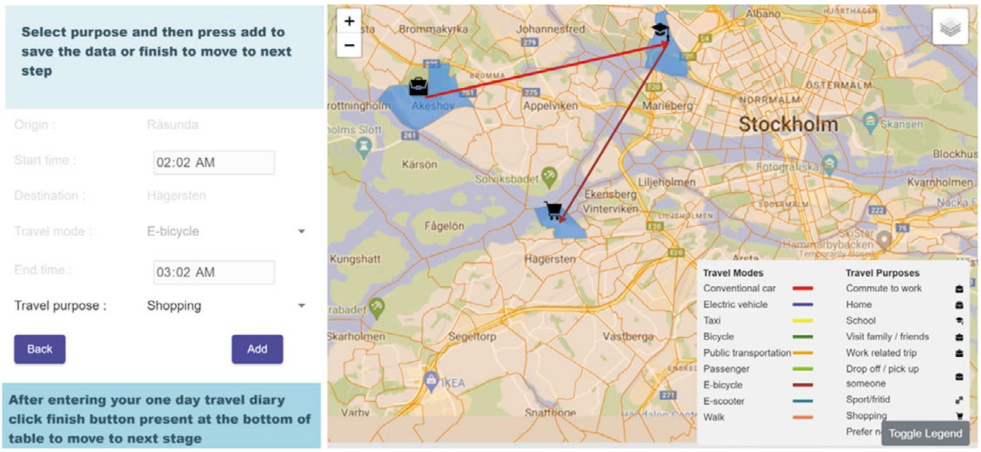


Figure 11. Travel diary entry

Each entry of travel diary is added to a table which is shown below the form (Figure 12). The user can delete latest entry from the table. Once satisfied with travel diary, the user presses the ‘finish’ button to move to next the next section.

Delete	Start time	Origin	End time	Destination	Travel mode	Travel purpose
	00:00	Västerled	00:00	Råsunda	Conventional car	School
	02:02	Råsunda	03:02	Hägersten	E-bicycle	Shopping
	04:10	Hägersten	05:30	Stockholms domkyrkodistrikt	Passenger	Home

Finish

Figure 12. Travel diary table

SECTION 3: STATED ADAPTATION

The ‘Section 3’ in the system is named as ‘stated adaption’. The system offers incentive to the user in this section (Figure 13).

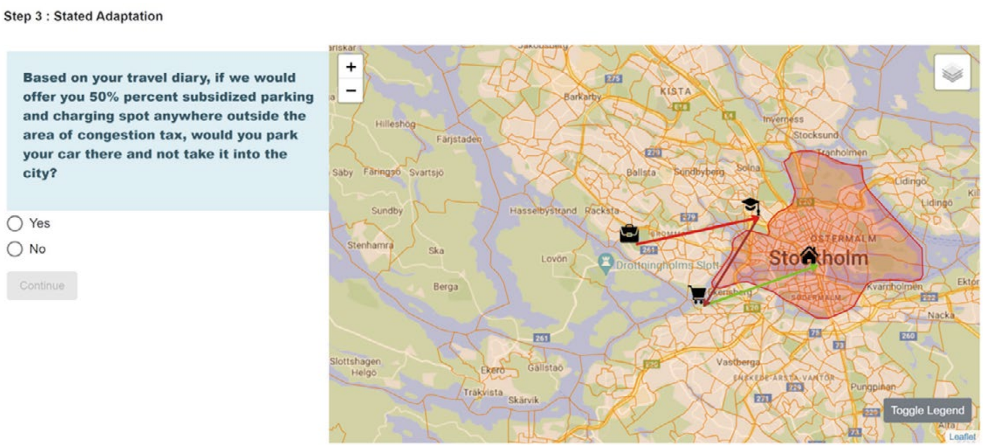


Figure 13. Incentive offer screen

The offering of the incentive depends upon the user travel diary filled in 'Section 2'. There are a total of four possible cases that can came out from travel diary filling section (Table 3). Each case will change the information shown to the user in the 'Section 3'.

Table 3: Cases for conditional incentive offering and stated adaptation survey.

Scenario	Trip origin	Trip destination	Decision on incentive offering
Case 1	Outside congestion tax area	Inside congestion tax area	Offer incentives
Case 2	Outside congestion tax area	Outside congestion tax area	Screening question: Do you travel sometimes in the congestion tax area? yes -> Offer incentives no -> No incentives offered
Case 3	Inside congestion tax area	Inside congestion tax area	No incentives offered
Case 4	Inside congestion tax area	Outside congestion tax area	No incentives offered

The following incentive question is asked by the system in case of 'Case 1' or if the answer to 'Case 2' is 'yes'.

If the user decides to take the incentive, then the user is then asked to add a location on the map for his preferred parking and charging spot (Figure 14).

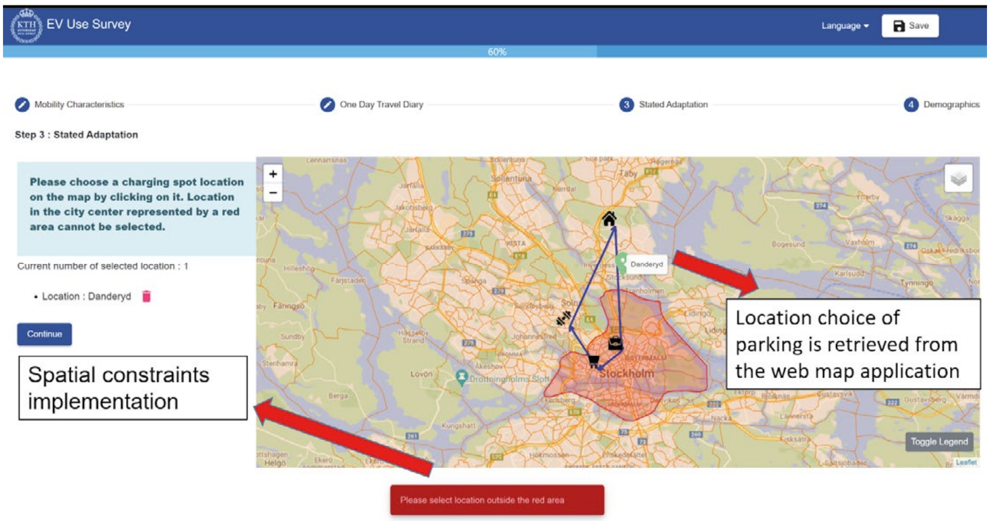


Figure 14. Choose incentive location

The user can then alter the travel diary trips that were filled out previously in 'Section 2' (Figure 15).

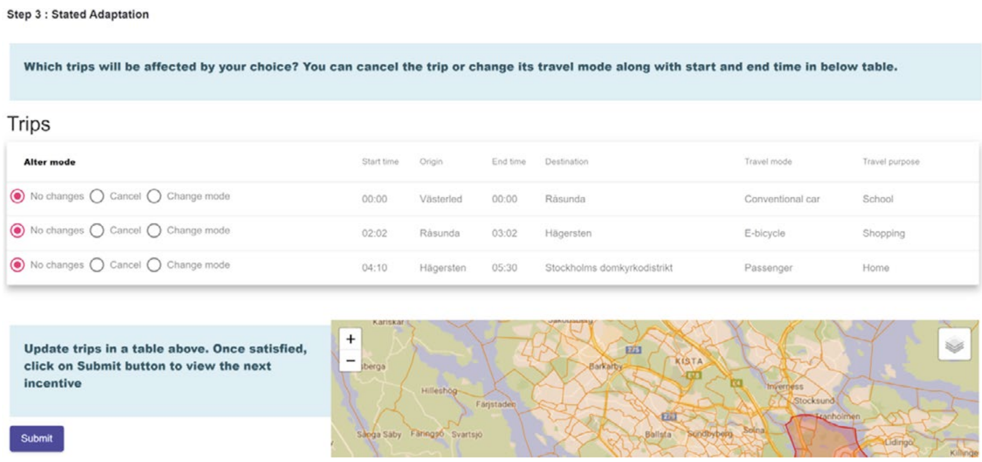
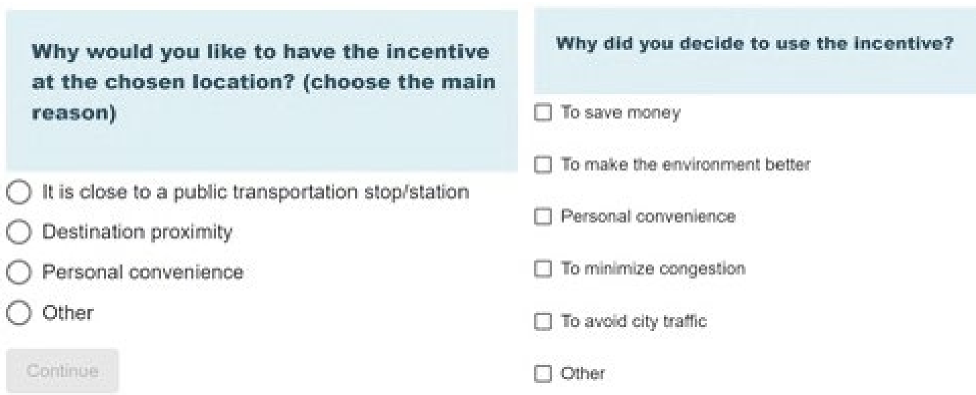


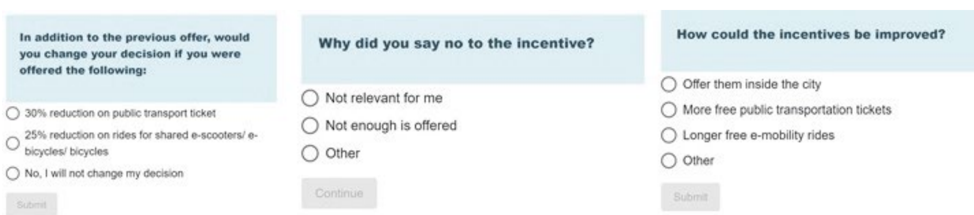
Figure 15. Stated adaptation

In case of user takes the incentive, the system shows him or her other questions regarding the incentive to collect more information. Similar questions are asked if the user does not take the incentive.

The system will ask following question in case the user takes the incentive:



The system will ask following question in case user do not take the incentive:



After completing ‘Section 3’, the user is taken to ‘Section 4’.

SECTION 4: DEMOGRAPHICS

The system will ask the user some basic demographics information (Figure 16). On completing the form, the user can submit the survey. The system then logs out the user automatically.

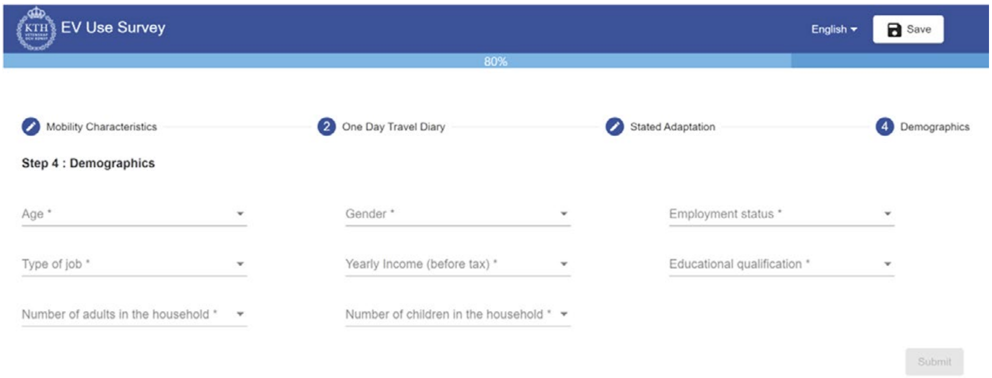


Figure 16. Demographics section

FEEDBACK

Once the survey is completed, the system allows the user to provide free-text feedback regarding the survey and/or the tool.

THE ADMIN MODULE

An admin module of the system was also developed. As shown on Figure 17, it allows the administrator to create new users (i.e., authentication codes). The admin can also check survey status ('not started', 'partially completed', 'completed') and completion percentage for each user authentication code (Figure 18). The admin panel is accessed through a secure username and password.

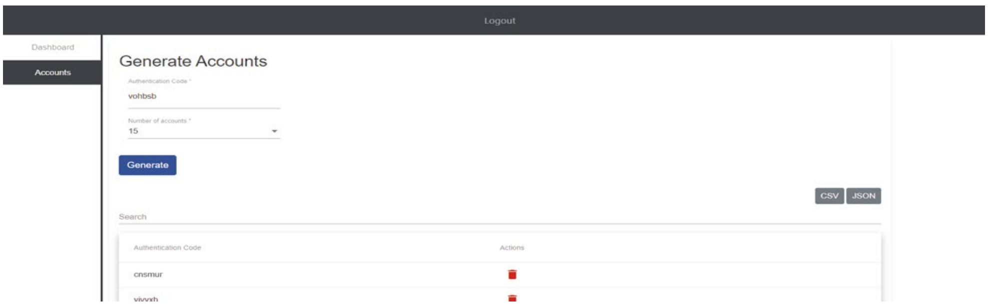


Figure 17. Admin panel - Create multiple accounts

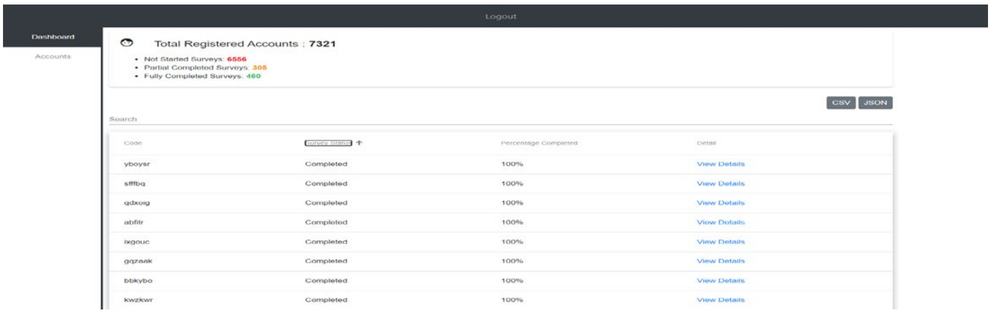


Figure 18. Admin Panel - Dashboard statistics

5.2.2 Survey data analysis

DESCRIPTIVE STATISTICS AND GEOVISUALIZATION

Section 0: Screening question

Question: How often do you use your EV?

Value	Percentage
3–4 days a week	20.06
More seldom	0.86
1–2 days a week	7.74
5–6 days a week	30.66
Never	1.43
Every Day	39.26

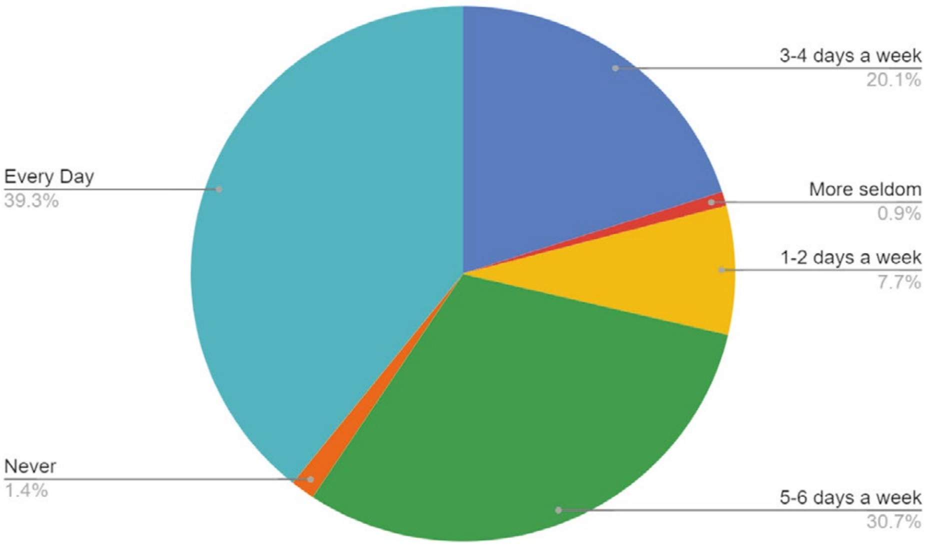


Figure 19. How often users use their EV – chart

Section 1: Mobility characteristics

Question: What type of access to EV you have?

Value	Percentage
I lease an EV privately	46.12
I lease an EV privately | My company provides access	1
I lease an EV privately | Other	0.25
I own an EV	50.38
I own an EV | I lease an EV privately	0.5
I own an EV | My company provides access	0.5
I own an EV | Other	0.25
My company provides access	0.75

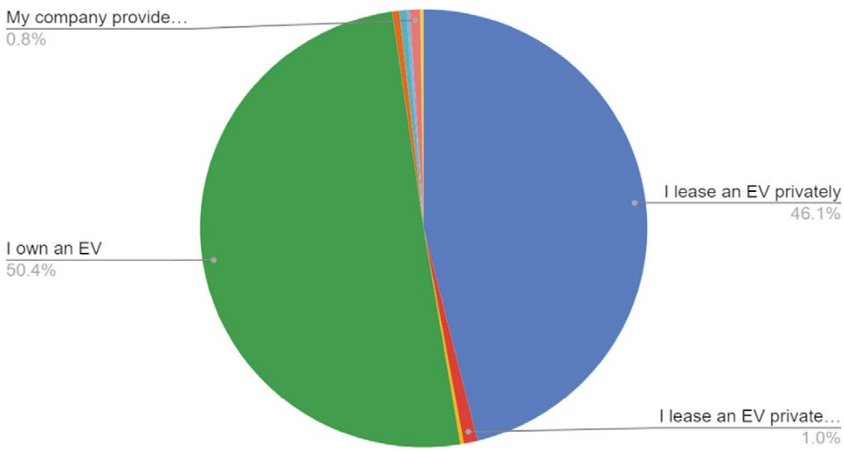


Figure 20. What type of EV access users have – chart

Question: Which type of public transport pass do you have?

Value	Percentage
24 hours pass	0.5
3–day pass	0.25
I don't normally use the public transport	13.03
Monthly pass	12.03
One time pass	73.93
Weekly pass	0.25

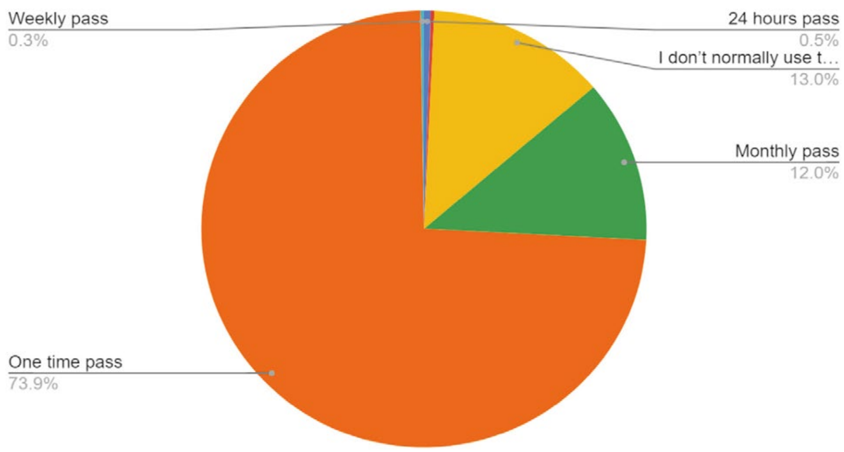


Figure 21. What type of public transport pass users have – chart

Question: Where do you change your EV?

Value	Percentage
At a charger provided by housing cooperative	10.03
At a private property	51.63
At a private property | At a charger provided by housing cooperative	0.25
At a private property | At a public spot	8.52
At a private property | At a public spot | Other	0.25
At a private property | At a working place	6.77
At a private property | At a working place | At a charger provided by housing cooperative	0.25
At a private property | At a working place | At a public spot	1.75
At a private property | Other	0.5
At a public spot	9.02
At a public spot | At a charger provided by housing cooperative	1.25
At a public spot | Other	0.25
At a working place	2.01
At a working place | At a charger provided by housing cooperative	0.75
At a working place | At a public spot	3.01
At a working place | At a public spot | At a charger provided by housing cooperative	0.75
At a working place | At a public spot | Other	0.5
At a working place | Other	0.5
Other	2.01

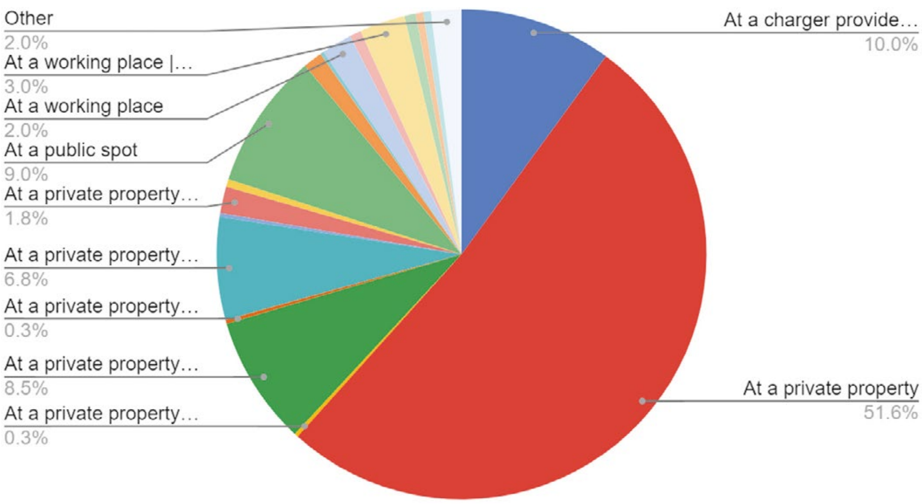


Figure 22. Where do users charge their EV? – chart

Question: What is your main reason to use EV?

Value	Percentage
I care for the environment	33.58
I care for the environment | I like to try new products	5.76
I care for the environment | I receive a subsidy to use it	0.75
I care for the environment | I receive a subsidy to use it | I like to try new products	0.25
I care for the environment | Other reason	1.5
I like to try new products	5.76
I like to try new products | Other reason	0.25
I receive a subsidy to use it	0.5
It is cheaper	13.03
It is cheaper | I care for the environment	20.55
It is cheaper | I care for the environment | I like to try new products	7.77
It is cheaper | I care for the environment | I like to try new products | Other reason	0.5
It is cheaper | I care for the environment | I receive a subsidy to use it	1.75
It is cheaper | I care for the environment | I receive a subsidy to use it | I like to try new products	2.26
It is cheaper | I care for the environment | I receive a subsidy to use it | Other reason	0.25
It is cheaper | I care for the environment | Other reason	0.5
It is cheaper | I like to try new products	2.26
It is cheaper | I receive a subsidy to use it	0.5
Other reason	2.26

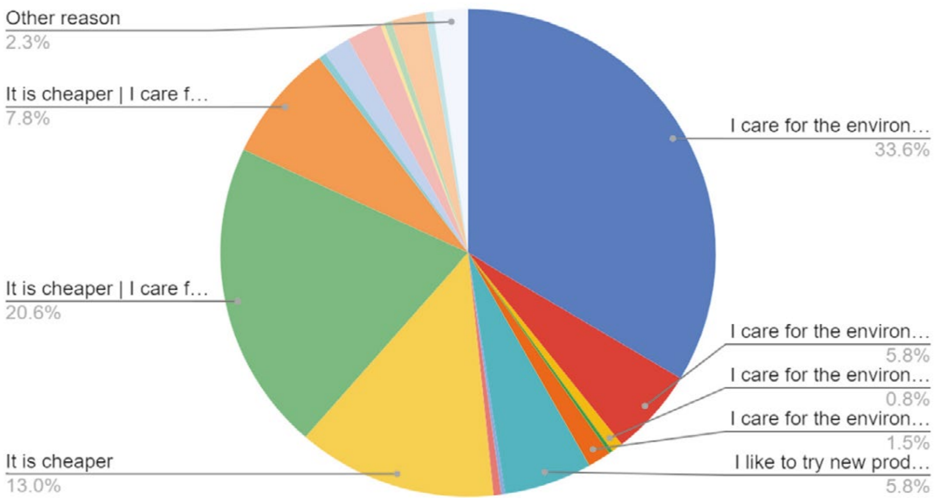


Figure 23. Users' main reason to use EV – chart

Question: How often do you park inside the area of congestion tax?

Value	Percentage
A few times a month	25.06
A few times a week	15.79
Daily	9.27
Never	10.28
Rarely	39.6

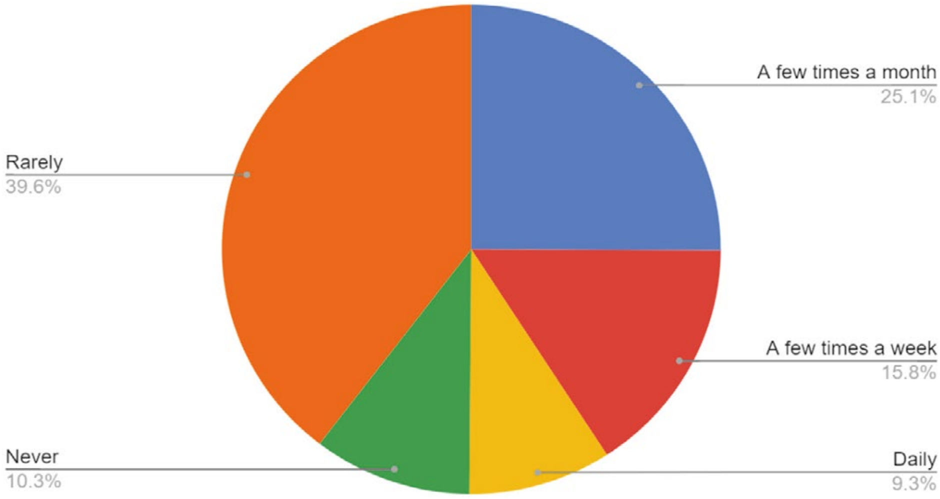


Figure 24. How often users park inside the area of congestion area – chart

Question: Do you think congestion tax is too high?

Value	Percentage
Agree	19.8
Disagree	31.08
Indifferent	33.08
Strongly agree	3.76
Strongly disagree	12.28

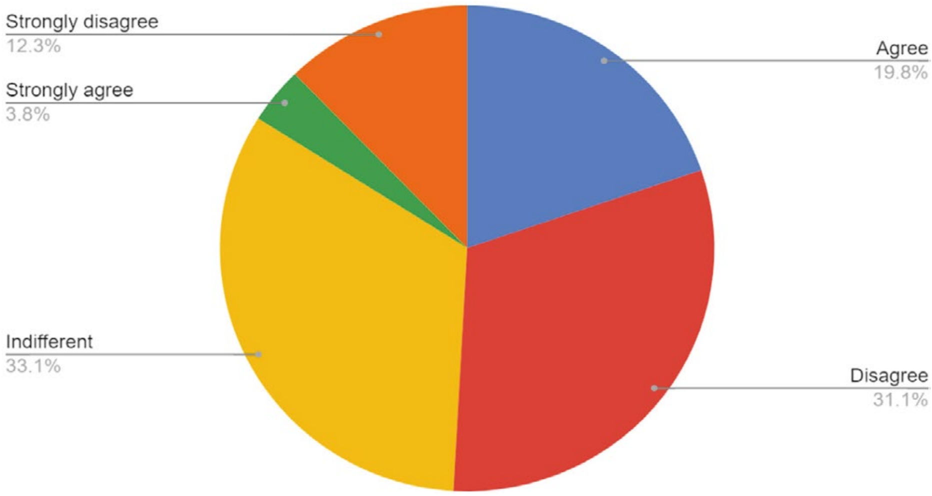


Figure 25. Congestion tax is too high chart – chart

Question: How much do you agree with this statement? "I enjoy using public transport"

Value	Percentage
Agree	35.59
Disagree	18.05
Indifferent	19.3
Strongly agree	17.54
Strongly disagree	9.52

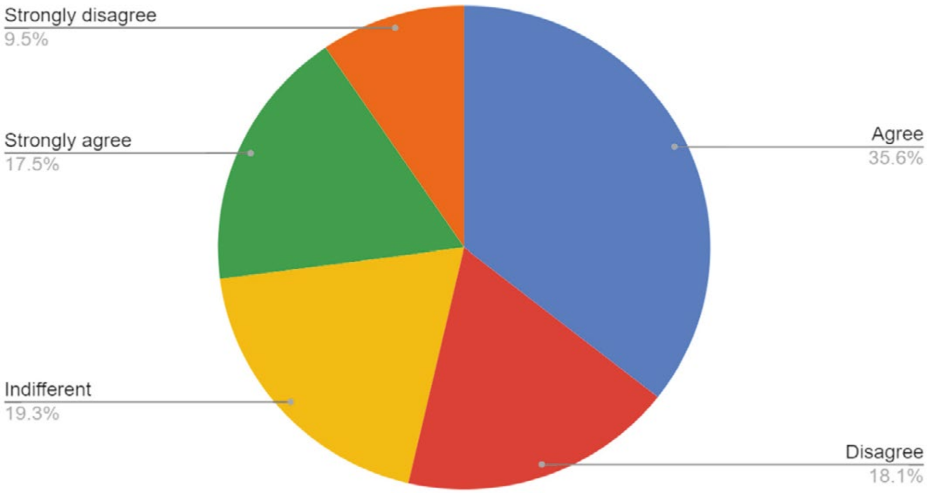


Figure 26. Users enjoy using public transport – chart

Question: How much do you agree with this statement? "I feel safe using public transport"

Value	Percentage
Agree	37.59
Disagree	7.27
Indifferent	12.53
Strongly agree	41.6
Strongly disagree	1

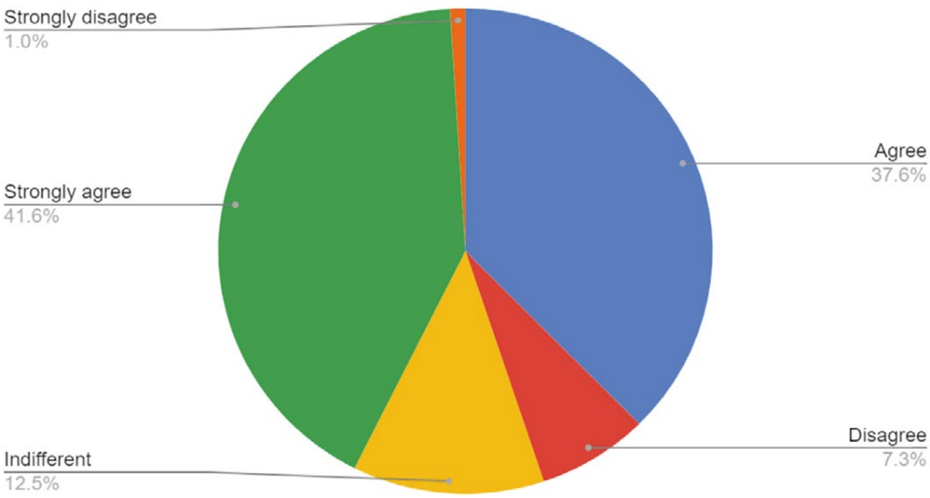


Figure 27. Users like using e-scooters / e-bicycles – chart

Question: How much do you agree with this statement? "I like using e-scooters / e-bicycles"

Value	Percentage
Agree	14.04
Disagree	16.54
Indifferent	26.07
Strongly agree	12.78
Strongly disagree	30.58

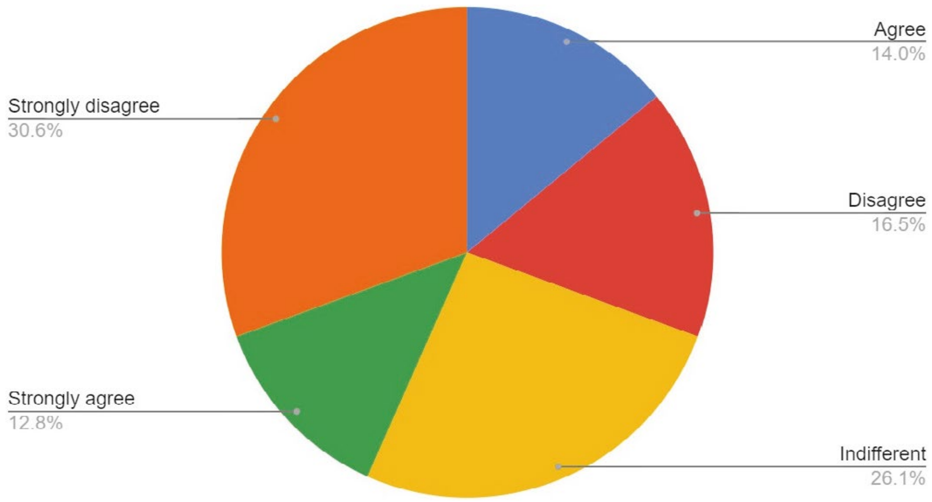


Figure 28. Users like using e-scooters / e-bicycles – chart

Question: How much do you agree with this statement? "I feel safe using e-scooters / e-bicycles"

Value	Percentage
Agree	16.54
Disagree	12.28
Indifferent	38.35
Strongly agree	9.27
Strongly disagree	23.56

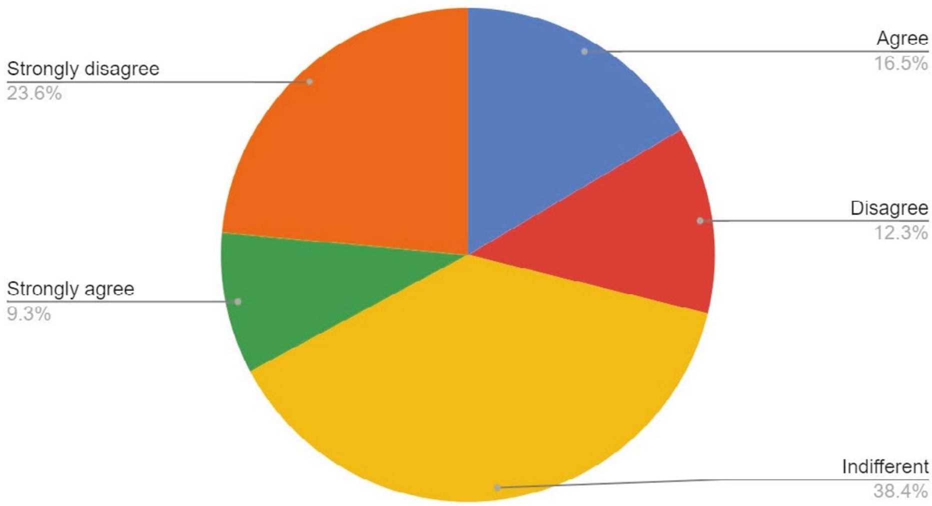


Figure 29. Users feel safe using e-scooters / e-bicycles – chart

Section 2: One day travel diary

The users provide an approximate location for starting their trips. About 9.5% of the trips started from inside the city (congestion tax area) while 90.5 % are from the outside main city.

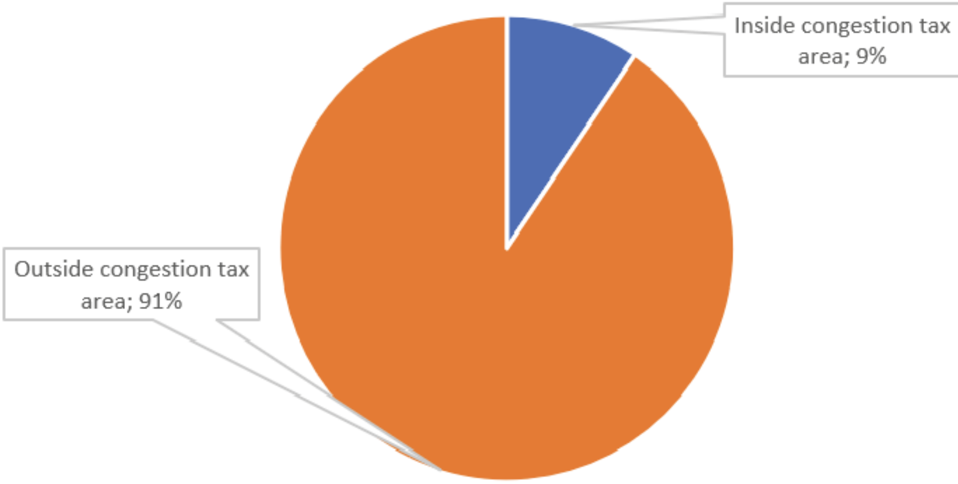


Figure 30. First trip starting location – chart

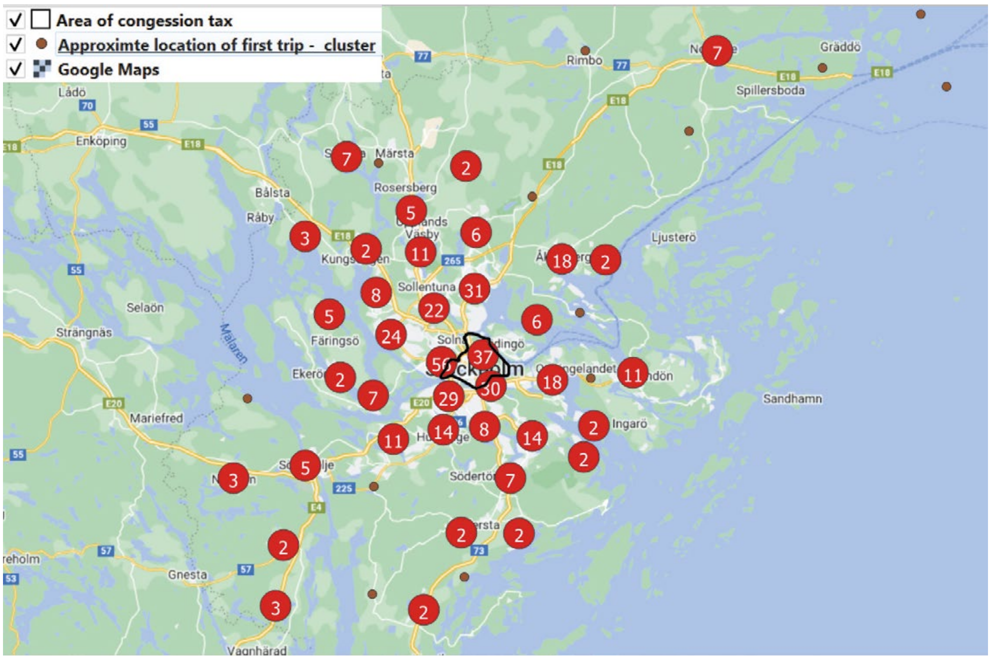


Figure 31. Approximate location of first trip – map

The user's movement is extracted from the travel diary. The following movement categories are observed:

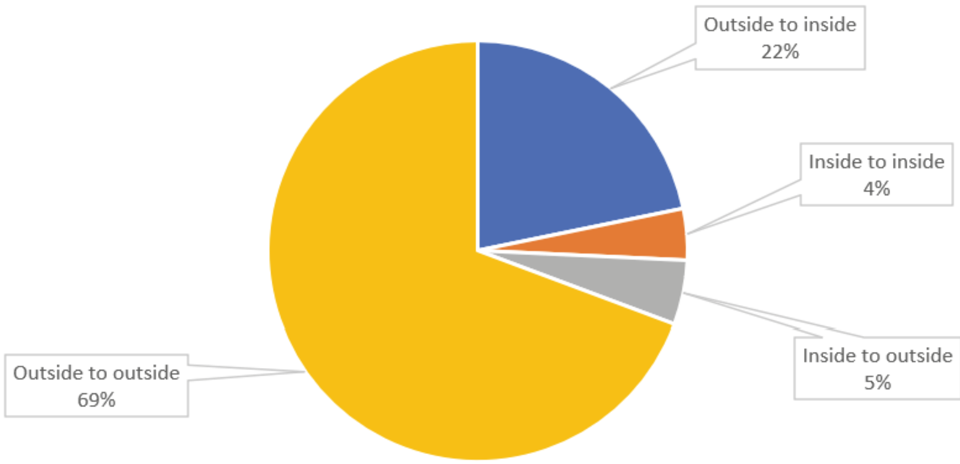


Figure 32. Movement category – chart

Section 3: Stated adaptation

The incentive was offered to the users who were traveling from outside the city to inside the area of congestion tax. It was also offered to those whose travel diary is from outside-to-outside city but they answered yes to the question of sometimes coming in the city. The following is observed when the incentive was offered:

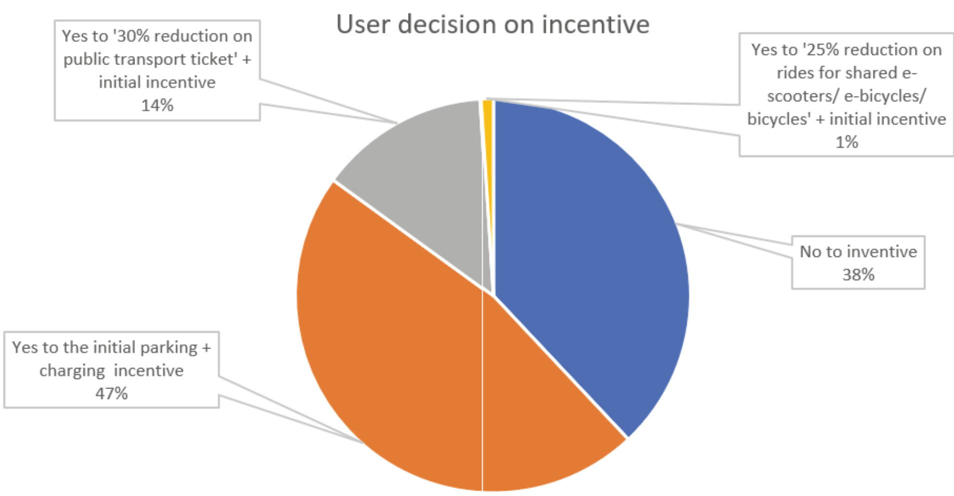


Figure 33. User decision on inventive – chart

The following maps cluster the charging and parking spot chosen by the users.

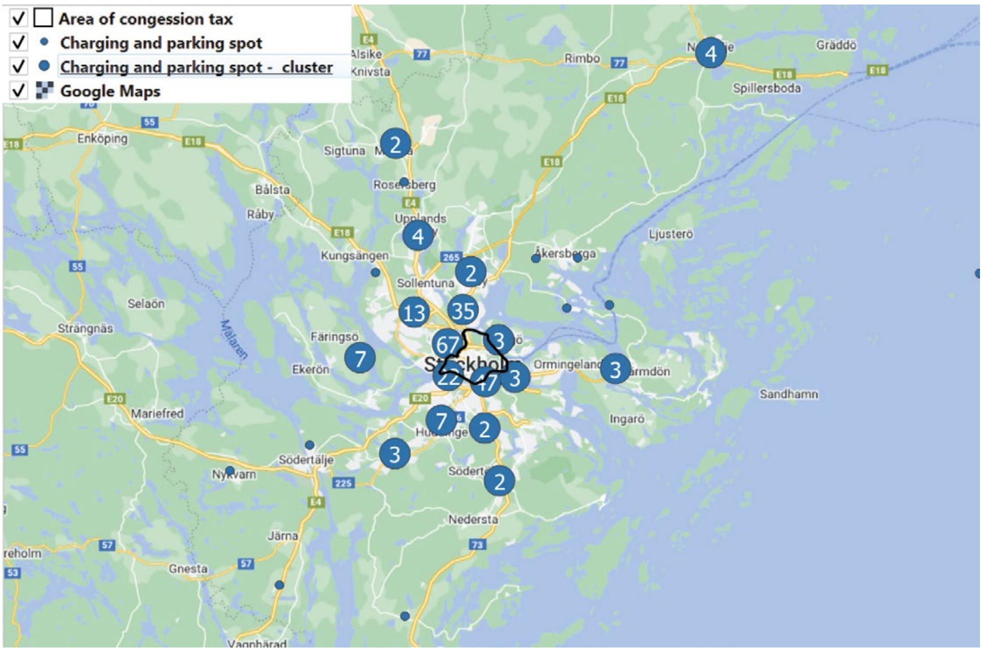


Figure 34. Charging and parking spot cluster - map

Question: Why would you like to have the incentive at the chosen location?

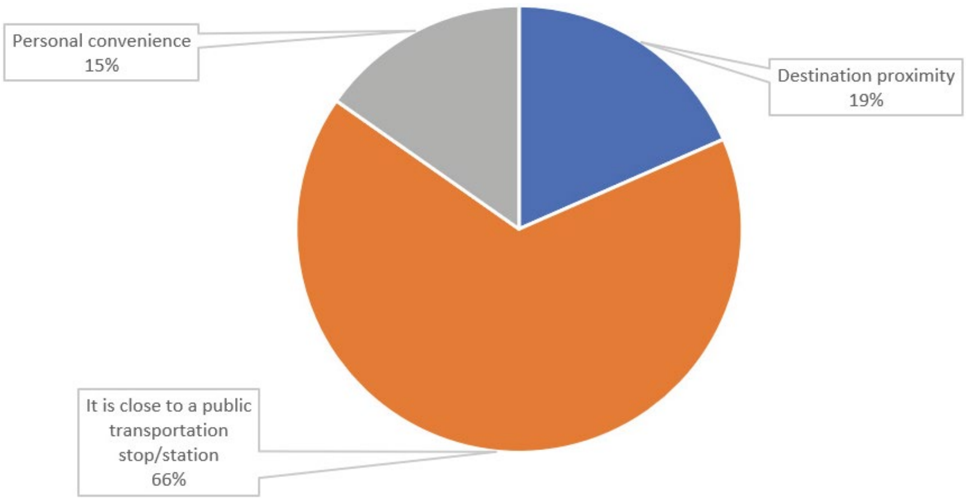


Figure 35. Reason for choosing the incentive location chart – chart

Section 4: Demographics

Question: What is your age?

Value	Percentage
18 – 24	3.01
25 – 34	7.52
35 – 44	30.33
45 – 54	26.32
55 – 64	21.3
Above 65	11.53

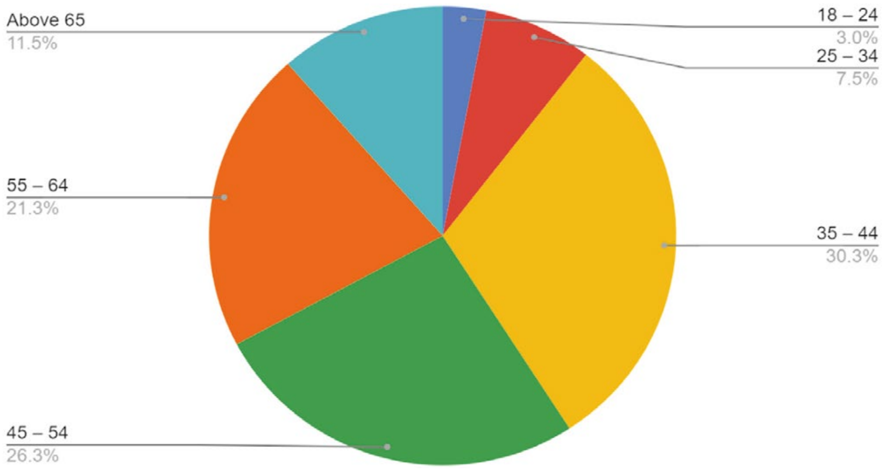


Figure 36. Users age – chart

Question: What is your education?

Value	Percentage
Postgraduate degree	12.03
Prefer not to say	5.51
Primary school	1.25
Undergraduate degree	55.64
Upper secondary school	25.56

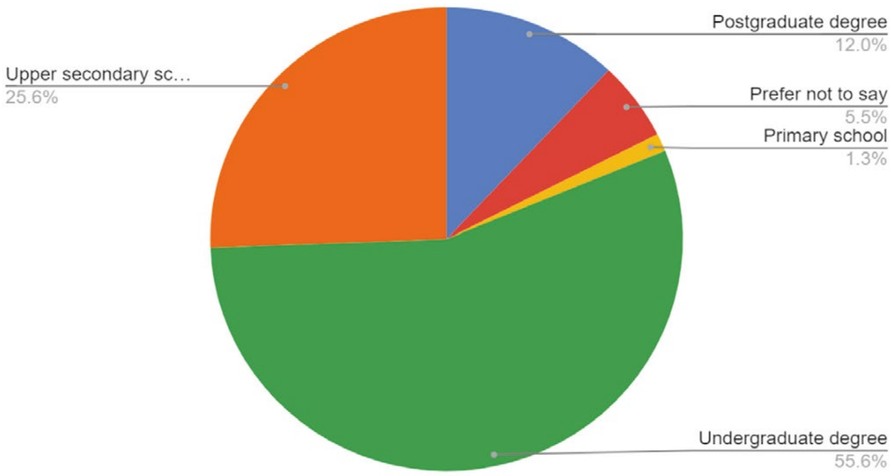


Figure 37. Users education – chart

Question: What is your employment status?

Value	Percentage
Prefer not to say	1.5
Retired	9.52
Student	3.51
Unemployed and not looking for job	0.75
Working full-time	78.2
Working part-time	6.52

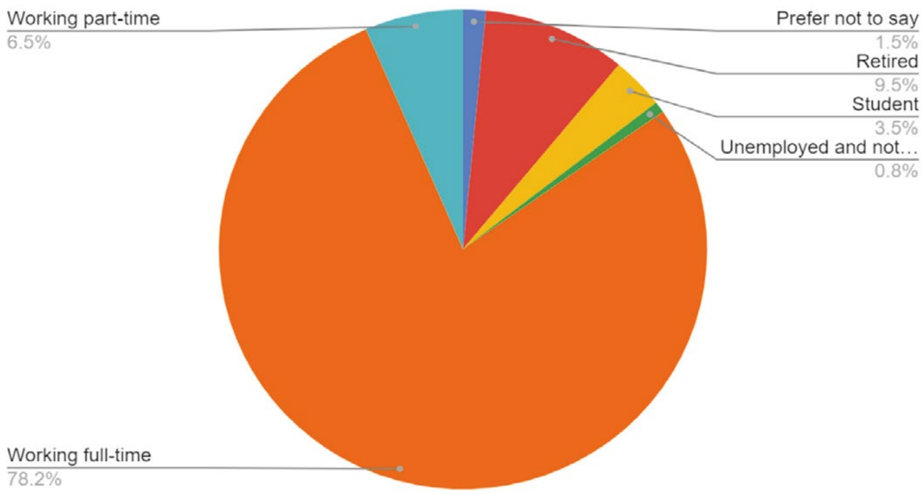


Figure 38. Users employment status – chart

Question: What is your gender?

Value	Percentage
Female	37.34
Male	61.65
Prefer not to say	1

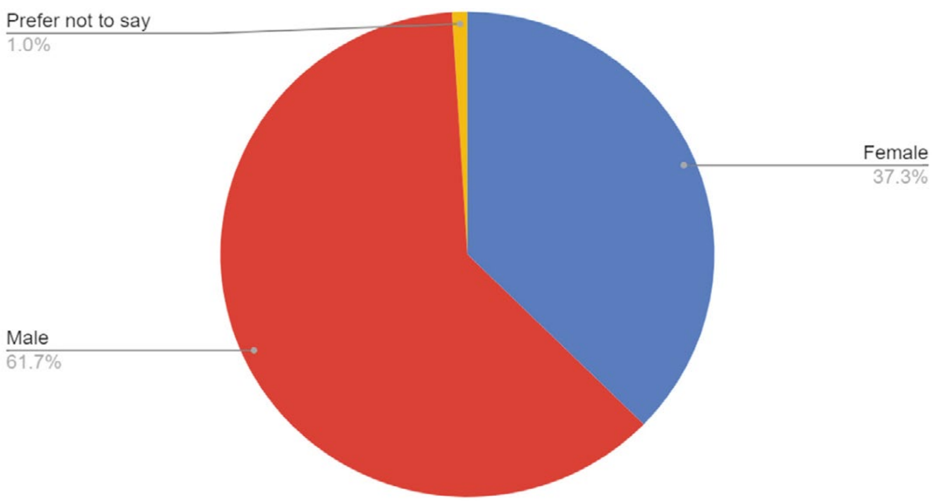


Figure 39. Users gender – chart

Question: Number of adults in house

Data	Percentage
0	0.5
1	11.03
2	72.93
3	10.78
4	4.26
5	0.5

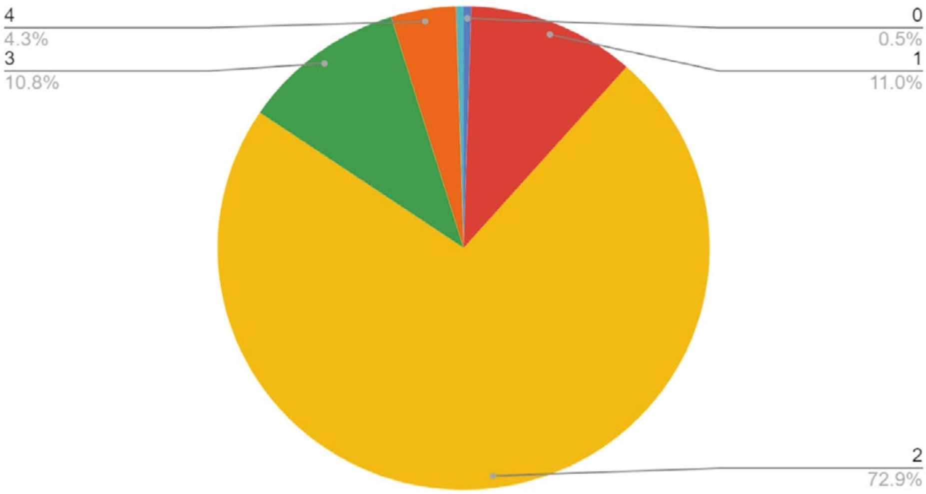


Figure 40. Number of adults in house – chart

Question: What is your job type?

Value	Percentage
Other	6.98
Prefer not to say	1.12
Self-employed	11.17
Work for a company	54.19
Work for the public sector	26.54

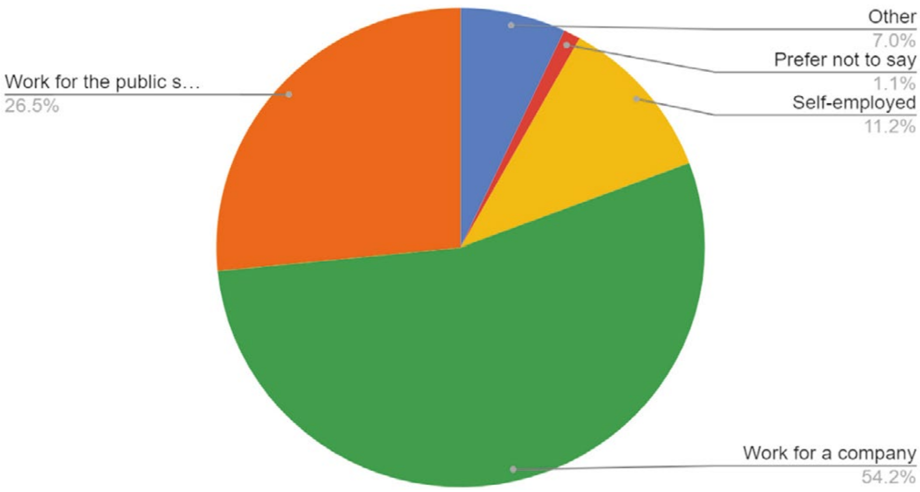


Figure 41. Users job type – chart

Question: What is your yearly income?

Value	Percentage
100.000 – 299.000 kronor	4.76
300.000 – 499.000 kronor	27.82
500.000 – 699.000 kronor	33.58
700.000 – 899.000 kronor	15.79
Below 100.000 kronor	4.26
More than 900.000 kronor	9.77
Prefer not to say	4.01

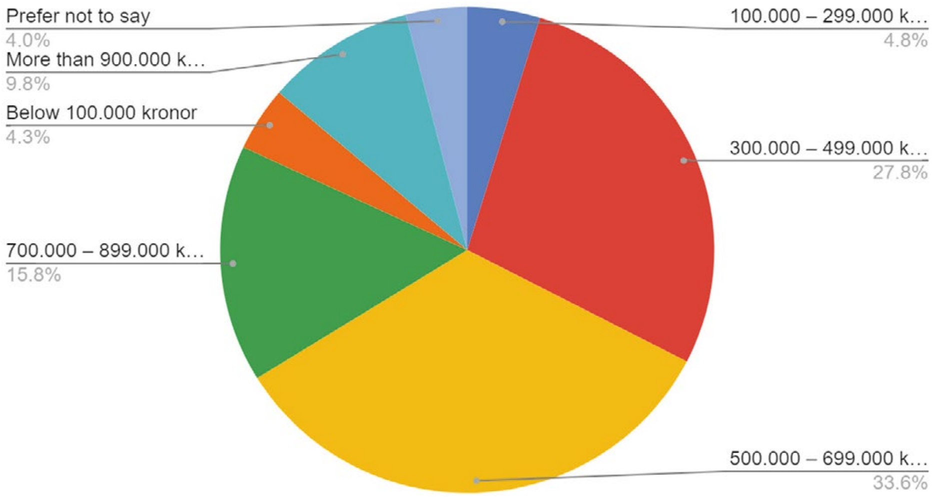


Figure 42. Income – chart

STATISTICAL TRAVEL BEHAVIOR MODELLING

The first step of the modelling concerns the estimation of the correlations between the dependent (choice) and the potential independent variables for the development of the utility functions.

To this extent, the choice variable was disaggregated to its individual components (incentive 0, incentive 1, incentive 2, incentive 3) so the significant correlations between the incentives with the rest of the potential independent variables. The significant correlations for each choice are summarized in the following table.

Table 4: Significant correlations between the choices with potential independent variables

Choice	Potential independent variables	Pearson's R coefficient	Asymptotic significance (p-value)
Incentive 0_ (no incentive selected)	employment_status	.191	<.001
	age	.235	<.001
	gender	-.112	.041
Incentive 1 (free parking and charging)	how_ofter_do_you_park_inside_the_area_of_congestion	.176	.001
	how_easy_to_find_parking_inside_the_area_of_conges-tion	.116	.035
Incentive 2_ (PT reduced fare)	public_transport_pass	-.207	.001
	enjoy_using_pt	-.207	.001
	safety_using_pt	-.207	.001
Incentive 3_ (E-scooters reduced fare)	enjoy_using_escooters	-.167	.002
	safety_using_escooters	-.170	.007

Many different trial and error tests were conducted for the definition of the utility functions. Also, many of the potential independent variables were disaggregated into their individual categories. Thus, more variables were defined, e.g., the income variable was split to its individual categories. The variables which were first considered for the utility functions' definition were: distance, the frequency of the EV use, the gender, the income, the charge location of the EV and some variables related to the specific incentives. For example, the incentive 2 is related to the reduction in the price of public transport and therefore the variable related to the public transport pass was included. Concerning the incentive 3 (reduction in the price of e-scooters/e-bicycles) the perceived safety of the e-scooters use is integrated in the utility function. A first definition of the utility functions is the following:

- Incentive0 = f (age, employment_status, gender)
- Incentive1 = f (how_ofter_do_you_park_inside_the_area_of_congestion, how_easy_to_find_parking_inside_the_area_of_congestion)
- Incentive2 = f (public_transport_pass, enjoy_using_pt, safety_using_pt)
- Incentive3 = f (enjoy_using_escooters, safety_using_escooters)

There are some interesting findings from the model's results. First, the number of nests proved to be statistically insignificant (p-value >.05). This finding implies that the existence of the designed nest does not significantly affect the results. Therefore, a simple logit model can be used as well.
Moreover, the trial and error in building such a model made further encoding technique necessary. Some of the variables have one or more categories that was

more significant more than others, thus, the encoding was further expanded as follows:

No.	Variable	Category	Dummy Variable
1	Employment Status	Full-time	0
		Part-time	1
		Other[1]	2
2	Gender	Male	0
		Other[2]	1
3	Parking in Congestion Charge Area	Often[3]	0
		Rarely	1
4	Public Transport Pass	Monthly Pass	0
		Other[4]	1
5	Public Transport Safety	Agree	0
		Other[5]	1
6	E-scooter Enjoyment	Strongly Agree	0
		Other[6]	1
7	E-scooter Safety	Other[7]	0
		Strongly Disagree	1

Two models were tested and based on the model parameter values, their significance, and the differences between the models, the modelling results can be interpreted as follows:

- Female respondents are more likely to choose at least one of the offered incentives, compared to the male respondents, suggesting females, for unobserved reasons, are more disposed to avoid driving an EV into the center.
- Young respondents (18–24) are more likely to select at least one of the incentives compared to the other age groups, suggesting these young people are also more disposed to avoid driving into the center.
- Respondents with part-time employment are more likely to select an incentive compared to other employment status (full-time, other), suggesting those without full-time employment are less likely to persist driving into the center.
- Respondents who rarely park inside the congestion zone are more likely to accept incentive 1, compared to those who often park in the congestion zone now. This result highlights that the offer of incentive 1 can “attract” respondents who are currently not parking in the congestion zone in the absence of an incentive.
- Respondents who “strongly disagree” that they can find a parking spot in the congestion zone are more likely to accept incentive 1, compared to those who “strongly agree”. This suggests those who already have confidence in parking opportunities are harder to sway toward leaving the car outside the city center.
- Holders of a monthly public transport pass select incentive 2 to a higher degree than the respondents with a different public transport pass (weekly, 24h, 72h). This suggests those invested in regular public transport usage are easier to attract.
- Regardless of the public transportation enjoyment level, respondents seem not to prefer choosing incentive 2.

- Respondents who have higher perceived safety in public transportation are more likely of choosing incentive 2 compared to those who have lower perceived safety levels.
- Respondents who “strongly” enjoy the use of e-scooters and e-bicycles are more likely to take incentive 3 compared to the respondents who chose another answer (indifferent, disagree, strongly disagree). This makes intuitive sense in that this incentive increases their opportunities to use those “enjoyed” modes.

The estimated parameters of the models can be found in the Appendix of this report.

5.3 Roadmap for sustainable use of electric vehicles

The project management issues described in Section 4.1.3 has introduced unfortunate and difficult-to-manage delays in the project and due to the sequential dependence between the survey study (in particular the survey data collection and analysis including the main statistical travel behavior modelling in Section 4.3.5 and Section 4.3.6, respectively) and the planned stakeholder analysis to form the basis for the “Roadmap for sustainable use of electric vehicles” could not be carried out during the project period. However, based on the results of the statistical travel behavior modelling, Section 6.3 outlines several methodologies for stakeholder analysis and roadmap creation.

6. Discussions

The following subsections discuss the assumptions and limitations of this study and are in part based on the authors' learning during the study and the valuable comments of the reviews that are gratefully acknowledged.

6.1 EV developments since study onset

A fair amount of development has happened in the space of electric vehicles since the onset of the project. First, the assumption about increased car used after EV adoption has become undisputed knowledge and most forecasting systems today consider that the marginal cost of car use will decrease when the share of EV's increases and therefore lead to increased car use. Second, with the improvements in battery technologies and reduction of costs, and with the predominant availability of overnight home charging EV range has become less of a problem for battery electric vehicles for average daily trips. For plugin hybrid electric vehicles, due to their limited electric range (approx. 50 km), accessibility to public charging still remains challenge. In particular, the lack sufficient charging infrastructure at desired destinations or enroute (mostly for long distance trips) is quickly becoming the bottleneck of EV adoption[1]. Consequently, providing subsidized charging (especially in connection to dedicated EV parking) could still be a powerful inventive for EV users.

6.2 Survey study

The developed stated adaption web survey tool is one of the main outcomes from the project. In the initial phases of the project a lot of effort have been made to develop a theoretical framework and a prototype tool that uses the framework which tries to associate the chosen incentive with individual trips of a user. Although the prototype has been radically simplified to monitor less of the trip diary consistency relative to the chosen incentive, the low response rate (6%) and the less than expected number of reported trips per day (1.6) indicate that despite all efforts the tool may have been perceived by the users as a tool that is "designed by engineers for engineers". Other possible explanation for the lower than usual response rate and quality of data could include the relatively long survey (10–15 minutes), the less than perfect user interface of the tool on mobile devices with a small screen size (i.e., mobile phone), the use of which was explicitly discouraged in the instructions but was the device that the users received the invitation on and may have been the only device available to the user. As pointed out by the reviewers an arguably more appealing survey incentive

[1] International Energy Agency: Global EV Outlook 2022 - Trends in charging infrastructure https://www.iea.org/reports/global-ev-outlook-2022/trends-in-charging-infrastructure

in the form of a prepaid charging card could have also increased participation. Regardless of the reasons, given the low response rate, the results of this should be taken with caution. Conversely, one can look upon the survey and the study as a pilot that checks the survey tool and the analytic processes.

6.3 Stakeholder Analysis

This project initially planned to build on the survey data and discrete choice modeling by integrating the results into an analysis of stakeholder preferences, set against the context of those results. The approach builds on previous work by Marcucci, Le Pira, and others integrating stakeholder analysis into discrete choice modeling and agent-based modeling in the context of urban freight transport planning (Le Pira et al 2017a, Le Pira et al 2017b, Marcucci et al 2017). As shown in Figure 44, the approach integrates stakeholders at two stages: first, as respondents to surveys used to calibrate the model of the transport system under study; and second, as co-creators of an integrated package of policies based on model simulation results.

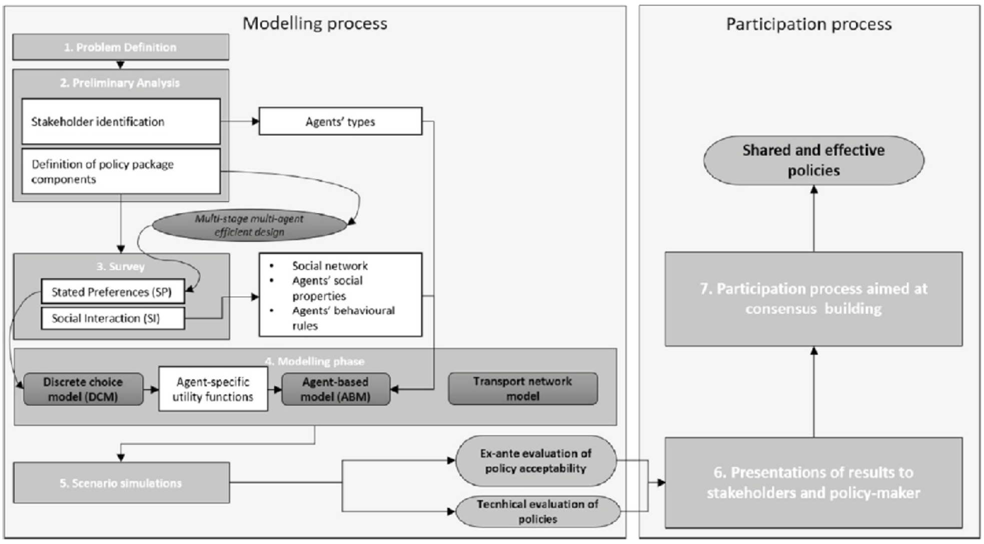


Figure 43. Integrated Stakeholder Analysis and Modeling Framework (Le Pira et al. 2017a)

However, our case differs from the Le Pira et al approach, in that for urban freight transport, identifiable stakeholders such as shippers, receivers, logistics firms, etc. play an active role in the day-to-day dynamics of trip-making; whereas in our case, for EV and public transport usage in personal travel, the identifiable stakeholders (city, public transport operator, charging infrastructure operator, etc.) only influence the long-term conditions such as charging availability, public transport service availability, and price levels. Hence their integration in the first stage is not essential, as exhibited by our choice not to include them as respondents to the stated adaptation survey.

Based in the work by Le Pira et al, a first natural continuation of the research reported here would be to implement the latter stage of stakeholder integration where a range of policies to facilitate more sustainable travel are formulated, tested using simulation based on the survey results found herein, and a consensus selection of policies. Alternatively, a more advanced approach would be to refine the survey tool used here and redesign the incentive options in collaboration with a selection of relevant stakeholders. This latter option would seem to be motivated by the low survey turnout levels found in this present research and would benefit from further refinement of the survey tool to facilitate user-friendliness.

In either case, the implementation of a stakeholder analysis at the final policy-selection stage would also benefit from the development of a software tool to bridge between a calibrated travel behavior model and associated scenario simulations on the one hand, and the group of stakeholders and fora for interaction with them on the other hand. Rather than be designed as a single-user interface for individual policy exploration, this should be designed to be used by a facilitator while interacting with a mixed group of stakeholders, meeting a very high standard of ease-of-use and transparency.

7. Conclusions and suggestions

This research study has aimed to increase the understanding of how different (packages of) incentives and related policies can be used to influence EV users towards a more sustainable use of electric vehicles. In particular, based on a modest set of explorative user interviews, the study has confirmed the increase of private car trips of EV users and that this increase is fueled by the low marginal costs of EV travel as well as the all too frequent misconception of users who equate sustainability with no damage to the environment. Thus, to combat expected increased levels of congestions due to this increase in private trips, the study has designed three incentives that aim to reduce private car trips into the already congested city centers. The incentives were a combination of 1) free EV parking and charging outside of the congestion area (of Stockholm) and an additional reduced-fare 2) public transport- or 3) e-scooter. To test the effectiveness of the incentives, the study has designed a stated adaptation experiment and a custom web map based survey tool that most importantly allowed the respondents to record desired locations for their incentives, thereby providing an indication of public charging demand and "entrance parking" (infartsparkering). The survey has been sent out to 7 000 registered EV users via SMS, but likely due to the less-than-perfect user interface of the tool on mobile phones, the length of the survey, or the complexity of the survey and the tool, only about 400 respondents (approximately 6%) completed the survey. The so collected data was analyzed using both descriptive statistics and statistical travel behavior modelling.

While based on the small sample size the modelling results should be treated with caution, the modelling results can be interpreted as follows:

- The incentives are more effective in deterring female, young (18–24), or part-time employed respondents from driving into the city centers than their male, older, or full-time employed counterparts.
- The offer of free parking and charging can "attract" respondents who are currently not parking in the congestion zone or have a difficult time finding parking spot in the congestion zone. Conversely, those who already have confidence in parking opportunities are harder to sway toward leaving the car outside the city center.
- Respondents who are regular public transport users (i.e., are holders of a monthly public transport pass) are easier to attract with an offer of a reduced-fare public transport.
- Independent of their public transportation enjoyment level, respondents who have higher perceived safety in public transportation are more likely of choosing an offer of a reduced-fare public transport compared to those who have lower perceived safety levels.
- Respondents who "strongly" enjoy the use of e-scooters and e-bicycles are more likely to take an offer a reduced fare for this mode of transport since this incentive increases their opportunities to use these "enjoyed" modes.

Finally, while due to the delays caused by project management issues and the sequential dependencies of project parts, the planned stakeholder analysis to derive a “Roadmap for sustainable use of electric vehicles” could not be carried out during the project period, based on the above results the study outlined several methodologies for stakeholder analysis and roadmap creation. Moreover, the above knowledge gained from the travel behavior modelling work is believed to be useful input for ongoing and future policy work towards sustainable electric vehicle use.

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9. Publications

Langbroek, J.H.M., Susilo, Y.O., and Gidofalvi, G. 2019. Changing travel habits of electric vehicle users. The 15th Network on European Communications and Transport Activities Research, Helsinki. Online book of abstracts. Winner of the NECTAR PhD Award

Guo, J., Cumbane, S., Gidofalvi, G., and Y. Susilo. 2019. Towards a Sustainable Use of Electric Vehicles: The Design of a Stated Adaptation Web Survey Tool. The 24th International Conference of Hong Kong Society for Transportation Studies, Hong Kong.

Two additional publications are planned about 1) the descriptive and geospatial analysis and statistical modelling of the stated adaptation survey data and 2) the roadmap for sustainable use of electric vehicles derived through interviews with stakeholders.

Additionally, the source code of the final stated adaptation web survey tool will be released as an open-source project on Github.

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Finally, the useful comments of Joanna Dickinson, Martin Boije, and Staffan Algers, who acted as reviewers of this project report, are also gratefully acknowledged.

11. Appendices

Table 7: First model results (Model 1)

	Value	Std err	t-test	p-value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_three	-14.2786	9.325364	-1.53116	0.12573	0.178902	-79.8127	0
B_age_18_24	-8.92997	67.26462	-0.13276	0.894384	0.399033	-22.379	0
B_age_25_34	2.355972	11.4691	0.205419	0.837245	0.447541	5.264261	1.40754E-07
B_age_35_44	2.278713	11.46359	0.198778	0.842436	0.27103	8.407602	0
B_age_45_54	2.70214	11.46348	0.235717	0.813652	0.262015	10.31292	0
B_age_55_64	2.638663	11.46337	0.230182	0.81795	0.262813	10.04009	0
B_age_above_65	2.618781	11.46664	0.228383	0.819349	0.368082	7.114674	1.12177E-12
B_age_nottosay	0	-	0	1	--	0	1
B_cong_often	-0.15675	0.579439	-0.27053	0.786756	0.549539	-0.28524	0.775456675
B_cong_rarely	0.635964	0.248725	2.5569	0.010561	0.252093	2.522735	0.011644615
B_emp_fulltime	-1.1836	0.482336	-2.45389	0.014132	0.484417	-2.44335	0.014551572
B_emp_other	-0.89878	5.006784	-0.17951	0.857535	0.293882	-3.05831	0.002225896
B_emp_parttime	-1.62573	5.009995	-0.3245	0.745562	0.322086	-5.0475	4.47618E-07
B_escooter_like_other	-4.28047	31.8094	-0.13457	0.892955	0.56239	-7.61122	2.70894E-14
B_escooter_like_strongly-agree	13.99373	25.06522	0.558293	0.576644	0.542383	25.80048	0
B_escooter_safe_other	-0.26685	19.89668	-0.01341	0.989299	0.731945	-0.36457	0.715432451
B_escooter_safe_strongly-disagree	9.366948	19.89537	0.47081	0.637776	0.632563	14.80792	0
B_gender_male	0.074081	5.001076	0.014813	0.988181	0.170646	0.43412	0.664200963
B_gender_other	-0.31309	5.000842	-0.06261	0.950079	0.172221	-1.81795	0.069071973
B_parking_agree	0.330238	1.770041	0.186571	0.851997	0.258677	1.276641	0.201729125
B_parking_disagree	0.767094	1.767309	0.434046	0.664255	0.245487	3.124783	0.001779363
B_parking_indifferent	0.172792	1.767721	0.097749	0.922132	0.241843	0.71448	0.474930369
B_parking_stronglyagree	-0.49443	1.891992	-0.26133	0.793839	0.710388	-0.696	0.486427862
B_parking_stronglydisagree	0.866312	1.780363	0.486593	0.626547	0.319189	2.714102	0.006645576
B_pass_monthly	1.760901	2.242905	0.785099	0.432396	0.318228	5.533466	3.13964E-08
B_pass_other	0.397034	2.230474	0.178004	0.85872	0.233355	1.701416	0.088864891
B_pt_like_agree	-0.97349	1.210258	-0.80436	0.421186	0.257896	-3.77473	0.000160179
B_pt_like_disagree	-1.33516	1.248955	-1.06902	0.285061	0.393682	-3.39146	0.000695224
B_pt_like_indifferent	-1.02918	1.233743	-0.83419	0.404173	0.363544	-2.83096	0.004640877
B_pt_like_stronglyagree	-1.30335	1.248451	-1.04397	0.296498	0.42046	-3.09982	0.001936381
B_pt_like_stronglydisagree	-0.66513	1.267936	-0.52458	0.599877	0.448109	-1.4843	0.137728289
B_pt_safe_agree	0.26795	0.566603	0.472906	0.63628	0.537358	0.498644	0.618030491
B_pt_safe_other	-0.36994	0.532441	-0.6948	0.487184	0.502546	-0.73613	0.461653654

Table 8: Final model results (Model 2)

	Value	Std err	t-test	p-value	Rob. Std err	Rob. t-test	Rob. p-value
ASC_three	-14.7065	10.5038	-1.40011	0.161481	0.17867925	-82.30649221	0
B_age_18_24	-8.98924	68.76424	-0.13073	0.895992	0.391284968	-22.97364975	0
B_age_25_34	2.3106	10.52921	0.219447	0.826302	0.458782477	5.036372863	4.744E-07
B_age_35_44	2.233378	10.52296	0.212239	0.831921	0.279160925	8.000325546	1.332E-15
B_age_45_54	2.656809	10.52279	0.252481	0.800669	0.268004047	9.913317011	0
B_age_55_64	2.593345	10.52275	0.246451	0.805333	0.272072175	9.531826715	0
B_age_above_65	2.573566	10.52616	0.244492	0.806849	0.369977989	6.955997417	3.501E-12
B_cong_often	-0.15681	0.579439	-0.27063	0.786679	0.549541351	-0.285348365	0.7753773
B_cong_rarely	0.635957	0.248724	2.556875	0.010562	0.252092237	2.522717164	0.0116452
B_emp_fulltime	-1.18347	0.48233	-2.45365	0.014141	0.484406688	-2.443137763	0.0145602
B_emp_other	-1.34304	8.127376	-0.16525	0.868748	0.329712928	-4.073366929	4.634E-05
B_emp_parttime	-2.06987	8.130398	-0.25458	0.799044	0.368260242	-5.62066854	1.902E-08
B_escooter_like_other	-5.80051	32.83345	-0.17666	0.859772	0.562313673	-10.31543577	0
B_escooter_like_strongly-agree	12.39358	24.37391	0.508478	0.611119	0.542603196	22.84096987	0
B_escooter_safe_other	0.551423	17.38396	0.03172	0.974695	0.73217552	0.753129264	0.4513722
B_escooter_safe_strongly-disagree	9.875063	17.38246	0.568105	0.569964	0.632445762	15.61408626	0
B_gender_male	0.387161	0.260663	1.485294	0.137466	0.256607588	1.508765056	0.1313588
B_parking_agree	0.153873	2.616438	0.05881	0.953103	0.2581068	0.596158667	0.5510692
B_parking_disagree	0.590735	2.614448	0.22595	0.82124	0.242420028	2.436824648	0.0148169
B_parking_indifferent	-0.00356	2.61467	-0.00136	0.998912	0.24086934	-0.014800428	0.9881914
B_parking_stronglyagree	-0.67056	2.70306	-0.24807	0.804078	0.721062908	-0.929955058	0.3523944
B_parking_stronglydisagree	0.689939	2.623732	0.262961	0.792581	0.320809734	2.150617876	0.0315064
B_pass_monthly	0.551075	2.726859	0.202091	0.839845	0.320272144	1.720645413	0.0853152
B_pass_other	-0.81279	2.716391	-0.29922	0.764774	0.233794686	-3.476526884	0.000508
B_pt_like_agree	0.059971	1.493699	0.040149	0.967974	0.257381653	0.23300359	0.8157586
B_pt_like_disagree	-0.30166	1.525363	-0.19777	0.843228	0.392890582	-0.767807808	0.4426014
B_pt_like_indifferent	0.004289	1.51298	0.002835	0.997738	0.363799112	0.011788336	0.9905945
B_pt_like_stronglyagree	-0.26989	1.524911	-0.17699	0.859517	0.42134638	-0.640549491	0.5218154
B_pt_like_stronglydisagree	0.368419	1.541177	0.23905	0.811067	0.448808107	0.820882048	0.4117135
B_pt_safe_agree	0.268064	0.566605	0.473105	0.636139	0.537364406	0.498848841	0.6178859
B_pt_safe_other	-0.37004	0.532445	-0.69498	0.487067	0.502554739	-0.736316099	0.4615384

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Towards a sustainable use of electric vehicles

Final report

To combat the negative externalities of increased car use, that is a result of the low marginal costs after an initial electric vehicle purchase and adoption, this study has designed and evaluated three incentives that aim to reduce private car trips into the already congested city centers. The incentives were a combination of 1) free EV parking and charging outside of the congestion area (of Stockholm) and an additional reduced-fare 2) public transport- or 3) e-scooter. The respondents recorded desired locations for their incentives, thereby providing an indication for public charging infrastructure- and "entrance parking" (infartsparkering) demand. Selected modelling result interpretation include: 1) the incentives are more effective in deterring female, young (18–24), or parttime employed respondents from driving into the city centers than their male, older, or full-time employed; 2) parking is a good incentive for those who need it; and 3) reduced-fare public transport and e-scooter incentive is best for existing users. The report outlines several methodologies for stakeholder analysis and policy roadmap creation.

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