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Sustainable transformation of the mobility system

The interplay between mobility services and electric vehicles

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Note

This thesis is a cumulative dissertation comprising three scientific research contributions published or under review in peer-reviewed journals. The dissertation was conducted externally within the ZHAW Institute for Sustainable Development, where I am employed as a researcher. In the following, I use the personal pronoun "I" when describing the research, even though it was conducted by a team of several authors with me being the first author.

Summary

The transport sector is the backbone to our economy and society. However, transport accounts for 24% of global greenhouse gas (GHG) emissions and is the largest emitting sector in many developed countries. While other sectors such as housing and industry have been able to reduce their emissions in recent decades, emissions from the transport sector are increasing substantially in some countries. One of the reasons we have not succeeded in reducing transport-related GHG emissions is the increasing share of larger and more powerful vehicles in new car registrations. It is estimated that the rise of sport-utility-vehicles (SUVs) and large cars just about cancel the emission reductions we would have acquired from the increasing adoption of battery electric vehicles (BEVs). Other externalities are often neglected, such as increases in pedestrian fatalities and particulate matter emissions that are harmful to health. To counteract these negative externalities, scholars suggest spurring the adoption of BEVs. BEVs can drastically decrease GHG emissions from a lifecycle perspective (cradle to grave) compared to conventional cars fuelled by gasoline and diesel, if the electricity used for charging the BEV stem from renewable energy sources, e.g., solar and wind. Yet, simply replacing conventional cars with large BEVs could lead to potential problems such as increased GHGs and other toxic emissions for the production of large batteries, raw material depletion and supply-chain shortages, increased particulate matter emissions, increased accident severity and increased land use.

A small BEV with a usable range of 250km is capable to satisfy more than 96% of trips per year on average, without the need for recharging during the day, given that one could charge the BEV at home. Hence, the number of times per year, where one would need to opt for an alternative is rare. The occasional long-range and special purpose trips (e.g., including large luggage) could be conducted by emerging mobility services like carsharing, car-rental, public transport or the convenient integration of these mobility services in one app, called Mobility as a Service (MaaS). If people would switch from owning a large car to a smaller BEV, capable to satisfy almost all trips and combine it with the occasional use of mobility service, substantial sustainability benefits could be possible.

In this thesis, I investigate these alternative mobility lifestyles to owning a large car by conducting several choice experiments within the Swiss Household Energy Demand Survey in 2018 and 2020.

In the first contribution, I investigate the challenges and needs of Swiss households in using MaaS for commuting, weekday leisure and weekend trips. The results underline the importance of experience with mobility services like carsharing and public transport, which increases the openness to use MaaS. The needs in using MaaS differ regarding the trip purpose, where fast transfer times and low price are important for commuting, and luggage carrying possibilities and flexibility are important for leisure trips. Policies directly addressing consumers, e.g., increasing fuel levies, vehicle import restrictions and a ban of non-electric vehicles in the city centre, were found to significantly increase the openness to use MaaS. This could be specifically relevant for the hard-to reach groups, i.e., frequent car users.

In the second contribution, I directly investigate the effect from experience with carsharing on the likelihood to opt for a micro to mid-sized BEV as the next car replacement for Swiss households. By controlling for a large set of potential influential variables like socio-demographics, mobility characteristics, attitudes, and values, I find a significant correlation between carsharing experience and likelihood to choose a micro to mid-sized BEV for people living in the countryside and agglomerations. This finding suggests that owning a small BEV in combination with mobility services could be marketed especially to people who live outside the city and rely on a car. I am the first to find an additional potential sustainable effect resulting from experience with carsharing, that is, deciding to own a smaller car due to the certainty of having access to long-distance and specialized vehicles when needed.

In the third contribution, I investigate the probability of Swiss households to choose a mobility lifestyle comprising the ownership of a small BEV in combination with mobility services for long-range trips. By including different push and pull measures as treatments, I find that providing charging at home and at work can significantly increase the probability to switch from previously owning a conventional car to owning a small BEV and using carsharing, car-rental and public transport for occasional long-range trips, especially for households that currently own large cars. The provision of carsharing and car-rental close to the place of residents increases the openness to switch as well. By combining secured charging at home and at work with a 50% fuel tax, up to 51% of conventional car-owning households would switch to own a small BEV and occasional use mobility services for long-range trips.

Two conclusions for society, mobility planners, and policy makers emerge from my findings. First, experience with carsharing can encourage willingness to use MaaS, as well as the purchase of a small BEV. Second, a large proportion of households with conventional vehicles could be convinced to switch to a small BEV and combine it with mobility services through a combination of push and pull measures. The work can serve as a guide on how to curb or stop the trend towards ever larger cars and boost the acceptance and attractiveness of BEVs and mobility services alike.

Zusammenfassung

Der Verkehrssektor ist das Rückgrat unserer Wirtschaft und Gesellschaft. Er ist jedoch für 24 % der weltweiten Treibhausgasemissionen verantwortlich und ist in vielen Industrieländern der grösste Emissionssektor. Während andere Sektoren wie die Industrie und die Haushalte ihre Emissionen in den letzten Jahrzehnten verringern konnten, nehmen die Emissionen des Verkehrssektors in einigen Ländern erheblich zu. Einer der Gründe für diesen Misserfolg, ist der zunehmende Anteil grösserer und leistungsstarker Fahrzeuge an den Neuzulassungen. Es wird geschätzt, dass die Zunahme von Sport Utility Vehicles (SUVs) und grossen Autos, die Emissionsreduzierungen, die wir durch den erhöhten Anteil von batterieelektrischen Fahrzeugen (im Folgenden Elektrofahrzeuge genannt) in den Neuzulassungen erzielt hätten, nahezu zunichtemacht. Andere externe Effekte werden oft vernachlässigt, wie z. B. die Zunahme tödlicher Unfälle und gesundheitsschädlicher Feinstaubemissionen. Um diesen negativen externen Effekten entgegenzuwirken, schlagen Wissenschaftler vor, Elektrofahrzeugen zu fördern. Aus einer Lebenszyklusperspektive (Produktion, Nutzungsphase und Recycling) können Elektrofahrzeuge die Treibhausgasemissionen im Vergleich zu konventionellen, mit Benzin und Diesel betriebenen Autos drastisch senken, vor allem, wenn der zum Aufladen des Elektroautos verwendete Strom aus erneuerbaren Energiequellen stammt, z. B. aus Sonnen- und Windenergie. Der blosse Ersatz herkömmlicher Autos durch grosse Elektroautos könnte jedoch zu potenziellen Problemen führen, z. B. zu erhöhten Treibhausgas- und anderen Schadstoffemissionen bei der Herstellung grosser Batterien, zur Verknappung von Rohstoffen und Engpässen in der Lieferkette, zu erhöhten Feinstaubemissionen, zu einem erhöhten Unfallrisiko und zu einem erhöhten Flächenverbrauch.

Ein kleines Elektroauto mit einer nutzbaren Reichweite von 250 km ist in der Lage, mehr als 96 % der Fahrten pro Jahr eines durchschnittlichen Autonutzenden zu bewältigen, ohne dass es tagsüber aufgeladen werden muss, vorausgesetzt, man kann das Elektroauto zu Hause aufladen. Die Anzahl der Fahrten pro Jahr, bei denen man sich für eine Alternative zum kleinen Elektroauto entscheiden müsste, ist entsprechend gering. Die gelegentlichen Langstrecken- und Sonderfahrten (z. B. mit grossem Gepäck) könnten durch Mobilitätsdienste wie Carsharing, Autovermietung, öffentliche Verkehrsmittel oder die Integration dieser Mobilitätsdienste in einer App, genannt Mobility as a Service (MaaS), durchgeführt werden. Falls Haushalte vom Besitz eines grossen Autos auf ein kleineres Elektroauto umsteigen würden und dies gelegentlich mit anderen Mobilitätsdienstleistungen kombinieren würden, könnten erhebliche Nachhaltigkeitsvorteile erzielt werden.

Mittels mehreren Choice Experimente im Rahmen des Swiss Household Energy Demand Surveys (SHEDS) in den Jahren 2018 und 2020, untersuche ich in dieser Dissertation Alternativen zum Besitz eines grossen Autos.

Im ersten Beitrag untersuche ich die Herausforderungen und Bedürfnisse der Schweizer Haushalte bei der Nutzung von MaaS für Pendel-, Freizeit- und Wochenendfahrten. Die Ergebnisse unterstreichen die Bedeutung von Erfahrungen mit Mobilitätsdienstleistungen wie Carsharing und öffentlichem Verkehr, die

die Bereitschaft zur Nutzung von MaaS erhöhen. Die Bedürfnisse bei der Nutzung von MaaS unterscheiden sich je nach Fahrtzweck, wobei schnelle Umsteigezeiten und niedrige Preise für Pendler wichtig sind, während Gepäckmitnahmemöglichkeiten und Flexibilität für Freizeitfahrten von Bedeutung sind. Ich stelle fest, dass politische Massnahmen, die sich direkt an die Verbraucher richten, z. B. die Erhöhung von Kraftstoffabgaben, Einfuhrbeschränkungen für Fahrzeuge und ein Verbot von nicht-elektrischen Fahrzeugen im Stadtzentrum, die Bereitschaft zur Nutzung von MaaS deutlich erhöhen. Dies könnte insbesondere für die schwer zu erreichenden Gruppen, d. h. häufige Autonutzende, von Bedeutung sein.

Im zweiten Beitrag untersuche ich direkt die Auswirkungen von Erfahrungen mit Carsharing auf die Wahrscheinlichkeit, dass sich Schweizer Haushalte für ein kleines bis mittelgrosses Elektroauto als nächsten Autoersatz entscheiden. Durch die Kontrolle einer grossen Anzahl potenzieller Einflussvariablen wie Soziodemografie, Mobilitätsmerkmale, Einstellungen und Werte, finde ich einen signifikanten Zusammenhang zwischen Carsharing-Erfahrungen und der Wahrscheinlichkeit, sich für ein kleines bis mittelgrosses Elektroauto zu entscheiden. Dies vor allem für Personen, die auf dem Land und in Agglomerationen leben. Dieser Befund deutet darauf hin, dass der Besitz eines kleinen Elektroautos in Kombination mit Mobilitätsdienstleistungen besonders für Menschen vermarktet werden könnte, die ausserhalb der Stadt leben und auf ein Auto angewiesen sind. Diese Arbeit zeigt, als einer der ersten, einen zusätzlichen, potenziell nachhaltigen Effekt, der aus der Erfahrung mit Carsharing resultiert. Nämlich den Kauf eines kleineren Autos aufgrund der Gewissheit, bei Bedarf Zugang zu Langstrecken- und Spezialfahrzeugen zu haben.

Im dritten Beitrag untersuche ich die Wahrscheinlichkeit, dass Schweizer Haushalte einen Mobilitätsstil wählen, der den Besitz eines kleinen Elektroautos in Kombination mit Mobilitätsdienstleistungen für Langstreckenfahrten umfasst. Indem ich verschiedene Push- und Pull-Massnahmen in die Umfrage integriere, stelle ich fest, dass die Bereitstellung von Lademöglichkeiten zu Hause und am Arbeitsplatz die Wahrscheinlichkeit, auf diesen alternativen Mobilitätslebensstil umzusteigen, signifikant erhöhen kann, insbesondere für Haushalte, die derzeit grosse Autos besitzen. Die Bereitstellung von Carsharing und Autovermietung in der Nähe des Wohnortes erhöht die Bereitschaft zum Umstieg ebenfalls. Bei einer Kombination aus Lademöglichkeiten zu Hause und am Arbeitsplatz und einer Kraftstoffsteuer von 50 % würden bis zu 51 % der Haushalte, die ein herkömmliches Auto besitzen, auf ein kleines Elektroauto umsteigen und gelegentlich Mobilitätsdienste für Langstreckenfahrten nutzen.

Aus meinen Ergebnissen ergeben sich zwei Schlussfolgerungen für die Gesellschaft, Mobilitätsplaner und Politik. Erstens; Erfahrungen mit Carsharing kann die Bereitschaft zur Nutzung von MaaS, sowie den Kauf eines kleinen Elektroautos fördern. Zweitens; ein Grossteil der Haushalte mit konventionellen Fahrzeugen könnte durch eine Kombination von Push- und Pull-Massnahmen überzeugt werden, auf ein kleines Elektroauto umzusteigen und dieses mit Mobilitätsservices zu kombinieren. Die Arbeit kann als Anleitung dienen, wie man den Trend zu immer grösseren Autos eindämmen oder stoppen, und die Akzeptanz und Attraktivität von Elektroautos und Mobilitätsdiensten gleichermassen ankurbeln kann.

Table of contents

Summary **3**

Zusammenfassung **5**

1 Introduction **9**

1.1 The evolution of the car as we know it today 12

1.2 The dilemma of range and environmental impact of BEVs 14

1.3 Mobility services as a complement to a small BEV 19

1.3.1 Carsharing 19

1.3.2 Car-rental 20

1.3.3 Mobility as a Service 21

1.4 Research design 22

1.5 Overview of the three contributions to the literature 24

1.5.1 First contribution 24

1.5.2 Second contribution 25

1.5.3 Third contribution 26

1.6 Switzerland as a case study for my work 27

2 What are the factors and needs promoting mobility-as-a-service? Findings from the Swiss Household Energy Demand Survey (SHEDS) **28**

2.1 Introduction 28

2.2 Background 30

2.3 Methodology 34

2.4 Results 38

2.5 Discussion and limitations 43

2.6 Concluding remarks 45

3 Carsharing experience fostering sustainable car purchasing? Investigating car size and powertrain choice **47**

3.1 Introduction 47

3.2 Background 49

3.3 Methodology 51

3.4 Results 57

3.5 Discussion 64

3.6 Conclusion and recommendations 66

4 Push and pull strategies to increase the uptake of small electric vehicles 68

4.1 Introduction 68

4.2 Methodology 72

4.3 Results 83

4.4 Discussion 95

4.5 Conclusion and recommendations 97

5 Discussion 100

5.1 Key contributions 100

5.2 Recommendations 102

5.3 Limitations and outlook 105

Acknowledgements 108

Appendix A: Contribution 1 109

Appendix B: Contribution 2 111

Appendix C: Contribution 3 115

References 125

1 Introduction

Switzerland and many other countries set targets to achieve the goal of the Paris Agreement, which is to keep global warming well below 2° Celsius above pre-industrial levels by the end of this century (United Nations, 2015). The transport sector is responsible for 24% of greenhouse gas (GHG) emissions worldwide (IPCC, 2022) and even 32% in Switzerland (SFOE, 2022). Taking the available carbon budget into account, the transport sector needs to be drastically transformed to a net-zero system by 2050 in order to achieve the Goal of the Paris Agreement (Fankhauser et al., 2022). Matthews et al. (2018) argue that the reduction aims for 2030 need to be increased considerable, so that the effort needed to achieve net zero during the period of 2030 to 2050 becomes feasible. Hence, many countries now recognized the urge to commit to stricter climate targets. The European Union, for example, now targets to become climate-neutral by mid-century, which has previously been set to 80% reduction of GHG emissions by 2050 compared to 1990 levels. The European Union further increased the domestic GHG emissions reduction target for 2030 to 55% compared to 1990 levels, which was previously set to a 40% reduction (European Parliament, 2020). Switzerland, as a signatory of the Paris Agreement, commits to achieve a net-zero transport system by 2050 through the Energy Strategy 2050 (SFOE, 2020).

The foremost sector that needs to be decarbonized is the energy sector since emissions of other sectors like transport depend on the renewable energy production (i.e., mostly electricity). The technology to achieve a decarbonized energy system is already available. Yet, the widespread adoption of, for example, rooftop solar power, wind power, hydropower and geothermal power is hampered by a complex mix of incumbent lobbying, lack of political support, lack of standards and behavioral factors (Asante et al., 2020; Marra & Colantonio, 2021). Still, the future of energy supply is foreseen to be mostly based on renewable electricity production (Pickering et al., 2022).

The highest share of transportation GHG emissions stem from passenger cars, due to the sheer number of around 67 billion cars produced worldwide each year (pre-corona level) (OICA, 2022). Decarbonizing the transport sector thus entails a switch from conventional gasoline and diesel cars to an alternative. While the decarbonization should follow the avoid-shift-improve framework (Creutzig et al., 2018), especially in cities where public transport is much more efficient than private cars, avoiding car trips and shifting from car to public transport and other low carbon transport modes like cycling, require strong behavioral change for those accustomed to the comfort of private cars, and would not be a viable option in dispersed environments with sparse public transport and infrastructure. Solely nudging society to avoid and shift their car use thus encounter resistance and might hinder a fast transformation to carbon neutrality in the transport sector (Patt, van Vliet, et al., 2019). Hence, for people who can't live without a car out of necessity or want to retain the flexibility and freedom that a private car offers today, the current consensus is to switch from gasoline and diesel cars to battery electric vehicles (BEVs). As the renewable electricity production is gaining momentum, the GHG footprint of BEVs compared to conventional cars is decreasing. Even with the electricity mix of 2020, BEVs would emit less GHGs over their lifetime compared to conventional cars in 29 out of 30 analyzed countries in Europe (Sacchi et al., 2022).

However, especially in the transport sector, the private gasoline and diesel car is the prevailing regime, which has been established through over a century, creating strong resistance to change. Or put in other words by Holtz et al. (2008):

"We consider the currently dominant mobility system to be a regime which is based on individually owned cars, gas, service stations, streets, traffic regulations, preferences like flexibility and the perception of cars as being also life-style objects." (Holtz et al., 2008, p. 629)

Urry (2004) further explains why the combustion engine car is the current prevailing transport regime:

"Automobility is a source of freedom, the 'freedom of the road'. Its flexibility enables the car-driver to travel at any time in any direction along the complex road systems of western societies that link together most houses, workplaces and leisure sites" (Urry, 2004, p. 28)

He goes further on: *"Automobility thus produces desires for flexibility that so far only the car is able to satisfy."* (p. 29)

The actions to trigger a faster transformation to a net-zero transport system by 2050 thus need to be made on several levels. Geels (2002) describes three analytical levels in which a non-linear process of transition happens (also called multi-level-perspective, in short MLP) (Figure 1.1). The niches describing a place for radical innovations, the socio-technical regime representing established rules, habits and practices and last, the socio-technical landscape putting pressure on the regime by overarching megatrends, beliefs, societal values being beyond the control of individual actors. I adapted the MLP from Geels (2002) and focus on the private fossil fuel car as the established and dominant mobility regime, which we want to transform into a connected, multimodal, electrified and sufficient mobility system meeting the needs of society and policy to reach net zero emissions in 2050 (Figure 1.1).

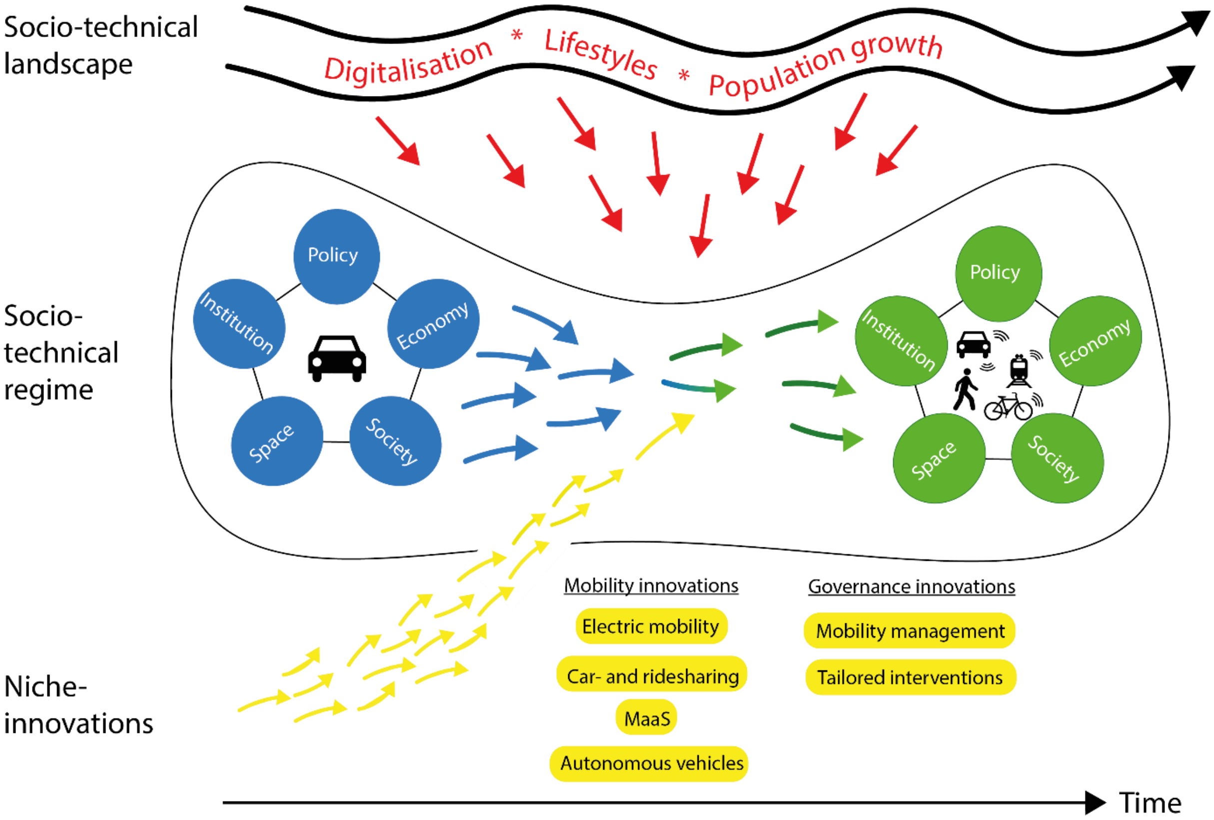

Figure 1.1: Transformation framework adapted from Geels (2002).

The socio-technical regime is defined through the main dimensions belonging to policy, economy, the society, built environment (space) and institutions, which currently define the private fossil fuel car dominated transport regime. However, niche-innovations try to dig into this prevailing regime eventually creating a new transport system. We further experience overarching landscape developments like digitalization, lifestyle changes and population growth, which weaken the bonds of the prevailing regime creating windows of opportunities for the niche innovations to take roots in the mass market.

This thesis contributes to this transformation by focusing on electric mobility, carsharing and new mobility services like Mobility as a Service (MaaS) as niche innovations digging into the well-established, private car dominated, transport regime. While I also investigated autonomous vehicles, mobility management and tailored interventions, they are not part of this thesis and are summarized in Hoerler et al. (2021). I further provide insights into relevant combinations of push, pull and push & pull measures to support the actors within the car dominated transport regime to take the opportunities of these niche innovations in spurring the transformation forward.

In order to understand the relevance of the well-established private car regime, it is important to know the path to today's mobility system from the initial mass market car produced in 1908 (Fords' model T) (Womack et al., 2007). While the car enabled tremendous economic growth until the 1970s (Deloitte, 2022), the car as a means to spur economic growth is increasingly being replaced by digital technology (e.g. teleconference, digital twins) and alternative modes (e.g. bicycle, trains, trams, e-scooters), which weakens the justification to priorities the car as the central means of transport. In the first subsection, I will thus provide an overview of the evolution of cars how we know them today. After understanding the history and place of the private car in modern societies, we can better understand the dilemma with range and environmental impacts, if we want to maintain the same comfort and mobility behavior as with conventional cars. The second subsection therefore digs into the dilemma between range and environmental impacts of BEVs. In the third subsection, I will provide reasons as to why the trend toward new and already established mobility services help in reducing this dilemma. In the fourth and fifth subsection of the introduction, I provide the research design of the thesis and summarize the contribution to the literature of each paper. The last subsection serves as a justification of Switzerland as a case study.

1.1 The evolution of the car as we know it today

One of the most remarkable regime changes happened in the transport sector in the beginning of 1900. The then dominant transport regime, horse carriages, suffered from several problems: congestion, pollution from horse-droppings, lack of safety and high cost due to thousands of horses that required care and food. It was no surprise, that concern about public health rose drastically, as the streets got covered by horse excrements. In addition, population growth lead to sub-urbanization, increasing the size of cities and travel distances that were not suitable for horse-carriages (Geels, 2005b). During that time, several niche innovations emerged, e.g., steam tram, electric tram, bicycle, steam cars, electric cars and gasoline cars. Some of these new transport options stimulated wider change such as the flexibility and individuality provided by the bicycle (much like cars today). As the popularity of bicycles increased, so did the need for smoother surfaces, which spurred the asphalt industry. Another change in perception stems from the electric tram, which changed the streets primary function of a meeting place to transport arteries (Geels, 2005b). In the 1890s and 1890s, the middle-class expanded and real salary rose, which led to a new culture of entertainment since people had more money and free time for leisure. Some of these leisure activities were racing and touring in the countryside. A niche that eventually meant to be detrimental for the gasoline car regime. While battery-powered electric cars competed well with gasoline-powered cars over short distances, the latter were superior in speed and range. The racing niche formed the perception of what 'the automobile' should be able to do (Geels, 2005a). Hence, the sales of gasoline cars raced ahead, while those of electric vehicles and steam cars remained constant. Finally, in 1908, Ford created the Model T, which was a huge success, especially in the countryside. With prices decreasing from 850$ in 1908 to 360$ in 1916, the Model T became affordable to the middle class for commuting. Soon in 1920, the car challenged the electric tram as the dominant urban transport regime, strongly supported by policy makers, which for example, widened existing roads and created new roads (Geels, 2005b). Overall, the duration of the replacement process of horse carriages by cars was only 12 years (Grübler, 1996) (Figure 1.2).

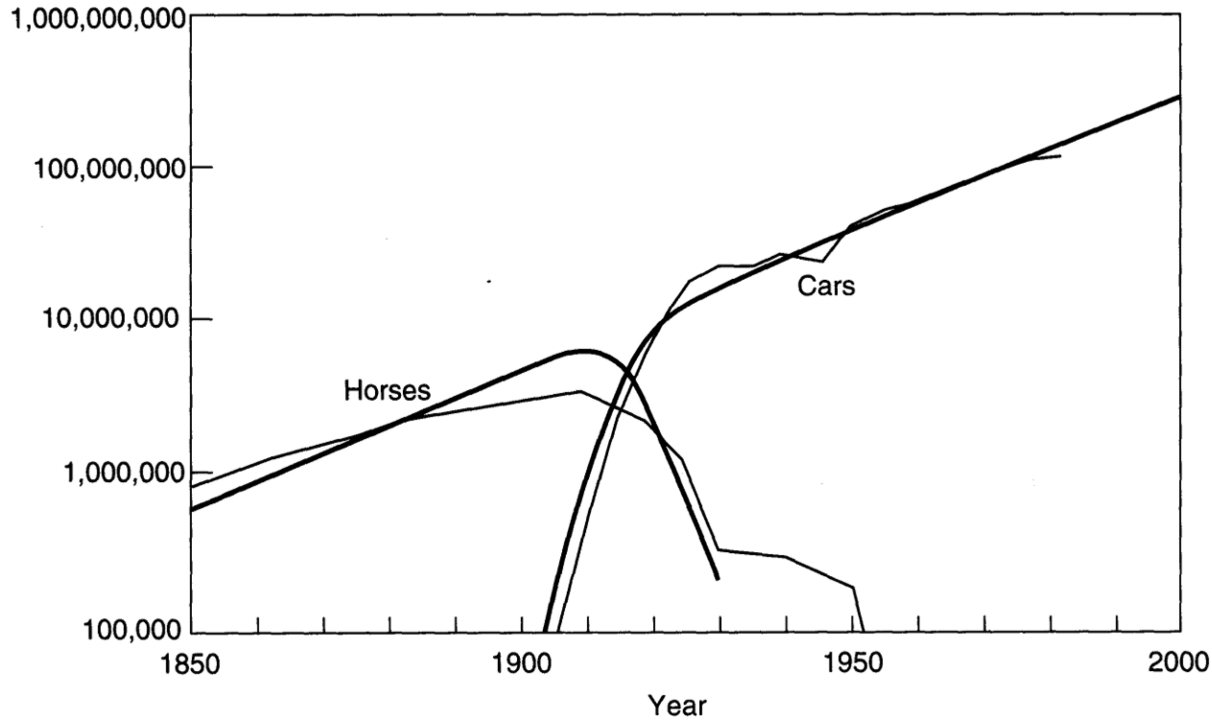

Figure 1.2: Diffusion of horse-drawn carriages and cars in the US. Source, Nakicenovic (1986), graph taken from Grübler (1996).

Since the car replaced horse carriages in 1930, a whole new set of opportunities emerged. Higher average speeds and better weather reliability increased its advantage over trams and trains, creating suburbs, which in turn led to more demand for cars, eventually displacing trams in urban areas (Grübler, 1996). With its capacity to eliminate constraints of time and space, the petroleum-based car mobilized an array of other industries, activities and interests, further strengthening its path dependency (Urry, 2008). The improvement of road infrastructure further facilitated the emergence of a "car culture" by, e.g., fast food restaurants on highways, shopping malls on the edge of the cities or just touring with the car as a recreational activity (Geels, 2005a). This led to consumers prefer the car also because the built environment like traffic arteries in cities, parking spaces, and location of malls were tailored to the car itself (Sanne, 2002). Even today, with plethora of alternative transport options available in cities, the largest share of urban space is allocated to cars (ITF, 2022).

While the car could boost the economy substantially, it also increased road accidents and emissions, which led car manufacturers to continuously improve safety (van Ratingen et al., 2016), comfort and efficiency (US EPA, 2021). The safety of the car occupants could be improved substantially through seatbelts, electronic stability control (ESC), antilock-brake systems (ABS), airbags and buffer zones (Bhalla & Gleason, 2020). However, together with a general preference for more legroom, luggage space and other comfort aspects, this led to an increase in vehicle size and weight, reducing the safety of pedestrians and smaller vehicles during a crash (W. Hu & Cicchino, 2018; MacKenzie et al., 2014). Thus, people started to prefer larger cars for their own safety. This is a common vicious cycle also specified as an "arms race" in the US (S. Li, 2012; White, 2004), where the average car size rose dramatically between 1980 and 2020 (US EPA, 2021). While a larger, heavier car is safer for the occupants, being hit by a vehicle that is 450kg heavier leads to an increased fatality risk of up to 50% (Anderson & Auffhammer, 2014). The trend towards more powerful cars also plays into this problem since the research by McCartt and Hu (2017) show that high powered cars are more likely to speed and exceed speed limits, potentially increasing the severity of an accident. Between 1970 and 2020 the typical width, lengths and height of the same car models increased substantially (Teoalida, 2002). Models like the Volkswagen Golf increased its area occupation by 40% (Zuto, n.d.). This also leads to potential ripple effects on parking, as the norm dimensions of parking lots in many countries might need to be adapted to the larger cars, leading to increased space occupation of cars (Ewert et al., 2020).

Similarly, the average power of the car increased significantly over the last decades. As an example, the US average new vehicle horsepower rose by almost 80 % between 1975 and 2021 (US EPA, 2021). Yet, this power development is not reflecting the actual driving needs and pattern of drivers as almost all countries have a maximum driving speed limit in place (with exceptions like Isle of Man and some highway stretches in Germany), rendering the capability to exceed 140 km/h almost worthless. Advertisements of cars are very emotional, leading to further induced desires and needs, that can't be exploited in real life, like driving off-road with SUVs. Together with the generally better sight in SUVs, higher safety feeling and pressure from social norms, people bought more SUV models, leading to an SUV boom in the last decade in Switzerland, the EU, the US and China (IEA, 2021; Jato, 2021; Vögele et al., 2021).

Since 2012, the share of battery electric vehicles in new car registrations rose significantly and even set new record during the corona pandemic years in 2020 and 2021 (IEA, 2022). As a comparison: about 120'000 BEVs and PHEVs were sold worldwide in 2012. The same number of cars were sold in a week in 2021 (IEA, 2022). With the clear trend towards a transformation to BEVs, OEMs also shift from producing conventional cars to BEVs. However, BEVs lack a major feature that people used to take for granted with conventional cars: no fear of being stranded. Since the range of a BEV is smaller and charging stations less frequent than petrol and gasoline stations today, people create the so called "range anxiety" (Franke et al., 2012; Franke & Krems, 2013; Habla et al., 2021; Noel et al., 2019). This range anxiety is a common misconception, since the majority of trips could easily be covered by modern BEVs (Franke & Krems, 2013; Melliger et al., 2018; Plötz & Sprei, 2021). While it was certainly a real fear in the beginning of the BEV renaissance, when the first BEVs were only capable to drive 100km in one charge, this has changed today. Research around the globe show similar results regarding typical daily travel needs, which rarely exceed 200km, a range easily conducted by modern small BEVs (Meinrenken et al., 2020; Plötz & Sprei, 2021). However, since the range anxiety and habit of using a conventional car strongly influences the consumer, they expect BEVs to deliver ranges similar to conventional cars (Kowalska-Pyzalska et al., 2022; Noel et al., 2020).

1.2 The dilemma of range and environmental impact of BEVs

With this range anxiety in mind, people tend to buy BEVs with a high range, which are usually larger and heavier than BEVs with a smaller range. Manufacturers react to this demand producing electric versions of popular SUVs and large cars but also because larger cars and SUVs provide higher profit margins (Bailo et al., 2018). More than 60% of available EV models (BEVs + PHEVs) belong to the SUV and "large" car model category in the EU and even over 70% in the US (IEA, 2022). However, the trend towards large BEVs with a high range could lead to the following problems:

1. Increased depletion of raw materials for producing large batteries and larger cars
2. Increased GHGs and other toxic emissions for the production of the larger batteries
3. Increased energy consumption during the use phase of the large BEV
4. Increased particulate matter (PM) emissions from braking, tires, road surface wear and resuspension of road dust due to increased weight of the car
5. Increased severity in pedestrian crashes and crashes with other mobility users
6. Increased occupation and competition of space, especially in cities

Problem 1 and 2: Raw material demand and GHGs in battery production

Several developments and innovations focus on reducing raw material depletion, GHGs and other toxic emissions in EV battery production. Recycled metals are critical in reducing the need for primary raw materials in producing batteries. Therefore, and in line with suggestions from Baars et al. (2021), the EU proposed a new regulation, which potentially enters into force in 2023 (European Union, 2020). The regulation addresses four key elements in increasing the sustainability of lithium-ion batteries: 1) transparency and traceability across battery life cycle 2) carbon footprint threshold and declaration 3) mandating the use of recycled materials in new batteries and 4) longevity and performance management to verify the state of health before the battery is assigned for recycling. Despite these measure, potential conflicts and unintended side effects from policies might hinder a fast transformation to net-zero supply chains in battery production. According to Melin et al. (2021), one problem could be slowing innovation by creating barriers for start-ups and small businesses in complying with these regulations or increasing market advantage of Chinese recycling firms and EV manufacturers that already have experienced with stricter regulations. Further, Neidhardt et al. (2022) and Abdelbaky et al. (2021) forecast that the availability of materials from recycling won't be able to meet the demand for lithium, nickel and manganese before 2035. Only the need for cobalt might be satisfied through recycling and deployment of low-cobalt or cobalt-free batteries by early 2030 (Neidhardt et al., 2022). This shows that the need for raw materials will not diminish in the short- to medium-term and that a reduction in raw material need through smaller batteries would help in reaching a closed-loop recycling faster, especially if the adoption of carsharing and other sharing services like car-rentals and on-demand sharing services are increased, as they have a much shorter lifespan than private cars, thus increasing availability of batteries for recycling (Kamran et al., 2021). A decrease in demand for large BEVs could further decrease supply shortages of critical metals like cobalt and manganese. The increase in demand for BEVs is rated as a critical threat to cobalt supply, since the current mining output is far from the needed output in the future, which is estimated to be 20 times the current amount (Backhaus, 2021; Karabelli et al., 2020).

New technologies, in which many hopes are placed are, e.g., solid-state lithium-ion batteries, which could increase energy density and safety features of the battery, therefore decreasing the resources needed to achieve the same range requirements compared to traditional batteries (C. Li et al., 2021). However, current research do not show that this technology would be available before 2030 (Karabelli et al., 2020; Zeng et al., 2019). Other potentials for "greener" batteries are seen in lithium-free batteries, e.g. based on aluminum or magnesium, or batteries based on zinc and air, yet these are on a very early research and development stage (Dühnen et al., 2020; F. Santos et al., 2020). New manufacturing processes of batteries, such as water-based manufacturing, could reduce emissions of CO_{2eq} by 27% compared to traditional manufacturing, which currently use N-methyl-2-pyrrolidone to process the electrode materials (C. Yuan et al., 2021).

To sum it up, several technologies are available, some already developed and others in early research stage, to achieve a net-zero battery production system based on recycling and renewable energy. If we would achieve a closed-loop net-zero battery production system by 2050 (i.e., all EV battery metals are recovered, re-used and recycled), the main problems stemming from large batteries from larger cars with a high range could be overcome. To get there, however, tremendous investments and policy efforts are needed. Lower raw material demand for producing smaller BEVs could accelerate to achieve this goal and decrease supply bottlenecks in the short to-medium-term (until 2035) (Abdul-Manan et al., 2020).

Problem 3: Energy consumption in the use phase of the BEV

BEVs with a larger battery capacity increase energy consumption due to the increased weight of the battery (Hung et al., 2021), however, weight and power do matter less in the use phase of BEVs compared to conventional vehicles (Buberger et al., 2022; Woody et al., 2022). Still, each 100 kg increase in vehicle mass increases real-world energy consumption by 0.6 kWh/100 km or put in another way; a doubling of vehicle mass leads to a 46% increase in real-world energy consumption of BEVs (Weiss et al., 2020). A doubling of power leads to 6% increase in real-world energy consumption (Weiss et al., 2020). According to Galvin (2022), each 1% increase in average weight of BEVs leads to an increase in BEV electricity consumption of about 1%, which makes it all the more difficult to meet the electricity demand with fully decarbonized electricity.

Looking at the total lifecycle GHG emissions from cradle-to-grave, a 640km range BEV (110kWh) has an approximately 28% higher lifecycle GHG emissions compared to a 320km range BEV (47kWh) (Woody et al., 2022). Similarly, Hung et al. (2021) estimate the difference between a Nissan Leaf with a 62kWh battery to have 12% lower lifecycle GHG emissions compared to a VW ID.4 with a 82kWh battery. Generally, a 10kWh increase in battery capacity leads to an approximate 6% increase in lifecycle GHG emissions.

In the long run, assuming that we would reach 100% renewable energy production and that we would have abundant renewable energy for all sectors (housing, agriculture, industry and transport), the increased GHG emissions from the increased energy consumption of larger, heavier BEVs compared to smaller, lighter BEVs could be neglected. Still, major benefits beyond reduced GHG emissions in the short- to medium-term are possible, such as lower electricity consumption reducing the risk of electricity shortages and peak loads, thereby relaxing the pressure on the grid (Galvin, 2022).

Problem 4: Particulate matter emissions

Particulate matter emissions from BEVs originate from brake wear, tire wear, road abrasion and resuspension of road dust, which are harmful for human health (Beji et al., 2020). A large share of these emission stem from the brake pads (Beji et al., 2020). Generally, heavier vehicles emit higher levels of brake, road and tire particles (Oroumiyeh & Zhu, 2021). In order to decrease $PM_{2.5}$ and PM_{10} emissions from BEVs, regenerative breaking is key, thus reducing the need to brake via the brake pads. However, changing from conventional cars to similar sized BEVs does not decrease PM_{10} emissions in urban environments if not at least 90% regenerative breaking is used (Beddows & Harrison, 2021), since BEVs are on average 24% heavier than similar sized conventional cars (Timmers & Achten, 2016). On motorways, however, Beddows and Harrison (2021) estimate that the increased weight of the BEV increases PM_{10} emissions compared to conventional cars, even with 100% regenerative breaking. Beddows and Harrison (2021) thus suggest a decrease of vehicle weight by at least 22% to counteract this increase in PM emissions. Other measures to decrease PM emissions from cars are discussed, such as limiting driving speeds, smoothing traffic flow and optimization of tire and brake pad materials (Baensch-Baltruschat et al., 2020, p.; Beji et al., 2020; Piscitello et al., 2021). While some technologies like brake dust collection devices could collect up to 92% of brake wear dust in tests (Fieldhouse & Gelb, 2016; Hascoët & Adamczak, 2020), others researchers proposed the addition of rubber crumbs – derived from tire grinding or other secondary rubbers sources – to the asphalt mixture to reduce traffic noise, road and tire wear (Bressi et al., 2019). This road type could reduce tire wear emissions by 30%–50% compared to conventional concrete pavements (Bressi et al., 2019). However, whether, how and when we would achieve a significant breakthrough in technological improvements to reduce PM emissions is unclear and a reduction of vehicle weight through the adoption of smaller BEVs could prove a valuable prevention strategy in the short- to medium-term (Fussell et al., 2022).

Problem 5: Pedestrian and road accidents

As has been described in the previous section, a larger, heavier vehicle is safer for the occupants but deadlier for pedestrians and mobility users in a smaller vehicle, presenting a large external cost to society (Anderson & Auffhammer, 2014; Saylor, 2021; Tyndall, 2021). The focus of the discussion of vehicle safety has, so far, mainly concentrated on the in-vehicle safety, thereby neglecting these costs. Anderson & Auffhammer (2014) estimate that being hit by a vehicle that is 450kg heavier generates an up to 50% increased fatality risk and amounts to a yearly external cost of up to 136 billion dollars annually in the US. Other research shows that children are eight times more likely to die in an SUV crash compared to a passenger car, i.e. a medium sized car, and that SUVs increase fatality risk of pedestrians and cyclists compared to passenger cars (Edwards & Leonard, 2022). Further, Claus & Warlop (2022) find that driving larger cars increase risk taking since it makes people feel more secure. Hence, larger cars not only increase incidents (based on the aforementioned behavioral effect) but also the severity of an accident due to their increased weight. New sensor technology could reduce pedestrian injuries and fatality risks by installing pedestrian crash prevention (PCP) systems in on-road vehicles. Test data show that PCP could automatically detect pedestrians and avoided crashes in 70% of the tests and further decreased impact speeds by more than 50% (Mahdinia et al., 2022). Still, the authors suggest that reducing vehicle weight is crucial in improving the performance of the PCP system. In order to decrease external costs stemming from larger, heavier BEVs due to their increased fatality risk, sensor technologies could help in preventing a large share of these costs in the future, however, a residual risk is likely to remain even if we would achieve a fully automated car fleet.

Problem 6: Occupation of space

A large share of public space is dedicated for parking lots and streets (Manville & Shoup, 2006; C. McCahill & Garrick, 2014). According to McCahill & Garrick (2014), between 10 to 40% of urban space is dedicated for parking lots in urban central business districts of US cities, leading to adverse environmental effects like flooding and polluted runoff (J. Chen et al., 2017), increased heat (urban heat island effect) (Gentili et al., 2020) and life-cycle emissions in constructing the parking lots (Chester et al., 2010). Scheiner et al. (2020) estimate that adapting roughly 50% of parking lots to the size of a small vehicle (in their case a VW polo with a length of 4.05m), could increase the number of parking lots by up to 32%, without increasing land-use. However, the supply of parking lots is directly related to more car driving (C. McCahill & Garrick, 2014; C. T. McCahill et al., 2016). Policy makers and transport planners could thus focus on reducing the land area defined for parking lots but still provide enough individual spaces through smaller parking lots suitable for smaller cars. Generally, urban street space has been found to be allocated and constructed for cars, calling for more ethically just distributions, especially for cycling (Creutzig et al., 2020). Smaller BEVs, that need less space on streets, could provide room for active modes such as walking or cycling, or can be rededicated to open spaces for social interaction, increasing the livability of cities (Ewert et al., 2020). However, a mode shift from private cars to slow modes, e.g., walking and cycling, would have a much greater potential to decrease parking lot demand and thus free space for other purposes. In the long-term, shared automated vehicles (SAVs) could reduce parking space need (González-González et al., 2020). Still, the extent to how wide a road can be is limited and will face further limits with increasing densification of urban areas. Hence, reducing road width due to smaller BEVs could free road space for dedicated safety measures, e. g. bicycle lanes, or wider sidewalks (Gössling & McRae, 2022). Also for "problem 6", a desired future cannot negate potential benefits to the occupation of space gained from adopting smaller BEVs.

In summary, the benefits in choosing a smaller BEV are substantial for human health, environment and economy, especially for the short- to medium-term. Once a fully carbon-neutral energy system and a circular economy are established, the benefits of a smaller BEV compared to a larger BEV are reduced, but still relevant regarding the efforts needed to maintain the circular economy, accident risk and occupation of space.

These six problems with increased range and size of the BEVs leads to the alternative of switching to a small BEV with a battery adapted to the actual range needs. However, small BEV would not always be comfortable, e.g., for long-range trips and holidays or carrying large luggage. Mobility services could thus serve as a complement to a small BEV.

1.3 Mobility services as a complement to a small BEV

A mobility service can be understood as a service commodity provided by a private company, the public or the society. The core feature thereof is the purchase of a service instead of a product (like a car). Especially for occasional use cases, like going on holidays, car rentals and carsharing became popular for households not needing a car in their everyday life and tourists valuing the flexibility it provides while travelling (Julsrud & George, 2020; Lempert et al., 2019; Schaefers, 2013). While carsharing is not new and has originated from an economic need to save cost in Switzerland (S. Shaheen et al., 1998), new services emerged rapidly within the last few years, e.g. scootersharing, e-bikesharing, peer-to-peer sharing and on-demand sharing like Uber and Lyft (Guyader et al., 2021). As such, the variety of mobility service are large and complement the traditional public transport system and the private car.

However, the adoption of new mobility services is slow, not only due to the inertia of the established conventional car regime described in chapter 1, but also because of habits and the comfort cars provide (Matthews & Wynes, 2022; Mattioli et al., 2020). Motivating car-savvy households to switch to a mobility lifestyle comprising of owning a small BEV for everyday trips and mobility services for occasional long-range trips should thus entail as little behavior change needed as to still be an attractive alternative. One of the main limitation of a small BEV compared to a larger high-range car is perceived to be range (Kowalska-Pyzalska et al., 2022). Hence, the crucial factor for adopting such a mobility lifestyle is the frequency of the occasional use cases where the small BEV would not have sufficient range for a specific trip. Several researchers investigated the total distance travelled by car per day and how frequent certain trips distances are on a yearly basis (e.g., frequency of daily driving distance above 200km). Neuenschwander (2020) used GPS-based data in Switzerland to estimate the number of trips per year for different range categories. He finds an average of 10.7 trips per year exceeding 199 km. Likewise, Plötz et al. (2017) investigated the number of days per year a daytrip exceeds 200km in Sweden using GPS measurements. They find very similar results with 11.9 days per year on average, and a median of 3.8 days per year. Melliger et al. (2018) investigated the compatibility of a BEV with a range of 230km to replace trip legs in Switzerland and Finland. They show that the BEV is sufficient to replace 87% of all trip legs in Switzerland and 85% of trip legs in Finland. Even in the US, Needell et al. (2016) found that a BEV with a range of 120km could already be sufficient to replace 87% of daily car trips, without the need to recharge the BEV during the day. Plötz and Sprei (2021) investigated real-world driving behavior in the US with a long observation period (2011 until 2020). They show, again, comparable results to previous studies indicating that daily distances above 200km occur at 13 days per year on average. Consequently, the frequency of the occasional long-range trips is low for a large share of car owners, even in large countries with a dispersed road network.

In the following sub-chapters, I will provide a short overview of the three mobility services discussed in the literature to serve as a complement to a small BEV.

1.3.1 Carsharing

Carsharing emerged through economic interests after the second world war, traced back to the "Sefage" (Selbstfahrgemeinschaft) initiated in Zurich, Switzerland. Since people would not be able to buy a car on their own, they would jointly pay for a car and share it within the Sefage (S. Shaheen et al., 1998). Until the late 1980s, a number of small-scale carsharing organizations emerged, yet without any significant success. One of the oldest and largest carsharing organizations also emerged in Switzerland with the merging of Auto Teilet Genossenschaft (ATG) and ShareCom, both starting as an initiative with a dozen households sharing private cars in 1987. Until the merging in 1997, both cooperatives experienced exponential growth rates. The new cooperative has been renamed to Mobility Car Sharing Switzerland (Truffer, 2003). The cooperative is still in operation today and now called Mobility Carsharing (or in short Mobility), covering the whole country with 1560 stations offering 3010 cars by the year 2022 (Mobility, 2022b).

While early carsharing systems would be operated on a round-trip basis, i.e., that the car needs to be picked up and brought back at the same station or parking lot, other forms like one-way carsharing, free-floating carsharing and peer-to-peer carsharing are available today (Nansubuga & Kowalkowski, 2021). In 2008, the first free-floating carsharing system, where one can park the car on any official public parking lot, was invented by Daimler in Germany and now called FreeNow (Nansubuga & Kowalkowski, 2021). Also, the Swiss carsharing operator Mobility piloted free-floating carsharing in two Swiss cities. However, as with all free-floating system, the redistribution of cars to places with high demand is resource intensive and challenging to manage, resulting in the closure of the pilot project in the case of Switzerland due to non-rentability (Mobility, 2022a). Even FreeNow in Germany, who were owned by the large car manufacturers Daimler and BMW, struggled to reach profitability. FreeNow was sold to Stellantis in the beginning of 2022, making Stellantis' mobility services branch, "Free2moove", the worlds' largest mobility service provider with a fleet of more than 450'000 cars offering carsharing, car-rental and subscription services (Stellantis, 2022).

Despite difficulties in reaching profitability, carsharing cooperatives and firms have spread all over the world, experiencing substantial growth (S. Shaheen & Cohen, 2020). Different carsharing models emerged for varying purposes and are best summarized in Nansubuga & Kowalkowski (2021). Especially station-based carsharing has been found to decrease car-ownership and adheres to a sustainable mobility lifestyle (Blumenberg et al., 2021; Lempert et al., 2019), while free-floating carsharing has less potential in reducing car ownership and car travel, since it also replaces public transport trips and slow modes (Papu Carrone et al., 2020). Overall, the literature suggests that carsharing could increase sustainability substantially, because it reduces peoples' decision to drive a car, reduces the number of private cars and carsharing fleet owners increasingly choose to buy BEVs (Ceccato & Diana, 2021; Liao et al., 2020; Mounce & Nelson, 2019; Storme et al., 2021).

1.3.2 Car-rental

Car-rentals already started as early as 1918 as a simple business. They evolved similarly to carsharing due to economic interests of customers wanting access to a car without the need to buy one. Initially, the business models focused on providing car rental services for the employees of large corporations. By 1950, car rentals provided various types of cars at airports, railroad stations and hotels, among others. While car-rental grew, one of the gamechanger was the airline deregulation in 1978 and the advent of discount air fares, which largely increased air travel, and in conjunction, increased demand for rental cars. With that, the business of car-rental shifted to leisure travel (Carroll & Grimes, 1995).

Compared to carsharing, car-rental focuses on multi-day travels and holiday travels rather than short-time renting within the same day. However, car-rental firms now increasingly also provide short-time car-rental, i.e., carsharing, to increase their customer base (Svennevik, 2021). Research about car-rental is less frequent than carsharing and its effect on mobility behavior or substitution of other modes is less understood. One of the few researchers investigating sustainability of car-rental in the tourism sector are Martín et al. (2019). They conclude that car-rental is pivotal for the tourists and that hardly any other mobility services could provide the needs and flexibility the tourists desire. As a solution to mitigate GHG emissions, they suggest to electrify the car-rental fleet and substantially increase charging infrastructure (Martín et al., 2019). This suggestion is mirrored by Gómez-Déniz et al. (2021) who further propose a tax to counteract negative environmental effects stemming from the increasing number of rental cars, which would increase with each rental day but would also deceases for environmental-friendly cars, such as BEVs. Fitt (2022) thoroughly reviews and discusses the potential of BEVs in car-rental and tourism, concluding that BEV tourism is rapidly becoming a realistic prospect for an increasing number of drivers. The literature reviewed suggests correspondent changes in practices, including instrumental changes to the kinds of trips taken, their patterns, destinations, and planning.

In 2021, car-rental had 24.5, 38.5 and 89.5 million users in Europe, the US and China, respectively (Statista, 2021). This is significantly higher than carsharing, which had 15.9, 4.7 and 13.5 million users in Europe, the US and China, respectively (Statista, 2021). We see that, relatively speaking, carsharing has a much higher influence in Europe compared to the US and China. Statista (2021) expects the car-rental market to increase substantially in Europe, to approximately 65.2 million users by 2026.

1.3.3 Mobility as a Service

The core idea that underpins most MaaS developments is to make it easier for people to complement public transport with other mobility services, such as carsharing, car-rental, bikesharing or scootersharing through a single mobility service accessible on demand (MaaS Alliance, 2021). MaaS further provides the travel planning, reservation and payment through one single platform accessed through a website or a mobile app (Jittrapirom et al., 2017). It is thus supposed to increase the flexibility and attractiveness of public transport as well as provide alternatives to the private car. In Switzerland, several MaaS pilots like yumuv and ZüriMobil have been launched recently. Yumuv is a research project of the Verkehrsbetriebe Zürich (VBZ), Swiss Federal Railways (SBB), Bernmobil, the Basler Verkehrsbetriebe and the Swiss Federal Institute of Technology in Zürich (ETHZ), to test the acceptance of different MaaS subscription plans in various cities (Yumuv, 2021). Similarly, ZüriMobil, a project by VBZ and the Civil Engineering Department of Zürich, also provides a MaaS platform for multimodal travel in the urban region of Zurich and further tests stations, at which the various different transport options are located closely together simplifying the changeover from one means of transport to the other (VBZ, 2021).

Several other MaaS trials exist across Europe, Asia, Australia and North America (Hensher et al., 2020). Yet, so far, only few have been empirically assessed by research with the exception of two pilots in Gothenburg (Smith et al., 2022; Sochor et al., 2016), one in Ghent (Storme et al., 2020) and one in Sydney (Hensher et al., 2021). The conclusions from these studies are the following:

Based on the pilot in Ghent, Storme et al. (2020) find that MaaS is rather a complement to car ownership than a substitution, since the participants did not fully substitute private car use during the pilot despite being given a mobility budget of up to 350 EUR to spend on mobility services per month. Still, more than 70% of the participants reduced car use. A similar range of reduction of car use was found in the Sydney trial (Hensher et al., 2021). Participants of the UbiGo pilot in Gothenburg stated that the MaaS service made multi-modal travelling less expensive and more convenient (Sochor et al., 2015a). Generally, more than 80% of participants stated that they would be willing to continue using the MaaS service after the pilots in Sydney and Gothenburg (Smith et al., 2022). From analysing the MaaS trial in Gothenburg, Smith et al. (2022) conclude that a mutually reinforcing relationship between the introduction of MaaS and policies aiming to reduce private car use exist. The availability of different mobility services made the interviewees comfortable to move to the studied neighbourhood despite an intentional lack of residential parking (Smith et al., 2022). Further, Hensher et al. (2021) note that by providing bundles, i.e. monthly description packages including a combination of mobility services and discounts depending on the bundle fee, is important to attract customers and increase the appeal of MaaS.

1.4 Research design

As we have seen in the previous chapters, the combination of a small BEV for everyday trips and mobility services for occasion long-range trips could be a sustainable and attractive alternative for a large share of households. Yet, very few research has been conducted on this topic. Scholars investigated either the influence of carsharing experience on adopting an EV (Jenn et al., 2018), or the motives and barriers to participate in carsharing (Nansubuga & Kowalkowski, 2021) and MaaS (Butler et al., 2021), but only few studies investigated the rational of using mobility services as a complement to own a small BEV, which might be limited for certain occasional trips. One of the few authors who investigated this idea to provide an alternative for long-range trips are Gyimesi and Viswanathan (2011). In their report, they suggest that car manufacturers could alleviate range anxiety by a business model based on flexible vehicle access. In this scenario, consumers who purchase an EV also receive access to a variety of other vehicles on an as-needed basis, e.g., increased luggage space and range for holidays or a weekend trip. Later, King et al. (2015) built on this work and suggested an on-demand model, whereas car manufacturers are suggesting a model that guarantees access for a fixed but small number of days. King et al (2015) find that such a model would be more economical than the EV purchase price subsidies in place at that time. Another study that tried to disentangle the use of the car for everyday trips and mobility services for long-range trips was done by Sprei and Ginnebaugh (2018). They analyzed this rational through literature and expert interviews including representatives from carsharing and car-rental companies in California and Sweden. They find that, if carsharing operators provide a wide range of car models to choose from, e.g., including larger cars, it could support the unbundling of the vehicle to frequent use and infrequent use (Sprei & Ginnebaugh, 2018). One of the most comprehensive analysis of the potential to replace conventional cars with BEVs in combination of supporting infrastructure and mobility services was done by Wei et al. (2021). They used driving data from 334 vehicles that were each tracked for a year in the Seattle metropolitan area, finding that home charging alone allows 12% of the vehicles to meet all of their range needs with a BEV including a 40kWh battery capacity. Work charging enables an additional 2% of vehicles to become fully electrified. Adding additional fast charging to home and work charging to allow the vehicle to charge on highway trips raises the potential to electrify vehicles in Seattle to 41%. Finally, Wei et al. (2021) find that adding supplementary long-range vehicles to these charging scenarios on at most ten days per year could increase the electrification potential to 80% of the Seattle vehicles. While they could show that the potential of supplementary long-range cars is indeed high, they didn't account for user preferences. Since there is an apparent lack of quantitative studies in the literature that focus on user behavior and decisions, the main research question for this thesis is the following:

Do households see a combination of owing a small BEV with occasional use of mobility services as a real alternative to owning a conventional car?

Several sub-questions dig deeper into the main question:

- *What are the challenges and needs regarding the adoption of MaaS?*
- *Can experience with carsharing increase the likelihood to opt for a micro to mid-sized BEV?*
- *What push&pull measures can increase the adoption of small BEVs in combination with mobility services?*

In order to answer these questions, I conducted stated-preference surveys and choice experiments integrated within the Swiss Household Energy Demand Survey (SHEDS). SHEDS has been developed as part of the research agenda of the Competence Center for Research in Energy, Society, and Transition (SCCER CREST), designed to collect a comprehensive description of the Swiss households' heating-, electricity- and mobility-related behaviors, their longitudinal changes and the existing potentials for future energy demand reduction between 2016 and 2020 (SCCER-CREST, 2022).

I designed the thesis in such a way, that each study focuses on one of the sub-questions but also supports the other contributions in one way or another. Figure 1.3 illustrates these connections between the three contributions with the overall goal of increasing the adoption of small BEVs. Contribution 1 illuminates the factors and needs promoting MaaS and how people react to supporting BEV policy measures. This builds a basis for the other two contributions, as we show the relevant aspects a MaaS service needs to provide to attract customers, which then further help in reaching the goal of increased adoption of small BEVs by serving as complementary mobility services. Contribution 2 directly investigates the link between carsharing experience and openness to buy a small BEV providing evidence of a correlation between the two. Finally, push and pull measures in supporting the uptake of a combination of a small BEV and mobility services are tested in contribution 3.

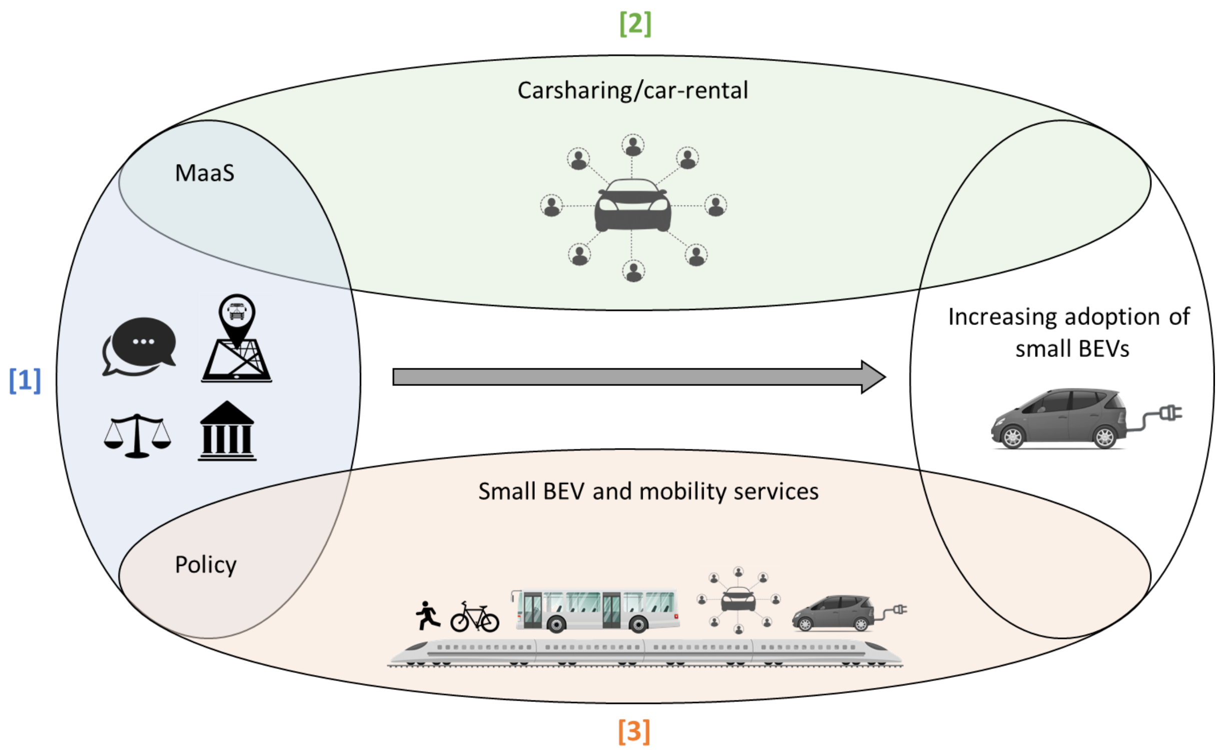

Figure 1.3: Thematic overlaps of the three contributions.

In the next chapter, I summarize the three papers and highlight their contribution to the literature.

1.5 Overview of the three contributions to the literature

1.5.1 First contribution: What are the factors and needs promoting mobility-as-a-service? Findings from the Swiss Household Energy Demand Survey (SHEDS)

Mobility as a Service was a relatively new term back when this paper was written. The few studies available focused on subscription plans, business models, motives and barriers for the uptake of MaaS (Ho et al., 2018, 2019; Matyas & Kamargianni, 2019; Schikofsky et al., 2019). With this paper, I provide a differentiated view on the trip purpose for which MaaS would be used and additional mobility-related and psychological factors potentially influencing the openness to use MaaS. I further focused on the user needs that would need to be fulfilled to motivate the use of MaaS, which so far, has not been investigated.

The survey, integrated within SHEDS 2018, included a control and two treatment groups. Within the treatments, I wanted to test whether the announcement of future policies directly affecting consumers could increase the willingness to use MaaS. Participants are informed about the greenhouse gas emission intensity of the transportation sector and about the international climate targets agreed in Paris 2015. Following that, they are informed about emissions in transportation in Switzerland and Swiss emission reduction targets as well as measures taken in other countries to mitigate emissions. Finally, they are informed that the Swiss government has set a BEV quota to be reached by 2023. In the first treatment, the specific policy measures to achieve the target are not yet defined, while in the second treatment, measures are defined with implementation starting in 2021. In the first treatment, consumers are thus only informed about potential consumer-addressing policies, while in the second treatment, they have to expect their implementation in the near future.

I found that respondents increased their openness to use MaaS if they received the decided policy treatment information text, even though the policy does not directly affect MaaS, but rather the increased uptake of BEVs. This suggest that people might see MaaS as an opportunity to respond to such policies and that the policies focusing on increased uptake of BEVs could have a mutualistic relationship with new mobility services like MaaS. I also found that carsharing experience significantly increased the openness to use MaaS. Hence, I recommend targeting experienced carsharing users as first movers into MaaS and market the utility of an easy-access and easy-to-understand MaaS service as a complement to a BEV.

1.5.2 Second contribution: Carsharing experience fostering sustainable car purchasing? Investigating car size and powertrain choice

Several scholars investigated the effect of carsharing experience on BEV ownership or the use of BEVs within carsharing systems (Clewlow, 2016; Liao & Correia, 2022; Luna et al., 2020; Mounce & Nelson, 2019; Schlüter & Weyer, 2019). The general findings suggest that carsharing users own more BEVs (Clewlow, 2016) and that BEV within carsharing fleets increase the easy access to the BEV technology, spurring its adoption (Schlüter & Weyer, 2019). However, no study investigated the influence of carsharing, and with that having alternative cars at one's disposal, on the size preference in purchase decision of mobility users. I fill this gap with a representative study of the German- and French-speaking population of Switzerland within SHEDS 2018. The literature suggests that, despite demographics and mobility characteristics, also attitudes and values play a major role in mobility decisions (Herberz et al., 2020). Hence, I adopted a holistic approach by screening the literature for any potential influential factor regarding, car size preference, powertrain preference and adoption of carsharing. Through this holistic literature review, I was able to screen the most relevant factors that might influence the choice decision within the choice experiment survey and consequently control these effects.

I find that carsharing experience could, indeed, increase the openness of Swiss households to opt for a small to mid-sized BEV as their next car replacement, especially for people living in rural environments or within the agglomeration. I advise mobility planners and policy to consider the following: 1) advertising the benefits of smaller cars in combination of carsharing at hand, including a wide spectrum of car models to choose from, 2) focus on the advertisement of private micro to mid-sized BEVs in the countryside and agglomerations in combination of long-range cars in carsharing to complement the current range disadvantages of micro to mid-sized BEVs, 3) establish e-carsharing in the perimeter of the inner city to exploit the visual effect of BEVs in the fleet and facilitate first experiences with the technology together with reduced local pollution and, 4) focus on a mixed carsharing fleet of BEVs and long-range cars (e.g. PHEVs) in the perimeter of agglomerations to leverage the possibility of cross subsidizing the non-profitable BEVs and the higher openness to buy a BEV.

1.5.3 Third contribution: Push and pull strategies to increase the uptake of small electric vehicles

Within the third paper, I combine the experience and findings from the first two papers by focusing on push and pull measures that could increase the adoption of small BEVs in combination with mobility services. Since the openness of households in switching from owning a conventional car to using mobility services in combination of an own small BEV has not been investigated by research so far, I am the first to provide an empirical estimate of what share of households might opt for such a switch. I conducted a multiple price list choice experiment in the SHEDS 2020 survey wave. By including control and treatment groups, I further test the potential of push and pull measures in increasing the openness to switch, providing valuable guidance for policy and practice in the efficient design of measures aiming to increase the adoption of small BEVs and mobility services.

One of the most pressing barriers to the adoption of a BEV is the lacking charging infrastructure (Giansoldati et al., 2020). Scholars suggest that providing charging at home and at work could significantly increase the openness to buy a BEV (Hardman et al., 2018; Patt, Aplyn, et al., 2019). Hence, the first treatment group received a scenario with full access to a charging station at home (regardless of the living situation, e.g., owner or tenant, living in a house or apartment) and charging possibility at the place of work, as a pull measure to increase the adoption of small BEVs. As a second treatment and pull measure, I described a scenario with easy access to a carsharing or car-rental station close to the place of residence. The final treatment group received information on the total cost of ownership (TCO) of their current conventional car and the TCO of a small BEV combined with mobility services. All participants were presented with a scenario in which their primary households' car broke down and could not be repaired. They then had to do several binary choice tasks by either keeping a similar mobility lifestyle they were used to (including a conventional car) or switch to the alternatives including a small BEV for everyday trips and mobility services for occasional long-range trips. For all participants, an increasing tax on fuel was implemented if they would keep their conventional mobility lifestyle including a gasoline or diesel car, which serves as the push measure in our experiment.

I find that up to 30% of conventional car owners would be open to switch to a small BEV in combination with mobility services. This can be increased to 41% through secured charging at home and at work. Combined with a CO_2 tax on fuel, up to 67% would switch. The easy access to carsharing and car-rental could increase the odds to switch to a small BEV and use carsharing/car-rental from previously owning a conventional car, especially for those respondents who currently don't know whether the current number of carsharing stations are sufficient to motivate them to use carsharing. The information treatment about TCO only increases the odds of choosing an alternative without owning a car. Accordingly, the information about TCO seems to be especially relevant when fostering mobility lifestyles that are not bound to car ownership.

1.6 Switzerland as a case study for my work

Switzerland serves as a good case study for this work due to several reasons. First and foremost, Switzerland is a pioneer in platform-based carsharing, being the only country that provides carsharing in urban and rural areas, covering the whole country. Since carsharing in Switzerland mostly consists of one operator (i.e. Mobility Carsharing), it is convenient for the customer, as they only need to get accustomed to one app or platform. The potential of carsharing as a complement to owning a small BEV is thus best examined in situations, where this could be a real alternative. But not only carsharing, also car-rental and the concept of MaaS are present in Switzerland, with the former being available in all major cities and the latter tested in various neighborhoods and regions. Second, the public transport network is considered to be well established, also serving as a real alternative to car trips for a large share of the population even in rural areas (Petersen, 2016). Accordingly, the Swiss have one of the highest shares of public transport mode share in total person-kilometers-travelled in Europe (European Commission, 2021). This demonstrates that convenient modes of sustainable transport are taken up by the Swiss and that trips unsuitable for a small BEV could - to a certain degree - be conducted by public transport instead of conventional cars.

Another aspect that makes Switzerland a good case study is the sustainable electricity mix and relatively cheap electricity prices, which together with a high purchase power, decreases some of the hurdles in adopting BEVs, such as the typically higher purchase prize compared to conventional cars.

All in all, the alternatives discussed in this work are not utopian but rather well-suited for the Swiss households studied.

2 What are the factors and needs promoting mobility-as-a-service? Findings from the Swiss Household Energy Demand Survey (SHEDS)

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Abstract

Mobility-as-a-Service (MaaS) is a service that supports customers' transportation needs by providing information and ticketing for a multitude of transport modes in one interface; thus, buy potentially fostering multimodality and public transport, it represents an important lever to reduce negative transportation impacts such as emissions and congestion. By means of an online survey conducted in Switzerland, we try to understand potential user needs as well as factors that would motivate the use of MaaS. Comparing the openness to use MaaS for specific trip purposes like commuting and leisure activities, we find the lowest level of openness for commuting and the highest for weekend leisure trips. Intention to reduce car usage was positively related to openness to MaaS in commuting. On the other hand, factors that positively influence openness to using MaaS for leisure activities include a higher education degree, experience with carsharing and the use of transport-related climate policy announcements directly affecting consumers. These findings suggest focusing specifically on either commuting or leisure activities when designing policy measures.

2.1 Introduction

Mobility is a basic need of society in that it serves as a connection between spatial structures that enables commuting to and from the workplace as well as leisure trips, ultimately driving industry and society forward. The demand for mobility is steadily rising while simultaneously posing serious environmental and societal challenges such as local pollution, congestion and greenhouse gas emissions. Mobility-as-a-Service (MaaS) is a new concept that could address these challenges: a platform providing customers with a holistic service that enables the booking and planning of routes with just one app that includes all mobility offers, such as buses, trains, carsharing, ridesharing or bike-sharing. Sufficiency principles such as the sharing of cars or rides are an integral part of MaaS and thus have the potential to foster a transition towards sharing and reduction of car use, potentially fostering car-free households and the reduction of the total vehicle kilometers driven (Mounce & Nelson, 2019; G. Santos, 2018; S. A. Shaheen & Cohen, 2013). Such schemes could prove particularly useful in reducing vehicle kilometers driven when used for covering "last-mile" situations and efficiently connecting users to public transport hubs. Further, MaaS concepts might act as enablers for alternative electric drivetrain technologies by reducing common hurdles such as higher purchase costs, range anxiety and mistrust towards new technologies due to lack of experience (Schlüter & Weyer, 2019). MaaS could thus prove important in reducing CO2 emissions and improving quality of life through reduced car usage (Glotz-Richter, 2016). Wilson et al. (2019) foresee the greatest potential of MaaS in CO2 emission reduction from transport as well as transformation capabilities created by the combination of electric mobility and MaaS.

To date, a few studies have analyzed the use patterns and behavior of carsharing users, finding that carsharing could indeed serve a large share of current travel demand, especially by bridging gaps in existing public transportation networks (Becker et al., 2017a, 2017b; Ciari & Becker, 2017; Tyndall, 2019; Yoon et al., 2019). Lempert et al. (2019) further investigated differences in travel patterns between one-way and two-way carsharing in Vancouver, Canada, concluding that participants of a two-way carsharing service plan their trips more in conjunction with public transport. The potential impact of MaaS on the mobility system and willingness to pay and its relevance to public transport are also increasingly being investigated (Ho et al., 2018; Mulley et al., 2018; Russ & Tausz, 2015). Still, to date, very little is known about the general attitude and needs of society regarding these services. Hoerler and Hoppe (2019) and Hoerler et al. (2019) analyzed the openness of commuters in Basel (Switzerland) towards car- and ridesharing as well as the openness of mobility-related stakeholders towards MaaS. They found that the openness of the general public to using these new services is still very low, although mobility-related stakeholders would be open to actively supporting such proposals. Further, the literature investigating user needs is still sparse. Especially when considering MaaS and its strong user focus, a better understanding of user needs would help in providing targeted services and achieving more widespread adoption and diffusion of these new mobility services. This paper explores the needs and expectations of potential users in order to identify ways for increasing openness to using MaaS services.

Mobility needs differ for commuting, short weekday leisure trips and weekend trips. Separately analyzing these three travel situations, the present paper will elaborate: i) the demographic characteristics that are relevant to openness to using MaaS and ii) the characteristics that MaaS (also referred to as a combined mobility service within this paper) needs to have in order to achieve higher acceptance and usage rates. Accordingly and based on literature about MaaS, we derive six hypotheses. In addition, two further hypotheses are then derived to discuss behavioral mechanisms, which are experimentally tested with respect to their potential to increase openness to using MaaS: iii) whether peer effects play a role in stated openness to using combined mobility services and, last, iv) whether respondents differ in openness to using a combined mobility service when they are informed about future policy measures. These research questions are then investigated through the statistical analysis of a representative survey of Swiss households within the Swiss Household Energy Demand Survey (SHEDS) 2018.

The paper starts with an overview of current challenges and experiences with MaaS and reviews the literature pertaining to the two behavioral mechanisms tested in this study. The section that follows sets out the survey design and regression model used to estimate factors that might influence openness to using MaaS. The results are presented and discussed in Sections 4 and 5, respectively. Finally, the study provides conclusions and recommendations for future research on how to effectively increase the adoption of MaaS by the general public.

2.2 Background

2.2.1 Openness to using MaaS – current challenges and experiences

MaaS is a relatively new concept. One of the first comprehensive descriptions of it is presented in a study by Hietanen (2014). He summarizes the function of MaaS as a "mobility distribution model in which a customer's major transportation needs are met over one interface and are offered by a service provider" (Hietanen, 2014, p. 3). Heikkilä (2014) further popularized the term MaaS, spreading the notion across the personal transport sector. The core idea is to integrate various transport options into a single mobility service through a digital interface. It is accessible on demand and thus supposed to increase the flexibility of public transport as well as provide alternatives to the private car (MaaS Alliance, 2021). The digital interface, a medium commonly used with smartphones or web pages, allows trip planning, booking, ticketing, payment and real-time information provision that can be personalized and customized to meet the end users' needs (Jittrapirom et al., 2017). The transport options offered within MaaS are not limited to public transport but aim to include taxis, carsharing, ridesharing, and bike-sharing as well as other forms of mobility services. This also allows for a multi-modal approach to mobility in which various trip options are available to the user, who can then make choices based on personal needs. A comprehensive overview of MaaS definitions is provided by Sochor et al. (2018).

At the time of writing, only a limited number of studies have considered the openness of the general public to using MaaS. Sochor et al. (2015b) examined users' motives for using the UbiGo service – a MaaS project that has been trialled in Gothenburg – before and after they took part in a six-month field operational test. They conclude that the users' predominant motive before taking part in the trial was mainly curiosity, indicating that MaaS users could be considered early adopters (Sochor et al., 2015). During and after the experiment, the participants had the possibility to test living without a private car. Following that, the motives convenience and flexibility increased substantially in contrast to the motives indicated before participating in the field test. The aim of city planners and the government to reduce private car usage converge with the results of this MaaS field test since the participants rated their use of carsharing and rental services as more frequent and their attitudes towards these services as more positive than before. Similarly, Matyas & Kamargianni (2019) find through a stated preference survey covering the Greater London area that respondents, once decided for a MaaS bundle, would be willing to try sharing modes previously not used. However, Sochor et al. (2015) also identified issues that would need to be addressed for a successful implementation of MaaS. These include the possibility of making a profit, service providers losing their brand exposure (as they were all summarized under UbiGo), defining a payment procedure that suits low-income households, uniting already available travel services and issues related to smartphone technology, such as battery life, network access and proof of a valid ticket.

A new study by Schikofsky et al. (2019) investigated the role of values in acceptance of several different hypothetical MaaS plans, finding that a mix between communicating functional benefits and emotional values would be most effective. Also the feeling of being related to an associated user group could spur adoption.

Ho et al. (2018) conducted a stated choice study of 252 individuals in Sydney, Australia, to investigate the uptake and willingness to pay for MaaS (the transport options included public transport, carsharing, taxi and UberPOOL). In their study, the frequency of current car usage significantly influenced the potential uptake level, with the frequent car user (three or four days per week) being most open towards MaaS, the infrequent car user (one or two days per week) slightly less so, the very frequent car users (five to seven days per week) exhibiting below average openness and the car non-users being the least likely adopters. Furthermore, participants aged between 35 and 44 showed a significantly higher likelihood of subscription to the MaaS scheme as opposed to their younger (18–24 years) and older (55 years or above) counterparts. This result doesn't reflect the generally higher openness of the younger generations to using new mobility concepts like carsharing or ridesharing commonly found in other studies (Münzel, Boon, et al., 2019). The only other demographic influence that has been found is the number of children in the household, where households with two or more children were significantly less likely to subscribe to MaaS than households with only one child or none. Building on this research, Ho et al. (2019) conducted a similar stated choice analysis in Tyneside, UK comparing the new results to study previously done in Sydney. They find similar motives and barriers for the uptake of MaaS yet the actual adoption level strongly depends on local public transport and sharing offers. MaaS travel bundles customized to the travel needs would be key for adoption. Generally, MaaS plans including public transport are strongly preferred over plans with only sharing offers (e.g. bikesharing, carsharing) (Matyas & Kamargianni, 2018). Availability of child seats, reliability and security were some of the reported caveats with carsharing within a MaaS bundle (Matyas & Kamargianni, 2018).

The above studies provide important insights into challenges with designing MaaS subscription plans, business models, socio-demographic characteristics of adopters and, to some extent, specific needs that would have to be fulfilled for higher acceptance rates. With this paper we add a differentiated view to the adoption intention by analyzing the openness for MaaS for different trip purposes. We provide additional socio-demographic and psychological factors not yet studied in context of openness to use MaaS and test two potential levers to increase this openness. Last, we provide a thorough analysis of needs that could motivate the openness to MaaS for the different trip purposes in an open-ended design.

Based on the above experiments and results from scholars, a review of the literature and general insights obtained from technology diffusion, we hypothesize that the openness to use a combined mobility service for commuting, short weekday leisure trips and weekend leisure trips is significantly higher for the following groups:

H1) middle-aged (ages 35–54) participants as compared to younger (ages 18–34) and older (55 and above) participants;

H2) more educated participants, as they tend to exhibit a higher awareness of sustainable innovations and understanding of complex topics like MaaS (Sovacool et al., 2018); and

H3) infrequent car users (predominantly using public transport) as compared to very frequent car users (predominantly using a private car).

Based on the research of Fairley (2013), Schlüter and Weyer (2019) and Sovacool et al. (2018), we further hypothesize that openness to using a combined mobility service for commuting, weekday leisure trips and weekend leisure trips is significantly higher for the following groups:

H4) participants that use carsharing (including peer-to-peer carsharing) at least a few times a month compared to those that never use carsharing (thus having experience with carsharing);

H5) participants with pro-environmental attitudes since MaaS is thought to increase sustainability (by reducing car usage, congestion and emissions); and

H6) participants with the intention to reduce car usage.

2.2.2 Accelerating the uptake of innovations – two behavioral mechanisms

In this section, two additional hypotheses related to mechanisms which can accelerate the uptake of innovation and, particularly, of MaaS are derived. These hypotheses have then been tested by means of two experiments. Due to the increasing role of media and other online information sites in shaping behavioral decisions, the first experiment includes the widely encountered peer effects via online ratings. The second experiment is based on providing information about future policy measures. Both experiments and their treatments are described in detail in section 2.3.

The term *peer effect* reflects the idea that one's own behavior is moderated by the actions of others, be they family members, friends or complete strangers. A wide range of studies finds that peer influence is a strong determinant of social behavior (Nook et al., 2016; Park & Shin, 2017; Rudorf et al., 2019). As such, framing social reference points is a way to provide information on and ultimately influence other people's behavior (Szaszi et al., 2018). Gaker et al. (2010) set up an experiment with a job-and-housing scenario that set participants the task of deciding whether to buy a conventional car, a hybrid car or no car at all. One group of participants were told what other participants in the same experiment chose to do (and thereby set a reference point). The results show that the auto-purchasing decision was significantly adjusted and aligned to the decisions made by peers. Other forms of peer effects are increasingly magnified by online interaction and widespread access to the internet and social media. Customers increasingly rely on the internet for information as it greatly reduces the effort needed to obtain desired content. Especially within the tourism industry, positively framed reviews have been demonstrated to significantly increase intention to book. This effect was demonstrated to be even greater with the addition of positive numerical ratings (Sparks & Browning, 2011). Likewise, although targeting the transport sector, Rasouli and Timmermans (2016) studied the effect of electric vehicle (EV) car reviews on the intention to buy an EV through a stated preferences survey. The results show that positive reviews increase the utility of the intention to buy an EV. Through this variety of studies, it becomes apparent that the influence of social media, especially through the effect of information about peer behavior and reviews, should not be neglected when promoting sustainable alternatives to the car. Hence, we hypothesize that peer reviews and ratings could also positively affect the willingness to try MaaS solutions.

H7) Showing participants a hypothetical top rating (for example, five out of five stars) for a combined mobility service increases the likelihood of their being open to using a combined mobility service as compared to showing them a lower rating (four stars out of five).

Clear and transparent policy communication is generally regarded as key for industries and businesses to be able to adapt to a new policy environment (Moosa et al., 2016; Schmidt et al., 2012). Early communication can help industries to plan investments cost-effectively (Bretschger & Soretz, 2018). A well-known example is communication by central banks with respect to their future/planned monetary policies (R. G. King et al., 2008). In contrast, the effect of policy announcements on individuals is not much explored. This is surprising because policies directly addressing consumers (product bans, restrictions in usage, etc.) are being discussed more and more often in the context of emission reductions regarding mobility and transportation. Hence, it may well be that through certain policy announcements, people would also reflect upon their proper mobility behavior and change their attitude towards new products and services (Stünzi, 2019). Particularly in light of future restrictions due to such policies, people may consider accepting or at least trying other transportation options where they would not face those restrictions. This leads to the following last hypothesis:

H8) the announcement of future policies directly affecting consumers increases the willingness to try MaaS solutions.

Table 2.1 provides an overview of all eight hypotheses.

Table 2.1: Overview of hypotheses tested within this study.

Openness to use a combined mobility service for commuting, short weekday leisure trips and weekend leisure trips is significantly higher for the following groups:
H1: Middle-aged (ages 35–54) participants as compared to younger (ages 18–34) and older (55 and above) participants
H2: More educated participants
H3: Infrequent car users as compared to very frequent car users
H4: Participants that use carsharing (including peer-to-peer carsharing) at least a few times a month compared to those that never use carsharing
H5: Participants with pro-environmental attitudes
H6: Participants with the intention to reduce car usage
H7: Participants who were shown a hypothetical top rating (for example, five out of five stars) for a combined mobility service compared to showing them a lower rating (four stars out of five)
H8: Participants who receive an announcement of future decided policies directly affecting them

2.3 Methodology

To examine these questions empirically, we developed a set of questions that were embedded in the larger online Swiss Household Energy Demand Survey (SHEDS). The SHEDS is a sequential choice and socio-demographic as well as attitudinal questionnaire that started in 2016. It addresses the energy-related behavior of Swiss citizens in the three fields of heating, electricity and mobility, providing insights into longitudinal changes and energy consumption reduction potential. The respondents are chosen randomly, with approximately 5,500 participants per year (wave). More details about the design of the SHEDS can be retrieved in Weber et al. (2017). Overall, 5'514 household individuals took part in the SHEDS 2018 wave, while 995 respondents were assigned to this paper's experimental study. In order to test H7 and H8 (peer and policy effects), two treatments for each hypothesis (each treatment receiving a different set of information) were prepared. Among the 995 respondents, 288 subjects were selected randomly to receive the peer and policy effect treatments, respectively.

Figure 2.1 represents the overall experimental setup, which also addressed other aspects not investigated in this paper. The introductory questions collected information about demographics, mobility behavior and psychology. The 995 participants were then split into the two peer effect treatments T1 and T2 (n = 70 each), policy treatments T3 and T4 (n = 74 each) and the control group comprising the remaining 707 respondents. The core exercise of the experiment was to choose a vehicle (private car) from a list of cars with different engine types (traditional fuel combustion, hybrid, electric) and indicate how often they would use the vehicle for the different types of trips (for commuting, weekday leisure trips (less than 10 km from place of residence) and weekend leisure trips). At the end of the experiment, the respondents were asked to state whether they would be open to using a combined mobility service for the three types of trips and had to answer some additional questions about MaaS. An informational text was shown to all participants explaining the term combined mobility to mitigate erroneous understandings.

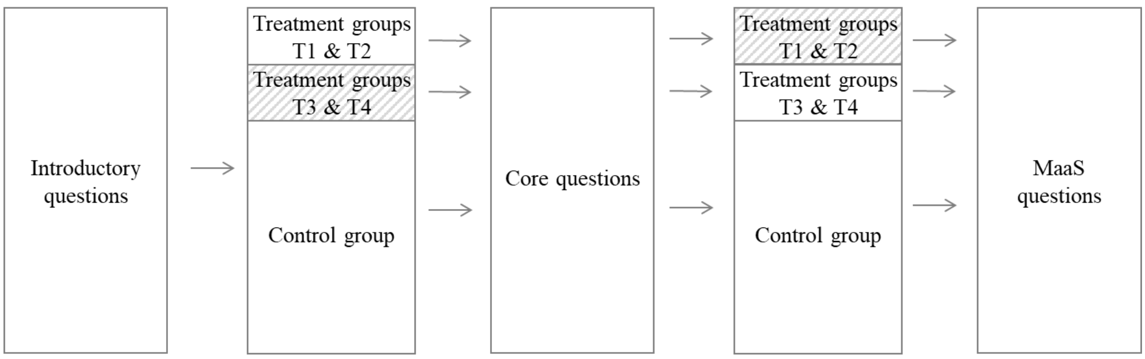

Figure 2.1: Experimental setup. The treatment blocks with diagonal shading represent the time point of applying the treatment.

2.3.1 Description of treatments

In order to simulate the effect of peer assessment, a five-star rating, frequently used in various rating systems, was applied. After reading the general informational text about "combined mobility", the participants were told that a survey about a number of different sharing systems in Switzerland had been conducted, resulting in a satisfactory rating. In the first treatment (T1), four sharing systems, namely public transport, carsharing, car with driver (e.g. taxi, Uber) and a combined mobility service were given a rating of three or four stars. In the second treatment (T2), all modes received the same rating as in T1 except the combined mobility service, which was changed from four to five stars (see Appendix A) in order to enforce a stronger sense of satisfaction.

The policy treatment (T3 and T4) is designed as an informational text that is shown before the core part of the experiment. Participants are informed about the greenhouse gas emission intensity of the transportation sector and about the international climate targets agreed in Paris 2015. Following that, they are informed about emissions in transportation in Switzerland and Swiss emission reduction targets. Then, they are presented with different policies in other countries directly addressing consumers, such as fossil-powered vehicle bans in city centers. Finally, they are informed that the Swiss government has set an EV quota to be reached by 2023. In T3, the specific policy measures to achieve the target are not yet defined, while in T4, measures are defined with implementation starting in 2021. In T3, consumers are thus only informed about potential consumer-addressing policies, while in T4, they have to expect their implementation in the near future. The exact wording can be found in Appendix A.

2.3.2 Overview of parameters and experimental study

The sample consisted of roughly 52% male participants, with 51% living in the city, 28% in agglomerations and 21% in the countryside. More than 50% hold a higher education degree (university, university of applied sciences or higher vocational school), 13.5% a high school diploma and 32.7% an apprenticeship. The sample has a medium gross monthly income range of 6'000-8'999 CHF (30.1%). On average, there are two participants (2.25) per household, and the average age is 49 years. Comparing the study sample with the overall SHEDS sample, we see that we have an overrepresentation of men and a slightly older sample. Other characteristics, such as place of residence, education and household income do not differ significantly. The SHEDS 2018 sample is representative for the German-speaking and French-speaking populations of Switzerland for the variables gender, age, language distribution and residential ownership/tenant status (see Table 2.2). On the other hand, the education level is significantly higher than the overall Swiss population ($\chi 2$ (2, N = 890) = 34.4, p < 0.001).

Table 2.2: Representativeness of study sample.

		Study (n = 995)	SHEDS 2018 (n = 5'514)	Difference Study/SHEDS	Swiss population
Age	Average	48.65	44.25	$t(994) = 9.20, p = < 0.001$	
Gender	Male	51.5%	47.3%	χ^2 (1, N = 995) = 6.90, p = 0.009	49.6 %[a]
	Female	48.5%	52.7%		50.4 %[a]
Education	Apprenticeship	32.7%	33.3%	χ^2 (2, N = 890) = 0.19, p = 0.91	41.1%[b]
	High school	13.5%	13.6%		9.4%[b]
	Higher education	53.8%	53.1%		49.5%[b]
	City	50.9%	50.1%	χ^2 (2, N = 995) = 1.13, p = 0.57	

Place of residence	Agglomeration	28.3%	27.7%		
	Countryside	20.8%	22.2%		
Gross Household income	Less than 3'000 CHF	4.1%	6.0%	χ^2 (5, N = 845) = 7.60, p = 0.18	10'033 CHF[c] (average)
	3'000–4'500 CHF	10.3%	10.0%		
	4'501–6'000 CHF	18.9%	17.9%		
	6'001–9'000 CHF	30.1%	28.9%		
	9'001–12'000 CHF	21.9%	20.9%		
	More than 12'000 CHF	14.7%	16.3%		

[a](Bundesamt für Statistik, 2018b); [b](Bundesamt für Statistik, 2019); [c](Bundesamt für Statistik, 2018a).

The variables of interest (dependent variables: DVs) are openness to using a combined mobility service for commuting, weekday leisure trips and weekend leisure trips, coded as a binary response variable (yes/no). In order to test the hypotheses advanced earlier, we used a binary logistic regression model. Therefore, we tested the variables listed in Table 2.3 (independent variables: IVs) to see whether they have a significant influence on the outcome of the DV. If the answer to the DV was "no", we posed an open-format question asking the respondent to state the characteristics that a combined mobility service would need to have to be able to persuade him/her to use the service for the specific trip purpose (commuting, weekday leisure trips, weekend leisure trips). Each answer was grouped into one of 16 categories depicting common themes and meanings to facilitate the evaluation process. For the analysis of questions related to commuting (both binary logistic regression as well as analysis of open-format questions), we excluded retired participants as they often do not work anymore.

We included common demographics such as age, gender, place of residence and income in the study. Together with the type of public transport tickets and time from home to work/leisure/weekend destinations, they ensure that the regression results are not confounded by these variables. To investigate hypotheses H1 to H6, we included (from the variables available in SHEDS) education, mode choice, carsharing frequency, pro-environmental attitudes and plans to reduce car usage, as described in Table 2.3. The variable plans to reduce car usage was obtained through a Likert scale from 1, very unlikely, to 5, very likely, while the pro-environmental attitudes were calculated as the mean of 12 questions with a range from 1, totally disagree, to 5, totally agree. Details on the description of the 12 pro-environmental questions can be found in Appendix A.

Table 2.3: Sample characteristics (n = 995).

Items	Categories	Distribution
Dependent Variable (DV)		
Openness to using a combined mobility service for commuting	No	62.0%
	Yes	38.0%
Openness to using a combined mobility service for weekday leisure trips	No	52.6%
	Yes	47.4%

Openness to using a combined mobility service for weekend trips	No	46.1%
	Yes	53.9%
Treatment (IV)		
Policy and peer effects[a]	Control	71.1%
	4-star review (T1)	7.0%
	5-star review (T2)	7.0%
	No policy yet (T3)	7.4%
	Policy decided (T4)	7.4%
Socio-Demographics (IV)		
Age[c]	Average (*standard deviation*)	48.65 (*15.09*)
Age group[a]	18–34 years	24%
	35–54 years	40.8%
	More than 55 years	35.2%
Gender[b]	Male	51.5%
	Female	48.5%
Education[a]	Apprenticeship	32.7%
	High school	13.5%
	Higher education	53.8%
Place of residence[b]	City	50.9%
	Agglomeration	28.3%
	Countryside	20.8%
Household income[b]	Less than 3’000 CHF	4.1%
	3’000–4’500 CHF	10.3%
	4’501–6’000 CHF	18.9%
	6’001–9’000 CHF	30.1%
	9’001–12’000 CHF	21.9%
	More than 12’000 CHF	14.7%
Mobility behaviour (IV)		
Dominant mode choice: commuting[a]	Private car	33.7%
	Public transportation	42.1%
	Soft mobility (bike, foot)	17.1%
	Multimodal mobility	1.4%
	Does not work	5.7%
Dominant mode choice: leisure[a]	Private car	47.5%
	Public transportation	29.1%
	Soft mobility (bike, foot)	20.1%
	Multimodal mobility	3.3%
Mobility sharing: car[a]	Never	61.1%
	Every few months	22.6%
	Once a month	9.1%
	One a week	4.4%
	Several times a week	2.7%
Type of public transport pass[b]	GA travel card 1st class	4.3%
	GA travel card 2nd class	19.4%

	Regional pass	21.3%
	None	55.0%
Time used for commuting home-work (min)[b]	Average (*standard deviation*)	29.26 (*25.89*)
Time used for commuting home-leisure activity (min)[b]	Average (*standard deviation*)	17.56 (*20.62*)
Time used for commuting home-weekend trip (min)[b]	Average (*standard deviation*)	50.59 (*57.00*)
Importance of mobility service attributes (Mean (*standard deviation*) from Likert scale: 1, not at all important, to 5, extremely important)[c]	Availability of all possible options	3.09 (*1.31*)
	Cheap price	3.55 (*1.16*)
	Intuitive and easy to use	3.76 (*1.19*)
	Route with lowest CO_2 emissions	2.84 (*1.24*)
	Find fastest possible route	3.52 (*1.21*)
	Waiting time < 30 minutes	3.65 (1.26)
Psychology (IV)		
Pro-environmental attitudes[a]	Mean Likert scale (1, totally disagree to 5, totally agree) from 12 items	3.66 (*0.75*)
Plans to reduce car usage[a]	Likert scale (1, very unlikely, to 5, very likely)	2.58 (*1.22*)

[a]Indicates variables included as hypotheses; [b]indicates control variables; [c]indicates variables not included in the regression model

2.3.3 Statistical analysis

To decide which IVs to include in the model, we followed four basic steps. First, continuous variables were checked for outliers and extreme values. Second, we checked for multicollinearity among explanatory variables through a correlation matrix and the inspection of the variance inflation factor (VIF). No correlations above r = 0.6 were detected nor were any VIF higher than 2.5. We thus reason that multicollinearity is not an issue in our study (Allison, 1999). Third, the assumption of linear relationships, that is, linearity of logit, has been tested using the model fit statistics (Hosmer-Lemeshow test). Fourth and last, all variables and their two-way interactions were included in the model. In a stepwise procedure, each interaction was removed from the model if the p-value was above 0.05. Also, individual regression parameters were excluded from the model if they didn't improve the model significantly (i.e. model fit or pseudo R2). No two-way interactions remained significant. Subsequently, we used the Wald chi-square statistic (Wald $\chi 2$) to test the statistical significance of each regression parameter. Furthermore, we accounted for the accumulation of type 1 errors (rejecting the null hypothesis when it is actually true) by using the Bonferroni-Holm method. This is necessary when testing several hypotheses with one model. The Bonferroni-Holm method is slightly less conservative than the Bonferroni correction yet also increases the possibility of finding real effects (Abdi, 2012). The final set of variables included for each DV is shown in the next section.

2.4 Results

Overall, 53.9% of participants declared being open to using a combined mobility service for weekend leisure trips, which was significantly more open than for using it for weekday leisure trips (47.4%), $\chi 2$ (1, N = 995)

= 16.5, p < 0.001, or commuting (38.0%), $\chi2$ (1, N = 995) = 106.5, p < 0.001. The following section describes factors that could increase this openness for all three trip purposes.

2.4.1 Binary logistic regression

In order to test the hypotheses pertaining to the demographical (H1 and H2), mobility-related (H3 and H4) as well as psychological factors (H5 and H6) described in Section 2.2.1 and the treatments mentioned in Section 2.2.2 (H7 and H8), we conducted a binary logistic regression model for commuting, weekday leisure trips and weekend leisure trips (Table 2.4). The Hosmer-Lemeshow test was non-significant for all models, indicating that the models show good fit to the data. Additionally, the Wald chi-square statistic signals the significance of the effect for each variable, whereas the Exp(B) reflects the odds ratio and CI stands for the confidence interval of the odds ratio. The reference category of each variable is written in parentheses.

Odds ratios are defined as the likelihood of an outcome occurring for one category of a variable versus the outcome occurring for the reference category of the same variable. For example, a public transport user has a 2.4 higher likelihood of being open to using a combined mobility service for commuting than does a private car user. If the variable is continuous, which is the case for "plans to reduce car usage", the odds ratio indicates the increase in likelihood of being open to using a combined mobility service for commuting for a one-point increase of the continuous variable (in this case, it would be one point on the Likert scale).

Table 2.4: Results of the binary logistic regression.

Commuting (Nagelkerke R^2 = 12.9%)						
	Treatments/ Hypotheses	Wald $\chi2$	P-value	Exp(B)	95% CI for Exp(B) Lower	Upper
Treatment (*control*)		2.863	0.581			
4 stars	T1	0.044	0.834	1.067	0.581	1.961
5 stars	T2 (H7)	1.559	0.212	0.642	0.320	1.287
Policy planned	T3	0.077	0.781	1.096	0.575	2.086
Policy decided	T4 (H8)	0.928	0.335	1.338	0.740	2.420
Age group (*55+*)		6.409	0.041			
18–34		4.386	0.036	1.680	1.034	2.730
35–54	H1	0.125	0.723	1.083	0.696	1.685
Gender (*Male*)		0.163	0.686	0.934	0.669	1.302
Education (*Apprenticeship*)		1.344	0.511			
High school		0.502	0.479	1.223	0.701	2.135
Higher education	H2	1.317	0.251	1.258	0.850	1.861
Place of residence (*City*)		3.921	0.141			
Agglomeration		3.549	0.060	1.478	0.984	2.219
Countryside		1.583	0.208	1.325	0.855	2.055
Household income (CHF)		2.369	0.124	1.048	0.987	1.113
Mode choice (*Private car*)		12.528	0.014			
Public transport	**H3**	**8.924**	**0.003****	**2.358**	**1.343**	**4.141**
Soft mobility (bike, foot)		1.099	0.294	1.318	0.787	2.208
Multimodal mobility		2.471	0.116	2.772	0.778	9.881

Does not work		0.913	0.339	0.632	0.247	1.620
Mobility sharing: Car (*Never*)	H4	8.829	0.066			
Every few months		1.285	0.257	1.257	0.846	1.868
Once a month		2.833	0.092	1.586	0.927	2.713
Once a week		2.305	0.129	0.524	0.227	1.207
Several times a week		2.747	0.097	2.110	0.873	5.100
Public transport passes (*None*)		8.388	0.039			
GA 1st class		0.230	0.632	1.241	0.513	3.007
GA 2nd class		6.244	0.012	0.488	0.278	0.857
Regional pass		1.665	0.197	0.697	0.402	1.206
Time home-work (min)		1.978	0.160	1.005	0.998	1.012
Pro-environmental attitude	H5	1.085	0.298	1.128	0.899	1.415
Plans to reduce car usage	**H6**	**8.592**	**0.003****	**1.227**	**1.070**	**1.407**
Constant		6.919	0.009	0.171		
Weekday leisure trips (Nagelkerke R^2 = 14.1%)						
Treatment (*control*)		9.404	0.052			
4 stars, T1	T1	0.618	0.432	1.243	0.723	2.136
5 stars, T2	T2 (H7)	0.271	0.603	1.166	0.654	2.081
Policy planned, T3	T3	0.381	0.537	1.192	0.683	2.080
Policy decided, T4	**T4 (H8)**	**9.034**	**0.003****	**2.321**	**1.340**	**4.019**
Age group (*55+*)		3.332	0.189			
18–34		3.053	0.081	1.423	0.958	2.114
35–54	H1	1.763	0.184	1.254	0.898	1.752
Gender (*Male*)		0.001	0.972	1.005	0.751	1.345
Education (*Apprenticeship*)		10.474	0.005			
High school		0.141	0.707	1.094	0.684	1.749
Higher education	**H2**	**9.208**	**0.002****	**1.675**	**1.200**	**2.337**
Place of residence (*City*)		0.181	0.914			
Agglomeration		0.160	0.689	0.933	0.662	1.313
Countryside		0.075	0.784	0.947	0.642	1.397
Household income (CHF)		4.943	0.026	1.062	1.007	1.119
Mode choice (*Private car*)		10.522	0.015			
Public transport	**H3**	**7.804**	**0.005****	**1.666**	**1.165**	**2.384**
Soft mobility (bike, foot)		0.018	0.894	1.026	0.699	1.508
Multimodal mobility		2.858	0.091	1.985	0.896	4.396
Mobility sharing: Car (*Never*)		22.260	0.000			
Every few months	**H4**	**13.453**	**0.000*****	**1.936**	**1.360**	**2.755**
Once a month		13.252	0.000	2.616	1.559	4.389
Once a week		0.340	0.560	1.234	0.609	2.501
Several times a week		0.308	0.579	1.287	0.528	3.138
Pro-environmental attitude	H5	4.712	0.030	1.247	1.022	1.522
Plans to reduce car usage	H6	2.559	0.110	1.103	0.978	1.244
Constant		28.554	0.000	0.098		
Weekend leisure trips (Nagelkerke R^2 = 19.9%)						
Treatment (*control*)		6.908	0.141			
4 stars	T1	0.670	0.413	1.264	0.721	2.214

5 stars	T2 (H7)	0.045	0.832	1.068	0.583	1.955
Policy planned	T3	0.217	0.642	1.146	0.645	2.038
Policy decided	**T4 (H8)**	**6.538**	**0.011****	**2.124**	**1.192**	**3.785**
Age group (*55+*)		6.454	0.040			
18–34		4.468	0.035	1.555	1.033	2.343
35–54	**H1**	**5.071**	**0.024***	**1.480**	**1.052**	**2.082**
Gender (*Male*)		0.007	0.933	1.013	0.750	1.367
Education (*Apprenticeship*)		12.899	0.002			
High school		0.004	0.951	1.015	0.632	1.630
Higher education	**H2**	**10.590**	**0.001*****	**1.752**	**1.250**	**2.456**
Place of residence (*City*)		5.857	0.053			
Agglomeration		3.712	0.054	0.710	0.501	1.006
Countryside		4.212	0.040	0.661	0.445	0.982
Household income (CHF)		4.269	0.039	1.058	1.003	1.116
Mode choice (*Private car*)		17.979	0.000			
Public transport	**H3**	**12.384**	**0.000*****	**1.936**	**1.340**	**2.798**
Soft mobility (bike, foot)		3.368	0.066	1.442	0.975	2.133
Multimodal mobility		7.987	0.005	3.732	1.497	9.301
Mobility sharing: Car (*Never*)		26.240	0.000			
Every few months	**H4**	**22.425**	**0.000*****	**2.483**	**1.704**	**3.618**
Once a month		7.106	0.008	2.063	1.211	3.514
Once a week		1.922	0.166	1.676	0.808	3.479
Several times a week		0.214	0.643	1.240	0.499	3.085
Pro-environmental attitude	**H5**	**7.984**	**0.005****	**1.344**	**1.095**	**1.649**
Plans to reduce car usage	H6	2.956	0.086	1.116	0.985	1.265
Constant		29.586	0.000	0.089		

The decisive variables for openness to MaaS services vary among commuting, weekday leisure trips and weekend leisure trips. Only the use of public transport (H3) significantly increases the likelihood of being open to MaaS in all three scenarios. Thus, we can be confident in not rejecting H3 (predominantly use public transport). The hypotheses H1 (middle aged), H2 (higher education), H4 (experience with carsharing), H5 (pro-environmental attitudes) and H6 (intention to reduce car usage) cannot be supported for all scenarios. For weekday and weekend leisure trips, a higher education degree (H2) and using carsharing at least every few months (H4) positively influence openness. For weekend leisure trips, the age group of 35–54 (H1) and pro-environmental attitudes (H5) also positively influence openness. For commuting, on the other hand, plans to reduce car usage (H6) significantly increase the likelihood of being open to using a combined mobility service.

The peer effects treatments (T1 and T2) and the undecided policy treatment (T3) have no significant effect on openness to such services. On the other hand, T4 is significant at the 5% level for weekday and weekend leisure trips. Participants who were informed about future policies and a fixed implementation plan of measures that would affect their usage were thus more likely to be open to a combined mobility service. We would therefore not reject hypothesis H8 for weekday and weekend leisure trips.

2.4.2 The ideal characteristics of a combined mobility service

Sixty-two per cent of the "commuting" group, 53% of the "weekday leisure" group and 46% of the "weekend leisure" group were unwilling to use a combined mobility service for commuting, weekday leisure trips and weekend leisure trips, respectively (refer to Table 2.3). To better understand the reasons and needs that would motivate them to use such a service, we posed an open-format question. The respondents were asked to specify what characteristics such a combined service would need to have in order to make them willing to use it for the said purpose (either commuting, weekday leisure trips or weekend leisure trips). The results are shown in Figure 2.2, in which, from the answer totals of 369 (commuting), 404 (weekday leisure) and 346 (weekend trip), those related to being more ecological, usable without a smartphone, more comfortable, usable without a driving license, wheelchair accessible and promoting active mobility were mentioned too few (fewer than 10) times and were thus excluded from Figure 2.2. On the other hand, Figure 2.3 depicts those participants that either do not see the necessity of a combined mobility service or just cannot be motivated to use one. The answers provide insights into the specific needs of the society concerning this new mobility service, thus supporting decision-makers and transport planners in the design and implementation of related proposals.

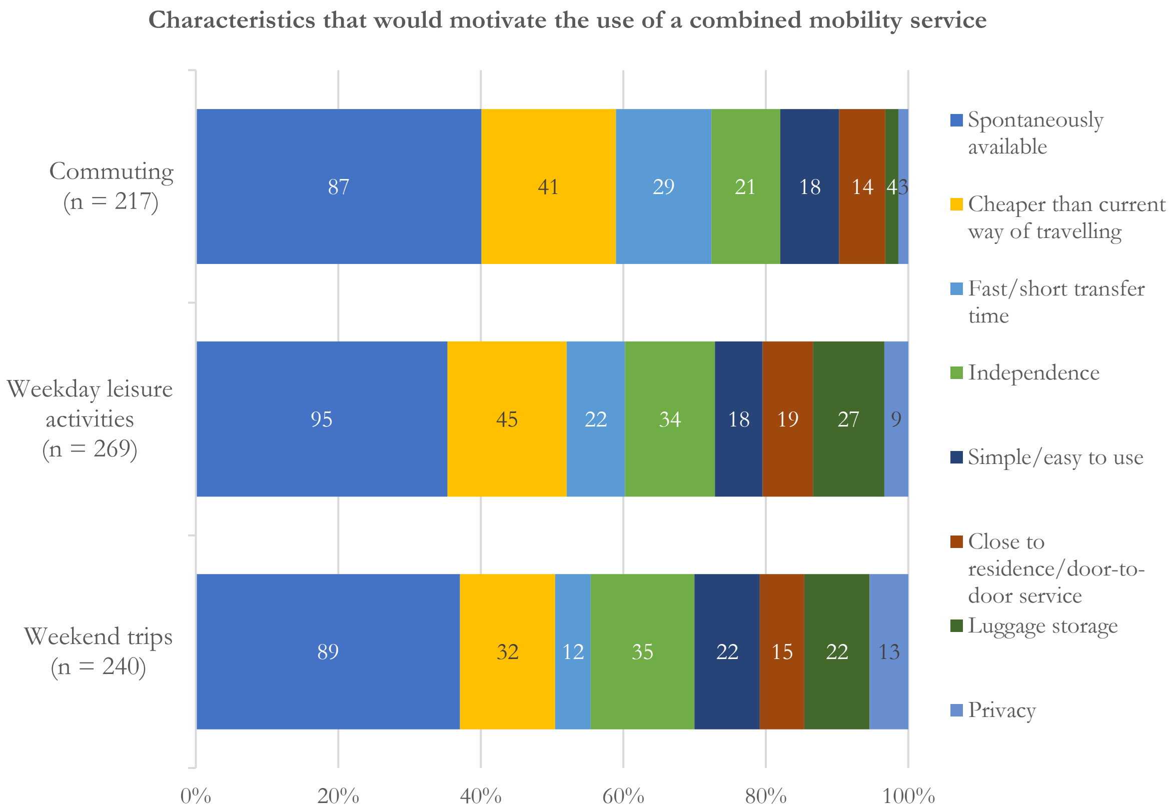

Figure 2.2: Characteristics that would motivate the use of a combined mobility service for commuting, weekday leisure and weekend leisure trips.

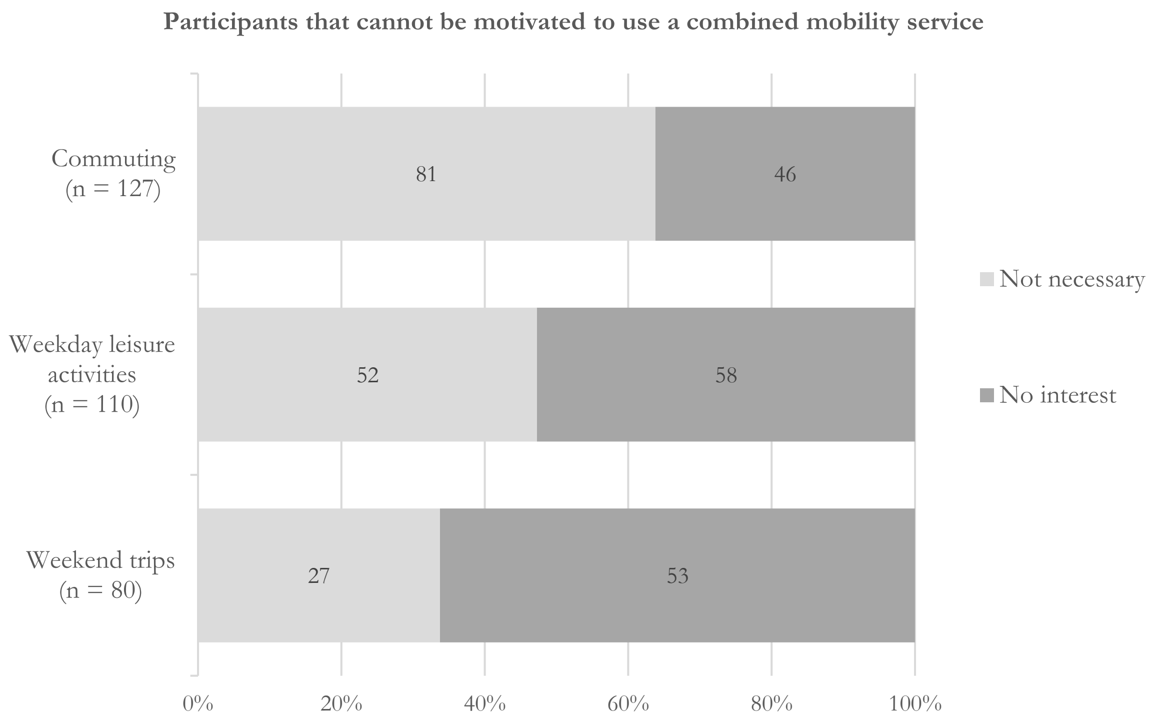

Figure 2.3: Number of participants that did not mention any reason that could motivate them to use a combined mobility service, either saying it's not necessary or they have no interest.

2.5 Discussion and limitations

With the present study, we are able to discuss factors influencing openness to combined mobility services. It has to be noted that the results do not give a clear-cut interpretation of the decisive variables. The non-rejection of H3 may be interpreted as MaaS being perceived as an addition to current public transportation offers rather than an overall new mobility concept, which is in line with public transport users being more open to it. Similar to Ho et al. (2018), we find that participants over 35 and under 55 years old are more open, in contrast to multiple studies on general innovation diffusion. A higher education degree, using carsharing at least every few months, the intention to reduce car usage and pro-environmental behavior also seem to partly influence openness to MaaS. Interestingly, the higher the level of carsharing use, the less significant were the results (here, sharing refers to both general peer-to-peer sharing through family or friends as well as company-based carsharing). This might be explained by the very few participants that actually use carsharing once a week (4.4%, n = 36) or several times a week (2.7%, n = 23); thus, the sample size might be too small for a significant effect. An alternative explanation could be that people that already use carsharing very frequently do not need a MaaS platform to use a specific service they are already very accustomed to. One of the core expectations of MaaS is that it may reduce the use of private cars. It is thus promising that those who aim to reduce their car usage are more open to using MaaS in their daily commute as they might perceive MaaS as a suitable alternative (Storme et al., 2019). The reasons that the intention to reduce one's own car usage is not significant for weekday and weekend leisure trips might stem from the fact that congestion levels are highest during commuting (BFS & ARE, 2017) and thus negatively influence the satisfaction level of travel and, in turn, increase the intention to reduce car usage in commuting, although not for leisure trips, during which congestion is less prevalent (Ye & Titheridge, 2017).

The significantly higher probability of choosing MaaS solutions following T4 but not T3 supports the hypotheses that people would take into account policy announcements directly addressing them as consumers. The clear announcement of implementation plans for policy measures may represent a promising lever to reduce the emissions of the transportation sector by influencing openness to changing mobility behavior. Nevertheless, the variable is only significant for weekday and weekend leisure trips. One reason may be that people (who do not want to reduce their car usage, as discussed above) do not see any suitable alternative to the car with respect to commuting and are thus less willing to change their current routine (Curtis & Headicar, 1997); however, this has to be analyzed in future research. A promising alternative might be vanpools integrated into MaaS, as Ditmor and Deming (2018) report consequently reduced commuter stress levels.

The peer effect treatment of a better rating for a combined service (T2) did not increase openness to using such a service and therefore cannot provide confirmation of previous findings of scholars (Rasouli & Timmermans, 2016). However, the present work only includes ratings without reviews. The influence of ratings could be amplified when shown together with reviews (Sparks & Browning, 2011). Furthermore, the difference between already positively framed ratings of four to five stars might be perceived as too small to have a significant effect. Especially with a small sample size of n = 74, finding a significant effect is difficult. Last, when lacking personal experience with such a service, hypothetical ratings may be perceived as less trustworthy and therefore hamper the positive valence of the rating (Lüders et al., 2017).

For those participants that were not open to trying a MaaS service, the most important aspects to potentially change their minds are spontaneous availability/flexibility, cheaper price than current modes and being independent. This is not surprising since the majority of participants use their car predominantly for leisure activities, which have a high level of flexibility and independence. Due to the user-centric approach of MaaS as well as the strong focus on sharing, cost reductions are possible (Baptista et al., 2014; Danielis et al., 2014). Clear communication of these cost reductions might be helpful since the price of mobility is generally perceived as high in Switzerland (Hoppe et al., 2018) and lower prices would have a positive effect on openness to using MaaS. What is most striking, however, is the high number of participants who feel there is no need for such a combined mobility service for commuting (81 in Figure 2.3). Respondents in this study claimed to use public transport for commuting more often than using a private car. As such, people might not see the need for an additional service when the train, bus or tram they usually take already satisfies their travel needs (see also Ho et al. (2019)). The lack of need for MaaS declines for weekday leisure trips and even more for weekend leisure trips. This is encouraging since nearly half of the participants currently use a private car for leisure trips (see Table 2.3), a trend which could be effectively countered by the flexibility and mode variability of MaaS concepts in leisure route planning. Luggage storage possibilities and, to a lesser degree, privacy were also mentioned as motivators to use MaaS for leisure activities, although they do not seem to be relevant to commuting. A constant number of 46 to 58 participants could not be motivated to use a combined mobility service in any way (no interest), reflecting aversion to change. However, in relation to the total of 995 study participants, the actual number of "unchangeable minds" is quite small.

MaaS is a new concept for most people. Despite the short text explaining the MaaS concept to all participants, it is possible that not all of them fully understood its potential. As it is based on an online survey, the current study certainly has some additional limitations with respect to its validity. The share of higher education graduates, for example, is above the Swiss average, and one has to be aware of common biases of participants when responding to surveys. Furthermore, the treatment samples were rather small. Last, it has to be noted that we conducted the survey in Switzerland, where digital travel information platforms are well developed but no fully operational MaaS service exists. Despite a long history of carsharing, strong popularity of scooter-sharing and a reliable public transport network, the awareness of the MaaS concept might be different than in other countries.

2.6 Concluding remarks

With this paper, we provide an important addition to the literature on MaaS by investigating factors and needs that would motivate the use of such a combined mobility service. By separately analyzing three distinct trip purposes, commuting, weekday leisure trips and weekend leisure trips, we provide additional insights into potential MaaS users compared to previous studies.

Based on a comprehensive online survey in Switzerland, we find that openness to using MaaS for commuting is lowest. Still, those who plan to reduce their car usage might be motivated to switch to a seamless travel service if it is sufficiently flexible and fast. For leisure activities, on the other hand—for which most people use their private car—a different set of factors is relevant. Here, higher education and previous experience with carsharing significantly increased openness to using MaaS. Further, the participants see MaaS as a sustainable alternative; as such, pro-environmental attitudes as well as announcements of future consumer-addressing policy measures would increase openness to use. Generally, participants that predominantly use public transport for travelling are more open to using MaaS than those who predominantly travel by private car. This result implies some challenges for one of the core expectations of MaaS—to reduce private vehicle ownership. We would thus encourage an increased focus on this group as well as develop MaaS services that target the following three key commuting needs: spontaneity, lower costs and short transfer times. For leisure trips (both weekday and weekend trips), we emphasize not only looking at spontaneity and lower price but also independence and luggage storage possibilities.

Overall, we conclude that providing information and experience is key in designing such combined mobility services. Future studies should pay attention to the differences in needs and motives for using MaaS for commuting and leisure trips. Once MaaS services become more widely available, large-scale surveys could benefit from a more established technical jargon that could mitigate biases due to misunderstandings. Furthermore, MaaS also benefits from the increasing popularity of sharing systems such as car-, bike- and scooter-sharing. Having some experience with such programs has been shown to increase openness to using

MaaS. As MaaS is still in its infancy, preferences might continuously change, calling for regular research into these preferences and the needs of potential users.

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3 Carsharing experience fostering sustainable car purchasing? Investigating car size and powertrain choice

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Abstract

Scholars suggest that carsharing may lead to a reduction in car ownership and car travel. Research on how carsharing is connected to other sustainable effects such as an increased openness to micro to mid-sized battery electric vehicles is limited, however. We thus adopted a stated choice survey with 995 participants from Switzerland to test the car purchase preference of mobility users with and without carsharing experience. Results suggest that - for people living in the countryside - carsharing users have a 3 times higher likelihood of choosing a micro to mid-sized battery electric vehicle compared to participants without carsharing experience. We find a similar trend for people living in the agglomerations. We therefore recommend policy makers and mobility planners to take these benefits into account when planning carsharing services and its role in mobility systems.

3.1 Introduction

Private motorized transport is one of the main contributors of negative external effects through congestion, greenhouse gas emissions, health problems and noise – a situation which is likely to worsen considering the trend for increasing population. Many stakeholders thus actively support mobility concepts like carsharing in order to reduce vehicle miles travelled and the aforementioned negative externalities through a reduction in car ownership and car travel (Hoerler et al., 2019; Le Vine & Polak, 2019; Martin et al., 2010; Nijland & van Meerkerk, 2017). For example, Chen and Kockelman (2016) estimate reductions of greenhouse gases of over 50% when shifting from private car use to station-based carsharing. Moreover, today's private cars are over-dimensioned for most of their trip purposes, even for car owners living in urban environments where space is commonly scarce. Further, in order to reduce some of the negative externalities from conventional car use, scholars agree to switch to battery electric vehicles (BEVs) fueled with renewable energies as they have substantial less CO_2, noise and other pollutant emissions (Cox et al., 2020). Yet the uptake of BEVs remains small in different regions around the globe (Bratzel, 2019; McKinsey & Company, 2020). Even in Switzerland, where a considerable growth in sales has been observed, less than 5% of total new car registrations were BEVs in 2019 (Swiss Federal Office of Energy, 2020). To achieve the targets of the Paris Agreement, a faster switch to BEVs is needed. Higher acquisition costs, range anxieties, insufficient charging infrastructure, long charging times and a general aversion to change are the main reasons for this resistance (Berkeley et al., 2017; Claudy et al., 2015). Overcoming anxieties and hindrances with this technology is thus important to accelerate the uptake. A number of scholars suggest that including BEVs in carsharing fleets could not only reduce vehicle miles travelled, but also increase the acceptance and diffusion of BEVs by their physical presence and low hurdles to trying out the new technology (Jensen et al., 2013; Schlüter & Weyer, 2019; S. Shaheen et al., 2020; Struben & Sterman, 2008; Wappelhorst et al., 2016). Overall, carsharing could therefore decrease CO_2 emissions and lead to more sustainable transports in four ways. First, through a reduction of vehicle ownership leading to less car use (e.g. Ko et al., 2019; Martin et al., 2010; Nijland & van Meerkerk, 2017). As an example, Rid et al. (2018a) summarized the private car replacement rate per carsharing car for European and American station-based and free-floating systems, finding a replacement rate between 4 to 15 cars for the station-based system and a replacement rate between 1 to 4 cars for the free-floating system. Second, by the provision of a fuel-efficient fleet (Martin et al., 2010; Namazu & Dowlatabadi, 2015). Third, by increasing the attractiveness of public transport through better accessibility (Namazu & Dowlatabadi, 2015), and forth, by enabling to get used and try out electric vehicles (EVs), and ultimately spurring their adoption, through a low hurdle and easily accessible presence in carsharing systems (Luna et al., 2020; Schlüter & Weyer, 2019; Schmalfuß et al., 2017; S. Shaheen et al., 2020; Wappelhorst et al., 2016).

However, despite this vast body of literature, little research elucidates the further benefits of carsharing experience on car purchasing decisions. Particularly, it has not been investigated, to the best of the authors' knowledge, whether experience with carsharing (and through that the awareness of having alternative cars at one's disposal) can have an influence on the size or the drivetrain technology in purchase decisions of mobility users. As an example, carsharing operators provide a set of different car models to choose from, reducing the need of owning a large car capable of transporting large luggage for the rare cases this is actually used. Especially since people overestimate their need for range in a car (Hao et al., 2020), small BEVs could be a reasonable alternative for many conventional car owners. Furthermore, carsharing could allow the use of a shared long-range car (i.e. combustion engine car, plug-in hybrid electric car and future long-range BEVs) for longer trips which exceed the range of common micro to mid-sized BEVs. This could allow to own a small electric vehicle, which only covers the every-day trips (and with its limited size would require less resources for its production and occupy less space) and use carsharing in those situations in which the range of a small electric vehicle is not enough (Needell et al., 2016). This rational has been investigated by Sprei and Ginnebaugh (2018) through semi-structured interviews of carsharing experts in Sweden and in California, USA. They refer to the car as a bundle, one needed for daily use and one for peak use (e.g. holidays, long trips). Sprei and Ginnebaugh (2018) conclude that a large variety of vehicles that cover the different needs should be present in carsharing and car-rental fleets, vehicles need to be close to the user and the availability of the needed vehicle should be high – characteristics that the carsharing operator Mobility is offering in Switzerland. Using carsharing in addition to BEVs could therefore overcome the common hurdles of owning a BEV and especially, smaller more environmentally friendly BEVs for everyday trips. Having experience with carsharing could therefore act as an enabler for the diffusion of small, electrified cars in standard daily mobility.

We therefore pose the following research question:

- Are carsharing users more likely to buy a micro to mid-sized BEV from a set of alternatives than non-carsharing users?

The corresponding null and alternative hypotheses are thus the following:

H_0: Carsharing users are not significantly more likely to choose a micro to mid-sized BEV than non-carsharing users

H_1: Carsharing users are significantly more likely to choose a micro to mid-sized BEV than non-carsharing users

In order to test H_1 we conducted a stated choice survey including a car size choice question and a powertrain choice question. The questionnaire was part of the Swiss Household Energy Demand Survey (SHEDS) conducted in April 2018.

We structure the remainder of the paper as follows: within the second section, we develop a general overview of user characteristics of carsharing adopters and give a brief overview of related work. In the third section, we explain the structure of the questionnaire together with the applied statistical methods, followed by the results in section four. Finally, we discuss the findings and draw a conclusion, as well as provide recommendations for future research in sections five and six, respectively.

3.2 Background

3.2.1 Carsharing and carsharing adopters

Today, consumers can choose between four different carsharing models; round-trip station-based, one-way station-based, free-floating and peer-to-peer carsharing. Round-trip station-based carsharing is the most traditional form of carsharing where one needs to return the car at the same designated parking lot. Another form of station-based carsharing includes one-way trips, where the vehicles can be dropped off at a different station form the pick-up point. Free-floating as well as company based peer-to-peer carsharing are newer forms of carsharing. The former does not rely on designated parking lots, instead, vehicles can be picked up and returned anywhere within a given service area. In peer-to-peer carsharing, private car owners make their vehicles temporarily available for shared use directly or via a platform provided by a third-party operator. A good overview of these different carsharing models is provided in Machado et al. (2018).

Scholars find that especially round-trip station-based carsharing attracts people with a sustainable lifestyle (Lempert et al., 2019). Contrary, one-way members self-report that they carshare for convenience and use their own private car more frequently than round-trip station-based carshare members, even though they use the carsharing service more often than the round-trip station-based members (Lempert et al., 2019). Station-based carsharing platforms normally require a fixed membership fee and thus attract more financially committed people (with a higher income) in comparison to peer-to-peer carsharing members. Furthermore, having a public transport subscription and zero cars in the household increases the likelihood to subscribe to a station-based service instead of a peer-to-peer service (Münzel, Boon, et al., 2019). As such, station-based carsharing is mostly used as a complement to public transport and replacing a private car, while freefloating and peer-to-peer carsharing are used to satisfy spontaneous needs and for convenience (Knie et al., 2016; Lempert et al., 2019). Generally, older people are less inclined to join a carsharing service, probably due to established habits and convenience. Also other socio-economic factors play a key role in carsharing adoption. A higher education, being a man (due to less safety concerns) and living in the city centers increase the likelihood of adoption (Prieto et al., 2017). However, while different carsharing business models attract different users, the preference for EVs within a carsharing service is in line with the affinity to carsharing in general (Burghard & Dütschke, 2019). A variety of these socio-economic factors found to be relevant in carsharing adoption will later serve as explanatory variables in our study and are summarized in section 3.3.2.

3.2.2 Related work and research gaps

To the best of the authors' knowledge, no research insights into car size preferences in combination of powertrain choice of future car purchases between carsharing users and non-users are available to date. Still, we want to refer to relevant studies that separately investigated car size choice and the interaction of carsharing with EVs. Baltas and Saridakis (2013) for example, applied a multinomial logit model to test the preference of participants of an online survey for different car types (ranging from micro cars to SUVs), finding that gender, income, education, marital status, place of residence as well as openness for buying an electrified version of the car significantly influences the car type choice. Nayum et al. (2016) analyzed the differences between five conventional car buyer groups and one electric car buyer group on a range of socio-psychological variables. They find that attitudes towards convenience of the car like comfort differed strongly among buyers of small to medium sized cars and buyers of big and powerful cars and especially to buyers of EVs. Higgins et al. (2017) applied a large online survey to measure the preferred next vehicle body type (from economy to SUV and pickup truck) in combination of preference for powertrain (ICEV, HEV, PHEV, BEV). They show that the SUV and pickup segments are more ICE oriented compared to the smaller car size segments. Yet, they did not investigate carsharing in their study.

So far, several studies investigated different aspects of the interaction of carsharing with EV ownership. Clewlow (2016), for example, investigated the differences in vehicle ownership characteristics between carsharing members and non-members in the San Francisco Bay Area utilizing a large household travel survey (n = 63'082). The findings suggest that carsharing members own significantly more EVs (including hybrid, plug-in hybrid and BEVs) than non-members. Whether this is an effect of subscribing to the carsharing service is unclear, however. Schlüter and Weyer (2019) adopted the technology acceptance model (TAM) to investigate the perceived usefulness and perceived ease of use of EVs, which together determine intention to adopt, among the users of a carsharing service in Germany. They find that carsharing experience leads to a higher perceived usefulness of EVs, because people using carsharing services have a mobility mindset that is in line with EV characteristics. Carsharing experience was not found to influence perceived ease of use of EVs. Schlüter and Weyer further asked the participants whether they would buy an EV as their next car finding that those who have experience with carsharing are more open to buy an EV as their next car compared to participants without carsharing experience. This effect was even higher for users of an EV carsharing service, which was confirmed by a study from Shaheen et al. (2020). Schmalfuss et al. (2017) also find that providing short-term BEV experience, i.e. through carsharing, could have the potential to enhance acceptance and satisfaction with BEVs. Similarily, Burghard and Dütchke (2019) report that those interested in carsharing are also more likely to own, have an intention to own and be interested in an EV. They further suggest that carsharing users exhibit characteristics that are conducive to the acceptance of EVs, such as less concern about dealing with limited range compared to conventional vehicles. While these studies already indicate a link of carsharing and EV adoption and provide useful information regarding our research question, they did not investigate the relevance of car size. Further, both Schlüter and Weyer (2019) and Burghard and Dütchke (2019) didn't focus on BEV but rather investigated the broader term of EVs including plug-in hybrid electric vehicles. Last, the conclusions from Clewlow (2016) and Shaheen et al. (2020) are based on descriptive analysis, without controlling for further factors such as attitudes and values.

Nonetheless, the studies summarized above are important in defining influential variables in car size and powertrain adoption, which are summarized in section 3.3.2 of the Methodology.

To strengthen the literature and close the gap mentioned above, we implemented a binary logistic regression model to investigate the influence of experience with carsharing on choosing a micro to mid-sized BEV instead of a large/SUV BEV, plug-in hybrid electric vehicle (PHEV), hybrid electric vehicle (HEV) or internal combustion engine vehicle (ICEV) as their next car or car replacement.

3.3 Methodology

We designed a stated choice survey as part of the Swiss Household Energy Demand Survey (SHEDS) 2018 to answer our research question (for more details on SHEDS see Weber et al. (2017)). In total 995 respondents were randomly assigned to and completed the experiment. The respondent assignment ensured a representative sample over a range of categories – specifically age, gender language region (French-speaking and German-speaking) and tenancy status. More information including a comparison with the overall SHEDS 2018 sample and the Swiss population can be found in Table B1 in the Appendix. The survey first asked details about the respondents' experiences and decisions around mobility, followed with the hypothetical sequential stated choice section. In the latter, we elicited respondents' stated preferences for car purchasing, including car size and powertrain, followed by that for public transport passes, and finally their transport mode choices. For a detailed explanation of the survey design, as well as analysis of transport mode choices, see van Dijk et al. (2020).

3.3.1 Stated choice survey

The stated choice section was designed in such a way as to first remind respondents of their current, real-life transport decisions, and then followed up by a hypothetical car choice. This structure offered each respondent a realistic and relatable choice situation and allowed us to obtain accurate and reliable responses, overcoming potential hypothetical bias.

We started by asking about respondents' access to and use of public transport services, and their habitual transport modes for commuting, local leisure, and weekend trips. Following this, we set up the realistic, hypothetical vehicle choice situation. In line with the stated preference literature, we primed the respondents to encourage truthful responses (Vossler et al., 2012) and reminded them about their budget constraint (e.g., Johnston et al. (2017)). We then framed the imminent car purchase decision, limiting it to currently available technologies and prices. We asked respondents to imagine they decide to purchase a new primary household car within the next year. The first choice task is to then choose the car size, between 'micro', 'small', 'small-medium', 'mid-size', 'large' and 'SUV' - based on the standard categories of the Touring Club Switzerland (Touring Club Switzerland, 2018). We also gave the option of 'none' for respondents who preferred not to buy a car at all or for which the displayed range of car size did not cover their preferences. Based on the information given in the experiment, it is legitimate to assume that the majority of respondents who chose 'none' did not want to buy a car. This is backed by the fact that 70% of respondents choosing 'none' do not own a car.

Respondents who chose a car size proceeded to the second choice task, to choose a specific car. This was in the form of a choice table with six options and six attributes. Only one choice was made per respondent. The primary attribute was the car's powertrain, including two 'electric' (i.e., BEV) alternatives, two 'plug-in hybrid' (PHEV), one 'hybrid' (HEV), and one 'internal combustion engine' (ICEV). The attributes were 'price', 'driving cost per 100km', 'battery range', 'max. speed', and 'CO_2 emissions (g/km)'. The attribute levels were determined by the previous choice of car size and within each car size, every respondent received the same attribute levels. These levels were calculated using data from the TCS on all cars available in Switzerland at the time (Touring Club Switzerland, 2018). Figure 3.1 displays a sample of the car size choice questions and the powertrain choice question including the various attributes that were calculated according to the car size chosen before. For readability, only attributes for the "SUV" case are shown in the figure. For each of the two BEV and PHEV options we created a cheaper and more expensive option according to the cars on the market in Switzerland. The full experiment is described in more detail in van Dijk et al. (2020).

For the next set of questions, please imagine that you decide to purchase a car or replace your car within the next year.

Which of the following options best describes your most preferred choice of primary car?

None | Micro | Small | Small-medium | Mid-size | Large | SUV

Which of the following car options would you purchase?

Additional information is provided if you place the mouse over the column or row headers.

	1	2	3	4	5	6
	Electric	Electric	Plug-in hybrid	Plug-in hybrid	Hybrid	ICE
Price (CHF)	68,000	85,000	65,000	85,000	70,000	61,000
Driving cost (CHF/100km)	4.10	3.50	5.00	7.70	8.00	11
Range of battery (km)	380	410	35	20	-	-
Max speed (km/h)	180	210	170	210	190	230
CO_2 emissions (g/km)	0	0	40	80	105	155

	1 Electric	2 Electric	3 Plug-in hybrid	4 Plug-in hybrid	5 Hybrid	6 ICE
Your choice:						

Figure 3.1: Car size choice question and an example of the powertrain choice question (attributes related to the car size "SUV"), as shown in the survey.

3.3.2 Variable set included in our study

As we focus on estimating the effect of carsharing experience on car size and powertrain choice, we want to reduce possible confounding effects to the minimum – that is latent variables associated with the outcome variable but also with carsharing experience potentially distorting the effect of carsharing experience on car size and powertrain choice. We thus conducted a comprehensive literature research to capture the most important variables in socio-demographics, mobility characteristics, attitudes and values explaining the adoption of carsharing, car size and powertrain. Prieto and Caemmerer (2013) as well as Orlov and Kallbekken (2019) provide a good summary of studies investigating car size and powertrain choice, respectively. Table 3.1 summarizes the variables included in our study and corresponding literature finding a significant effect on carsharing adoption, car size choice and powertrain choice. The categories and frequency of these variables as well as the car size and powertrain choice variable used in our study can be found in Table B2 in the appendix.

Table 3.1: Overview of variables in this study and corresponding literature.

Variables included in this study	**Literature about the adoption of carsharing, car size and powertrain**		
	Carsharing	**Car size**	**Powertrain**
		Socio-demographics	
Age	(Dias et al., 2017; Lempert et al., 2019; Prieto et al., 2017)	(Herberz et al., 2020; Kim et al., 2020; Prieto & Caemmerer, 2013)	(Ferguson et al., 2018; Higgins et al., 2017; Ziegler, 2012)
Gender	(Acheampong & Siiba, 2020; Kawgan-Kagan & Popp, 2018, p. 2018; Prieto et al., 2017)	(Baltas & Saridakis, 2013; Kim et al., 2020; Prieto & Caemmerer, 2013)	(Ferguson et al., 2018; Herberz et al., 2020; Ziegler, 2012)
Education	(Becker et al., 2017; Dias et al., 2017; Münzel et al., 2019; Prieto et al., 2017)	(Prieto & Caemmerer, 2013)	(Ferguson et al., 2018; Herberz et al., 2020)
Type of living area	(Dias et al., 2017; Prieto et al., 2017)	(Baltas & Saridakis, 2013; Prieto & Caemmerer, 2013)	(Ferguson et al., 2018; Jones et al., 2020)
Household income	(Dias et al., 2017)	(Baltas & Saridakis, 2013)	-
HH structure	(Dias et al., 2017)	(Baltas & Saridakis, 2013)	(Orlov & Kallbekken, 2019)
HH size	(Efthymiou et al., 2013)	(Nayum & Klöckner, 2014; Prieto & Caemmerer, 2013)	(Higgins et al., 2017)
		Mobility characteristics	
Public transport passes	(Becker et al., 2017a; Münzel, Piscicelli, et al., 2019)	-	-
Number of cars in HH	(Dias et al., 2017; Münzel et al., 2019; Namazu et al., 2018)	(Nayum & Klöckner, 2014)	-
Mode choice	(Efthymiou et al., 2013; Münzel et al., 2019)	-	-
Travel time	(Efthymiou et al., 2013)	-	-
		Attitudes and values	
Importance of safety	-	(Herberz et al., 2020; Mohammadi & Kermanshah, 2019)	(Daziano, 2012)
Importance of comfort	(Acheampong & Siiba, 2020)	(Nayum et al., 2016)	-

Importance of privacy	(Kim et al., 2017)	-	-
Importance of owning a car	(Kim et al., 2017; Paundra et al., 2017)	(Baltas and Saridakis, 2013; Herberz et al., 2020)	-
Biospheric values	(Kim et al., 2017; Münzel, Piscicelli, et al., 2019; Schaefers, 2013)	(Nayum and Klöckner, 2014)	(Herberz et al., 2020; Ziegler, 2012)
Egoistic values	(Buschmann et al., 2020)	-	-
Altruistic values	(Buschmann et al., 2020; Schaefers, 2013)	-	-
Hedonic values	(Alonso-Almeida, 2019)	(Nayum and Klöckner, 2014)	-

3.3.2.1 *Carsharing experience*

Carsharing in Switzerland is dominated by the company Mobility Carsharing (or in short, Mobility), which has been established since 1997. Switzerland thus has a long history of carsharing and is already well-known throughout the country. They offer mostly round-trip station-based carsharing with freefloating being tested in two major cities. With 1530 stations offering a total of 3120 cars, Mobility covers whole Switzerland. Yet, so far, less than 5% of the fleet is electrified (Mobility, 2020). We measured the level of carsharing experience on a five point scale with the categories "Never", "Every few months", "Once a month", "Once a week" and "Several times a week". The experience could either be through sharing cars with families and friends or through a carsharing fleet operator like Mobility Carsharing. Figure 3.2 shows the answer frequency per category.

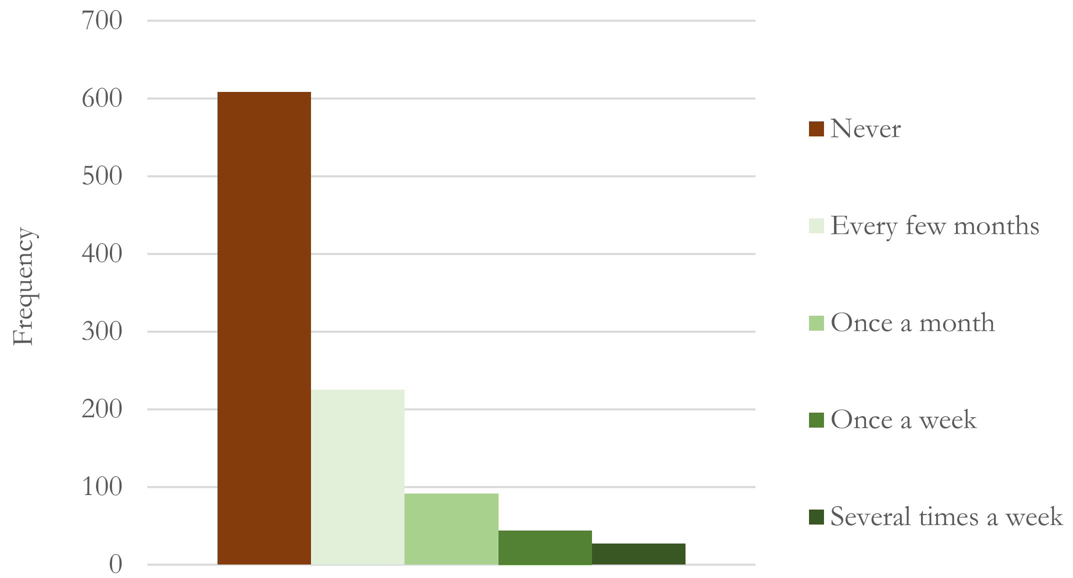

Figure 3.2: Frequency of carsharing use (n = 995).

As only very few respondents use carsharing more than once a month, and to increase the statistical power of the regression model, we combined the categories "Every few months", "Once a month", "Once a week" and "Several times a week" into "Some carsharing experience", leaving those with the category "Never" as "No carsharing experience", creating a binary variable.

3.3.2.2 Socio-demographics

Many scholars like Baltas and Saridakis (2013), Prieto et al. (2017), Ferguson et al. (2018) or Acheampong and Siiba (2020) show the importance of socio-economic variables in explaining mobility choices like car size and powertrain or interact strongly with carsharing adoption. These include age, gender, education, type of living area, household (HH) income, HH structure and HH size.

3.3.2.3 Mobility characteristics

The most influential mobility characteristics were found to be the number of cars in the household (Dias et al., 2017; Namazu et al., 2018; Nayum & Klöckner, 2014), public transport passes (Becker et al., 2017) and mode choice (Efthymiou et al., 2013). Efthymiou et al. (2013) further show that travel time to go to work was a significant predictor for carsharing adoption.

3.3.2.4 Attitudes and values

Many scholars state the importance of including psychological and sociological attributes in explaining mobility behavior and purchase intentions (Bamberg, 2013; Herberz et al., 2020; Klöckner & Matthies, 2004; Steg, 2005; Ünal et al., 2018; Wall et al., 2007). Also the study from Nayum and Klöckner (2014) confirm that hedonic and biospheric values are crucial in explaining intention to buy fuel efficient cars. Nayum et al. (2016) further show that attitudes towards convenience of the car like comfort differed strongly among buyers of small to medium sized cars and buyers of big and powerful cars. Hence, we included the short version of the value scale originally developed by Schwartz (Schwartz, 1992) and adjusted by de Groot & Steg (de Groot & Steg, 2008), which is based on 16 questions and includes four values: biospheric, egoistic, altruistic and hedonic. We further included questions related to whether one would already consider an EV as the next car, the importance of safety, of comfort, of privacy and of owning a private car.

3.3.3 Statistical analysis

We followed a 4-step procedure to ensure the validity of our results. First, we checked the data for outliers and illogical answers as well as excluded participants who used less than 5 minutes to finish the choice survey (with a median of 10 minutes, we considered less than 5 minutes as too rushed for a meaningful completion of the questions). As such, we removed 21 cases from the survey. Second, the survey also includes two treatment groups not related to this paper, which received information prior to taking our stated choice questions. These were thus excluded from the study to mitigate potential response bias. A final sample of 826 respondents remained. Then, we created a binary variable with the categories 'micro to mid-sized BEV' and 'Not micro to mid-sized BEV' using the variables 'car size choice' and 'powertrain choice' (see Table B2), which then served as the independent variable in the binary logistic regression model. We applied an explorative stepwise backwards Ward approach to find relevant interactions of carsharing experience with the other independent variables. As such, all variables mentioned in Table B2 are included in the model together with all 2-way interactions of carsharing experience and the other independent variables. The interactions were then removed one-by-one if they exceed the p value of 0.1, remaining with the only significant interaction of carsharing experience with type of living area. Variables were further manually dropped if they did not significantly improve the model fit or explained variance. Third, all variables included in the regression analysis were checked for multicollinearity with Spearman's rho (see Table B3 in the appendix.). Last, the model fit statistic (Hosmer–Lemeshow test) was used to test for goodness of fit of the regression model.

3.3.4 Limitations

First, being a stated preference study, the answers of the participants might not mimic their real behavior as if they really were about to buy a new car. This is commonly referred to as the "hypothetical bias" (Beck et al., 2016) or the "attitude-action gap" (Lane & Potter, 2007). This is especially true for technologies that are new or still in a test-phase like BEVs if one considers their still relatively low diffusion rate. However, as each year new EVs are entering the market with models like Tesla, Nissan or Renault already widely known in Switzerland and Europe and the overall steadily growing interest in electric mobility (Swiss Federal Office of Energy, 2020), we estimate this effect to remain small. Furthermore, the purpose of our study is to estimate beta coefficients instead of forecasting, where normally revealed preferences are used best (Axsen et al., 2009). Second, we did not sample according to carsharing experience in order to have a random sample. Yet this lead to only few participants which use carsharing on a weekly basis and forced us to combine the categories with carsharing experience into one "experience" category in order to have a high enough n for statistical analysis. In order to still be able to account for the various latent effects summarized in Table 3.1 without overfitting the regression models, we ensured to stay in the range of 5 to 9 cases per predictors as suggested by Vittinghoff and McCulloch (2007). We thus acknowledge the need to also specifically target carsharing users in future studies to complement this research. Generally with non-experimental data, unobserved latent variables that both affect the dependent variable and correlate with independent variables are a concern, as for example, reversed causality could exist. We accounted for that by implementing a random sample and including a wide selection of known and potential confounders into the model like socio-demographics, mobility characteristics, attitudes towards comfort, biospheric and hedonic values. Nevertheless, traces of such effects cannot be ruled out. Last, the six car models (two BEVs, two PHEVS, one HEV and one ICEV) from which respondents could choose is a simplification of the real-world, even though great attention was put into using up-to-date attributes for the respective car (i.e. price, driving cost, range, max. speed and CO_2 emissions).

3.4 Results

We first present descriptive results to the car size choice and powertrain choice question followed by the results of the regression model to estimate the likelihood to choose a micro to mid-sized BEV. The regression results are distinguished between socio-economic factors, mobility characteristics, attitudes and values.

3.4.1 Descriptive results

Table 3.2 serves as first overview of the relation between carsharing experience, car size choice and powertrain choice. Note that around the same percent of respondents with and without carsharing experience chose not to select one of the displayed car size categories (represented with the option "None").

These cases were subsequently excluded in the further analysis, which can be seen in the row of powertrain where the total n drops from previously 826 to 730. Figure 3.3 shows the combination of car size and powertrain according to our research question. Clearly, respondents with carsharing experience seem more likely to prefer a micro-to mid-sized BEV in comparison to respondents without carsharing experience. Whether this difference is significant will be elaborated in the subsequent section.

Table 3.2: Percentage and frequencies for each category of the car size choice and powertrain choice.

Category	**No carsharing experience**	**Some carsharing experience**
	Car size choice (n = 826)	
None	12% (58)	12% (38)
Micro	2% (11)	1% (4)
Small	25% (127)	34% (112)
Small-medium	24% (120)	22% (71)
Mid-sized	15% (73)	17% (54)
Large	4% (21)	3% (9)
SUV	18% (90)	12% (38)
	Powertrain choice (n = 730)	
BEV	29% (130)	41% (117)
PHEV	14% (64)	20% (58)
HEV	16% (70)	14% (41)
ICEV	40% (178)	25% (72)

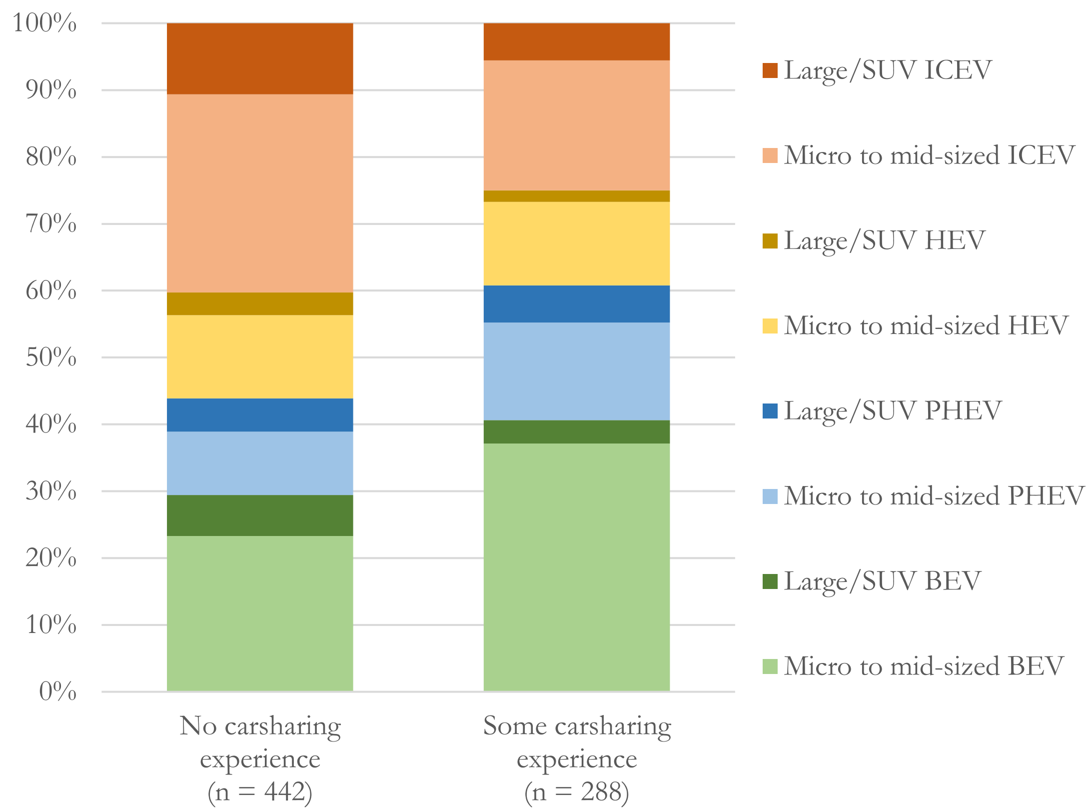

Figure 3.3: Share of powertrain choice separated by car size and carsharing experience.

3.4.2 Powertrain choice

We compare the results of the regression to test the likelihood to choose a micro to mid-sized BEV with and without the interaction term of carsharing experience and type of living area in Table 3.3. The Omnibus chi-square test, log likelihood, Nagelkerke R^2 and percent of correct classification are all superior in model 2 including the interaction. The likelihood ratio test between these two models shows that, indeed, model 2 is a better fit ($\chi2$ (df = 2) = 10.23, p = 0.006).

Table 3.3: Comparison of the regression model with and without the interaction term.

	Model 1 (Without interaction)	**Model 2 (Including interaction)**
Omnibus test (χ^2)	265.11 , $p < 0.0001$	275.34, $p < 0.0001$
-2 Log likelihood	524.72	514.49
Nagelkerke R^2	47%	49%
Percent correct classification	80.9%	82.2%
Hosmer-Lemeshow test	1.292, $p = 0.996$	6.162, $p = 0.629$
N	826	826
Degrees of freedom	21	23

Table 3.4 displays the results of the final model to test the influence of experience with carsharing (coded as 0, no carsharing experience and 1, some carsharing experience) on the likelihood to choose a micro to mid-sized BEV. Only variables significant on the p < 0.1 level are included in Table 3.4 to retain readability. Note that the reference categories specified in parentheses change for some variables in order to be able to show all significant results. The omnibus-test of model coefficients is highly significant ($\chi^2(23, N = 826) = 275.34, p < 0.0001$). Furthermore, the Hosmer-Lemeshow-test is non-significant ($\chi^2(8, N = 826) = 6.16, p = 0.63$), indicating a good model fit. The Nagelkerke R^2 of 0.49 is very high, explaining 49% of the variance in the powertrain choice question.

A positive beta coefficient (*B*) indicates a higher likelihood to choose a micro to mid-sized BEV compared to the reference category, which is indicated in parentheses. Contrary, a negative *B* indicates a lower likelihood to choose a micro to mid-sized BEV. For a better interpretation of the effect size, the odds ratio (exp(*B*)) can be used. It states how much more likely a specific level of a variable is to choose a micro to mid-sized BEV in comparison to the reference category. In case of a continuous variable, the odds ratio represents a one point increase of the variable. Odds ratios below 1 indicate a lower likelihood to choose the dependent variable. For an easier interpretation one can take the inverse of this value.

Table 3.4: Binary logistic regression results of the powertrain choice model.

Variable	**Level (reference)**	**B**	**Exp(B)**	**95% CI for Exp(B)**	
				Lower	**Upper**
		Socio-demographics			
Age group in years	35-54 (18-34)	-0.59**	0.55	0.31	0.97
	55+ (18-34)	-0.68**	0.51	0.27	0.96

HH structure	Couple without children (Single person HH)	0.50*	1.65	0.93	2.94
	HH with children (Couple without children)	-0.54*	0.58	0.33	1.02
Mobility characteristics					
Number of cars in HH	1 (0)	-0.63*	0.53	0.28	1.02
	2 or more (0)	-1.24***	0.29	0.12	0.68
	2 or more (1)	-0.62**	0.54	0.29	0.996
Attitudes and values					
Consider electric vehicle?	Yes (No)	2.77***	15.91	8.98	28.20
Importance of safety	Very important (Important or less)	-0.82***	0.44	0.27	0.73
Importance of privacy	Very important (Important or less)	-0.50**	0.61	0.37	0.98
Biospheric value	-	0.66***	1.93	1.31	2.84
Altruistic value	-	0.40**	1.49	1.00	2.22
Hedonic value	-	-0.38**	0.68	0.49	0.94
Interaction					
Carsharing experience * Type of living area	No carsharing exp. + City (No carsharing exp. + Countryside)	1.03**	2.81	1.22	6.45
	No carsharing exp. + City (No carsharing exp. + Agglomeration)	0.89**	2.42	1.21	4.88
	Some carsharing exp. + Agglomeration (No carsharing exp. + Agglomeration)	0.79*	2.21	0.87	5.61
	Some carsharing exp. + Countryside (No carsharing exp. + Countryside)	1.19**	3.28	1.24	8.67

B = parameter estimate, *, ** and *** significant at $p < 0.1$, $p < 0.05$ and $p < 0.01$, respectively, Exp(*B*) = odds ratio, CI = confidence interval

Since the dependent variable is a combination of car size and powertrain choice, similar variables found to have a significant impact on car size choice by previous literature (Table 3.1) show significant effects on the likelihood to choose a micro to mid-sized BEV. These include HH structure, number of cars in the HH, biospheric and hedonic values. Regarding relevant literature about the choice of powertrain, we confirm that age and type of living area seem to have a significant effect on the choice. We further find significant effects for whether the respondents would already consider an EV as the next car replacement, importance of safety, importance of privacy and altruistic values. We have a significant interaction in the model. The likelihood to choose a micro to mid-sized BEV not only depends on carsharing experience but also on type of living area. Figure 3.4 illustrates this interaction with a line plot.

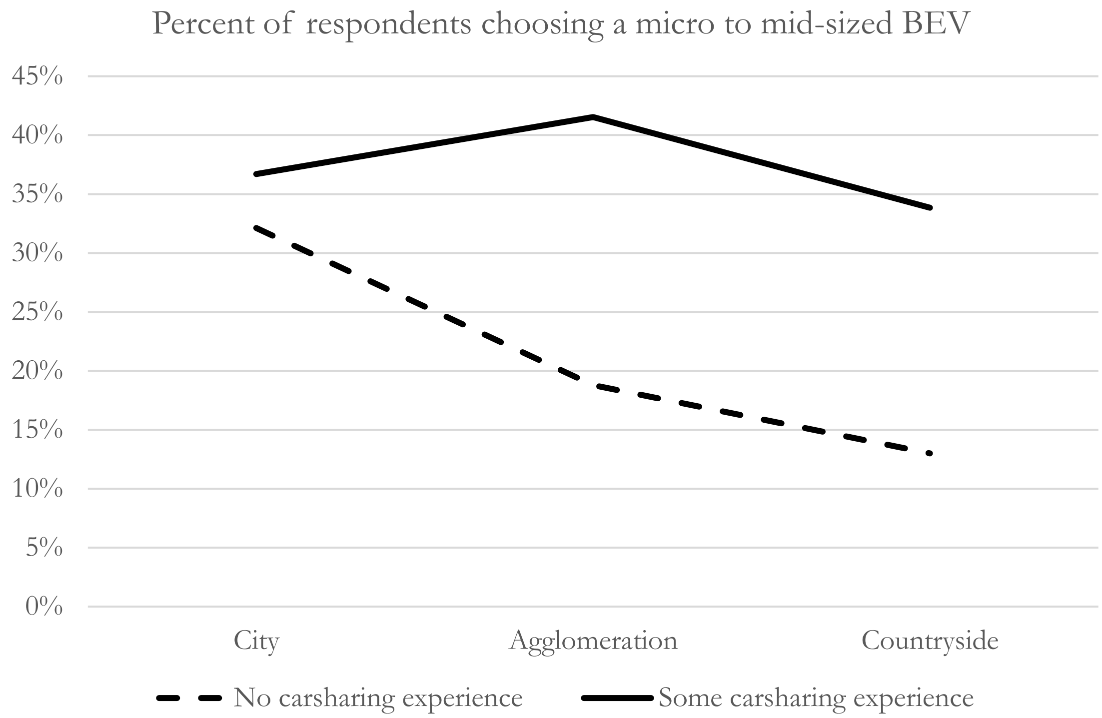

Figure 3.4: Interaction between carsharing experience and type of living area, line plot.

The graph shows that carsharing experience does not uniformly increase the openness to choose a micro to mid-sized BEV in contrast to the respondents without any carsharing experience. We see, however, that the openness to choose a micro to mid-sized BEV declines strongly once respondents are living in the agglomeration or countryside if they have no carsharing experience (dashed line). In Table 3.4 we see that persons living in the city are 2.8 times more likely to choose a BEV compared to persons living in the countryside (significant on the $p < 0.05$ level). Interestingly and supporting our alternative hypothesis that carsharing experience could lead to higher openness to choose a micro to mid-sized BEV, persons who have carsharing experience and live in the countryside are 3.3 times more likely to choose a micro to mid-sized BEV compared to persons without any carsharing experience also living in the countryside (significant on the $p < 0.05$ level). Table 3.4 further shows that a similar effect could be found for persons living in agglomerations although slightly weaker (odds ratio of 2.2 and significant on the $p < 0.1$ level).

For a clear overview of the effect size of each variable significantly ($p < 0.1$) influencing the likelihood to choose a micro to mid-sized BEV, we visualized the odds ratios including the 95% confidence interval in Figure 3.5. The dashed line corresponds to an odds ratio of 1. Confidence intervals who surpass this line are therefore not significant on the $p < 0.05$ level but still on the $p < 0.1$ level. Similar to Table 3.4, variables who have a p value above 0.1 are not included. Note that the x axis is in a logarithmic scale.

Figure 3.5: Odds ratios and 95% confidence interval of the powertrain choice model.

3.5 Discussion

The results confirm our alternative hypothesis that people with carsharing experience are more likely to choose a micro to mid-sized BEV, which, however, depends on the type of living area. We put special emphasis on including and controlling for the effect of biospheric and altruistic values in the model as especially people who rank high on these variables show greater interest in environmentally friendly mobility solutions potentially distorting the association between carsharing and preference for BEVs or smaller cars (e.g. Herberz et al., 2020; Nayum and Klöckner, 2014). We thus argue that people with carsharing experience might exhibit characteristic that go beyond the variables included in our study and influence their car size and powertrain choice.

Similar to Schlüter and Weyer (2019) who report that carsharing users have a mindset that is in line with the characteristics of BEV, such as accepting smaller range compared to ICEV, our study seems to confirm that people living in rural regions or in the agglomeration might develop such mindsets with carsharing experience. Persons living within the city are already more open towards buying a micro to mid-sized BEV, yet carsharing experience does not significantly increase this openness in contrast to people living in the countryside or agglomeration. The reasons for this interaction effect can be manifold. One possible explanation could be that for people living within the city, everyday trips are well covered by today's available BEV, reducing the need to rent a car from a carsharing operator or family and friends for a specific trip exceeding the range limit of current BEVs. Melliger et al. (2018) and Zhou (2020) already show that the majority of everyday trips can be covered by low-range BEVs in Switzerland, Finland and Bejing. On the contrary, everyday trips in the countryside are usually longer increasing potential range anxiety (Jones et al., 2020), which could be reduced through the possibility of carsharing at hand.

One of the core drivers to take the decision to buy a car is a change in the family structure like the birth of first child (Gu et al., 2019). Motivating these people to forego buying a car is challenging. However, our study indicates that experience with carsharing might reduce the likelihood to buy a large/SUV car. Establishing a station-based carsharing service including a variety of different models to choose from targeting these groups could provide them the security that their needs, which go beyond the capability of their small every-day car, are covered by this service. Further, as carsharing services generally attract younger people who might not yet have kids, the positive experience of sharing cars, the flexibility of different car models to choose from and the possible first contact with a BEV might spill over to the next life stage of having kids. This is in line with the findings from Burghard and Dütschke (2019) who state that changing circumstances, such as moving or starting a family, can turn carsharing users into electric vehicle buyers. We therefore argue to specifically target the younger generation and families with kids to decrease shifts from no car ownership or ownership of a small to mid-sized car to a large/SUV car. Especially in cities where space is a limiting factor, the adoption of smaller cars could relieve space needed for parking and provide additional opportunities for recreational areas or room for bicycles and pedestrians.

Within our study, the percentage of HHs owning at least one car is significantly higher in agglomerations (86%) or the countryside (91%) compared to HHs living in the city (62%) and thus represent a higher potential for electrification. Especially considering that cities generally provide good alternatives to the private car, policies in cities should focus on the shift from car use to public transport instead of private car electrification. Our findings are promising in this regard, as people from the countryside and agglomeration might be significantly more open to buy a micro to mid-sized BEV if they experienced the benefits of carsharing. The typically better access to a parking lot close to the residence and more space for the installment of a BEV charging station, facilitates the adoption of BEV in the countryside. However, Jones et al. (2020) point to the difficulties of adopting EVs in rural areas since public charging infrastructure is generally lacking compared to urban areas. Further, enabling people living in rural areas to experience carsharing is challenging. Rotaris and Danielis (2018) note that especially in rural areas carsharing demand is lower compared to densely populated areas like cities, demanding different business models that are more socially oriented and with greater involvement of local municipalities. Still, they find a non-negligible demand for carsharing among persons holding a driving license living in rural areas. In this regard, Münzel et al. (2018) suggest that especially the traditional round-trip carsharing and peer-to-peer carsharing business models could be successful in the long-term.

Another opportunity presents the integration of carsharing into a Mobility as a Service (MaaS) subscription plan facilitating the access to and possible first contact with carsharing. Further, Nayum and Klöckner (2014) find that car purchasers with a lower brand loyality are more likely to choose an EV, which could be fostered by the experience of using carsharing, as typically carsharing companies use different car brands, and the experience of a multimodal lifestyle supported by MaaS (Silvestri et al., 2020). Hoerler et al. (2020) further find that carsharing experience could increase the openness to use MaaS amplifying the range of possible contributions from carsharing to sustainable mobility.

In sum, we see two main opportunities by which a carsharing service could increase the openness of the general public to engage in sustainable mobility decisions. First by being present in urban areas with a divers set of car models to choose from in order to complement the needs of car-free HHs. A divers set of car types to choose from could be marketed especially to the younger generation, single person HHs and couples in the early stage of family planning in order to leverage the potential to forego buying a large car as the primary car, and instead, opt for a smaller car. Second by providing a fleet of long-range cars to complement current range shortages of BEV increasing the likelihood of people living in rural areas and agglomerations to buy a micro to mid-sized BEV.

In addition, another opportunity presents the provision of e-carsharing fleets enabling access to the BEV's new technology and reducing common misconceptions about range limitation (Schlüter and Weyer, 2019; Shaheen et al., 2020). According to our findings, e-carsharing should be provided in the perimeter of cities underlining the recommendations form Luna et al. (2020), while carsharing including long-range cars should be established in the countryside to use both potentials for increasing the uptake of BEVs. Further, especially as long as BEVs in carsharing fleet are less profitable than conventional cars (Rid et al., 2018b), providing a mixed fleet in the agglomeration could help cross-subsidizing the non-profitable electric cars in the e-carsharing fleet.

3.6 Conclusion and recommendations

Through a stated preferences survey with 995 participants from the German- and French-speaking regions of Switzerland we investigated whether carsharing experience could lead to an increased preference for micro to mid-sized BEVs. We find support for our hypothesis in the data and propose policy makers and mobility planners to not only see carsharing as a mean to reduce car ownership and car travel, but also consider the potential to increase the uptake of micro to mid-sized BEVs in agglomerations and rural regions. In light of these results, we advise mobility planners and policy makers to consider on the following 4 recommendations: 1) reduce the likelihood to purchase a large/SUV car for people experiencing life-changing events such as starting a family and people living in single person HHs, by advertising the benefits of smaller cars in combination of carsharing at hand, including a wide spectrum of car models to choose from; 2) focus on the advertisement of private micro to mid-sized BEV in the countryside and agglomerations in combination of conventional long-range cars in carsharing to complement the current range disadvantages of micro to mid-sized BEVs and profit from the higher openness to buy a micro to mid-sized BEV with carsharing experience; 3) establish e-carsharing in the perimeter of the inner city to exploit the visual effect of BEVs in the fleet and facilitate first experiences with the technology together with reduced local pollution and 4) focus on a mixed fleet of BEVs and long-range cars (i.e. conventional cars and PHEVs) in the perimeter of agglomerations to leverage the possibility of cross subsidizing the non-profitable BEVs and the higher openness to buy a BEV.

These policy suggestions should be evaluated together with the expected growth rate of BEVs. Since financial resources are limited, policies solely targeted to increase the uptake of BEVs might have a greater impact compared to splitting the resources to also foster carsharing in order to increase the uptake of BEVs through this mechanism. With the current growth rate of BEVs, the potential contribution to a fastened uptake of BEVs through experience with carsharing might be less relevant in the medium-term. Between 2018 and 2019 the market share of BEVs on new car sales in Switzerland has risen from 1.7% to 4.2%, indicating a growth rate of roughly 150% (Swiss Federal Office of Energy, 2020). While this high growth rate was attributed to a strong increase of different BEV models available in 2019, the most up-to-date scenario analysis of EV diffusion in Switzerland still expects a combined market share of BEVs and PHEVs on new car sales of roughly 50% by 2030, considering an optimistic scenario (EBP, 2020). With this growth rate and scenario analysis in mind, we propose to consider the potential effect of increased openness to buy a micro to mid-sized BEV by fostering carsharing with conventional cars in the short-term and the general effect of carsharing experience in reducing the likelihood to choose a large/SUV car in the long-term since no trend for an increased adoption of small cars is currently visible in Switzerland and other countries, even inclining to the opposite (statista, 2020; US EPA, 2020). In the future, the higher openness to buy a micro to mid-sized BEV due to carsharing experience could be supported by fully electrified carsharing fleets, with similar driving range, size and utilities as combustion engine cars today. Last, policy measures fostering the sharing of cars as one element of a multi-modal, public transport-centered transport system and a sharing economy in general are indispensable for a sustainable mobility system addressing the limited space and growing congestion induced by the growing population within the status quo of owning private vehicles.

The results and recommendations need to be viewed in relation to the characteristics of Switzerland with its dense public transport network, widespread possibilities of station-based carsharing and mountainous topography. The potential of carsharing as a complement to a small BEV might be different in other countries with a more dispersed road network and typically longer trips like in the United States and Germany. Still, as Needell et al. (2016) show, most car trips could already be covered by a low-range BEV even in the United States.

Future research might test our findings with a longitudinal study including car size and powertrain characteristics before and after subscribing to a carsharing service and thus add revealed preferences to the literature. Further importance should be given to new mobility lifestyles consisting of a combination of carsharing and/or public transport and small private BEVs, to analyze whether people would adopt such lifestyles and how these could be fostered.

Acknowledgment

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4 Push and pull strategies to increase the uptake of small electric vehicles

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Abstract

The demand for larger, heavier, and high range battery electric vehicles (BEVs) is growing. When relying on car utilization, smaller cars with sufficient battery range for typical daily distances could reduce greenhouse gas emissions, consumption of raw materials and pedestrian fatalities. Within our stated preference study with 859 participants, we used a combination of push and pull measures to motivate conventional car users to switch to a small BEV for everyday trips and mobility services for long-range trips. Our results suggest that up to 30% of conventional car owners would be open to switch to a small BEV in combination with mobility services. This can be increased to 41% through secured charging at home and at work. Combined with a CO_2 tax on fuel, up to 67% would switch. The results are relevant for transport planners and politicians in designing efficient strategies to increase the uptake of small BEVs.

4.1 Introduction

There is common agreement amongst scientists that fossil-fuel-based private car mobility is one of the main contributors to negative externalities such as CO_2 emissions, noise, lower air quality and accidents. It is thus imperative to reduce private car mobility with fossil fuels to reach a more sustainable transport system that is in line with the United Nations Development Goals and the Paris Agreement. Technological advances are among the various possibilities to increase sustainability. In particular, battery electric vehicles (BEVs) fueled with renewable electricity can lead to considerable CO_2 emission reductions (Franzò & Nasca, 2021; icct, 2021). In this context, BEVs are gaining in share of total new car registrations around the globe. Recently, Norway has been the first country to report a share of BEVs on new car registrations of over 70% (Holland, 2021) and other countries see substantial growth in BEV adoption as well (European Alternative Fuels Observatory, 2021). However, at the same time, the demand towards large cars and sport-utility-vehicles (SUVs) is increasing, and car manufacturers intensively provide electrified versions of popular SUVs. Furthermore, consumers expect BEVs to achieve ranges that are comparable to conventional cars, in order to cover also long-distance trips, e.g. for holidays, without having to repeatedly recharge the battery along the way (Morning Consult, 2021). In view of these developments, it is expected that a substantial share of large and high-range BEVs will be bought in the future.

However, simply replacing current fossil fuel cars with high-range BEVs bears several risks: Firstly, facing the characteristics of electric cars, CO_2 and other pollutant emissions strongly depend on the battery capacity, which increases with larger BEVs and range requirements (Ellingsen et al., 2016a; Franzò & Nasca, 2021). Secondly, through the extensive success of conventional and electric driven SUVs, the average size and weight of cars has been increasing considerably during the last decades, leading to higher consumption of raw materials in vehicle production and higher greenhouse gas and particulate matter emissions both during production and the use phase of vehicles (Craglia, 2020; icct, 2021; Yang et al., 2021). Third, large cars increase fatal pedestrian crashes (Tyndall, 2021). Finally, in view of the expected population growth, road infrastructure will increasingly face capacity limits with negative effects on quality of life, particularly in cities where competition with alternative utilizations of public space is highest. Increasing congestion and car presence are likely impacts if the stock of vehicles (and particularly large vehicles) continues to increase (Henderson, 2020).

Hence, under a sustainability point of view, the electrification of car mobility must go along with more systemic innovations challenging the overall mobility culture by downsizing of vehicles and batteries. Particularly, it is important that car-owning households adopt more environmentally sound solutions, for example, switching to a smaller BEV with lower battery capacities which are still compatible to the actual daily driving needs of most users. In Switzerland, for example, the daily average distances covered by car correspond to 24 km (BFS & ARE, 2017). Hence, the expectation of high ranges for BEVs often only have the purpose to cover very occasional long-distance trips without additional recharging while travelling. In this context, Meinrenken et al. (2020) show that matching the BEV range to drivers' typical trip distances has a high greenhouse gas emission reduction potential. Similarly, Wolfram et al. (2021) show that downsizing cars (e.g. from SUV to a small car) could reduce carbon life cycle emissions by 38%.

In the meantime, leading BEV manufactures included or announced small cars in their portfolio, e.g., Tesla, Renault, or VW. However, the adoption of small cars is exacerbated by misjudgments of customers: specifically, customers tend to overestimate their actual need for range of a car leading to range anxiety with regard to small BEVs (Hao et al., 2020; Noel et al., 2020). Needel et al. (2016) found that a 2013 Nissan Leaf, which has an average range of 120 km, could already be sufficient to replace 87% of daily car trips in the US, without the need to recharge the BEV during the day. Also the work from Melliger et al. (2018) show that a range of 230 km is sufficient to replace 87% of all trip legs in Switzerland and 85% of trip legs in Finland. Consequently, many small BEVs are sufficient to cover most of the daily trips already today.

4.1.1 Mobility services and long-distance trips

The remaining occasional long-distance trips that are not covered by the small BEV with smaller batteries, could be covered by other mobility alternatives like carsharing, car-rental or public transport. Needel et al (2016) therefore suggest that the availability of carsharing services of conventional internal combustion engine vehicles or BEV with a high range could play an important role for increasing the diffusion of privately owned small BEVs, as they act as a convenient backup for the rare cases when the range of a small BEV is not sufficient. Further, Hoerler et al. (2021) empirically show a correlation between carsharing experience and openness to buy a small to mid-sized BEV, underlining the suggestion by Needel et al. (2016). Finally, Brückmann et al. (2021) find that Swiss car owners who have a subscription to a carsharing provider are more likely to own a BEV. As such, combinations of small BEVs for everyday trips and carsharing/car-rental or public transport for the occasional long-range trips could be a sustainable alternative to owning a private fossil fuel driven car. Hence, to provide valuable options for occasional long-range trips, we are going to propose carsharing or car-rental as well as public transport alternatives to current car users to test the acceptance of small BEVs.

Despite of its potential advantages, an alternative option of a mobility lifestyle combining the ownership of a small BEV for everyday trips and using mobility services for the occasional long-range trips, to the best of our knowledge, has only been considered through qualitative research in earlier studies (e.g. the unbundling of cars to daily use and infrequent use by Sprei and Ginnebaugh (2018)). Yet, this requires a change in mobility behavior and a change of routines regarding the fueling/charging practice.

4.1.2 Push and pull strategies

In order to support the uptake of sustainable mobility behavior and decisions, Steg and Vlek (1997) distinguish between push measures, decreasing the benefits of conventional cars and car use, and pull measures aiming to improve alternatives to the private fossil fuel car. On the one hand, pull measures are more easily capable of creating political majorities, requiring no sacrifices by those getting "pulled" and are therefore much more likely to be accepted (Keizer et al., 2019; Steg, 2003). However, they often prove to be of limited success in initiating behavioral changes (Cools et al., 2011). On the other hand, push measures like an increase in CO_2 tax (Venturini et al., 2019) or the gradual intensification of fleet emission targets within the EU (Fekete et al., 2021) have been proven to be successful. Hoerler et al. (2020) also find through a hypothetical scenario that a gradual increase of a combination of push measures like fuel taxes, vehicle import restrictions and ban of non-electric vehicles in city centers increase the openness to change mobility behavior with regard to mobility services. Tilov and Weber (2021), for example, show that gasoline taxes could be effective in reducing vehicle kilometers travelled.

However, research also points to potential problems with such policies, since taxes and regulations increase opposition and are less accepted by persons with a right-winged ideology and those driving larger cars or reporting high annual mileage (Harring et al., 2017; Stradling et al., 2000; Wicki et al., 2019). Finally, Lilliestam et al. (2021) show that carbon pricing like emissions trading systems and carbon taxes don't currently accelerate a technological change.

Taking into account the difficulties described above, scholars suggest to combine strategies of discouragement (push) and encouragement (pull) (Rietveld & Stough, 2005; Thaller et al., 2021; Wicki et al., 2019). This way, valid alternatives are created for those who get "pushed" out of their comfort zone (Eriksson et al., 2008). The combination of push and pull measures has since been adopted by many scholars (e.g. Stoiber et al., 2019; Wang et al., 2020). We take up this discussion on push and pull measures, implementing in our survey additional incentives to increase acceptance of the proposed alternatives.

While some scholars stress the importance to foster fast charging stations to enable BEVs owners to drive long distance trips (Haustein & Jensen, 2018), others suggest that Home & Charge and Work & Charge (HC & WC) would be important in higher BEV adoption rates (Hardman et al., 2018; Melliger et al., 2018; Patt, Aplyn, et al., 2019), referring to the limited daily distance that car drivers cover on average. Since we propose the utilization of a small BEV to cover daily distances, the HC & WC obstacle seemed to be of higher relevance for our study. Hence, we hypothetically provide access to HC & WC as a first pull measure.

Carsharing is convenient if you have access to a carsharing station close to your place of residence. We therefore increase the comfort of carsharing by hypothetically increasing the number of carsharing stations and availability of a shared car as a second pull measure. Furthermore, consumers commonly misjudge the total cost of ownership (TCO) of cars underestimating or neglecting sunk and periodical costs in their cost-awareness, e.g. purchase price, maintenance, taxes, and insurance (Andor et al., 2020; Gössling et al., 2022; Lane & Potter, 2007). While studies show that BEVs could indeed lead to savings compared to owning a similar fossil fuel car, this is not yet considered by the general public (Andor et al., 2020; elementenergy, 2021). As such, awareness regarding cost advantages of BEVs as well as comparing the TCO of BEVs with similar conventional vehicles might increase its uptake. Hence, we argue, that information on TCO could be a promising third pull measure towards the uptake of the mobility alternatives.

As a push measure, we use a 4-step CO_2 tax increase on gasoline and diesel, since earlier research shows that this can be an effective and feasible policy to spur behavior change if combined with appropriate pull measures (Eriksson et al., 2008; Thaller et al., 2021; Wicki et al., 2019, 2020).

To the best of our knowledge, no study so far combined within one choice experiment different push and pull measures, enabling this way an integrated push and pull strategy in fostering the uptake of small BEVs in combination with mobility services. With our research, we fill this gap and provide practical insights for policy makers and mobility planners.

Summarizing, our study considers the following research gaps:

- Acceptance of small BEVs when switching from a conventional car in combination with mobility services for occasional long-distance trips
- Push and pull strategies to foster this combination

These research gaps lead to the following research questions:

- What percentage of conventional car users are open to: i) a mobility lifestyle with ownership of a small BEV in combination with public transport, ii) ownership of a small BEV in combination with carsharing/car-rental or, iii) a flexible combination of public transport and carsharing without car ownership?
- What push and pull measures like increasing levels of fuel tax, better availability of charging stations, increased carsharing availability and information on TCO might foster such a shift?

The remainder of this paper is structured as follows: Section 4.2 describes the survey design, the statistical model, and the limitations of the study. This is followed by Section 4.3 and 4.4, containing the results and the discussion. Finally, Section 4.5 summarizes the research and provides recommendations for policy and practice.

4.2 Methodology

4.2.1 Survey sample

We designed a multiple price list choice experiment within SHEDS 2020. SHEDS is representative for age, gender, and tenancy status for the German- and French speaking population of Switzerland. In total, 1’175 of the 5’500 SHEDS respondents were accounted to our choice experiment, from which 859 possess at least one household car. For a full description of SHEDS, see Weber (2017). The following table displays the differences between the Swiss population, SHEDS 2020 and our experiment sample for a set of socio-demographic and mobility related variables.

Table 4.1: Experiment sample and SHEDS 2020 sample compared to the Swiss population.

Variable	**Level**	**Experiment (n = 1175)**	**SHEDS 2020 (n = 5’500)**	**Swiss population**	**Difference Experiment / Swiss population**
Age[1]	Average	48.44	44.52	44.2	$t(1175) = 9.32, p < 0.001$
Gender[2]	Male	51.3%	48.1%	49.6 %	$\chi2$ (1, N = 1175) = 1.39, $p = 0.239$
	Female	48.7%	51.9%	50.4 %	
Education[3]	Less than university	52.3%	54.9%	50.5%	$\chi2$ (1, N = 1175) = 1.45, $p = 0.229$
	University	47.7%	45.0%	49.5%	
Gross Household income[4]	Less than 3’000 CHF	6.9%	6.9%	10’114 CHF (average)	
	3’000–4’500 CHF	10.6%	9.4%		
	4’501–6’000 CHF	16.2%	17.1%		
	6’001–9’000 CHF	29.0%	28.4%		
	9’001–12’000 CHF	20.7%	21.1%		
	More than 12’000 CHF	16.6%	17.1%		
Household car ownership[5]	No	25.6%	23.5%	22.0%	$\chi2$ (1, N = 1175) = 15.83, $p < 0.001$
	Yes	74.4%	76.5%	78.0%	
Public transport passes[5]	No	14.2%	15.2%	43.0%	$\chi2$ (1, N = 1173) = 395.93, $p < 0.001$
	Yes	85.8%	84.8%	57.0%	

[1]Swiss Federal Statistical Office (2021a), [2]Swiss Federal Statistical Office (2021d), [3]Swiss Federal Statistical Office (2021b), [4]Swiss Federal Statistical Office (2021c), [5]BFS and ARE (2017).

We have a slightly older sample and a small underrepresentation of car owning households compared to the Swiss population. Since we only focus on car owning households, a reweighting of the sample in the context of our study is not necessary. Gender, education, and income do not differ strongly from the overall SHEDS 2020 sample and the Swiss population. However, the experimental sample and SHEDS survey have an overrepresentation of public transport pass owners compared to the Swiss population.

4.2.2 Definition of alternative mobility lifestyles

Our target group were Swiss households owning a fossil-fuel driven car. We placed respondents in a hypothetical scenario three years into the future. After a car breakdown, they were faced with the decision of keeping their current mobility lifestyle and buying a new fossil fuel car or switching to an alternative that would replace the car and all trips conducted with that car (details are provided in Section 4.2.3). The alternatives were derived looking at innovative mobility scenarios currently proposed in literature (e.g. Sprei and Ginnebaugh (2018)) and discussing these in two expert workshops with the SCCER CREST network (Swiss Competence Center for Research in Energy, Society and Transition), which is composed of mobility experts, economists, psychologists and sociologists.

The alternatives focus on a small sized BEV like the Renault Zoe (52 kWh battery capacity and a range of 342 km according to WLTP) or BMW I3 (38 kWh battery capacity and a range of 310 km according to WLTP), since research shows that most trips could be covered by current small BEVs (Meinrenken et al., 2020; Melliger et al., 2018; Needell et al., 2016). Both cars are categorized as a small car but still offer up to 5 seats fulfilling the needs of an average family in Switzerland. In adverse climate conditions like extreme cold during winter, the range of BEVs could be reduced by 50% (Hao et al., 2020; Hollweck et al., 2018). Further, a reduction of up to 30 - 40% of driving range is expected while driving on a highway (X. Yuan et al., 2020). As our experiment took respondents three years into the future, new versions of the Renault Zoe and BMW I3 or similar cars are expected to deliver around 400 km WLTP (Renault Group, 2020). Hence, we used the threshold of 200 km per day, which could be easily covered by such a car even in adverse weather conditions without the need to recharge the car during the day. Trips which exceed the 200 km limit per day would be conducted by either public transport (Alternative 1) or carsharing/car-rental (Alternative 2). Elementenergy (2021) show that 67% of German car owners have 10 or fewer trips per year exceeding 200 km. Similarly, Neuenschwander (2020) finds through GPS data that Swiss car travelers exceed the overall distance of 200 km only on 3% of the days within a year. Accordingly, we assume that trips exceeding the 200 km threshold would be very rare and therefore, a large part of the population can estimate the number of the respective trips per year, which necessitate the usage and planning of public transport or carsharing/car-rental. We further included a third alternative for replacing the current fossil-fuel driven car through a flexible combination of public transport and carsharing/car-rental, providing an alternative without car ownership. Figure 4.1 provides an overview of these three alternatives as shown to the survey respondents.

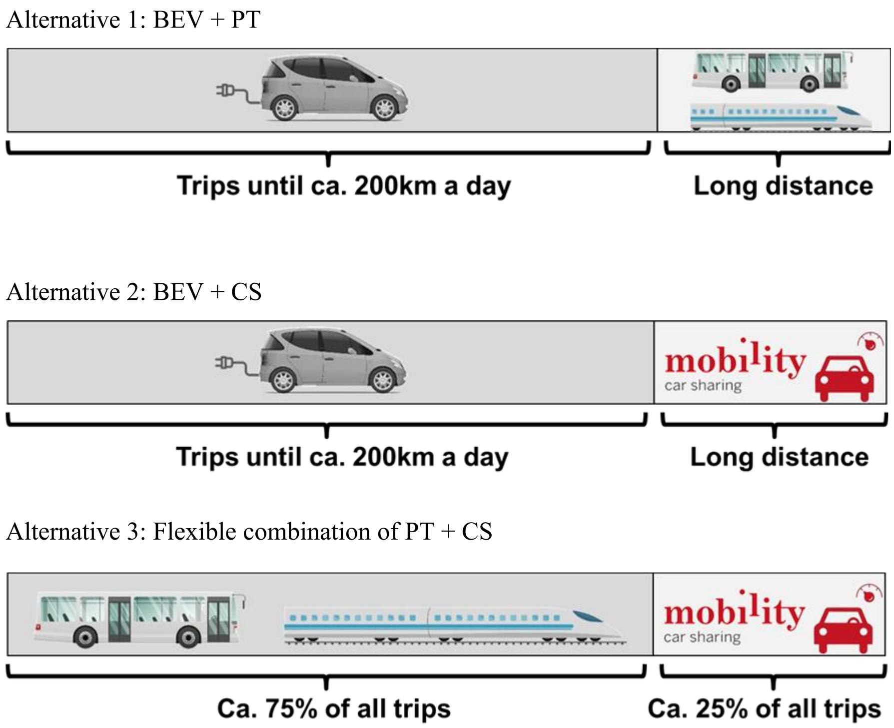


Figure 4.1: Visual depiction of the three alternatives studied in this work. Mobility is the largest carsharing operator in Switzerland covering the whole country.

4.2.3 Choice experiment - survey

We structured the choice experiment survey in four parts: 1) questions about the car and car usage characteristics, 2) introduction to the multiple price list choice experiment, 3) actual choice tasks and 4) follow-up questions. Other relevant socio-demographic, mobility-related, psychological, and sociological variables were drawn from the main survey of SHEDS 2020. Figure 4.2 provides an overview of the survey structure where PT stands for public transport, HC & WC for Home & Charge and Work & Charge, CS for carsharing and TCO for total cost of ownership. In the following, we describe each step of the survey.

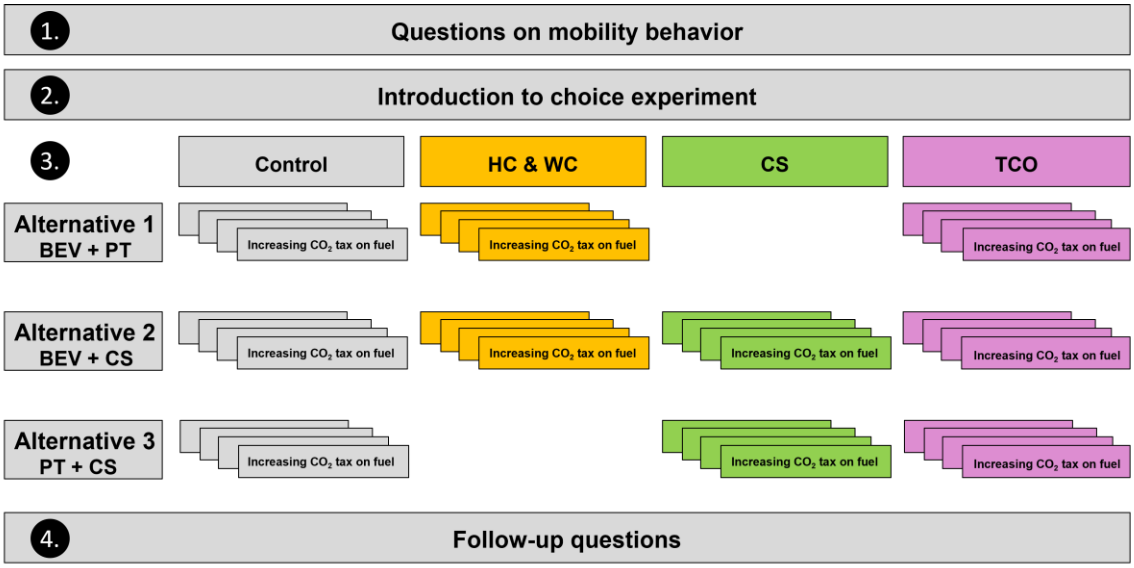


Figure 4.2: Overview of survey structure. Respondents in the HC & WC treatment group are not asked to answer the multiple price list for alternative 3 since a better charging situation is useless for this alternative consisting only of public transport and carsharing, without owning a BEV. Similarly, for the CS treatment group, alternative 1 does not include carsharing, which therefore is excluded for this treatment group.

1) Questions on mobility behavior

The questions on mobility behavior are used to tailor the choice experiment questions to the respondent's mobility situation in part 3. The following information of the currently owned conventional car is included:

- the fuel type (gasoline, diesel, electric, other)
- the mode of purchase (bought new, within a leasing contract, bought as a second-hand car)
- age of the car at purchase
- the price of the car
- average kilometers driven per year
- the number of daytrips exceeding 200 km per year
- the average lengths of these daytrips exceeding 200 km
- the number of car trips exceeding 400 km with at least one overnight stay per year
- the average distance covered for these car trips with at least one overnight stay.

All questions are targeted to the main household car (i.e., the car that is used most within the household).

2) Introduction to choice experiment

Within this second part of the survey, the respondents were told to imagine a situation in about three years, where their main household car breaks down and cannot be repaired. In this context, they are asked to decide whether they would buy a similar car again (same size and engine) or switch to an alternative. The three alternatives are then explained and visualized according to Figure 4.1. A randomization process assigned each person into one of the following four treatment groups (see Figure 4.2), each with a specific introduction:

- The control group reflects the current situation regarding infrastructure and sharing possibilities.
- This group is introduced to the next steps through following text: “Please assume for all choices: The public charging infrastructure has slightly increased. The availability of carsharing and car-rental stations is similar to today.”
- The treatment group HC & WC is offered improved charging infrastructure at the respective locations and is introduced to the next steps through the following text: “Please assume for all choices: The charging infrastructure has improved significantly. You have easy access to a charging plug at home, and most companies provide charging at work. As such, you can easily charge your battery at home during night or at work if required.”
- The treatment group CS is offered an increased accessibility of carsharing stations through the following text: “Please assume for all choices: The availability of carsharing stations and shared cars has increased significantly. You can easily access a car by foot from your home and one-way trips are possible. In rural regions, it is common to share cars via apps.”
- The treatment group TCO is informed about the full overall costs of their car use and is first addressed by the text “In each choice, you are presented the full costs of the options according to your current mobility behavior. These costs represent all expenses for the car (including amortization, parking, insurance, taxes, depreciation, fuel, registration, tires and repair & maintenance) and all expenses for public transport or carsharing/car-rental if applicable.”

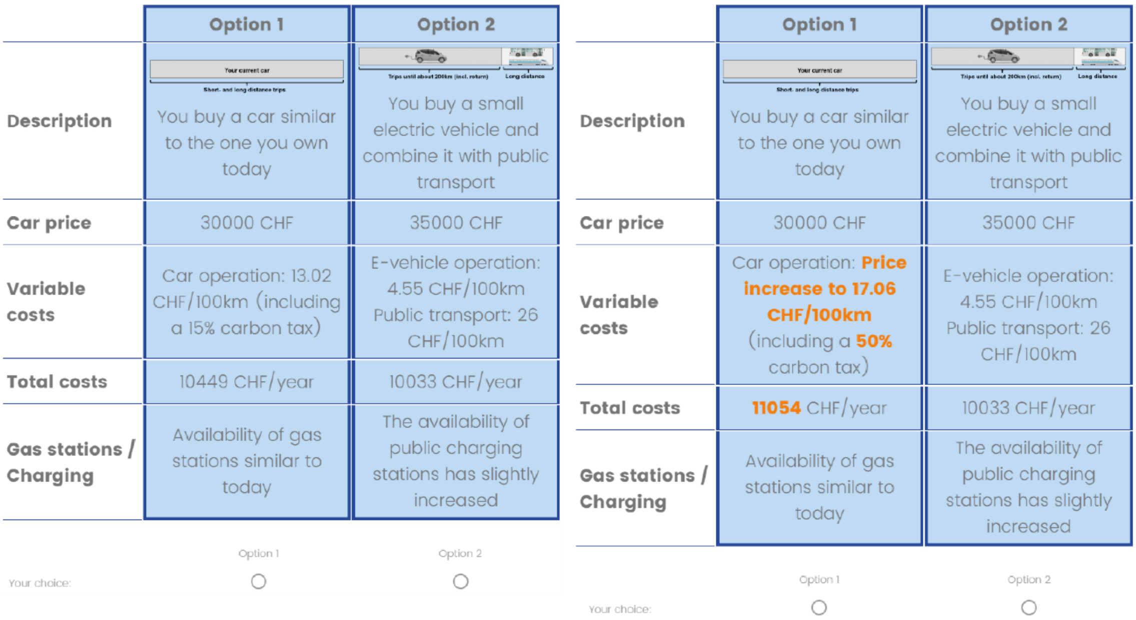
The TCO is calculated by utilizing the respondents’ answers to the questions about their car and mobility behavior in part 1 of the survey, combined with fixed costs and variable costs adapted from Touring Club Switzerland (TCS, 2021). Fixed costs include depreciation, interest on capital, road tax, third-party insurance, partial casco, ancillary expenses, garage costs and vehicle maintenance. Variable costs are mileage-dependent and include depreciation, fuel costs, tire exchange and general service and repair expenses. Details of the TCO calculations can be retrieved in Hoerler and Stoiber (2021).

3) Choice Experiment

After the treatment text and a message asking the respondent to carefully consider the coming decisions as if these really affected their preferences and household budget, the choice experiment starts.

Within the treatment groups described above, each person is presented, in random order, with the three alternatives shown in Figure 4.1. For each alternative, the respondents are confronted with a multiple price list experiment of four steps. The multiple price list starts with a baseline CO_2 tax on gasoline and diesel of 15%, individually calculated according to the mobility behavior of the respondent. Afterwards, the CO_2 tax increases stepwise to 50%, 100% and 200%. When the respondent chooses the alternative option, the process is interrupted. As such, over all three alternatives, each respondent conducts a minimum of 3 and a maximum of 12 choice tasks. The general idea of a multiple price list is to explore the level, at which the financial burden is so high, that a decision change to an alternative is induced. Respondents who would not switch even after introducing a 200% CO_2 tax on gasoline and diesel are thus less susceptible to financial push measures and should be addressed by other measures such as the pull measures tested with the treatments in the same survey.

Each question asks the respondent to choose between two options, where option 1 is their current fossil fueled car and option 2 is one of the three alternatives described above. Attributes of the options include car price (tailored to the respondents' answers in part 1 of the survey), variable cost (tailored to the car size and fuel type of the respondents' car), total cost for the TCO treatment, availability of fuel and charging stations, and sharing possibilities for alternative 2 and 3. Figure 4.3 illustrates an exemplary choice task for the TCO treatment group. If the respondent sticks to the current car (option 1), the multiple price list starts to trigger a CO_2 tax of 50% on gasoline and diesel representing a 35% increase of gasoline and diesel cost per liter (since the baseline already includes a 15% CO_2 tax on fuel). The same is followed stepwise to a CO_2 tax of 100% and 200% if the respondent keeps choosing option 1. The stepwise increase of the CO_2 tax is represented in the "variable cost" attribute of the choice task. For the TCO treatment group, the total cost attribute is also recalculated with each increase in CO_2 tax.



	Option 1	Option 2
Description	You buy a car similar to the one you own today	You buy a small electric vehicle and combine it with public transport
Car price	30000 CHF	35000 CHF
Variable costs	Car operation: 13.02 CHF/100km (including a 15% carbon tax)	E-vehicle operation: 4.55 CHF/100km Public transport: 26 CHF/100km
Total costs	10449 CHF/year	10033 CHF/year
Gas stations / Charging	Availability of gas stations similar to today	The availability of public charging stations has slightly increased
Your choice:	Option 1	Option 2

	Option 1	Option 2
Description	You buy a car similar to the one you own today	You buy a small electric vehicle and combine it with public transport
Car price	30000 CHF	35000 CHF
Variable costs	Car operation: **Price increase to 17.06 CHF/100km** (including a **50%** carbon tax)	E-vehicle operation: 4.55 CHF/100km Public transport: 26 CHF/100km
Total costs	**11054** CHF/year	10033 CHF/year
Gas stations / Charging	Availability of gas stations similar to today	The availability of public charging stations has slightly increased
Your choice:	Option 1	Option 2

Figure 4.3: Example of two consecutive pages of the multiple price list survey for the TCO treatment group. The first page representing the baseline 15% CO_2 tax scenario and the second page the 50% CO_2 tax scenario, after the respondent chose option 1 in the baseline scenario. Changes are marked in bold orange.

4) Follow-up questions

After the choice experiment, every respondent answered a set of follow-up questions. For each alternative (BEV + PT, BEV + CS, CS + PT), we asked the likelihood to really choose the alternative if the respondent needs to replace his/her main household car within the next few years on a 5-point Likert-scale (very unlikely to very likely). If the respondent chose "very unlikely", a possibility to explain the decision within a blank text field was implemented. This allowed us to validate the choice experiment answers and get a deeper insight into potential reasons restraining from adopting the sustainable alternatives.

Another set of questions asked about the satisfaction with the number of carsharing stations and whether the current range of small BEVs of approximately 250 km satisfy the needs for everyday trips. Last, we asked the respondents how close their home is located to a carsharing or public charging station and whether they have the possibility to charge an EV at home.

4.2.4 Data screening

To ensure validity of our results, we conducted several consistency checks. First, we examined the average duration of filling in the choice-experiment to check whether some respondents rushed in answering the questions. With a median of 6.8 minutes, we expect that overall responding times below 2 minutes would be too short for a thorough answering of the choice experiment's questions. Since we asked the respondents to report their annual mileage driven with their main household car and how many daytrips exceeding 200 km and overnight trips exceeding 200 km one-way they conduct per year (including an indication on how long these trips exceeding the threshold of 200 km are), we could check whether they can consistently estimate their number of long-range trips. In only two cases, respondents reported long-range trips exceeding the annual mileage driven with their main household car. These cases were removed from the analysis due to inconsistency. We further checked whether respondents were consistent in answering the choice questions and the follow-up questions. For respondents who switched to one of the three alternatives in the choice experiment task, we would expect a higher average rating in the follow-up question that asked whether the respondent would really switch to such an alternative in real life on a Likert scale from 1, very unlikely to 5, very likely. Figure 4.4 shows that this is the case for all three alternatives. The difference is less pronounced between the 100% and 200% CO_2 tax on fuel. This is expected since the biggest hurdle is a switch to one of the alternatives directly in the baseline condition without any CO_2 tax increase, or no switch at all.

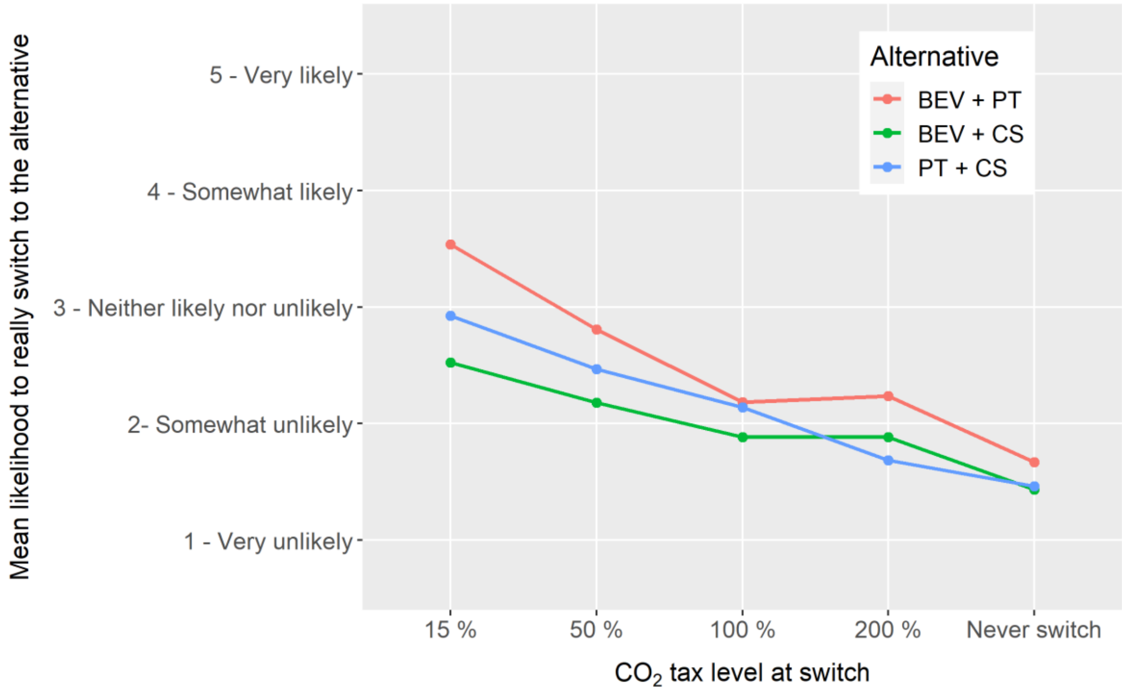


Figure 4.4: Mean likelihood to really switch to the alternatives for each CO_2 tax level at switch.

We checked the validity of respondents' assessment whether an EV range of 250 km is sufficient for their everyday trips (a Likert scale from 1, totally disagree to 5, totally agree). This was possible, since we know their number of daytrips exceeding 200 km per year from part 1 of the experiment (see section 4.2.6). We found a clear trend towards lower agreement with more daytrips exceeding 200 km per year (see Figure C1 in the appendix). We therefore assume that respondents were able to make reasonable decisions in their choice tasks. From the TCO treatment group, we deleted 15 cases with inconsistent purchase prices (e.g., no purchase price despite the car being new, or a clear mismatch between age of the car and the purchase price).

4.2.5 Statistical analysis

Since our data consists of structural zeros (respondents who never switch) and count data (switching at 15% CO_2 tax, 50% CO_2 tax, 100% CO_2 tax and 200% CO_2 tax), a hurdle model works best (M.-C. Hu et al., 2011). As our multiple price list only contains 4 steps, we transformed the fuel cost of the respondents' car into a count data, increasing the number of datapoints due to the differences in fuel type (gasoline and diesel) and car size to increase the interpretability of the results. Accordingly, we calculated the fuel cost of the respondents' car at the switch, which depends on the CO_2 tax levels, car size and fuel type. We checked for differences between the control and treatment groups regarding car size and fuel type through chi-square test and did not find any significant differences. The increase in fuel costs therefore depends on the CO_2 tax at the switch. Respondents who didn't switch at all received the value of 0, which denotes the hurdle in the hurdle model. The model first checks through a binomial logit link whether respondents decided to switch (fuel cost > 0) or not (fuel cost = 0). Then a count model with a negative binomial log link regression tests whether there is a significant difference in fuel cost at the switch between the control group and the treatment group. Since a switch at a higher CO_2 tax stage corresponds to higher fuel costs, people displaying larger fuel costs switched at a later stage. We rounded the fuel costs to integers and ensured that the first value starts at 1 by subtracting 9 from the lowest rounded fuel cost of 10 CHF / 100 km. Figure C2 in the appendix provides a histogram displaying the large amount of zeros represented in our data.

SHEDS contains many variables related to socio-demographics, mobility characteristics, attitudes, and values. Since previous research shows that mobility related decisions in stated preferences strongly depend on these variables (see e.g. (Hoerler, van Dijk, et al., 2021; Singh et al., 2020)), we checked whether there are significant differences between our control and the treatment groups by performing independent sample t-tests for continuous variables and chi-squared tests for categorical variables. An overview of these variables is shown in Table C1 in the appendix. All variables that exhibited significant differences were included in the hurdle model to account for these differences. Since we want to measure the effect of the treatment on the probability to choose the alternative mobility lifestyle, we applied an exploratory approach to find any significant interaction of the treatment variable with the socio-demographic, mobility characteristic or attitudinal variables shown in Table C1. In doing so, we followed the principle of weak heredity in selecting interaction terms and checked the AIC of the model with and without the interaction term. Weak heredity states that at least the interaction and one of the interacting variables need to have a significant effect to be included in the model (Wu & Hamada, 2011). In total seven hurdle models are calculated, one for each treatment and alternative. Table 4.2 compares the models without the interaction (model 1) and including the interaction (model 2). No significant interactions were found for Alternative 1 TCO and Alternative 2 TCO.

Table 4.2: Hurdle model with and without interactions for each alternative and treatment.

	Model 1 (Without interaction)	**Model 2 (Including interaction)**
Alternative 1 Charging	df = 13, AIC = 2016.838	df = 15, AIC = 2015.766
Alternative 1 TCO	df = 10, AIC = 1490.126	-
Alternative 2 Charging	df = 8, AIC = 1819.004	df = 12, AIC = 1791.634
Alternative 2 Sharing	df = 14, AIC = 1791.633	df = 18, AIC = 1783.980
Alternative 2 TCO	df = 9, AIC = 1000.971	-
Alternative 3 Sharing	df = 12, AIC = 1598.703	df = 14, AIC = 1592.915
Alternative 3 TCO	df = 8, AIC = 1733.83	df = 10, AIC = 1732.97

We further checked the qqr-plot, the rootogram and AIC to ensure that a binomial logit link fits best. Figures C3 – C5 in the appendix show the difference between a Poisson model and a binomial model with a rootogram clearly showing a visually better fit of the binomial model. Accordingly, the AIC is considerably lower for all models using a binomial logit link compared to a Poisson model.

Regarding the TCO treatment, we only want to test the effect of the TCO information treatment, if the TCO of the alternative is lower than their current car. Hence, the control and treatment group in the TCO hurdle model only contain cases for which the TCO of the alternative is lower, leading to a separate control group for the TCO treatment. Table 4.3 shows the percent of respondents being better off with the alternative for each alternative including all CO_2 tax levels.

Table 4.3: Frequency of respondents for whom the TCO of alternative is lower or higher than their current car for each of the 3 alternatives.

	Control		TCO Treatment	
	TCO of alternative lower	TCO of alternative higher	TCO of alternative lower	TCO of alternative higher
Alternative 1: BEV + PT	166 (83%)	34 (17%)	163 (82%)	36 (18%)
Alternative 2: BEV + CS	122 (63%)	71 (37%)	121 (62%)	73 (38%)
Alternative 3: PT + CS	195 (99%)	1 (1%)	194 (98%)	4 (2%)

4.2.6 Limitations

Firstly, an important general limitation is the nature of a stated choice experiment since we didn't observe actual behavior, often referred to as hypothetical bias. We accounted for this bias by using methods such as "cheap talk", budget reminders, referencing and follow-up questions, allowing a consistency check (Haghani et al., 2021). Still, investigating how people would behave in reality needs to be addressed by a revealed preference study. Furthermore, there are potential limitations due to the narrow system borders of our survey:

- Our survey follows mostly a price sensitive approach that does not consider habits, routines, and practices, that lead to a continuity of mobility decisions and lifestyles and might overestimate the acceptance of the proposed alternatives in our survey. We tried to manage this potential error focusing on a typical strategic long-term mobility decision (car purchase after a breakdown).
- We use a stepwise increase of CO_2 tax on diesel and gasoline as a financial incentive to switch to the proposed mobility options. This opens the discussion of what instrument to take when pricing CO_2. Whereas levies show positive distribution effects, taxes are more unpopular, generating a potential resistance among respondents to choose the proposed alternatives.
- Our survey has been undertaken in Switzerland. Average distances and the alternatives proposed are adapted to the Swiss transport system, which offers relatively high-quality public transport in the whole country and carsharing possibilities in lot of regions already today. For other countries, our survey would have to be adapted. Furthermore, the data of the survey has been collected in 2020 in the midst of the first wave of the Corona pandemic, which generally led to a stronger orientation towards the car in Switzerland. This might have influenced the choices conducted in the survey.

Furthermore, there are some potential errors referring to the specific conceptualization of our choice experiment:

- Investigating the answers to the open-stated questions as to why the respondents would not switch to the alternative in real life (shown if respondent has a score of 1 from 1, very unlikely to 5, very likely), we see that some respondents misinterpreted alternative 2 (combination of BEV and carsharing/car-rental) as they assumed their own car would be shared instead of using a carsharing service. While it was only a small fraction of respondents (roughly 6% of those who rated 1 on the Likert scale), we don't know whether respondents who did not answer the open-ended question interpreted alternative 2 correctly. We compared the results with and without the 6% who probably misunderstood alternative 2 finding no significant differences. Still, we assume that alternative 2 could be valued higher than represented in our experiment.
- Self reporting of car size could lead to different interpretations of the same car type. We checked this by examining the car model reported in SHEDS 2020 (e.g., VW Tiguan), which could then be compared to the official classification used by TCS. Only few respondents reported to own a small car, when in fact it was officially classified as a small-medium car. Differences were on maximum between two neighboring size classes, so, in general, the difference between small and large cars stays valid.
- Self-reporting of the number of trips per year exceeding 200 km could be over- or underestimated. We compared our average of 9.53 trips per year exceeding the 200 km threshold with Neuenschwander (2020), who used GPS-based data in Switzerland to estimate the number of trips for different range categories. With an average of 10.7 trips exceeding 199 km per year, the GPS-based data is very similar to our self-estimated data. Likewise, Plötz et al. (2017) investigated the number of days per year a daytrip exceeds 200 km in Sweden using GPS measurements. They find very similar results with 11.9 days per year on average, and a median of 3.8 days per year. Hence, we argue that the respondents made accurate choices regarding their number of daytrips exceeding 200 km per year. With respect to the sample of our study, Figure provides an overview of the number of daytrips exceeding the 200 km threshold per year and the number of overnight trips exceeding the 400 km threshold per year. We see that these trips are relatively rare. Almost 80% of respondents do have 12 or fewer daytrips per year exceeding 200 km. Therefore, 80% of car owners would need to switch to a long-distance alternative at most once a month. Nearly 80% of respondents have 2 or fewer overnight trips per year that exceed the 400 km limit.

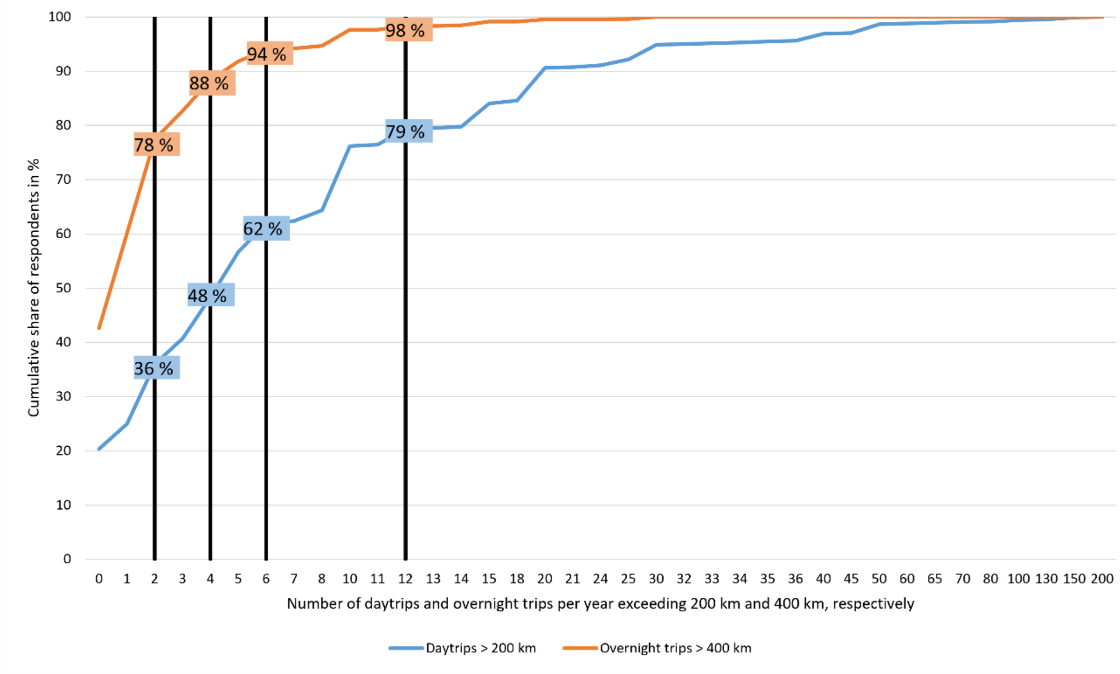


Figure 4.5: Number of days per year respondents exceed the threshold of 200 km for daytrips and 400 km for overnight trips. Vertical lines highlight 2, 4, 6 and 12 days per year the threshold is exceeded.

- We only compared the cost for trips driven with the main household car. This implies that for a respondent who currently also uses public transport, alternative 1 and 3 would come along with even greater financial benefits. To be accurate, the current public transport costs would have to be added to the TCO of the respondents' car use. We therefore assume that our estimations are rather conservative and that in reality, the potential financial benefit of switching to alternative 1 or 3 would be even higher.
- While the focus of our study is on the acceptance of small BEVs, we do not know whether respondents who did not indicate a switch to a small BEV would opt for a larger BEV instead. We will investigate this question in a follow-up study.

4.3 Results

4.3.1 Descriptive overview

Firstly, we provide an overview of the frequency of switches differentiated according to the levels of CO_2 tax for each alternative and treatment group. Figure 4.6 summarizes the results of the choice experiment in one graph.

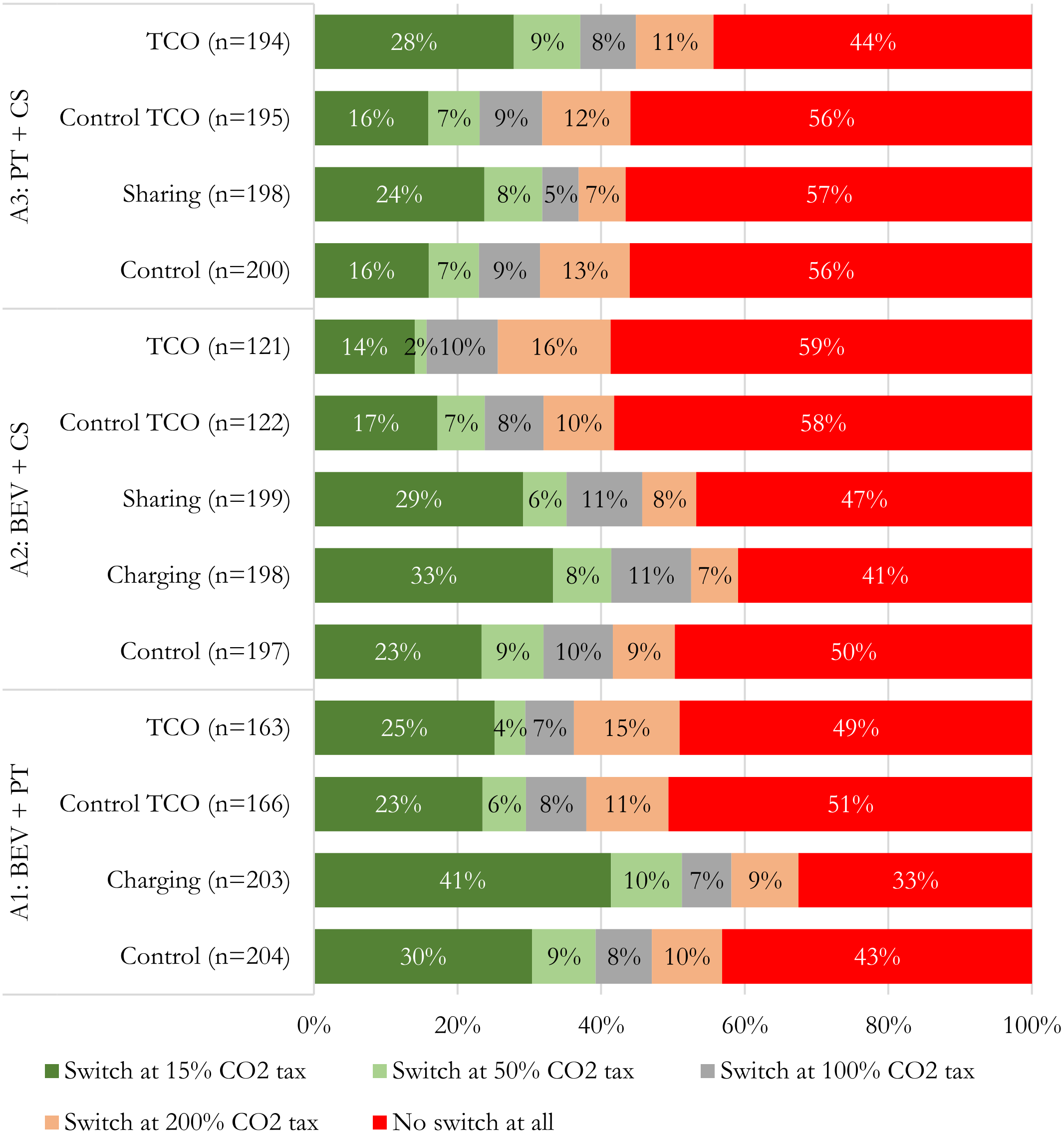


Figure 4.6: Descriptive overview of the percent of respondents switching in each CO_2 tax level and each alternative and treatment group.

Alternative 1 (combination of BEV and public transport): Already 30% of the respondents would switch to this alternative at a CO_2 tax of 15% (baseline condition) and without any additional pull measures. A further 27% could be motivated to switch to alternative 1 with increasing monetary push measures (50%, 100%, and 200% CO_2 tax on fuel), while 43% of respondents do not switch to alternative 1 even after including a 200% CO_2 tax on gasoline and diesel, indicated by the red bar in Figure 4.6. It is thus difficult to motivate these respondents to switch to alternative 1 through monetary punishment. The percent of respondents who switch already in the baseline condition increases from 30% to 41% for the charging treatment group. This group is offered a significantly better charging situation at home and at work. The share of respondents who could further be motivated through the increasing CO_2 tax levels is 26% and very similar to the control group. Lastly, we see a reduction of respondents who never switch from previously 43% to 33%. Regarding the TCO treatment, which includes additional information on the total cost of car ownership and of the utilization of mobility services, we see no observable effects. The TCO treatment group does not show strong differences to the respective TCO control group.

Alternative 2 (combination of BEV and carsharing/car-rental): Fewer respondents switch already in the baseline condition compared to alternative 1 (23% compared to 30%). The share of respondents who could be motivated to switch through increasing CO_2 tax levels is similar to alternative 1 (28% compared to 27%) and accordingly, the share who never switch is 7 percentage points higher compared to alternative 1. Similarly to alternative 1, the charging treatment increases the switch at the baseline condition (15% CO_2 tax) by 10% and reduces the percent of respondents who never switch by 9%. The sharing treatment has a smaller effect, increasing the switch at the baseline condition by 6 percentage points compared to the control group and reduces the percent of respondents who never switch by 3%. Comparing the TCO control group with the TCO treatment group, we don't see a strong difference regarding the switch at the baseline condition and regarding respondents who never switch.

Alternative 3 (combination of public transport and carsharing/car-rental): This alternative is the least preferred option, as only 16% of respondents switch directly at the baseline condition (compared to 23% for alternative 2 and 30% for alternative 1). Twenty-nine percent could be further motivated to switch by an increase in CO_2 tax on fuel and 56% of respondents never switch to alternative 3 in the control condition. In the case of alternative 3, the sharing treatment increases the share of respondents who switch at the baseline condition (24% compared to 16%) but doesn't decrease the number of respondents who never switch to alternative 3 (57% compared to 56%). The latter seem to reflect a group that cannot be motivated to reduce car ownership at all, even after strong financial measures. Finally, the TCO treatment increases the share of respondents who switch to alternative 3 at the baseline condition by 12% and decreases the share of respondents who never switch to alternative 3 by 12%.

4.3.2 Results of the Hurdle model

In the following, we describe the effects of the treatments separately for each alternative. The result tables (see Table 4.4-4.10) include the exponentiated beta coefficients exp(β), the 95% confidence interval of exp(β) and the significance level. The results of the hurdle model are divided in two parts; 1) the count model testing a difference in fuel cost (representing the level of CO_2 tax) at the switch and 2) the binary switch model (or zero-inflated model) testing whether a participant decided to switch or not. The reference group is provided in parentheses. We further provide line plots as a visual support in interpreting the interactions.

Model results alternative 1: Battery electric vehicle & public transport

The results of the hurdle model for the charging treatment are provided in Table 4.4. Within the binary switch model, we see a significant interaction between the charging treatment and car size. Since the coefficients of variables that are included in an interaction should always be interpreted together with all interacting coefficients, we calculated meaningful combinations of this interaction for easier interpretation of the results. The original output tables for all hurdle models can be found in the appendix (Table C2 – C8).

Charging treatment

Table 4.4: Hurdle model results for alternative 1 and charging treatment.

Predictors		*95% CI of exp(β)*		
	exp(β)	*Lower*	*Upper*	*Sign.*
Count model				
Treatment: Charging *(Control)*	0.91	0.71	1.16	-
Binary switch model - interaction				
Treatment: Charging + Car size: Until small *(Control + Until small)*	0.24	0.05	1.29	-
Treatment: Charging + Car size: Larger than small *(Control + Larger than small)*	1.96	1.19	3.24	***
Observations: 394	R^2 / R^2 adjusted: 0.418 / 0.411			

*, **, *** significant on the *p* < 0.1, 0.05 and 0.01 level, respectively.

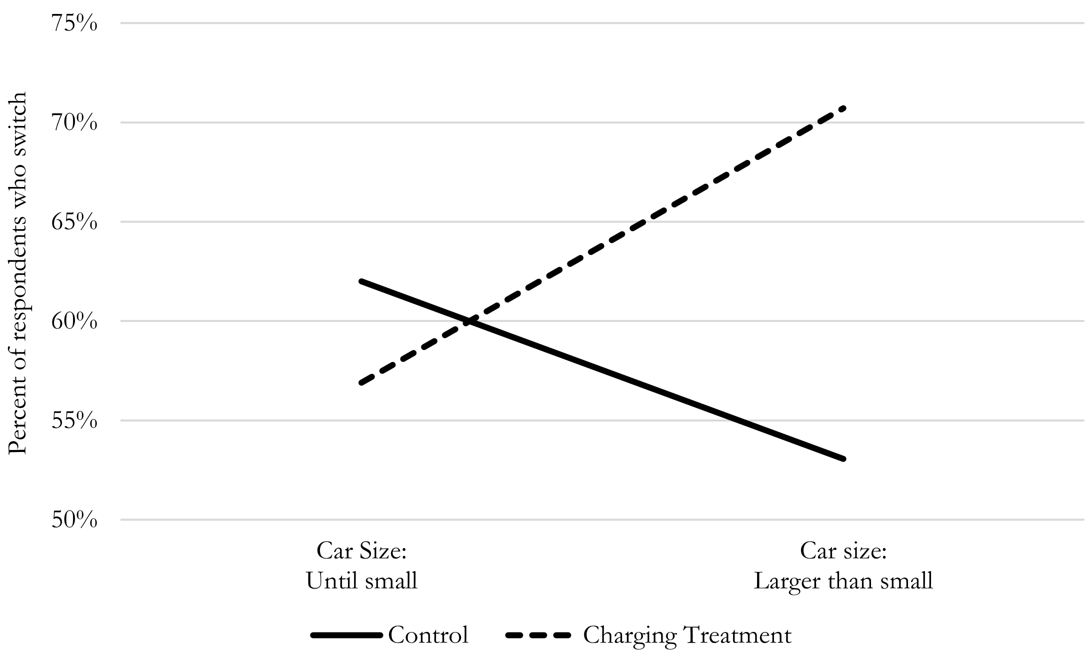


Figure 4.7: Interaction plot between car size and charging treatment.

As shown in Table 4.4 respondents owning a car that is larger than the small category (refer to Table C1 in the appendix) and received the charging treatment are almost two times (1.96) more likely to switch from their current car to alternative 1 (BEV + PT). Yet, respondents owning micro or small cars (until small) do not differ significantly between the treatment and control group. Moreover, we don't find a significant effect for the count model, indicating that the amount of CO_2 tax needed to further push the respondents to switch to the alternative is the same for the control group and the charging treatment.

Table 4.5 provides the results for the TCO treatment. Only respondents who are better off with the alternative are included in the model since we want to test whether respondents who receive information about the TCO and are better off with the alternative would be significantly more likely to switch to the alternative. We find no significant interaction nor a significant effect of the TCO treatment regarding the switch to alternative 1.

TCO treatment

Table 4.5: Hurdle model results for alternative 1 and TCO treatment.

Predictors		*95% CI of exp(β)*		
	exp(β)	*Lower*	*Upper*	*Sign.*
Count model				
Treatment: TCO *(Control)*	1.16	0.89	1.52	-
Binary switch model				
Treatment: TCO *(Control)*	1.09	0.70	1.71	-
Observations: 320	R^2 / R^2 adjusted: 0.558 / 0.552			

*, **, *** significant on the $p < 0.1$, 0.05 and 0.01 level, respectively.

Model results alternative 2: Battery electric vehicle & Carsharing/car-rental

Table 4.6 shows the results of the charging treatment in the hurdle model for alternative 2 (BEV + CS). We see no effect for the count model, yet a significant interaction between the charging treatment and BEV range for the binary switch model. Again, we visualize the interaction with a line plot in Figure 4.8. Respondents who received the charging treatment and stated that a BEV range of 250 km would be sufficient for their everyday trips are 2.5 times more likely to switch to alternative 2 (BEV + CS) compared to respondents who did not receive the treatment, indicating that even though an EV range of 250 km would be sufficient for everyday trips, increasing the possibility for home & charge and work & charge (charging treatment) could significantly increase the odds to switch to such an alternative. A smaller but still significant difference on the $p < 0.1$ level could be found for people indicating that they don't know if 250 km range for a BEV is sufficient for their everyday trips. Here they are more than 4 times more likely to switch, which however has a large CI due to fewer cases. Last, no difference regarding the probability to switch to alternative 2 (BEV + CS) could be found for people stating that they find a BEV range of 250 km to be insufficient for everyday trips.

Charging treatment

Table 4.6: Hurdle model results for alternative 2 and charging treatment.

Predictors		*95% CI of exp(β)*		
	exp(β)	*Lower*	*Upper*	*Sign.*
Count model				
Treatment: Charging *(Control)*	0.87	0.68	1.11	-
Binary switch model - interaction				
Treatment: Charging + BEV range: Sufficient *(Control + Sufficient)*	2.50	1.31	4.75	***
Treatment: Charging + BEV range: I don't know *(Control + I don't know)*	4.47	0.91	22.04	*
Treatment: Charging + BEV range: Insufficient *(Control + Insufficient)*	0.62	0.33	1.17	-
Observations: 385	R^2 / R^2 adjusted: 0.681 / 0.679			

*, **, *** significant on the p < 0.1, 0.05 and 0.01 level, respectively.

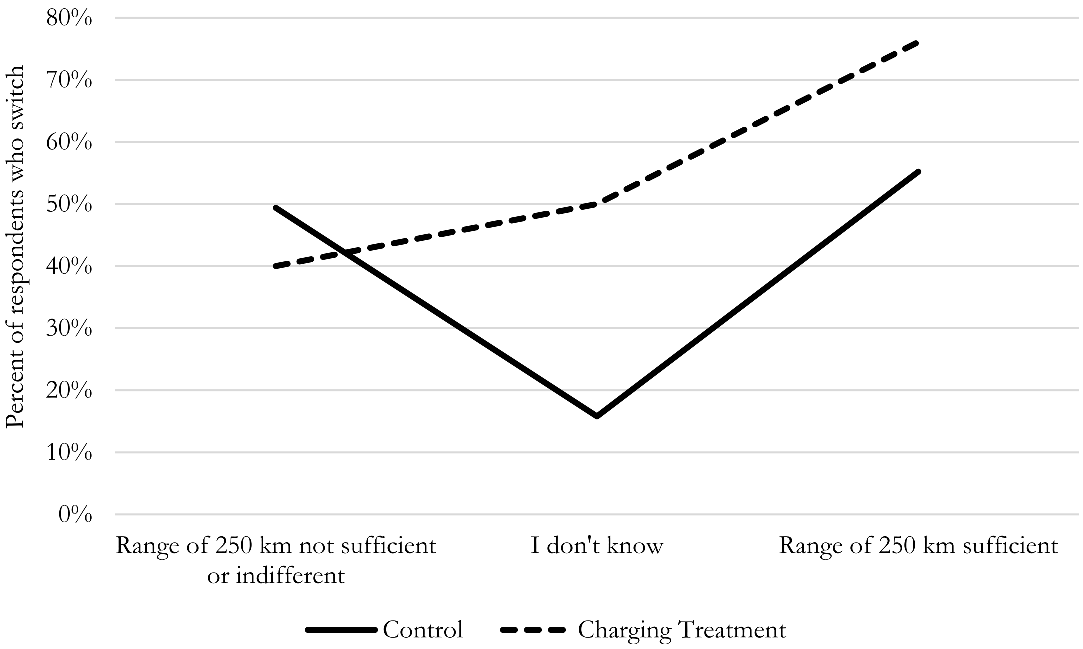


Figure 4.8: Interaction plot between BEV range sufficiency and charging treatment.

Table 4.7 provides the results for the sharing treatment. We find no significant effect for the count model but a significant interaction between the sharing treatment and carsharing station abundancy for the binary choice model. Together with Figure 4.9 we see that respondents who received the sharing treatment and don't know whether the number of carsharing stations are sufficient in motivating them to use carsharing more often, are 2.8 times more likely to switch to alternative 2 compared to the control group.

Sharing treatment

Table 4.7: Hurdle model results for alternative 2 and sharing treatment.

Predictors		*95% CI of exp(β)*		
	exp(β)	*Lower*	*Upper*	*Sign.*
Count model				
Treatment: Sharing *(Control)*	1.02	0.79	1.31	-
Binary switch model - interaction				
Treatment: Sharing + CS stations: Sufficient *(Control + Sufficient)*	0.59	0.26	1.34	-
Treatment: Sharing + BEV range: I don't know *(Control + I don't know)*	2.80	1.19	6.58	**
Treatment: Sharing + BEV range: Insufficient *(Control + Insufficient)*	0.94	0.51	1.74	-
Observations: 388	R^2 / R^2 adjusted: 0.477 / 0.468			

*, **, *** significant on the $p < 0.1$, 0.05 and 0.01 level, respectively.

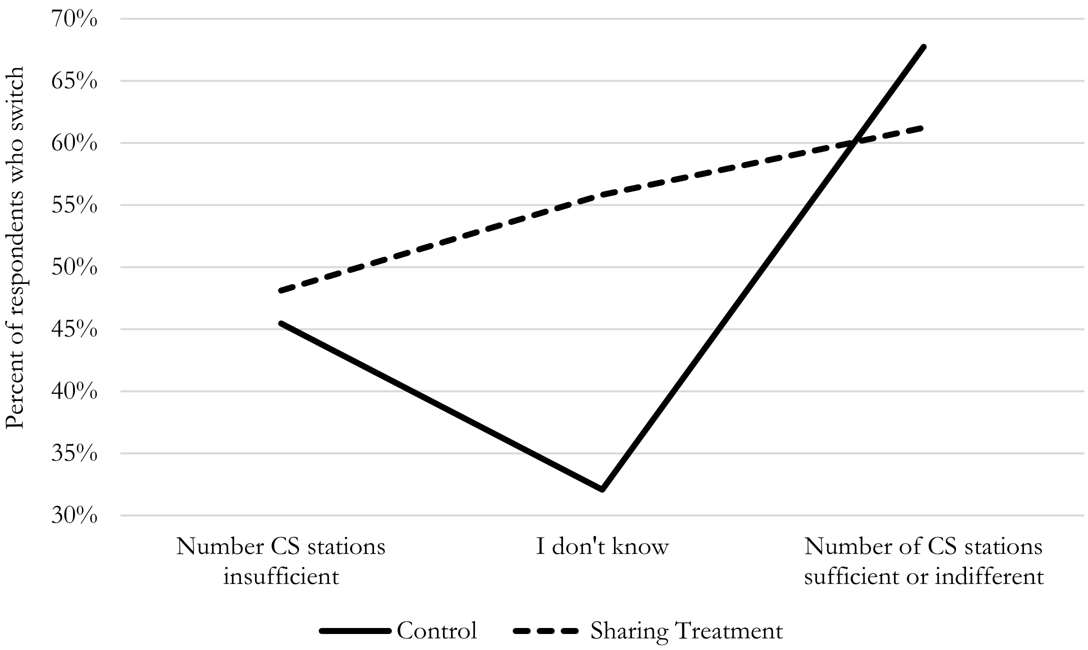


Figure 4.9: Interaction plot between sufficiency of carsharing stations and sharing treatment.

Respondents who received the TCO treatment are not significantly more likely to switch to alternative 2 (Table 4.8).

TCO treatment

Table 4.8: Hurdle model results for alternative 2 and TCO treatment.

Predictors		*95% CI of exp(β)*		
	exp(β)	*Lower*	*Upper*	*Sign.*
Count model				
Treatment: TCO *(Control)*	1.23	0.92	1.65	-
Binary switch model				
Treatment: TCO *(Control)*	0.96	0.56	1.64	-
Observations: 239	R^2 / R^2 adjusted: 0.681 / 0.675			

*, **, *** significant on the p < 0.1, 0.05 and 0.01 level, respectively.

Model results alternative 3: Public transport & Carsharing/car-rental

Table 4.9 displays the hurdle results for the sharing treatment. We find a significant interaction between education and the sharing treatment within the count model. The interaction is visualized as a line plot in Figure 4.10. Respondents who have a university degree and received the sharing treatment have, on average, a 1.79 (1/0.56) times lower fuel cost at the CO_2 tax level of their switch to the alternative, compared to the control group. Hence, respondents with a university degree seem to react earlier to increasing CO_2 taxes when combined with better carsharing availability than their counterparts. However, no differences could be found for respondents who have not a university degree. Moreover, no significant observations are provided by the binary switch model.

Sharing treatment

Table 4.9: Hurdle model results for alternative 3 and sharing treatment.

Predictors		*95% CI of exp(β)*		
	exp(β)	*Lower*	*Upper*	*Sign.*
Count model - interaction				
Treatment: Sharing + Education: University *(Control + University)*	0.56	0.40	0.79	***
Treatment: Sharing + Education: Less than university *(Control + Less than university)*	1.10	0.79	1.52	-
Binary switch model				
Treatment: Sharing (Control)	0.93	0.61	1.43	-
Observations: 391	R^2 / R^2 adjusted: 0.650 / 0.643			

*, **, *** significant on the p < 0.1, 0.05 and 0.01 level, respectively.

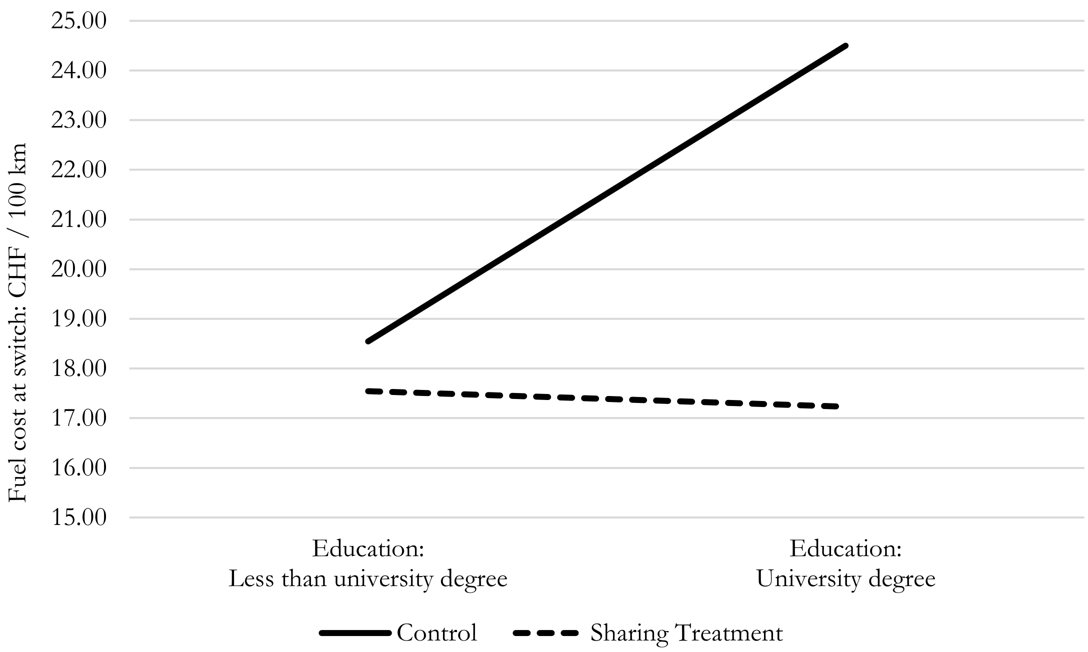


Figure 4.10: Interaction plot between education and sharing treatment.

The TCO treatment has a significant, although weak, effect on switching earlier (lower CO_2 tax needed) to alternative 3 (Table 4.10). On average, respondents who received the TCO treatment have a 1.22 (1/0.82) times lower fuel cost compared to the control group. We further find a significant interaction effect for the binary switch model (Figure 4.11). Here, respondents who own a micro, small or small-medium car (summarized as "until small-medium") were 6.52 times more likely to switch to alternative 3 if they received the TCO treatment compared to the control group. On the other hand, respondents who own larger cars (mid-sized, large and SUV) did not significantly differ between the treatment and control group regarding the switch to alternative 3.

TCO treatment

Table 4.10: Hurdle model results for alternative 3 and TCO treatment.

Predictors	*95% CI of exp(β)*			
	exp(β)	*Lower*	*Upper*	*Sign.*
Count model				
Treatment: TCO *(Control)*	0.82	0.65	1.03	*
Binary switch model				
Treatment: TCO + Car size: Until *small-medium (Control + Until small-medium)*	6.52	1.71	24.86	***
Treatment: TCO + Car size: Larger than small-medium *(Control + Larger than small-medium)*	1.05	0.58	1.89	-
Observations: 381	R^2 / R^2 adjusted: 0.377 / 0.373			

*, **, *** significant on the $p < 0.1$, 0.05 and 0.01 level, respectively.

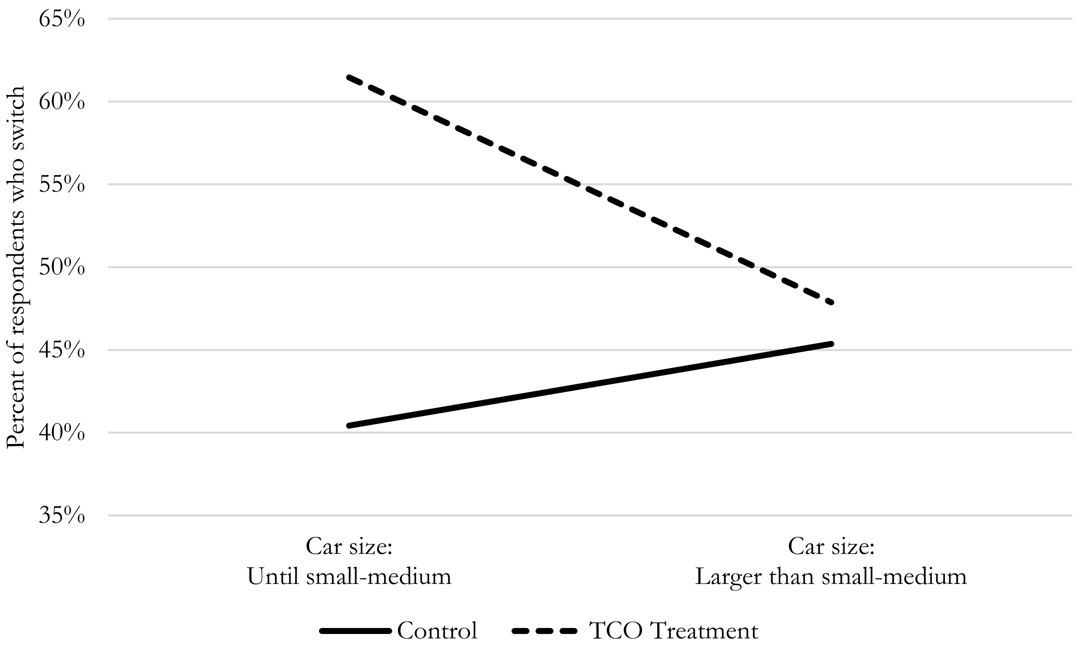


Figure 4.11: Interaction plot between car size and TCO treatment.

We provide an overview of all treatment effects distinguished by the count model, binary switch model and alternative 1 to 3 in Figure 1.12.

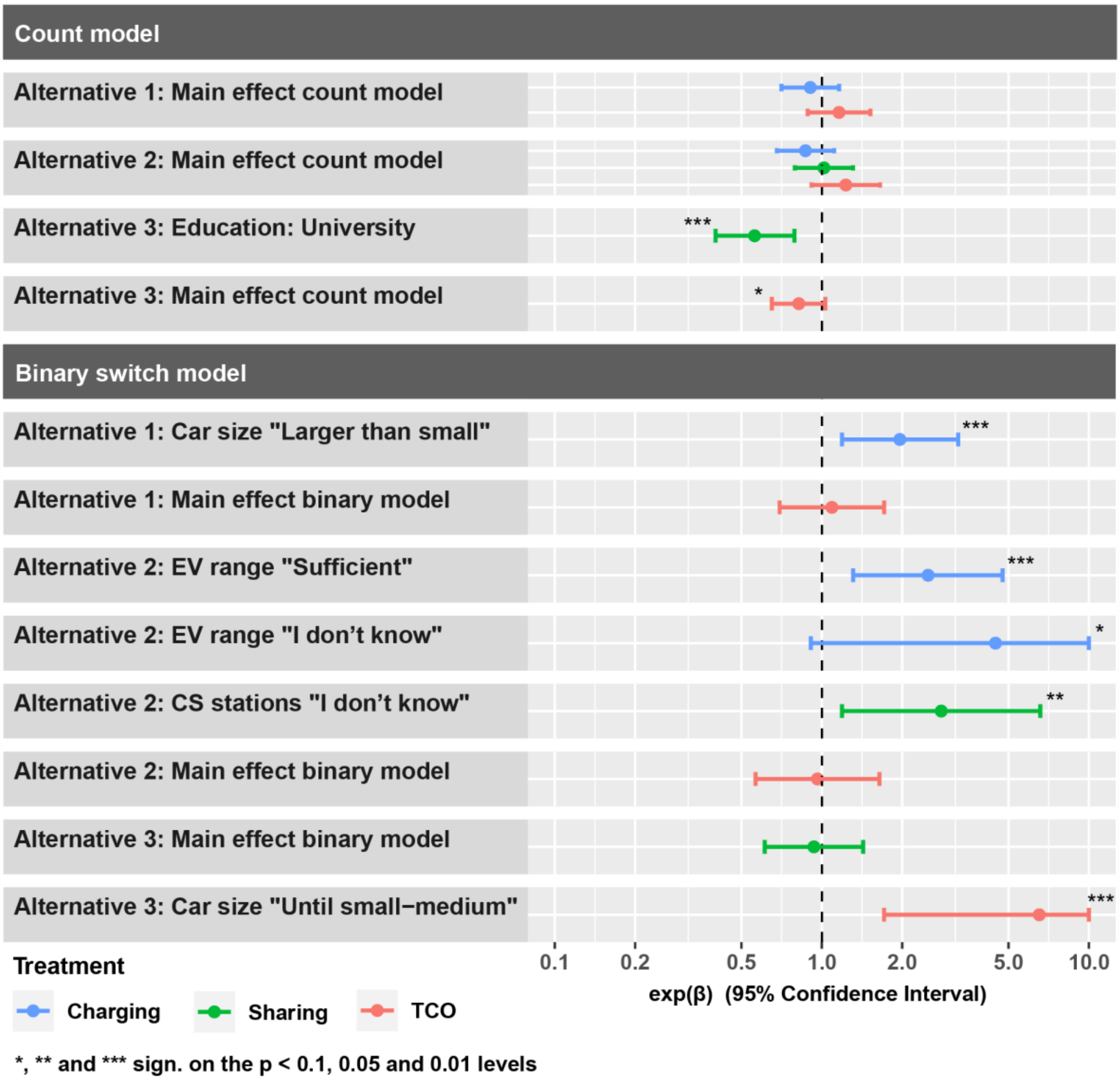


Figure 4.12: Summary of hurdle model results for each alternative and treatment.

4.4 Discussion

In general, our results show that even with a low CO_2 tax level an no additional pull measures, a large part of respondents would be open to switch from their current fossil fuel car to a small BEV in combination with public transport (30%, alternative 1) and in combination with carsharing/car-rental (23%, alternative 2). An additional 9%, 17% and 27% could be motivated through a 50% CO_2 tax on fuel, a 100% CO_2 tax on fuel and a 200% CO_2 tax on fuel to switch to alternative 1, respectively. The results for alternative 2 are very similar. Furthermore, the comparison between the count model (CO_2 tax level at the switch to the alternative) and the binary switch model (switch to an alternative, independent from the CO_2 tax level) in Figure 4.12 shows that the former provides less significant effects than the latter. Hence, the monetary push measure yields its effect irrespective of the combination with one of the three pull measures. However, despite of its effectiveness in our experiment, the reality has proven that it is difficult to win a political majority for an introduction of a CO_2 tax. In 2021, the Swiss population dismissed a CO_2 law, which included a potential rise of fuel prices by less than 10%, among other measures (Swissinfo, 2021). Hence, such a far-reaching policy would hardly be accepted by the Swiss without any supporting measures.

In our experiment, we see that the pull measures can significantly reduce the CO_2 tax level required to reach the same number of respondents who would switch to the alternative. As an example, by enabling HC & WC 41% could be motivated to switch to alternative 1 in the baseline condition. This is more effective than the control scenario including a 50% CO_2 tax on fuel, at which 39% of respondents would opt for the alternative. Combining the charging treatment with the 50% CO_2 tax scenario could increase the share of respondents willing to switch to 51%. These results are in line with previous research finding that the combination of push and pull measures can increase the efficiency of push measures (Thaller et al., 2021; Wicki et al., 2020). Shaffer et al. (2021) also argue that it may be difficult to incentivize the purchase of smaller BEVs without complementary measures such as a weight tax or a tax on annual mileage.

Referring specifically to the charging treatment, our results show that improved charging possibilities at home and at the workplace significantly increase the odds to switch from a fossil fuel car to a sustainable alternative, like the combination of a small BEV for everyday trips and public transport (alternative 1) or carsharing/car-rental (alternative 2) for long-range trips. This is in line with the findings from Wang et al. (2020) who show that improving the service quality of mobility services is important in individual's willingness to shift. Since small BEVs with a lower battery capacity would need to be charged more often compared to larger BEVs, the security that one can charge the car overnight at home or the reassurance that one may be able to recharge the vehicle at work, seems especially relevant for adopting small BEVs. Moreover, our choice-experiment indicates that fostering HC & WC further motivates people currently owning mid-sized to large cars to switch to a small BEV, which could be an important measure in cities and agglomerations, where space is scarce and the benefits of switching to a small BEV most noticeable due to their lower noise and zero exhaust gas emissions. Patt et al. (2019) show that people for whom private charging access is unproblematic are much more likely to indicate a high willingness to purchase an EV as those who park their car on the street or at a shared garage, underlining the need to foster HC & WC.

Hence, we consider it of high importance to improve charging opportunities at home for tenants, as charging access is typically less problematic for homeowners. Since respondents who currently own micro or small cars did not react to the charging treatment, we argue that improving HC & WC possibilities could be specifically targeted to large car owners.

We defined alternative 1 (BEV + PT) and alternative 2 (BEV + CS) to be a comfortable alternative for car-owning people, that is, no recharging of the BEV required if the BEV is charged at home. Car trips conducted by the conventional car would thus be replaced by the small BEV, requiring behavioral changes regarding fueling routines, but not regarding activity patterns and mode choice in daily mobility. Trips exceeding the 200 km threshold would be conducted with public transport or carsharing/car-rental with a car able to deliver the longer distance. This would require a strong behavioral change for car-owning people if these cases are frequent. We find that cumulative trips exceeding 200 km per day are very infrequent in Switzerland, making the use of alternative mobility services generally plannable without too much effort. This underlines the findings from Shi et al. (2019) who find that replacing the top 1% longest trips with an alternative could significantly increase the share of people who can conduct all trips with a BEV without the need to charge during the day.

An interesting interaction has been observed for the charging treatment. While the respondents who did not believe that a current BEV range of 250 km is sufficient for their everyday trips, could not be further motivated by the charging treatment to switch to a small BEV and carsharing/car-rental (alternative 2), respondents who state that the range of 250 km is already sufficient significantly increased the intention to switch to this alternative in the treatment condition despite, technically, not having to heavily rely on the extra charging opportunity. This suggests that people who feel that their daily mobility needs will be covered by a small BEV can further be motivated by the reassurance of charging availability at home or at the workplace, while people who feel that small BEVs will not be enough for their daily needs cannot be motivated through increased charging possibilities at home or at the workplace. In this context, however, it should be noted that the analysis of our data shows that for the majority of people, a small BEV would indeed meet their daily mobility needs. This further indicates that informing people about their actual daily range needs might increase the uptake of small BEV, which is in line with the work of Herberz et al. (2021) who find that information about compatibility of EV range with one's own mobility needs increases likelihood to buy an EV.

The sharing treatment (increasing the number of carsharing stations and possibility of peer-to-peer carsharing close to the place of residence) significantly increases the odds to switch to alternative 2 (BEV + CS) for people who don't know whether the current number of carsharing stations are sufficient to motivate them to use carsharing. As such, providing people the certainty that carsharing is available close to their place of residence could be a potential lever to a switch to a sustainable alternative to the private fossil fuelled car. The sharing treatment further reduces the necessary monetary push measures (CO_2 tax level on fuel) to motivate educated people (university degree) to switch from previously owning a fossil fuel car to a combination of public transport and carsharing/car-rental without car ownership. This suggests that people who have at least a university degree see a benefit in increasing the carsharing stations and availability of peer-to-peer carsharing in motivating them to switch to such an alternative earlier (i.e., with lower CO_2 tax on fuel). Similar to the result regarding charging stations, informing households about the proximity to carsharing stations could increase the attractiveness of such offers, especially since 27% of the respondents did not know whether the current number of carsharing stations was sufficient to motivate them to use carsharing and 31% of the respondents did not know how far the nearest carsharing station was from their home. Respondents who didn't know whether the number of carsharing stations was sufficient for them and received the carsharing treatment significantly increased the odds to switch to alternative 2 compared to the control group.

Regarding the TCO treatment (information about total cost of ownership of the current car and the alternatives), we found no significant effects for alternative 1 and alternative 2. However, respondents who received the TCO treatment and own a smaller car (size class until small-medium) were 6 times more likely to indicate a switch to alternative 3 compared to the control group. These results imply that people who own large cars seem to care more about convenience than money, whereas people who own smaller cars are likely to be more financially aware and thus react to the TCO treatment.

4.5 Conclusion and recommendations

Through a multiple price list choice-experiment with 859 Swiss households, we tested push and pull measures in motivating the respondents to switch from their current fossil fuel car to a sustainable mobility alternative. These include a small BEV for everyday trips and public transport (alternative 1) or carsharing/car-rental (alternative 2) for long-range trips, as well as a flexible combination of public transport and carsharing/car-rental without car ownership (alternative 3). As push measures, we utilized a four-step increase of CO_2 tax on fossil fuels. As pull measures, several treatments increasing the comfort and convenience of the alternatives (improved home & charge and work & charge (HC & WC) possibilities, better availability of carsharing stations (CS) and informing about total cost of ownership (TCO)) were implemented in the experiment.

The push measure tested in this paper yields consistent results regardless of whether it is combined with pull measures or used as the sole measure without any pull measures (control group). However, the pull measure of HC & WC and CS motivate additional respondents to switch before a further push measure is triggered (increase of CO_2 tax on fuel), thus creating a higher overall potential share of respondents willing to switch if combined with the push measures. The information treatment about TCO only increases the odds of choosing alternative 3, which does not include owning a car. Accordingly, the information about TCO seems to be especially relevant when fostering mobility lifestyles that are not bound to car ownership, which is still associated with status, and other values besides money (Zhao & Zhao, 2020).

Roughly 50% of respondents can't be motivated to switch through these push and pull measures. Hence, a stepwise and incremental increase of the CO_2 tax on fuel of up to 200% is consequently ignored by a significant share of our sample. At first glance, this seems surprising for such a far-reaching measure. Yet, other scholars confirm that aspects like believes, convenience and habits are hindering the switch to more sustainable alternatives (Mattauch et al., 2016; Tobler et al., 2012; Wang et al., 2020). Experiencing new mobility products and services could help breaking the routines and thus increase the willingness to change mobility habits regarding vehicle choice and the use of mobility services (Hoerler et al., 2020; Hoerler, van Dijk, et al., 2021; Schlüter & Weyer, 2019). Brückmann and Bernauer (2020) further find through a representative sample of Swiss residents that there is considerable room for more ambitious pull measures to increase the adoption of BEVs. Accordingly, we recommend implementing structural pull measures (like increased charging infrastructure at home and at the workplace or increased carsharing stations), soft pull measures (like information about TCO specifically targeted to small car owners or information about carsharing possibilities close to the place of residence) and other pull measures that provide easy access to these infrastructure (e.g., free trial day for e-carsharing). These should be combined with guiding push measures. The exact formulation of these push and pull measures depend on the local context and the ideology of the targeted population and should be adapted accordingly (Ejelöv et al., 2022; Wicki et al., 2019).

Our results provide information on how to increase the adoption of small BEVs from previously owning a fossil fuel driven car, which is not only relevant in the near term but also in the long-term, as small BEVs exhibit strong environmental benefits compared to larger BEVs with larger battery sizes (Ellingsen et al., 2016b; Wietschel et al., 2019). Since the range of 200 km is sufficient to cover most everyday needs not only in Switzerland (Melliger et al., 2018; Neuenschwander, 2020) but also elsewhere in the world like China (Hao et al., 2020), North America (Needell et al., 2016), or Norway (Figenbaum & Nordbakke, 2019), we argue that the use of mobility services like public transport, carsharing and car-rental to complement a small BEV could be, in general, a viable option in many countries.

Being representative for a large part of Switzerland, extrapolating the results of our study to other countries needs to be reflected against some key characteristics of the Swiss transport system, which hosts one of the densest public transport networks and a well-established carsharing operator covering the whole country. Further, Switzerland is a comparably small country and has a high density of public charging stations (Falchetta & Noussan, 2021).

In summary, we provide a strong basis for policy makers and mobility planners to foster sustainable and multimodal mobility lifestyles based on BEVs and mobility services by addressing a variety of push and pull measures. Switching from owning large conventional cars to a more sustainable mobility lifestyle is crucial in contributing to the mitigation of climate change and a better quality of life, especially in the growing cities.

Acknowledgment

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5 Discussion

5.1 Key contributions

The research presented in this work applies a new lens on sustainable alternatives to owning a conventional car. It also provides solutions to a much discussed and debated topic: the rise of sales in SUVs and large cars. While this topic has mostly been presented and taken up by the media, with emotional thought-provoking headings like “'A deadly problem': should we ban SUVs from our cities?” (Laker, 2019), the research community has not yet deep-dived into it but rather stayed in the shallow waters. Many authors and institutions mention the need to decrease car size in their discussion, conclusion and future research needs sections without investigating the topic themselves. As an example, Wicki et al (2022) write :

“(…) depending on BEVs' technology and price development, this desire for a long range could also lead to new BEVs becoming even larger and heavier - with negative effects on the environmental footprint of BEVs, energy efficiency, and space requirements (road space, parking spaces). To reduce range anxiety of potential buyers, expansion of the charging infrastructure would therefore counteract the subjective range anxiety and make it possible for other groups of people, who for example cannot charge at home, to charge and thus purchase a BEV. Whether this, together with the higher purchase price of long-range BEVs, can prevent or even reverse a trend towards (even) heavier and larger vehicles remains an open question, and additional government measures may be required here.” (Wicki et al., 2022, p. 8)

I also address recommendations from the International Energy Agency (IEA):

”To mitigate emissions from SUVs, the policy framework should focus on constraining their rise. Policies should support a quicker shift towards electric vehicles while also providing incentives for the early replacement of SUVs that run on petrol or diesel. The average size of vehicles in the car fleet is something that policy makers need to keep a close eye on. Apart from consuming more energy, larger cars drive up demand for critical minerals because battery-powered electric SUVs are equipped with a much larger battery (70 kilowatt-hours) than the average battery electric car (around 50 kilowatt-hours). Some governments have already started introducing relevant measures, such as France and Germany, which have put a tax on large and high-emissions cars like SUVs. Additional policies targeting SUVs will help to deliver a sustainable and low-carbon road passenger sector.” (IEA, 2021)

As another example, Blumenberg et al. (2021) mention the need for more studies investigating right-sizing of vehicle travel. They note:

“Finally, our analysis does not address the role of new technology services in influencing how households manage the vehicle fleets to which they have access. Technology-based services may enable the right-sizing of vehicle travel, a shift with potentially positive economic and environmental benefits (Cervero, 2017). For example, households may purchase smaller electric vehicles with the knowledge that they can access or rent larger vehicles—such as vans—when they might need them for weekend excursions. Conversely, they may take advantage of small electric shared vehicles for local trips rather than use a larger, less fuel efficient, private vehicle. Given its broad consequences, right-sizing travel options remains an important area for further study.” (Blumenberg et al., 2021, p. 93)

With this work, I contribute to this discussion and provide answers to the following research questions:

What are the challenges and needs regarding the adoption of MaaS?

The main challenge for MaaS is its' optimal integration into the available public transport network so to serve as a complementary service. Especially for people planning to reduce their car usage, MaaS seems to be an attractive alternative for commuting to work if it provides spontaneity, lower cost and short transfer times. However, the general openness to use MaaS for commuting was lowest and higher for leisure trips. Here, the possibility to store luggage should be given priority together with providing a sense of independence. People having experience with carsharing and those predominantly using public transport for travelling are more open to use MaaS than the respondents predominantly using their private car. This is a challenge and underlines the findings from Storme et al. (2020) that MaaS is rather a complement than a full substitution of private cars. Providing experience with new mobility services that are or could be integrated into a MaaS service, e.g., carsharing, could thus be a potential lever to a shift to MaaS. I further find that announcements of future consumer-addressing policy measures would increase openness to use MaaS. These findings provide evidence that the combination of a small BEV for everyday trips could be well complemented by a MaaS service including carsharing and other services targeted to provide the specific needs for commuting and leisure trips.

Can experience with carsharing increase the likelihood to opt for a micro to mid-sized BEV?

Yes, I find that people with carsharing experience are more likely to choose a micro to mid-sized BEV if they live in the countryside or the agglomeration after controlling for a large set of socio-demographics, mobility characteristics, attitudes and values. People living in the city do already have a high openness in choosing a micro to mid-sized BEV as their next car. Hence, the potential increase in openness from carsharing experience diminishes compared to people living in the agglomeration or countryside who have a much lower openness to choose a micro to mid-sized BEV without carsharing experience. This result shows the complementary nature of carsharing for smaller BEVs and that the "right" group, i.e., people living in the countryside and agglomeration usually characterized by owning larger cars, could be motivated to choose a small BEV as their next car. Further, this is the first study to provide empirical evidence of a potentially sustainable effect stemming from adopting carsharing besides the well-studied reduction of car use and car ownership.

What push and pull measures can increase the adoption of small BEVs in combination with mobility services?

I find that providing charging at home and at work has the highest potential in increasing the adoption of small BEVs and mobility services. The results from the choice experiment also indicate that especially people currently owning large conventional cars are more likely to switch with charging opportunities at home and at work. Providing carsharing and car-rental stations close to the place of residence further motivates respondents to adopt a mobility lifestyle owning a small BEV in combination with carsharing or car-rental for long-distance trips. Finally, push measures like an increase in fuel tax (gasoline and diesel), can consistently increase the share of households opting for the alternatives. The combination of push and pull has been found to be most effective.

Do households see a combination of owing a small BEV with occasional use of mobility services as a real alternative to owning a conventional car?

Yes, 30% of respondents switched to the alternative from previously owning a conventional car, which could be increased to up to 67% if home charging, work charging and a fuel tax of up to 200% is employed. This study thus provides a first estimate of the openness of the general public in adopting such alternative mobility lifestyles and the effect of push, pull and the combination of push and pull measures in increasing the share of potential switchers.

This dissertation provides the research community a first comprehensive summary of the openness of the general public in switching to a small BEV in combination with mobility services and what measures might increase this openness. Further, it has various implications for policy and practice. First, it serves as a summary of potential negative effects on the environment and human health if the trend towards large cars and SUVs is swapping over to BEVs. Second, it reveals the relevant characteristics that a MaaS service would need to provide in order to propel its uptake for commuting and leisure trips. Third, the dissertation finds new potentially sustainable effect from carsharing through its' complementary function to adopt small BEVs for people living outside the city. Last, it serves as a first estimate to what percentage of households with a conventional car could be motivated to switch to a small BEVs in combination with mobility services.

5.2 Recommendations

Concluding over all 3 papers presented in this thesis and reviewing the literature in this field, I argue that a large share of households could see the combination of owning a small BEV with mobility services for occasional long-range trips as a valuable alternative to the conventional car – given the right settings. The right settings are: 1) charging possibilities at home, also for households living as tenants in apartment blocks or multi-family dwellings, 2) access to a diverse set of cars including small to large and long-range cars in carsharing and car-rental services close to the place of residence, providing, for example, space for large luggage, towing capabilities or roof-racks, 3) easy-to use application, e.g., combined within a MaaS service that provides different mobility services in one platform, and 4) supporting policies like a weight and km-based tax or fee for larger, heavier cars (including BEVs), with exemptions for certain groups like professions dependent on large cars.

In detail, I recommend the following for policy and practice:

1. Charging infrastructure

In order to motivate the general public to buy a BEV, ensuring that one can charge a car at home, especially during off-peak hours where the electricity tariff is usually lowest, is key. While public fast charging stations can certainly decrease range anxiety once they are abundant with a similar spacing like fuel stations today, they provide less comfort than simply being able to plug your car at home, could be up to 10 times more expensive than charging at home and are costly to install (Borlaug et al., 2020). The total cost of electrifying the personal transportation sector could be reduced by focusing on home charging, which in turn, reduces the need for expensive fast-charging stations (Tamor, 2019). Thus, priority should be given to home charging. If very few detached houses are present and few private parking is available, as is the case, for example, in the Netherlands or Chinese megacities, public charging infrastructure is needed as a complement (Funke et al., 2019). Fast charging is relevant for long-range trips, hence mostly including highway sections. Since, in this thesis, I propose the adoption of a small BEV in combination of carsharing and car-rental or other mobility services as a complement for long-range trips, the cars rented in carsharing or car-rentals should optimally also be BEVs to mitigate GHG emissions and other pollutants. Fast charging is thus best suited to be first deployed on highway sections (Narassimhan & Johnson, 2018), enabling high range BEVs from rental services to compete with conventional cars (Habla et al., 2021). According to Wei et al. (2021), adding work charging to home charging only enables an additional 2% of vehicles to become fully electrified in Seattle, US, while allowing the vehicle to charge on highway trips enables another 27% of vehicles to be electrified. Therefore, charging at work seems to be less of priority compared to home charging and fast charging on highways.

2. Carsharing and car-rental services

Several scholars show that, to unbundle the use of cars to frequent and infrequent use, the services providing the infrequent use should optimally provide a diverse set of cars to choose from (Sprei & Ginnebaugh, 2018). These could, for example, follow the three different carsharing practices described by Svennevik et al. (2020). They find through interviews with 39 households using carsharing in Oslo, Norway, that carsharing practice can be grouped to 1) frequent, unplanned, short-term, and small-car use, 2) planned, occasional, longer-term, and larger-car use and 3) a combination of the first two practices. One interviewed person mentioned the increase in comfort a carsharing or car-rental service provides in contrast to owning a car:

"If you buy a car, then you have that one car, for all kinds of purposes. In principle, it must work for everything. While here [with car sharing] we have it all, and I enjoy having the freedom of choice when I need a small car or a large one." (Svennevik et al., 2020, p. 175)

This supports the claim of this thesis, that if you need a car, having the possibility to own a small car (small BEV) with lower costs than a larger car, could be more comfortable than having to use the large car for every kind of trip purposes. Since carsharing services typically provides smaller cars in urban areas, and car rental companies provide a wide array of small to large cars, I recommend increasing the service level of carsharing and car rental by offering bundles providing access to both car pools. Such efforts are currently done by Free2move owned by Stellantis, where you can rent cars on a minute, hourly and daily basis including a large variety of car models to choose from (Free2move, 2022).

Car-rental services are often less available close to the place of residence compared to carsharing. An opportunity to further optimize the service quality of car-rentals could be a car delivery service, which eliminates the need to first get to the car by other means of transport, reducing hurdles to try out this service and hence increase its attractiveness to customers (Thakur, 2021).

3. MaaS

MaaS has the potential to make alternatives to the private car more attractive through the combination of public transport and mobility services, combined in one app and booking system. However, as other scholars and I have shown, it will be difficult to motivate or maintain customers who are used to take their private cars (Hoerler et al., 2020; Storme et al., 2020). Hensher et al. (2022), for example, suggest including BEVs in MaaS services, calling it eMaaS. They also note that acknowledging that MaaS might have a very difficult time to be commercial without including cars in the services. One other opportunity of MaaS is the provision of bundles, e.g., monthly subscription plans including different mobility services and rebates for a fixed monthly fee depending on the bundle. In contrast, MaaS usually also provides pay-as-you-go, where customers just pay what they use without a monthly fee. Hensher et al. (2021) argues that pay-as-you-go won't bind customers to MaaS as bundle could do and that attention should be given to the local context in designing optimal MaaS bundles. Guidon et al. (2020) find through a discrete choice experiment with Swiss residents that the willingness-to-pay for carsharing is higher, if it is included within a bundle. I would thus suggest focusing on MaaS bundles including easy access to a long-range and large car, e.g., from a carsharing or car-rental service, targeted to current conventional car owners, who might switch to own a BEV. If these people experience the benefit and opportunities the access to this service provides, they might opt to not own a car or buy a small BEV, as I have shown in chapter 3. Another potential target group could be households experiencing life-changing events, such as families receiving their first child. Families with young children who don't own a car experience common frictions with mobility services like carsharing in accessing, assembling and disassembling the vehicles with child seats and personal items needed with young children (Doody et al., 2021). Hence, many families buy a car in this life stage. A small BEV might alleviate these problems, while MaaS could complement their small BEV for holiday and other occasional trips.

4. Supporting policies

While the BEV is sometimes already considered to be out of its' niche-stage and currently forming its' own regime, their share of the overall vehicle stock is still low and the increasing share in new car registrations need to maintain and rise to be able to replace the conventional car as soon as possible. Other mobility services like carsharing are already well developed in Switzerland, but currently play a neglectable role in overall mode share. Thus, several obstacles still remain for small BEVs and mobility services to dig deeper into the private fossil-fuel car dominated transport regime. Policy can help in supporting these niches to replace the current regime faster. I found that policy should focus on a combination of push- and pull measures to support this transformation.

Generally, the compatibility of a small BEV for everyday trips and potential to reduce cost (investigated in Hoerler & Stoiber (2021)) could be marketed more clearly through information campaigns. Herberz et al.

(2022) find that providing tailored compatibility information reduced range concern and increased preferences for BEVs. Further, research show that experience with BEVs could reduce range anxiety (Rauh et al., 2020) and increase its adoption intention (Brückmann, 2022; Thøgersen & Ebsen, 2019). I would thus suggest organizing events where one can easily try a BEVs for a day or weekend, e.g., through a carsharing operator providing BEVs. Governmental support could reduce the subscription fee to the carsharing service in an initial year in motivating respondents to try the service. In Wil, Switzerland, the carsharing operator Mobility cooperates with the city and the Swiss Federal Office of Energy, who financially support Mobility in providing a free carsharing subscription of residents in Wil for a year. Within two months, the number of carsharing members rose from 300 to over 500 (Mader, 2021). As I have described earlier, the charging infrastructure is key in increasing the adoption of BEVs. Policy should regulate the minimum amount of charging stations available in new and existing parking infrastructure, e.g., residential parking to counteract range anxiety. The government could further help in increasing the adoption of small BEVs by decreasing the attractiveness of conventional cars, through e.g., an increase in fuel tax, stricter fleet emissions targets or a differentiated vehicle registration and kilometer-based tax depending on the powertrain and weight of the car (Shaffer et al., 2021).

As a final comment on the recommendations for policy and practice, I would like to emphasize that my suggestion to focus on the adoption of a small BEV in combination with mobility services should target car-savvy households. Therefore, when designing policies and interventions, special care should be taken to avoid enticing households that do not currently own a car to purchase a small BEV. Such rebound effects could curtail the benefits of switching from owning a large car to a small BEV discussed in this thesis.

5.3 Limitations and outlook

I would like to focus on three main limitations, which can be addressed in future work:

1) Stated preference studies have an intention-behavior gap bias
2) Lack of alternatives in the choice experiments
3) Focus on range as the main limitation towards adoption of the alternatives

1) Stated preference studies have an intention-behavior gap bias

In this thesis, I worked with stated preference surveys, i.e., asking about the behavior and decisions of households in hypothetical scenarios. This leads to the well-known intention-behavior gap bias, since we don't know whether the respondents will actually do what they state in the survey in real life. Several methods exist to counteract this bias, and I tried to adopt as many as possible to ensure that the stated preferences adequately match real-life behavior. I used methods such as "cheap talk", realistic alternatives and follow-up questions, to allow consistency checks (Haghani et al., 2021). I also primed the respondents to encourage truthful responses (Vossler et al., 2012) and reminded them about their budget constraint (Johnston et al., 2017). Despite these efforts, a revealed preference study will be a valuable addition to the scientific literature. It could, for example, qualitatively assess the mobility behavior of households owning a small BEV as their main household car. This could include asking how they manage long-range trips and trips requiring space for large luggage and whether carsharing and car-rental services help them in keeping their mobility lifestyle. A quantitative study would also be valuable. A possible study could be to look at the share of small BEV main household cars in regions with similar settings but one without carsharing or car-rental services and one including these services. It would be important to control for various influential factors to be able to compare the two groups. Since not many households owning a small BEV exist today, such a study will be more practical to implement in the future, once more people adopt small BEVs.

2) Lack of alternatives in the choice experiments

A choice experiment is always an abstraction of the real-world, having to decide, which alternatives will be presented in the survey without overburdening the respondents but still have a valid abstraction of the real-world alternatives. In this thesis, I used two choice-experiments. While the first included four alternative powertrains and a variety of attribute levels describing the alternatives, the second focused on providing a single but thoroughly defined alternative to owning a conventional car. In both cases, not all real-world options are included, since, e.g., people could also opt to buy a gas-powered car or fuel-cell electric vehicle. However, the share of these car options on new car registrations are low and are also expected to be low in the near future. Hence, I decided to neglect these offers. Other issues remain regarding the diversity of attributes shown to the survey respondents. While I provided the most relevant information, i.e., purchase price, driving cost and range, other attributes might be of high relevance for the respondents that could influence their choice in real-life.

3) Focus on range as the main limitation towards adoption of the alternatives

I focused on range as the main limitation in choosing a small BEV over a larger BEV. In reality, however, several other issues could refrain households to opt for a smaller BEV, e.g., status, luggage capacity, car brand or safety.

I will provide answer to the second and third point with an additional choice experiment currently under analysis. Therein I focus on the influence of information provision (regarding the compatibility of mobility services with a small BEV), improved charging possibilities at home and improved carsharing/car-rental availability close to the place of residence on the car size and powertrain choice preference of current car owners. It will overcome one limitation of contribution 3 (Chapter 4), where I didn't include the possibility to choose a large BEV as the next car replacement, which is possible in this new experiment. Further, it allows to control the influence of personal preference in car purchase decisions, e.g., car brand, by including a combination of between- and within-subject survey design. The study further detaches the range preferences from the car size preference, which was fixed in contribution 3 (buying a small BEV with a range of 400km capable to conduct all everyday trips until 200km). In the new experiment, respondents can choose 3 different range categories from 200km, 400km and 600km.

Another aspect worth for future research is the role of carsharing and other car-rental services for the recycling industry and circular economy endeavors. Several researchers show that due to the higher utility rate of shared cars, the average lifespan is reduced, from the usually expected life of 10 to 15 years for private cars to roughly 3 to 4 years for shared cars (Rentizelas & Trivyza, 2022). This has implications for the recycling industry and a circular economy in general since waste or second-purpose batteries will be available faster. This could, e.g., reduce the need for primary materials, given that the overall stock of BEVs is not increased. Kamran et al. (2021) estimate that the United Kingdom could actually become a net supplier of lithium, cobalt, manganese and nickel by 2040 through a gradual increase of shared mobility services (including carsharing, car-rental and ride-sharing). However, many assumptions made in the literature are uncertain, especially for a timespan of up to 2050. It is unclear, for example, whether gains in battery energy density will be used to increase the range of BEVs, even outcompeting conventional ICEVs (such as over 1000km range) (Galvin, 2022), or if the high energy density batteries could support the uptake of smaller cars. Such interactions of technology developments and consumer behavior, and their implications for the circular economy, could be an interesting future research field.

Another topic, which wasn't in the scope of this thesis is vehicle-to-grid (V2G). When parked and plugged, BEVs equipped for bidirectional charging could serve as storage for renewable energy that can be fed back into the grid (Xu et al., 2020). A lot of research is currently funded in Europe regarding the potential of this technology to reduce peak-demand in charging, provide flexibility to the grid as well as cost benefits to BEV owners and grid operators (Brinkel et al., 2020; Noel et al., 2021). However, high investment costs are necessary to enable viable large scale V2G operations and it is unclear how V2G competes with stationary batteries, e.g., form end-of-life BEVs in the short to long-term (Sovacool et al., 2020). The competition of V2G with stationary batteries could be an interesting field for future studies.

Since V2G increase the number of charging cycles, the battery degrades faster. Other aspects, such as state of charge of the BEV, increased range anxiety and restrictions of freedom were further found to be a concerns for private vehicle owners (Ghotge et al., 2022). For households owning BEVs with a small to medium-sized battery capacity, e.g., 50kWh, V2G might be less accepted than people owning cars with larger batteries, e.g., 100kWh. Further, large batteries are most suitable for high-range applications, such as in carsharing, car-rental and ridesharing systems. Yet, the main goal of these systems is to increase their utility rate, which would decrease the potential for V2G. Battery swapping stations might help mobility service providers in this regard, since customers could still rent and drive cars, while the batteries in the swapping station could be charged or discharged (Sovacool et al., 2020). Research show that V2G might increase the profitability of carsharing services, which usually struggle to be profitable (Gschwendtner & Krauss, 2022; Zhang et al., 2021). Further research is necessary to understand how mobility service providers could adopt V2G and still maintain their customer base.

Acknowledgements

I would like to express my sincere appreciation for all people who supported me in this endeavour, whether in direct relation to the research or simply to distract me from the work.

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Finally, many thanks to my friends, family, and partner. You are the best!

Appendix A: Contribution 1

Table A1: Example of treatment 2 (five-star rating of a combined mobility service).

Public transport	★★★☆☆
Carsharing	★★★★☆
Car with driver (e.g. Taxi, Uber)	★★★☆☆
Combined mobility services	★★★★★

Table A2: Example of treatment 3 & 4.

T3 (policy planned)	**T4 (policy decided)**
With the Paris Climate Agreement the international community of states aims to keep global warming below 2 degrees. Following that, the Swiss government has defined a target to reduce national emissions by 50% compared to 1990 levels. Since the transportation sector is responsible for a large share of total CO2 emissions in Switzerland, one central climate policy pillar addresses mobility and transportation. Across the world one can observe similar efforts. The Chinese Government aims to achieve a quota of at least 8 percent of electric cars by 2019, rising up to 20% in 2025. To fulfil this target, they introduced a fixed sales quota for car suppliers, but also implemented various policies directly addressing consumers, such as the introduction of different number plates (with restricted quantities for non-electric cars). Other countries abolished highway fees for electric cars (Norway) or increased fuel levies (France). Oxford decided to ban all diesel and fuel-powered cars in the city centre from 2020 onwards and similar policies are discussed in several German cities. Assume now, that the Swiss government has announced, that it wants to achieve a new sales quota of 20% of electric cars by 2023. **The policy to achieve this target has not been defined yet and is matter of discussion in the parliament.**	With the Paris Climate Agreement the international community of states aims to keep global warming below 2 degrees. Following that, the Swiss government has defined a target to reduce national emissions by 50% compared to 1990 levels. Since the transportation sector is responsible for a large share of total CO2 emissions in Switzerland, one central climate policy pillar addresses mobility and transportation. Across the world one can observe similar efforts. The Chinese Government aims to achieve a quota of at least 8 percent of electric cars by 2019, rising up to 20% in 2025. To fulfil this target, they introduced a fixed sales quota for car suppliers, but also implemented various policies directly addressing consumers, such as the introduction of different number plates (with restricted quantities for non-electric cars). Other countries abolished highway fees for electric cars (Norway) or increased fuel levies (France). Oxford decided to ban all diesel and fuel-powered cars in the city centre from 2020 onwards and similar policies are discussed in several German cities. Assume now, that the Swiss government has announced, that it wants to achieve a new sales quota of 20% of electric cars by 2023. **From 2020 onwards several measures will be implemented step-wise, such as increasing fuel levies,**

	vehicle import restrictions and a ban of non-electric vehicles in the city centre.

Table A3: Wording of environmental attitude questions summarized as one pro-environmental attitude variable.

Likert scale: 1- totally disagree to 5 - totally agree
PROUD when I act in an environmentally friendly manner
HAPPY when I conserve or avoid wasting natural resources
GUILTY when I harm the environment
APPRECIATION towards others when they act in an environmentally friendly manner
WARM towards others when they conserve or avoid wasting natural resources
CONTENT when I act in an environmentally friendly manner
INDIGNANT when others act in an environmentally unfriendly manner
REGRET when I waste natural resources
ANGRY when others act in an environmentally unfriendly manner
ASHAMED when I act in an environmentally unfriendly manner
DISGUSTED when others waste natural resources
POSITIVE towards others when they act environmentally friendly

Appendix B: Contribution 2

Table B1 compares the study sample with the overall SHEDS 2018 sample and the Swiss population. SHEDS is representative of the Swiss population for age, gender, region (French-speaking and German-speaking) and tenancy status (tenants and owners).

Table B1: Comparison of the study sample, SHEDS 2018 and the Swiss population.

Variable	**Level**	**Study (n = 995)**	**SHEDS 2018 (n = 5'514)**	**Difference Study/SHEDS**	**Swiss population**
Age[1]	Average	48.65	44.25	$t(994) = 9.20, p = < 0.001$	*42.4*
Gender[2]	Male	51.5%	47.3%	χ^2 (1, N = 995) = 6.90, $p = 0.009$	49.6 %
	Female	48.5%	52.7%		50.4 %
Education[3]	Apprenticeship	32.7%	33.3%	χ^2 (2, N = 890) = 0.19, $p = 0.91$	41.1%
	High school	13.5%	13.6%		9.4%
	Higher education	53.8%	53.1%		49.5%
Gross Household income[4]	Less than 3'000 CHF	4.1%	6.0%	χ^2 (5, N = 845) = 7.60, $p = 0.18$	10'033 CHF (average)
	3'000–4'500 CHF	10.3%	10.0%		
	4'501–6'000 CHF	18.9%	17.9%		
	6'001–9'000 CHF	30.1%	28.9%		
	9'001–12'000 CHF	21.9%	20.9%		
	More than 12'000 CHF	14.7%	16.3%		

[1]Swiss Federal Statistical Office (2020).

[2]Swiss Federal Statistical Office (2018b).

[3]Swiss Federal Statistical Office (2019).

[4]Swiss Federal Statistical Office (2018a).

Table B2: Sample characteristics (n = 826).

Variable	**Level**	**Frequency**	**Percentage**	**Mean (Standard Deviation)**
		Socio-demographics		
Age	18-34	202	24.5	-
	35-54	324	39.2	-

	55+	300	36.3	-
Gender	Male	414	50.1	-
	Female	412	49.9	-
Education	Less than university degree	420	50.9	-
	University degree	389	48.1	-
Type of living area	City	415	50.2	-
	Agglomeration	232	28.1	-
	Countryside	179	21.7	-
Gross HH income	Until 5'999 CHF	219	27.0	-
	6'000–8'999 CHF	216	26.6	-
	9'000–12'000 CHF	146	18.0	-
	More than 12'000 CHF	114	14.1	-
	Prefers not to say	116	14.3	-
HH structure	Single person HH	243	29.4	-
	Couple without children	280	33.9	-
	HH with children	266	32.2	-
	Non-family shared HH	37	4.5	-
HH size	Mean	826	-	2.22 (1.16)
	Mobility characteristics			
Carsharing experience	No carsharing experience	500	60.5	-
	Some carsharing experience	326	39.5	-
Public transport passes	GA 1st class	35	4.2	-
	GA 2nd class	159	19.2	-
	Regional pass	167	20.2	-
	None	465	56.3	-
Number of cars in HH	0	205	24.8	-
	1	409	49.5	-
	2 or more	212	25.7	-
Dominant mode choice: commuting	Own car	310	39.7	-
	Public transport	365	46.7	-
	Bike or foot	106	13.6	-
Dominant mode choice: weekday leisure	Own car	351	43.9	-
	Public transport	216	27.0	-
	Bike or foot	233	29.1	-
Dominant mode choice: weekend trip	Own car	428	57.8	-
	Public transport	243	32.8	-
	Bike or foot	69	9.3	-
Car size choice	None	96	11.6	-
	Micro	15	1.8	-
	Small	239	28.9	-
	Small-medium	191	23.1	-
	Mid-sized	127	15.4	-
	Large	30	3.6	-
	SUV	128	15.5	-

Powertrain choice	BEV	247	33.8	-
	PHEV	122	16.7	-
	HEV	111	15.2	-
	ICEV	250	34.2	-
Time home-(commuting, weekday leisure, weekend trip)	Commuting	826	-	24.20 (25.34)
	Weekday leisure	826	-	17.15 (18.83)
	Weekend trip	826	-	49.82 (56.79)
Attitudes and values				
Consider electric vehicle?	No	399	48.3	-
	Yes	427	51.7	-
Importance of safety	Not at all important (1)	0	0	4.26 (0.73)
	Not important (2)	18	2.2	
	Indifferent (3)	88	10.7	
	Important (4)	382	46.3	
	Very Important (5)	337	40.8	
Importance of safety binary	Important or less	488	59.2	-
	Very important	337	40.8	-
Importance of being comfortable	Not at all important (1)	6	0.7	3.78 (0.82)
	Not important (2)	41	5.0	
	Indifferent (3)	228	27.6	
	Important (4)	402	48.7	
	Very Important (5)	149	18.0	
Importance of being comfortable binary	Indifferent or less	275	33.3	-
	Important and very important	551	66.7	-
Importance of privacy	Not at all important (1)	0	0	4.36 (0.70)
	Not important (2)	10	1.2	
	Indifferent (3)	75	9.1	
	Important (4)	351	42.5	
	Very Important (5)	390	47.2	
Importance of privacy binary	Important or less	436	52.8	-
	Very important	390	47.2	-
Importance of owning a car	Not at all important (1)	224	27.1	3.06 (1.52)
	Not important (2)	74	9.0	
	Indifferent (3)	135	16.3	
	Important (4)	212	25.7	
	Very Important (5)	181	21.9	
Importance of owning a car binary	Indifferent or less	433	52.4	-
	Important and very important	393	47.6	-
Values (Likert scale from 1 (lowest) to 5 (highest))	Biospheric	826	-	4.06 (0.74)
	Egoistic	826	-	2.65 (0.72)
	Altruistic	826	-	3.98 (0.69)
	Hedonic	826	-	3.76 (0.76)

GA = General Abonnement, a public transport pass with unlimited travel in Switzerland of most railways and other public transport.

Table B3: Spearman correlation matrix for all variables included in the final binary logistic regression model.

Spearman's rho	Age	Education	Type of living area	HH structure	Carsharing experience	Number of cars in HH	Mode choice: commuting	Mode choice: weekday leisure	Consider electric vehicle?	Importance of safety	Importance of privacy	Values: Biospheric	Values: Altruistic	Values: Hedonic	Carsharing experience * Type of living area
Age	--														
Education	-,186**	--													
Type of living area	0.014	-,117**	--												
HH structure	-,093**	0.029	,078*	--											
Carsharing experience	-,178**	,115**	-,087*	0.019	--										
Number of cars in HH	0.065	-,075*	,329**	,218**	-,211**	--									
Mode choice: commuting	-,096**	,151**	-,285**	0.012	,156**	-,509**	--								
Mode choice: weekday leisure	-0.031	0.056	-,206**	0.000	,114**	-,393**	,473**	--							
Consider electric vehicle?	-,085*	,241**	-,091**	0.036	,126**	-,091**	,152**	,126**	--						
Importance of safety	0.040	-,101**	0.002	-0.062	-,095**	0.062	-,153**	-,156**	-,086*	--					
Importance of privacy	-0.033	0.022	-0.017	-,086*	-0.014	-0.032	-0.064	-,082*	0.036	,364**	--				
Values: Biospheric	,166**	-0.038	-0.040	-0.052	-0.008	-,155**	,158**	,095**	,137**	,126**	,142**	--			
Values: Altruistic	,124**	-0.019	-0.053	-0.047	,089*	-,097**	0.061	0.002	,107**	,177**	,150**	,519**	--		
Values: Hedonic	-,215**	0.015	-0.012	-0.034	0.020	,096**	-,105**	-,090*	-0.023	,219**	,248**	,110**	,120**	--	
Carsharing experience * Type of living area	-,162**	,088*	,077*	,034	,968**	-,151**	,104**	,075*	,111**	-,107**	-,019	-,002	,085*	,017	--

* and ** significant at p < 0.05 and p < 0.01 (2-tailed), respectively

Appendix C: Contribution 3

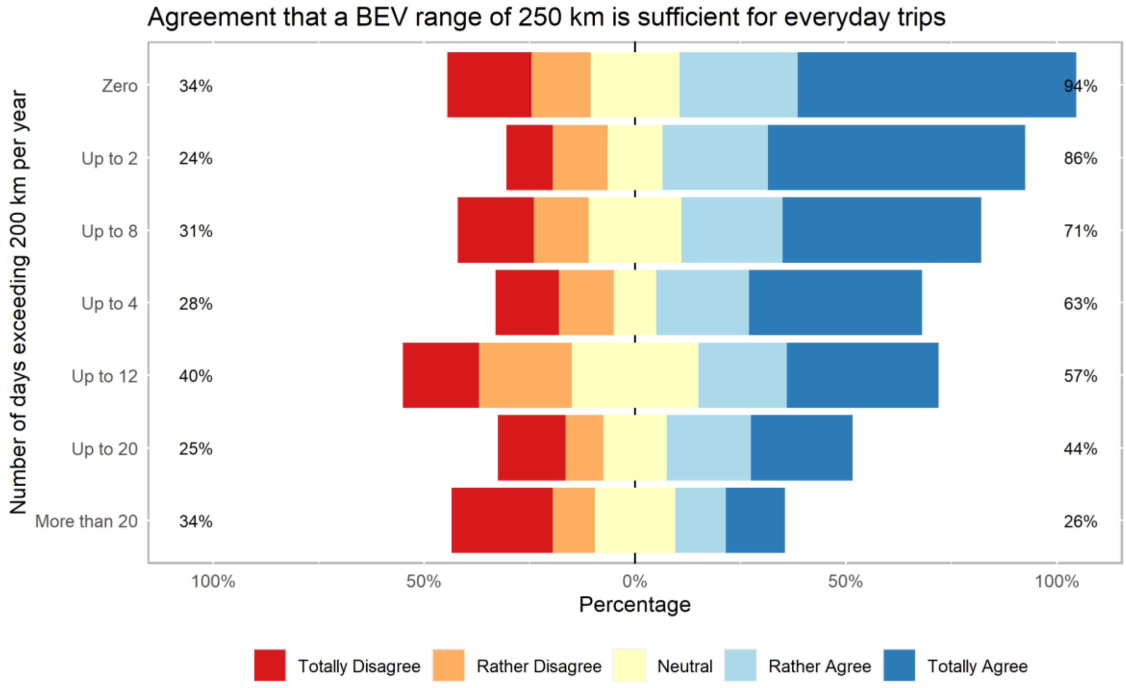

Figure C1: Agreement with BEV range sufficiency for the number of days exceeding 200km per year.

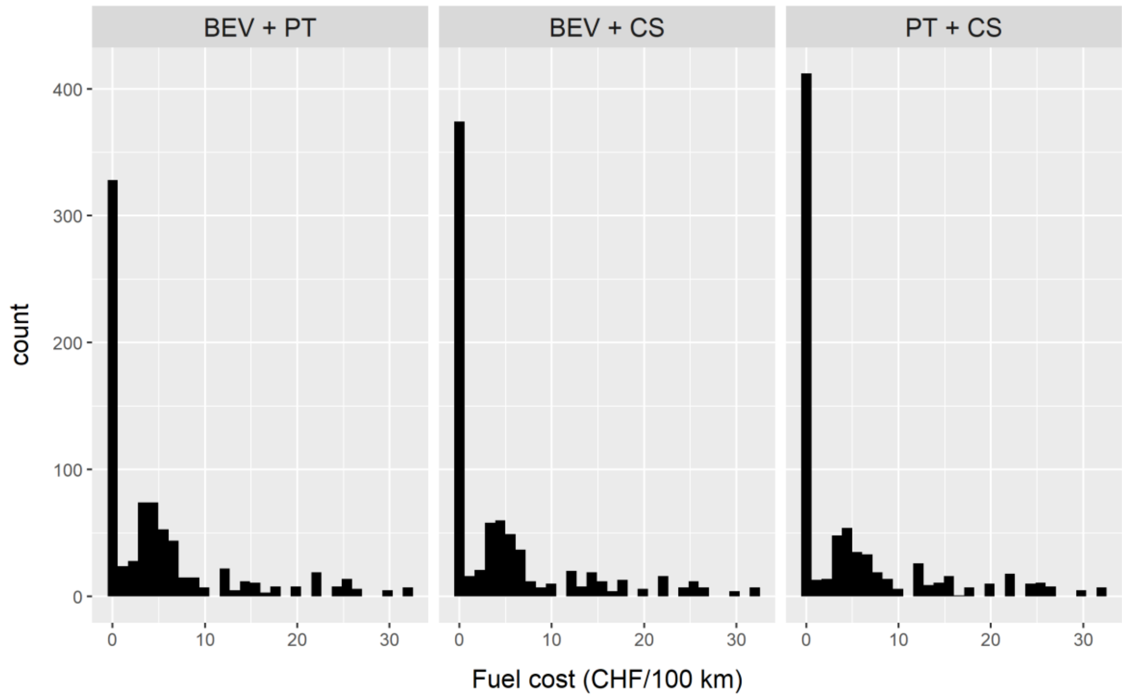

Figure C2: Histogram of fuel cost for each alternative. A fuel cost of zero represents “no switch”.

Table C1: Survey variables included in the study.

Variable	Level	Frequency	Percentage	Mean (Standard Deviation)
	Socio-demographics			
Age	18-34	170	20	-
	35-54	367	43	-
	55+	322	37	-
Gender	Male	462	54	-
	Female	397	46	-
Education	Less than university degree	456	53	-
	University degree	403	47	-
Type of living area	City	342	40	-
	Agglomeration	285	33	-
	Countryside	232	27	-
Gross HH income	Until 4'500	95	11	-
	4,501-6,000	77	9	-
	6,001-9,000	209	24	-
	9,001-12,000	196	23	-
	More than 12,000	141	16	-
	Prefer not to say	141	16	-
HH structure	Single person HH	181	21	-
	Couple without children	283	33	-
	HH with children	358	42	-
	Non-family shared HH	37	4	-
HH size	Mean	859	-	2.50 (1.24)
	Mobility characteristics			
Carsharing experience	No carsharing experience	831	97	-
	Some carsharing experience	28	3	-
Number of carsharing stations sufficient?	Number CS stations insufficient	379	44	-
	I don't know	228	27	-
	Number of CS stations sufficient or indifferent	252	29	-
Public transport passes	None	158	18	-
	General abonnement (GA)	144	17	-
	Half-fare	500	58	-
	Other	55	6	-
Number of cars in HH	1 car	545	63	-
	2 or more cars	314	37	-

Dominant mode choice: commuting	Private car	289	34	-
	Public transport	197	23	-
	Soft modes	122	14	-
	Other	251	29	-
Dominant mode choice: leisure	Private car	524	61	-
	Public transport	121	14	-
	Soft modes	172	20	-
	Other	42	5	-
Car size of primary car	Micro	16	2	-
	Small	211	25	-
	Small-medium	201	23	-
	Mid-size	196	23	-
	Large	52	6	-
	SUV	183	21	-
Range of small BEV sufficient for everyday trips?	Range of 250km not sufficient or indifferent	346	40	-
	I don't know	72	8	-
	Range of 250km sufficient	441	51	-
Number of daytrips with the main car exceeding 200 km per year	Until 6 trips per year	528	61	-
	More than 6 trips per year	331	39	-
Number of overnight trips per year with the main car exceeding 200 km oneway	Until 2 trips per year	667	78	-
	More than 2 trips per year	192	22	-
	Attitudes and values			
Importance of safety	Not at all important (1)	2	0	4.29 (0.70)
	Not important (2)	6	1	
	Indifferent (3)	91	11	
	Important (4)	397	46	
	Very Important (5)	362	42	
Importance of being comfortable	Not at all important (1)	6	1	3.83 (0.78)
	Not important (2)	25	3	
	Indifferent (3)	233	27	
	Important (4)	436	51	
	Very Important (5)	159	19	
Importance of privacy	Not at all important (1)	3	0	4.32 (0.70)
	Not important (2)	8	1	
	Indifferent (3)	74	9	
	Important (4)	398	46	
	Very Important (5)	376	44	

Importance of having nice possessions	Not at all important (1)	61	2	3.05 (0.99)
	Not important (2)	165	25	
	Indifferent (3)	358	23	
	Important (4)	220	23	
	Very Important (5)	55	6	
Importance of owning a car	Not at all important (1)	58	7	3.68 (1.18)
	Not important (2)	89	10	
	Indifferent (3)	166	19	
	Important (4)	301	35	
	Very Important (5)	245	29	
Values (Likert scale from 1 (lowest) to 5 (highest))	Hedonic	859	-	3.70 (0.73)
	Egoistic	859	-	2.75 (0.73)
	Altruistic	859	-	3.93 (0.68)
	Biospheric	859	-	3.96 (0.72)

HH = household, GA = General Abonnement, a public transport pass with unlimited travel in Switzerland of most railways and other public transport.

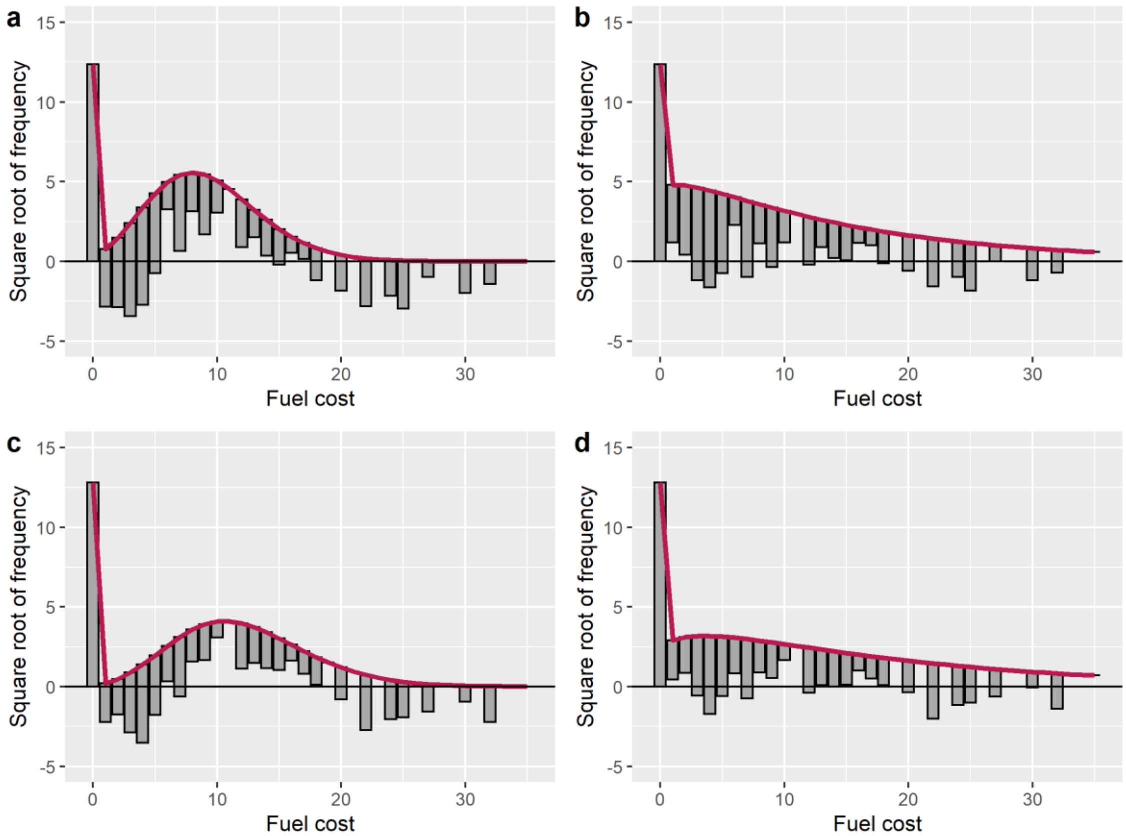

Figure C3: Rootogram for alternative 1 (BEV + PT). a) Charging treatment with poisson model b) Charging treatment with binomial model c) TCO treatment with poisson model d) TCO treatment with binomial model.

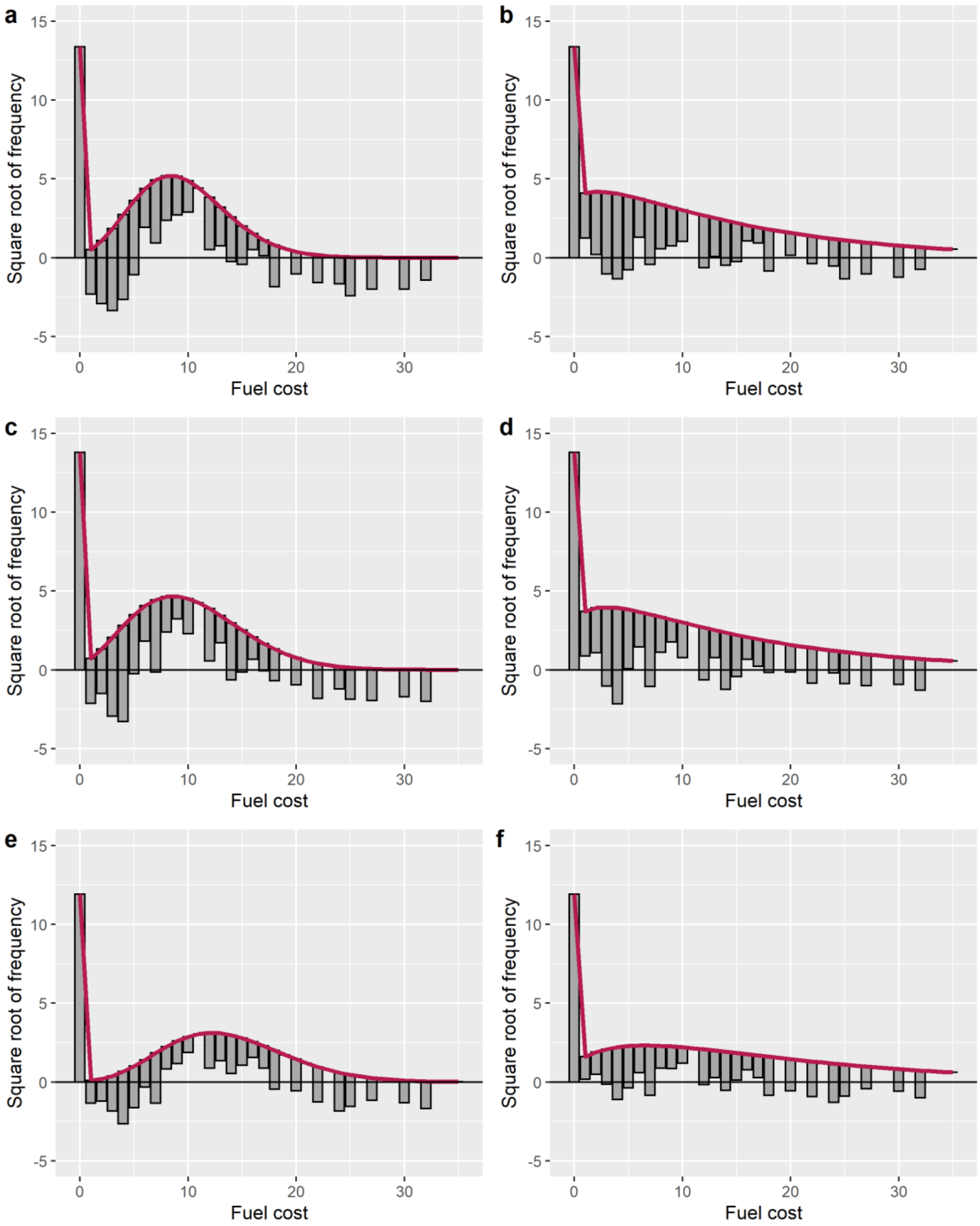

Figure C4: Rootogram for alternative 2 (BEV + CS). a) Charging treatment with poisson model b) Charging treatment with binomial model c) Sharing treatment with poisson model d) Sharing treatment with binomial model e) TCO treatment with poisson model f) TCO treatment with binomial model.

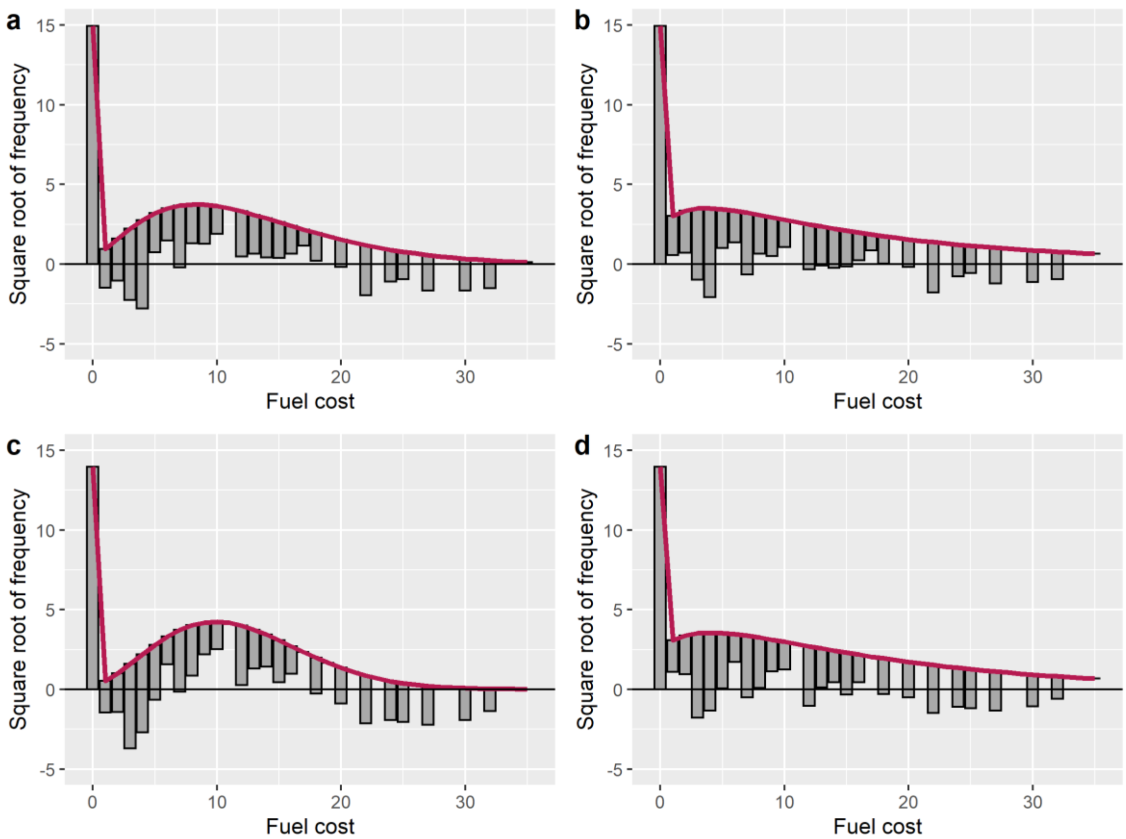

Figure C5: Rootogram for alternative 3 (PT + CS). a) Sharing treatment with poisson model b) Sharing treatment with binomial model c) TCO treatment with poisson model d) TCO treatment with binomial model.

Table C2: Hurdle model of alternative 1 for the charging treatment including control variables.

Hurdle model Alternative 1: Charging treatment			
Predictors	*OR*	*95% CI of OR*	*p*
Count model			
(Intercept)	6.34	4.07 – 9.86	<0.001
Charging treatment	0.91	0.71 – 1.16	0.434
Public transport pass: GA	0.82	0.60 – 1.12	0.211
Importance of owning a car	1.08	0.97 – 1.20	0.158
Dominant mode choice commuting: Public transport	1.17	0.88 – 1.55	0.287
Log(theta)			**0.0558**
Binary switch model (Zero-inflated model)			
(Intercept)	4.91	1.14 – 21.12	0.032
Charging treatment	0.24	0.05 – 1.29	0.096
Education: University	1.34	0.87 – 2.08	0.184
Gross HH income: 4'501-6'000 CHF	1.6	0.74 – 3.46	0.231
Gross HH Income: 9'001-12'000 CHF	1.25	0.75 – 2.10	0.396

GA public transport pass	1.22	0.73 – 2.02	0.448
Importance of owning a car	0.79	0.65 – 0.96	0.015
Car size of primary car: Larger than small	0.67	0.34 – 1.31	0.244
Charging treatment * Car size of primary car: Larger than small	2.84	1.11 – 7.24	0.029
Observations	394		
R^2 / R^2 adjusted	0.418 / 0.411		

Table C3: Hurdle model of alternative 1 for the TCO treatment including control variables.

Hurdle model Alternative 1: TCO treatment			
Predictors	*OR*	*95% CI of OR*	*p*
Count model			
(Intercept)	10.69	8.31 – 13.75	<0.001
Treatment TCO	1.16	0.89 – 1.52	0.282
Number of cars in HH: 2 or more cars	1.15	0.87 – 1.52	0.328
Range EV sufficient? Range of 250 km sufficient	0.79	0.60 – 1.05	0.104
Log(theta)			**0.00224**
Binary switch model (Zero-inflated model)			
(Intercept)	3.85	0.80 – 18.44	0.092
Treatment TCO	1.09	0.70 – 1.71	0.705
Number of cars in HH: 2 or more cars	0.91	0.56 – 1.48	0.713
HH size	1.13	0.93 – 1.36	0.213
Observations	320		
R^2 / R^2 adjusted	0.456 / 0.449		

Table C4: Hurdle model of alternative 2 for the charging treatment including control variables.

Hurdle model Alternative 2: Charging treatment			
Predictors	*OR*	*95% CI of OR*	*p*
Count model			
(Intercept)	9.06	7.54 – 10.89	**<0.001**
Charging treatment	0.87	0.68 – 1.11	0.264
Log(theta)			**0.0107**
Binary switch model (Zero-inflated model)			
(Intercept)	3.76	1.57 – 9.06	0.003
Charging treatment	2.5	1.31 – 4.75	0.005
Gross HH Income: 9'001-12'000 CHF	1.04	0.63 – 1.71	0.884
Dominant mode choice commuting: Public transport	1.1	0.66 – 1.83	0.725
Importance of owning a car	0.74	0.60 – 0.90	0.003

Range EV sufficient? Range of 250 km not sufficient	0.83	0.44 – 1.55	0.558
Range EV sufficient? I don't know	0.15	0.04 – 0.56	0.005
Charging treatment * Range EV sufficient? Range of 250 km not sufficient	0.25	0.10 – 0.61	0.003
Charging treatment * Range EV sufficient? I don't know	1.79	0.32 – 9.95	0.507
Observations	385		
R^2 / R^2 adjusted	0.681 / 0.679		

Table C5: Hurdle model of alternative 2 for the sharing treatment including control variables.

Hurdle model Alternative 1: Sharing treatment			
Predictors	*OR*	*95% CI of OR*	*p*
Count model			
(Intercept)	4.98	2.99 – 8.29	<0.001
Sharing treatment	1.02	0.79 – 1.31	0.888
Dominant mode choice leisure: Public transport	0.89	0.63 – 1.25	0.498
Number of cars in HH: 2 or more cars	1	0.78 – 1.30	0.987
Importance of owning a car	1.19	1.06 – 1.33	0.004
Public transport passes: Half-fare	0.98	0.76 – 1.26	0.872
Number of carsharing stations sufficient? Sufficient or indifferent	0.98	0.75 – 1.27	0.853
Log(theta)			**<0.001**
Binary switch model (Zero-inflated model)			
(Intercept)	0.82	0.21 – 3.18	0.769
Sharing treatment	2.8	1.19 – 6.58	0.018
Dominant mode choice leisure: Public transport	1.51	0.77 – 2.97	0.231
Number of cars in HH: 2 or more cars	0.99	0.63 – 1.55	0.958
Importance of owning a car	0.75	0.61 – 0.92	0.006
Number of carsharing stations sufficient? Insufficient	1.95	0.92 – 4.12	0.08
Number of carsharing stations sufficient? Sufficient or indifferent	4.33	1.95 – 9.63	<0.001
Sharing treatment * Number of carsharing stations sufficient? Insufficient	0.34	0.12 – 0.96	0.041
Sharing treatment * Number of carsharing stations sufficient? Sufficient or indifferent	0.21	0.07 – 0.69	0.01
Observations	388		
R^2 / R^2 adjusted	0.466 / 0.456		

Table C6: Hurdle model of alternative 2 for the TCO treatment including control variables.

Hurdle model Alternative 2: TCO treatment			
Predictors	*OR*	*95% CI of OR*	*p*
Count model			
(Intercept)	10.87	5.66 – 20.87	**<0.001**
TCO treatment	1.23	0.92 – 1.65	0.169
Number of cars in HH: 2 or more cars	1.15	0.85 – 1.54	0.371
Log(theta)			**<0.001**
Binary switch model (Zero-inflated model)			
(Intercept)	2.53	0.49 – 13.12	0.27
TCO treatment	0.96	0.56 – 1.64	0.891
Number of cars in HH: 2 or more cars	1.58	0.91 – 2.74	0.101
Observations	239		
R^2 / R^2 adjusted	0.612 / 0.607		

Table C7: Hurdle model of alternative 3 for the sharing treatment including control variables.

Hurdle model Alternative 3: Sharing treatment			
Predictors	*OR*	*95% CI of OR*	*p*
Count model			
(Intercept)	4.26	2.14 – 8.48	**<0.001**
Sharing treatment	1.1	0.79 – 1.52	0.584
Dominant mode choice leisure: Public transport	0.7	0.51 – 0.96	**0.026**
Public transport passes: Half-fare	0.79	0.62 – 1.01	0.063
Hedonic value	1.05	0.90 – 1.23	0.521
Importance of owning a car	1.22	1.10 – 1.36	**<0.001**
Education: University	1.63	1.18 – 2.24	**0.003**
Sharing treatment * Education: University	0.51	0.32 – 0.82	0.006
Log(theta)			**<0.001**
Binary switch model (Zero-inflated model)			
(Intercept)	6.29	1.78 – 22.21	**0.004**
Sharing treatment	0.93	0.61 – 1.43	0.754
Number of cars in HH: 2 or more cars	0.78	0.50 – 1.23	0.290
Importance of owning a car	0.68	0.56 – 0.82	**<0.001**
Observations	391		
R^2 / R^2 adjusted	0.646 / 0.638		

Table C8: Hurdle model of alternative 3 for the TCO treatment including control variables.

Hurdle model Alternative 3: TCO treatment			
Predictors	*OR*	*95% CI of OR*	*p*
Count model			
(Intercept)	6.4	4.32 – 9.48	**<0.001**
TCO treatment	0.82	0.65 – 1.03	0.086
Importance of owning a car	1.18	1.07 – 1.29	**0.001**
Log(theta)			**<0.001**
Binary switch model (Zero-inflated model)			
(Intercept)	2.78	1.22 – 6.37	0.015
TCO treatment	2.62	1.43 – 4.78	0.002
Car size of primary car: Larger than small-medium	1.41	0.78 – 2.55	0.253
Number of cars in HH: 2 or more cars	0.69	0.44 – 1.08	0.106
Importance of owning a car	0.7	0.57 – 0.85	<0.001
Treatment TCO * Car size of primary car: Larger than small-medium	0.4	0.17 – 0.93	0.033
Observations	381		
R^2 / R^2 adjusted	0.377 / 0.373		

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2013 – 2017	**Interviewer** Link Institute, Zurich, Switzerland
2014 – 2015	**Internship** Swiss Federal Laboratories for Material Science and Technology St. Gallen, Switzerland

Journal articles

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