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Flying to Thailand?

Quantifying and Comparing Consumption Induced Carbon Emissions of B2C Car Sharing Users

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Abstract

Car sharing (CS) is a growing phenomenon globally but its environmental implications are not yet fully explored. While many researchers agree that it could have multiple direct environmental benefits, indirect effects like carbon emissions induced through changed consumption patterns have been poorly explored. This thesis aims to quantify and compare consumption induced carbon emissions (CCE) of CS users with a baseline of non-CS users to better understand the environmental consequences of CS. A survey design was chosen to collect data from a sample of CS users in Berlin and Hamburg, analyse the potential changes in consumption patterns and calculate consumption induced carbon emissions by using carbon intensities of selected consumption categories.

The main finding is that when CS is perceived to induce savings, CCE of CS users are lower relative to an applicable baseline. However, when CS is seen as a more expensive option to personal mobility, the CCE increase. This study contributes to the CS literature by suggesting that altered consumption patterns may not partially offset but in some cases contribute to the positive environmental effects of CS. The findings also highlight the potential of CS to reduce transport induced carbon emissions because in many cases monetary savings compared to car ownership can be realised and thus also reductions in CCE. Further research must estimate CS users' consumption patterns and carbon intensities of consumption categories more precisely to arrive at more accurate findings for changes in CCE. Long-term implications of a shift towards CS also have to be examined because the findings indicate that in such a scenario the potential for increasing CCE and backfire rises. Both the magnitude of this effect and potential countermeasures need to be further investigated.

Keywords: Car Sharing, Consumption Induced Carbon Emissions, Rebound Effects

Executive Summary

Problem Definition and Research Questions

Many cities across the world are facing multiple issues related to their transport systems. The reliance on the private car as the main mode of transport has led to problems like rising carbon emissions, pollution, congestion, noise levels and land use (Miller & Spoolman, 2012). Growing urbanisation globally (Miller & Spoolman, 2012) only adds to the relevance of these concerns.

Car sharing (CS) is promoted by CS companies but also an increasing number of researchers as one measure to tackle these issues and is growing in popularity globally (S. A. Shaheen, 2018). Especially rising carbon emissions are addressed, mainly because CS users are reported to travel shorter distances by car (Martin & Shaheen, 2016), reduce their private car ownership (Chen & Kockelman, 2016), and use more sustainable modes of transport (Firnkorn & Müller, 2011).

These direct effects of CS are regarded as strong and sufficient positive sustainability implications for policy makers to support CS schemes, but the full implications of CS have yet to be explored. Little is known about indirect effects of CS, like the rebound effect and carbon emissions caused by changes in consumption patterns. This knowledge gap puts decisions makers in a difficult situation, especially when considering that these indirect effects could partially offset or in the worst case reverse the positive environmental effects of CS (Briceno, Peters, Solli, & Hertwich, 2005; Chen & Kockelman, 2016). But the studies discussing indirect effects are sparse and their findings have to be treated with caution because they involve numerous analytical assumptions. Exploring indirect effects, like consumption induced carbon emissions (CCE), helps to reduce the knowledge gap and adds to the academic discourse regarding the interrelationship between (CS) practices and CCE, thus providing more information for policy makers.

The following research questions are addressed in this thesis to quantify and compare CCE of B2C CS users with a baseline of non-CS users. The studied population consists of CS users in the German cities of Hamburg and Berlin.

RQ1: How does engaging in car sharing affect the disposable income of car sharing users?
RQ2: How do changes in the disposable income affect consumption patterns of CS users?
RQ3: How do altered consumption patterns influence consumption induced carbon emissions of CS users and how do they compare to a baseline scenario?

The following relationship between the variables in the research questions is postulated. It is assumed that CS influences the disposable income of CS users, which in turn affects consumption patterns and CCE. Other effects are acknowledged but considered to be out of scope.

Research Design and Methodology

Primary data was collected using a cross-sectional survey design which was used to assess the changes in CS users' disposable income and their redistribution of consumption from which CCE were calculated. Secondary data supported the analysis, particularly the classification of individual consumption by purpose (COICOP) categories established by the United Nations and the carbon intensities of these categories (European Environment Agency, 2013), measured in kg of carbon equivalents per Euro spent. The data was analysed using Microsoft Excel and IBM SPSS Statistics with descriptive statistics and various statistical tests, most notably the Pearson's chi-squared test, the One-Group t-test and the Shapiro-Wilk test statistic.

The calculation of environmental impacts was conducted for three subsamples, referred to as Group 1 (G1), Group 2 (G2) and Group 3 (G3). They differ by the direction of their reported disposable income change, with G1 reporting an increase, G3 a decrease and G2 no change, although a hypothetical savings value was used for G2 to estimate theoretical changes in CCE. The calculation was conducted step by step by assessing the changes in disposable income, then evaluating their impact on consumption patterns and translating the consumption patterns to carbon induced carbon emissions using the carbon intensities of the COICOP consumption categories. CCE are estimated for a representative baseline for each group based on consumption patterns of average Berlin residents (Amt für Statistik & BWV Berliner Wissenschafts-Verlag GmbH, 2018). This baseline is modified by incorporating the reported changes in consumption patterns of survey participants to arrive at a CCE value for CS users.

The literature review and the obtained data highlighted that results were sensitive to two variables, the size of the disposable income change and the carbon intensity of the consumption category Transport. Thus, alternative scenarios were simulated to assess the relative impact of these two variables on CCE. In the "Transport" scenario, the carbon intensity of the consumption category Transport was modified to a lower value, reflecting the larger share of more sustainable transport modes in the mobility portfolio of CS users. The "Savings" scenario was derived by estimating the size of the disposable income change caused from CS by comparing the mobility-related costs of average residents of Berlin with those of CS users. The third alternative scenario "Savings + Transport" combines the two changes.

Results and Implications

Figure I displays the main results, presenting the reductions in per cent of consumption induced carbon emissions among the three groups (G1, G2 and G3) compared to their respective baselines, under four different scenarios. In addition to the three scenarios described above, "Standard" refers to a scenario where an EU-wide average for the carbon intensity of the consumption category Transport is used and the value for the disposable income change is directly derived from the answers of the survey participants.

For G1 and G2 CCE are lower among CS users compared to the baseline. Under the condition that CS is perceived to cause monetary savings, this suggests that the changes in consumption patterns play a minor role and may even contribute to the positive environmental impact of CS. This stands in contrast to previous research which has found that altered consumption patterns partially offset the positive impacts of CS (Briceno et al., 2005; Chen & Kockelman, 2016).

The result for the subsample G3 should be interpreted somewhat differently. The group reduces CCE compared to its baseline as well but reports to incur additional costs due to CS use. To inquire what consumption CS had replaced, the members of G3 were asked how they would spend the amount that they are spending on CS, in a situation where they do not use in CS. Therefore, the answer collected from G3 on this aspect displays the CCE in case it would not use CS and spend the amount differently. In this scenario, the results show that not engaging in CS leads to lower CCE, which stands in contrast to the other two groups. This implies that when CS is seen as a more expensive option for personal mobility, CCE increase.

CCE reductions are largest under the Transport and Transport + Savings scenario (see Figure I), followed by the Standard and the Savings scenario. The combined scenario of Savings + Transport highlights that a lower carbon intensity of Transport influences results more strongly than a change in the disposable income. This leads to the conclusion that as long as the carbon intensity of Transport for CS users is considerably lower than for the baseline, the disposable income changes play a minor role in reducing CCE. This also sends a message to policy makers. Consumers are probably more easily attracted to CS through cost savings, while the environmental effect of switching to CS can be improved by reducing the carbon intensity of Transport for CS users.

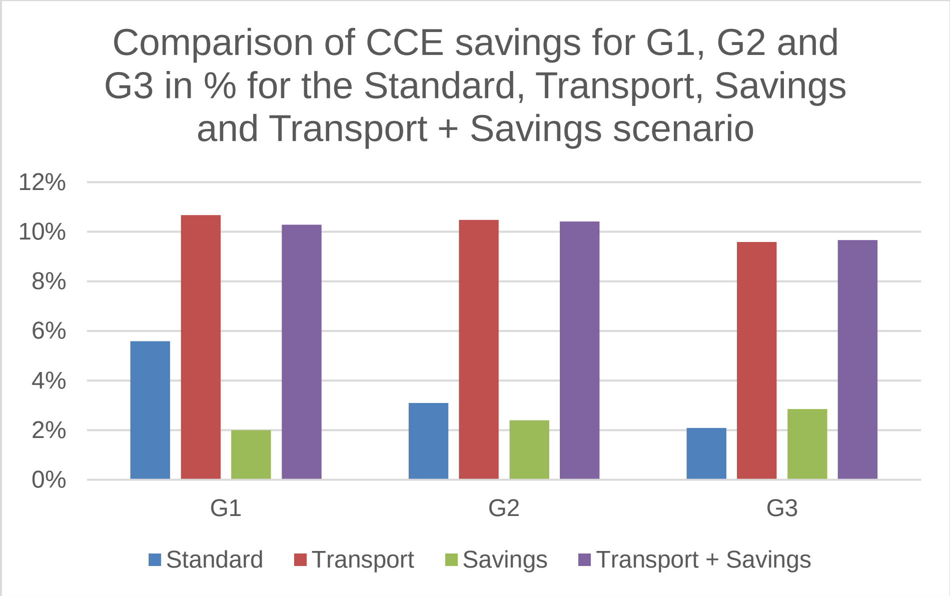

Figure I. Comparison of CCE reductions for G1, G2 and G3 in % for the Standard, Transport, Savings and Transport + Savings scenario.

Conclusions and Recommendations

The obtained data indicate that the proposed relationship between the variables in the research questions likely applies to the studied population. Changes in disposable income occur for most CS users. This causes altered consumption patterns and has an effect on consumption induced carbon emissions. For most German city dwellers the private car is still the main means of transport (Nobis & Kuhnimhof, 2018), and a switch towards CS would likely reduce transport-related costs and thus decrease CCE. This suggests that widening the support for CS schemes in Hamburg and Berlin, would lead to a decrease in transport-related carbon emissions, especially when people are incentivised to switch from private car ownership to CS.

The findings contribute to the CS literature by providing more comprehensive insights into broader environmental impacts of CS. In contrast to previous research, the examined indirect effect of consumption induced carbon emissions (CCE) among CS users, may contribute to the positive environmental impact of CS, suggesting that rebound effects are negligible and may not partially offset but induce additional carbon reductions.

The study also highlights areas for future research. To arrive at more precise results for changes in CCE, CS users' carbon intensities of consumption categories need to be estimated with higher accuracy and consumption patterns of CS users should be obtained via observation, not through stated answers. Long-term implications of a switch away from private cars towards CS also have to be examined, because the relative carbon intensity of the consumption category Transport is likely to be reduced and the potential for increasing CCE and backfire thus rises. Both the magnitude of this effect and potential countermeasures need to be further investigated. Finally, a study that assesses the full life cycle impacts of CS by combining approaches in this study with previous work would be interesting.

Ultimately, results suggest that CS seems to be one part of a solution towards a decarbonised, sustainable transport sector of the future. However, further research is needed to test these findings.

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1 Introduction

Many cities across the world are facing multiple issues related to their transport systems. The reliance on the private car as the main mode of transport has led to problems like rising carbon emissions, pollution, congestion, noise levels and land use (Miller & Spoolman, 2012). Growing urbanisation globally (Miller & Spoolman, 2012) only adds to the relevance of these concerns.

Car sharing (CS) is promoted by CS companies but also an increasing number of researchers as one measure to tackle these issues and is growing in popularity globally (Chen & Kockelman, 2016; Gao, Kaas, Mohr, & Wee, 2016; S. A. Shaheen, 2018). In this thesis business to consumer (B2C) CS is investigated. Car sharing is defined as the organised and collaborative usage of vehicles (Bundesverband Carsharing, 2007), B2C "refers to commerce between a business and an individual consumer" ('What is Business-to-Consumer (B2C)?', n.d. n.p.). "CS" in this thesis refers to business to consumer car sharing, unless stated otherwise.

Multiple studies have investigated the effects of CS and found that it offers many sustainability benefits. Members are reported to travel shorter distances by car (Chen & Kockelman, 2016; Martin & Shaheen, 2011a, 2016) and reduce their car ownership due to CS (Becker, Ciari, & Axhausen, 2017; Durand, Kennisinstituut voor Mobiliteitsbeleid, & Ministerie van Infrastructuur en Milieu, 2018; Firnkorn & Müller, 2011; Nijland, van Meerkerk, & Hoen, 2015). In addition, cars offered through CS tend to be more efficient than privately owned vehicles (Bundesverband Carsharing, n.d.-a; Chen & Kockelman, 2016; Firnkorn & Müller, 2011). Multiple studies found that a combination of these and other effects such as a more intensive use of public transport (PT) and biking/walking reduce mobility related carbon emissions among CS users (Chen & Kockelman, 2016; Firnkorn & Müller, 2011; Martin & Shaheen, 2016). These are often regarded as strong and sufficient positive sustainability implications of CS, therefore policy makers and city governments have started to incorporate CS schemes into their mobility agenda (Loose, 2010).

The full implications of CS, however, have yet to be explored. While the direct effects of CS, like impacts on distances driven or transport modes used, are studied rather comprehensively, little is known about indirect effects, like rebound effects and consumption induced carbon emissions (CCE) of CS users. The rebound effect can be divided into three effects, the direct, indirect and economy wide rebound effect:

- **Direct rebound effect:** The direct rebound effect refers to an increased demand for the same service (in this case car-driving) as a result of an improvement in efficiency and associated decrease in costs (Sorrell, 2007; Verboven & Vanherck, 2016). In other words, users drive more because it is cheaper for them. Especially the direct rebound effect is relatively well studied, mostly in the field of household energy use (Sorrell, Dimitropoulos, & Sommerville, 2009).
- **Indirect rebound effect:** The indirect rebound effect, then, refers to an increased demand for other goods or services because of the same cost-savings outlined above (Sorrell, 2007; Verboven & Vanherck, 2016). People using CS may save money and spend it on air travel, for example. Verboven & Vanherck (2016) also point out that the indirect rebound effect is more complicated to study because it occurs in many different forms. Therefore, less is known about it in comparison to the direct rebound effect.
- **Economy wide rebound effect:** When the two effects discussed before are combined and applied to an economy (region, country or globally) it is called the economy wide rebound or general equilibrium effect (Broberg, Berg, & Samakovlis, 2015; Sorrell, 2007). An economy wide rebound effect of CS may be a decrease in the price of cars due to the lower demand for them.

The economy wide rebound effect will not be discussed in this thesis. The direct and indirect rebound effect are closely intertwined and will be discussed together but the indirect rebound effect is most relevant for this thesis. When the term "rebound effect" is used, the direct and indirect rebound effect is referred to. One part of the indirect rebound effect are changes in consumption patterns and from that, changes in carbon emissions. These emissions are the focus of this thesis and they are referred to as consumption induced carbon emissions or CCE abbreviated. They incorporate emissions from the entire lifecycle of products and services.

Rebound effects are mainly studied in connection to efficiency improvements in electricity, heating and personal transport (Brännlund, Ghalwash, & Nordström, 2007; Chitnis, Sorrell, Druckman, Firth, & Jackson, 2013, 2014; Druckman, Chitnis, Sorrell, & Jackson, 2011; Kratena & Wüger, 2010; Lenzen & Dey, 2002; Mizobuchi, 2008; Murray, 2013; Thomas & Azevedo, 2013) but studies exploring indirect rebound effects of CS are scant. For instance, little is known whether and how CS affects the disposable income of CS users and how it affects consumption patterns. The disposable household income is defined as "the amount of money that households have available for spending and saving after income taxes have been accounted for" (Kenton, n.d. n.p.). If CS increases the disposable income, where is it re-spent? If it decreases the income, what consumption is replaced? Ultimately, the relevant question is how these changed consumption patterns affect consumption induced carbon emissions of CS users.

The purpose of this thesis is to explore these questions by analysing stated behaviour of CS users. The data is collected through an instrument-based survey. The geographical scope are the German cities Hamburg and Berlin because the CS market in both cities is large and dynamic and business models are mature (Bundesverband Carsharing, 2017). The results will help to form a more comprehensive picture of CS and will support policymakers and city governments interested in sustainable development of mobility systems and CS schemes.

1.1 Background and Problem Definition

1.1.1 Background

The underlying issue this thesis addresses is anthropogenic climate change, which is in part caused by the transport sector. In Germany, for instance, nearly 19% (forecast) of total carbon emissions were attributable to the transport sector in 2018 (German Environment Agency, 2017). 96% of these emissions were attributable to road transport of which 61% are caused by private cars (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2019).

To tackle these problems, it is common that the public sector subsidizes sustainable means of transport like PT and cycling, and recently CS (Loose, 2010). Several researchers (Chen & Kockelman, 2016; Loose, 2010; Martin & Shaheen, 2016) have concluded that CS could be a solution to make more sustainable use of vehicles and reduce transport-related carbon emissions and other associated problems. The full environmental implications of CS, however, have yet to be explored.

Arriving at robust conclusions about the impacts of CS is crucial because it already presents a globally significant phenomenon. Shaheen (2018) reports that in the year 2016 CS was present in 2 095 cities in 46 countries on all continents (except Antarctica), with about 15 million members who shared more than 157 000 cars. In terms of membership, Asia is reported to be the largest CS market, accounting for 58% of global membership and 43% of worldwide CS car fleets. Europe is the second-largest CS region, with 29% of global membership and 37% of the vehicle fleet (S. A. Shaheen, 2018). However, absolute numbers of CS membership are a limited indicator since they do not reflect the total mileage of CS. It is noteworthy that membership numbers do not necessarily reflect the number of regular and dedicated CS users. Rather often the data is based on the number of CS platform subscriptions, many of which are users that use shared cars less than once per month or even less frequently (Nehrke, personal communication, 2017). Little is known about the total mileage of CS users and what part of it indeed replaces the private car mileage.

In terms of type of CS Shaheen (2018) distinguishes between B2C one-way and roundtrip CS. In this thesis they are referred to as free-floating and stationary CS respectively. Peer to peer CS is not included in the analysis of Shaheen (2018) and is not relevant for this thesis because the survey is aimed at B2C CS users. For the sake of completeness, it will be included in the definitions.

- Stationary CS: The shared cars have a fixed station or parking spot and have to be returned there after use. In most cases it is possible to reserve the car weeks in advance (Bundesverband Carsharing, n.d.-b).
- Free floating CS: "Instead of relying on designated car-sharing stations it allows customers to pick-up and drop-off the vehicle anywhere within a city-wide service area" (Becker et al., 2017, p. 1).
- Peer to peer CS: The shared cars are owned by private individuals and are mostly offered via an online platform (Bundesverband Carsharing, n.d.-b).

Free-floating CS has been growing rapidly between 2014 and 2016 with a 23% and 76% upturn in fleet size and membership, respectively to nearly 31% of worldwide membership and 26% of the global fleet share. Stationary CS still holds the majority of the market with 69% of worldwide membership and nearly 74% of the global fleet deployed (S. A. Shaheen, 2018), but free-floating CS models in countries like Germany or the Netherlands are growing more quickly. The largest growth rate in worldwide membership was recorded recently between 2014 and 2016 with an increase of 76% to about 15 million users (see Figure 1). The fleet size grew 23% during the same period to about 160 000 but recorded its largest growth rate in the period between 2012 and 2014 of 55% (S. A. Shaheen, 2018). Gao, Kaas, Mohr, & Wee (2016) project that this trend will continue and that by 2030 up to ten per cent of all vehicles sold globally could be shared vehicles.

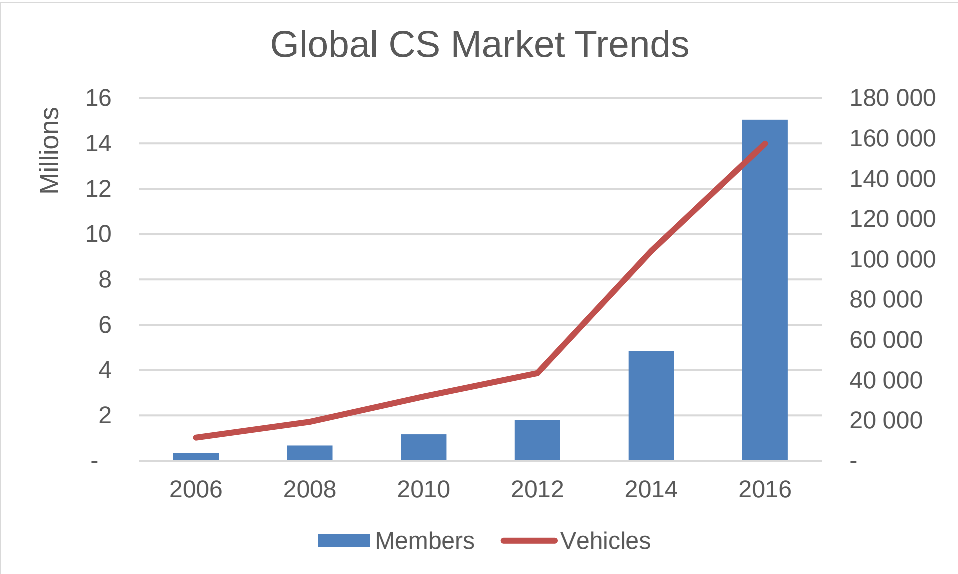

Figure 1. Global CS market trends for B2C free-floating and stationary CS.
Source: Shaheen (2018).

The global growth trend is also reflected in Germany (see Figure 2). According to the German federal CS association (Bundesverband Carsharing, 2019c) 2.46 million people used CS in Germany at the start of 2019. This is an increase of 16.6% or 350 000 users compared to 2018 (Bundesverband Carsharing, 2019d). In the same period stationary CS offers have been growing rapidly with a customer increase of nearly 22% while free-floating CS saw a smaller customer increase of almost 15% (Bundesverband Carsharing, 2019c). The number of CS cars has also been growing, with more than a 12% increase in 2018 to 20 200 vehicles in total (Bundesverband Carsharing, 2019d). At the same time, Bundesverband Carsharing observes that the rapid growth of CS membership only partly correlates with the increasing number of shared cars and even less so with the mileage (Nehrke, personal communication, 2017).

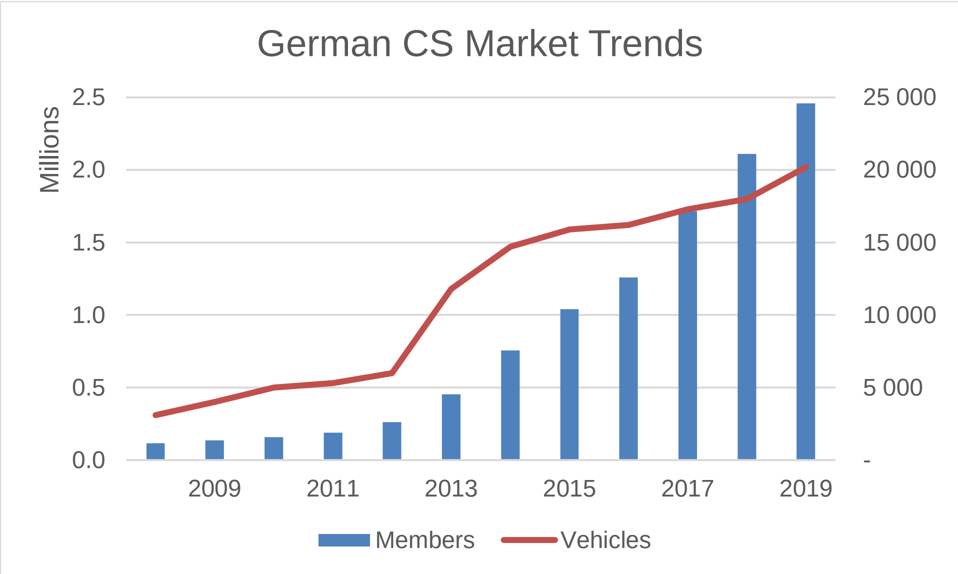

Figure 2. German CS market trends.
Source: Bundesverband Carsharing (2019c).

Table 1 provides a summary of the supply side of the B2C market segment of CS in Germany. In 2018 there were more stationary CS providers, sharing more vehicles in more places than free-floating CS offers. It is noteworthy that there were only 5 free-floating CS providers available in 18 places, compared to 176 stationary providers active in 740 places while the number of vehicles shared is similar. This can probably be explained by the size of the different companies behind these offers. The biggest free-floating CS providers are car2go and DriveNow (Bundesverband Carsharing, 2019b) which are subsidiaries of Daimler and BMW (S. Phillips, 2018), respectively. The two biggest stationary CS providers are Stadtmobil and Cambio, two medium-sized companies ('Über cambio', n.d.; 'Über stadtmobil', n.d.). The two large companies (Daimler and BMW) have more resources to provide more shared cars per company. In the future the free-floating CS market will be even more concentrated, as car2go and DriveNow have started to merge into a new joint venture, called Sharenow (Mooney, 2019; Stewart, 2019; 'The Joint Venture—Our Story', n.d.).

Table 1. Summary of CS providers, vehicles and the number of locations in Germany as of 2019.

	Free-Floating CS	**Stationary CS**
Providers	5	176
Vehicles	9 000	11 200
Available in … places	18	740

Source: Bundesverband Carsharing (2019a).

It is evident that CS is a phenomenon that is growing in relevance in Germany and globally. Why this increases the urgency of the problem addressed in this thesis will now be discussed.

1.1.2 Problem Definition

The full implications of CS have yet to be explored, which puts decisions makers in a difficult situation. From what is known at this stage CS can have multiple positive effects, such as reducing the distances driven by car (Martin & Shaheen, 2016), decreasing private car ownership of CS users (Becker et al., 2017) and making them shift towards more sustainable modes of transport (Chen & Kockelman, 2016). From a decision makers' point of view, CS schemes are thus worthy of support. However, the indirect effects such as re-expenditure of changes in the disposable income and consumption induced carbon emissions have not been sufficiently explored. According to some evidence, these indirect effects could partially offset (Briceno et al., 2005; Chen & Kockelman, 2016) or in a worst-case scenario reverse the positive environmental effects of CS.

The effects of CCE of CS users, however, is a topic that has found limited attention so far. Most studies discussing environmental effects of CS do not mention them at all. The studies that explore them are either quite dated and based on assumed scenarios (Briceno et al., 2005) or use previous estimations of rebound effects without estimating them themselves (Chen & Kockelman, 2016). From their findings, and those of other studies that explore CCE and indirect rebound effects of other measures, it is clear that both effects can be sizeable. Exploring them helps reducing the knowledge gap and adds to the academic discourse regarding the interrelationship between sharing practices and CCE. This study explores the relation between CS and CCE.

1.2 Aim and Research Questions

1.2.1 Aim

The aim of this thesis is to quantify and compare CCE of CS users with a baseline of non-CS users. A better understanding of these impacts will contribute to a more comprehensive picture of the environmental consequences of CS and will support policymakers in making more informed decisions. This is vital to reduce transport related carbon emissions and contribute to the decarbonisation of the transport sector.

To achieve this aim, the following research questions will be addressed.

1.2.2 Research Questions

1. How does engaging in car sharing affect the disposable income of car sharing users?
2. How do changes in the disposable income affect consumption patterns of CS users?
3. How do altered consumption patterns influence consumption induced carbon emissions of CS users and how do they compare to a baseline scenario?

The causal connection of these questions is visualised in Figure 3. It is assumed that CS use influences the disposable income of CS users, which in turn affects consumption patterns and CCE. The light blue arrows indicate that there are other possible effects outside the scope of this thesis.

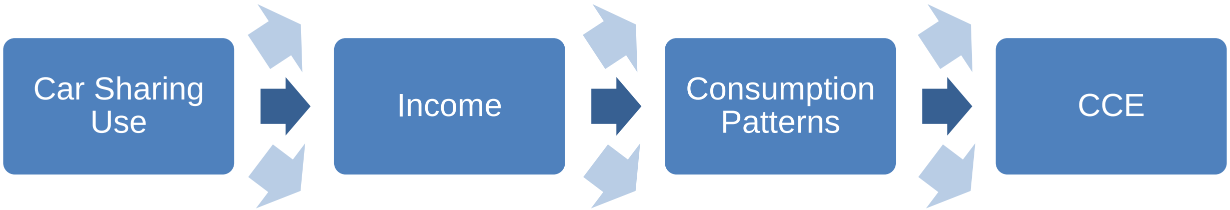

Figure 3. Depiction of the assumed relationship between CS use and CCE
Source: Author.

What these light blue arrows indicate in detail, is discussed below.

1.3 Scope

The focus of this thesis is on CCE which could be seen as a subsection of indirect rebound effects. Rebound effects are generally depicted in percentage terms, describing the share of the predicted energy or carbon savings of a measure that are not realised. A rebound effect of 20% for a more efficient boiler, for example, means that 80% of the predicted efficiency improvements are realised (Chitnis et al., 2014). In this thesis the size of rebound effects (the percentage value) are not estimated. Instead, CCE of CS users and a baseline are compared. This makes it possible to assess whether the rebound effect is positive or negative. Higher CCE for CS users compared to the baseline indicates a positive rebound effect, the opposite a negative one. In the example above a negative rebound effect would mean that more than 100% of the predicted savings are realised.

The relationship in Figure 3 is simplified and the impacts of CS are complex. As Plepys & Singh (2019) have pointed out savings induced through CS can lead to an increase in demand for CS services. More demand for CS may lead to longer distances driven with passenger vehicles and thus higher environmental impacts. However, an increase in CS use may also lead to a decrease in private vehicle ownership, an uptake of PT and lower environmental impacts. CS induced savings also influence overall consumption patterns (as explored in this thesis). Consumption patterns have an effect on the CCE of CS users but also on other industrial sectors because variations in final demand occur, which would, in turn, affect other producing sectors as well as induce changes in employment (Plepys & Singh, 2019). The implications of these variations would be the economy wide rebound effect. Macro-economic implications and long-term impacts of changes in income are outside the scope of this thesis.

In addition, CS may influence behaviour via other pathways. It may increase the amount of weekend holidays, for example, because it offers more people access to cars. This speculative example demonstrates that it is a relatively new service that may influence behaviour also directly, not just via changes in income. The author acknowledges the complexities of CS use and excludes possible direct impacts on behaviour from his scope.

To arrive at a representative sample, a cooperation with a CS company was established. A description of the company and possible ethical considerations are discussed below.

1.4 Cooperation with a CS Company and Ethical Considerations

To get access to a large number of CS users a cooperation with a German CS company was established. It is one of the bigger market players in Germany and operate in most major cities. The company facilitated the distribution of the survey by including a link into the company's newsletter in Berlin and promoted the survey via their Twitter feed, posting it with a reference to help a student in this thesis. The company wished to remain anonymous, so in this study it shall be referred to as "the company". No specific data or other company details will be revealed in this study either.

The interests of the company might not always be in line with the interests of the author. To reduce the likelihood of a potential conflict of interests, the author has clearly communicated the purpose of his thesis and the company understands that results might not be beneficial to their commercial or other interests. The findings presented in this thesis are free from interests of other parties and only serve to further the knowledge surrounding the topic at hand. The company also made no attempt to influence the content of this thesis.

The results were obtained with the help of a survey CS users completed. They did so voluntarily and agreed prior to the survey that their data would be stored anonymously by ticking a box in the online survey tool. Participants of the survey were also informed about its purpose and the non-commercial nature of the thesis project.

The obtained data was automatically anonymised by assigning number values to the participants. No inferences can be made about their identity. Even so, no personal data of participants was made publicly available. The analysed and aggregated data was then published in this thesis and made available to the company.

1.5 Audience

This thesis is aimed at decision makers and researchers who take an active interest in sustainable transportation. City government officials will be benefit from the findings presented because they address an issue that has found limited attention so far. The results contribute to a more complete assessment of CS which helps decision makers to form an opinion about the various impacts CS entails. They may be more certain whether to support or regulate CS and which adjustments may yield the most positive impact. For researchers the findings are also relevant because they address a gap in the literature. CS has rarely been studied in connection to CCE, especially in the German CS market, and results are thus somewhat a novelty. The needs for further research are perhaps even more significant for researchers. In this thesis particular aspects are highlighted that require further attention. Shedding light on them would further the knowledge around CS and sustainable transport systems for the future.

1.6 Disposition

The next chapter summarizes and discusses the literature around CS and indirect rebound effects to arrive at guiding assumptions and three hypotheses. It is structured according to Figure 3, first examining literature around CS use, then exploring indirect rebound effects to finally assess literature that discusses both variables. As a synthesis form the literature guiding assumptions are developed and three hypotheses are introduced.

Chapter three presents the methods used to arrive at the findings in this thesis. The survey is discussed, focussing on survey design and data collection methods. Next, the most important secondary data sources are presented and the main statistics to analyse the survey are introduced. The section also outlines how survey results were operationalised to arrive at CCE of CS users and the various baselines and how alternative scenarios to test survey results were estimated.

In chapter four results are outlined. First, the sample is described and then findings are presented for three subsamples. The distribution of re-expenditure across consumption categories is shown and one consumption category, Transport, is investigated in more detail before the difference in CCE between the three subsamples and the baselines are presented. In this section the results for three alternative scenarios are shown and the three hypotheses are tested.

Chapter five provides possible explanations and interpretations for the changes in disposable income, their effect on consumption patterns and implications for CCE. This also entails exploring the investigation of the Transport consumption category, the main conclusions from the three alternative scenarios and the significance of the tested hypotheses. Next, limitations in connection to the methodology, data and estimations and especially the survey are outlined and methods of addressing them are provided.

The final chapter presents the main conclusions, addresses the answering of the research questions and establishes how this thesis contributes to the literature about CS. Recommendations for the intended audiences are presented and areas for further research are suggested.

2 Literature Review

This literature review is organised according to the research questions and their relationship presented in Figure 3 where "CS Use" presents the independent variable and "CCE" the dependent variable. "Income" and "Consumption Patterns" are mediating variables (Creswell, 2014). CS use, i.e. the behaviour of CS users, includes questions about the use and effects of CS. CCE relate to indirect carbon emissions and indirect rebound effects. The conditions influencing them will be explored with a focus on how rebound effects are linked to CS. Then literature that explores both CS and CCE will be presented and discussed. The end of the literature review summarises the main issues, justifies the research approach and presents some guiding assumptions and hypotheses.

2.1 Car Sharing Use

In this section the independent variable CS use, with a focus on behaviour of CS users is discussed.

2.1.1 Usage Patterns

One of the main themes in the literature about CS use revolve around usage patterns. Usage patterns refer to the way users utilise CS schemes which may be specific to location, CS business models (pricing schemes) and the available transport alternatives. This includes variables like vehicle miles/kilometres travelled (vkt), characteristics of the CS trip (duration, time, location, purpose) and frequency of use. Vkt is a specifc measure of distance defined as "the total kilometers traveled by motor vehicles on the highway system during a given period of time" (Rudman, 1979, p. 19).

There seems to be an universal agreement that vkt seem to decline once CS is adopted, especially among previous car owners (Cervero, Golub, & Nee, 2007; Frost & Sullivan Research Service, 2010; Martin & Shaheen, 2011a, 2011b, 2016; Meijkamp, 1998; Muheim, 1998; Rydén & Morin, 2005; Sperling & Shaheen, 2000). Net vkt, the fact that CS tends to simultaneously increase and reduce mileage, has also been investigated and was found to be reduced (Martin & Shaheen, 2016) but no generalisations can be made. CS highlights the total driving costs more transparently, costs per pkm are higher and users might thus be inclined to use CS more effectively. Pkm refers to passenger-kilometre and "is performed when a passenger is carried one kilometre" ('Passenger-kilometres performed', n.d. n.p.).

However, estimates on how much vkt are reduced seem to be rather inconsistent. The highest estimation is a reduction of 72% among CS users in Switzerland (Muheim, 1998) while the lowest estimate is around 6% (Martin & Shaheen, 2016). Many factors can influence vkt, like regional conditions, the type of CS (free-floating or stationary) assessed, pricing models and methodological differences. More recent studies estimate a range of 6% and 43% reduction (Frost & Sullivan Research Service, 2010; Martin & Shaheen, 2011a, 2011b, 2016). Depending on regional circumstances, the type of CS assessed and assessment methods (especially the inevitable assumptions) adopted, this is where reductions in vkt typically lie.

In terms of trip purpose, most users seem to use CS for other purposes than commuting. Cervero et al. (2007), Millard-Ball, Murray, Ter Schure, Fox, & Burkhardt (2005) and Costain, Ardron, & Habib (2012) agree that CS is more likely used for shopping, personal business or recreation than commuting. Le Vine, Adamou, & Polak (2014) focused on the shopping aspect and found that CS users use cars less frequently for grocery shopping and spend less travel time for grocery shopping. Becker et al. (2017) discuss the differences of stationary and free-floating CS schemes and find that stationary schemes serve a more limited variety of trips.

Off-peak hours and weekends seem to be popular times to engage in CS and distances driven tend to be short. Frequency of use seems to be moderate with an average number of trips per year around 30. Not even 10% of members are stated to use CS more than three times a month (Costain et al., 2012). Other authors have also found that CS users take fewer and shorter trips (Barth & Shaheen, 2002; Cervero et al., 2007; Morency, Habib, Grasset, & Islam, 2012; Morency, Trépanier, & Martin, 2008; Nobis, 2006).

This section highlights that many fields connected to usage patterns have been investigated. The literature suggests that CS is not a day-to-day mode of transport and is used infrequently largely during off-peak hours and weekends. Environmental impacts are positive, as vkt are reduced when CS is adopted, especially among private car owners. The size of the reduction depends on many factors, like geographical circumstances, type of CS models assessed, pricing schemes and methodological differences.

Another effect of CS is that CS users seem to shift their preferred modes of transport.

2.1.2 Mode Shift

Mode shift includes changes in the frequency of use of private vehicles, PT, walking, cycling or taxis. A number of studies point out that CS seems to induce a shift away from private car use towards more environmentally friendly modes of transport, like PT, biking or walking (Becker et al., 2017; Chen & Kockelman, 2016; Cooper, Howe, & Mye, 2000; Durand et al., 2018; Lane, 2005; Meijkamp, 1998; Rydén & Morin, 2005; S. A. Shaheen, Cohen, & Chung, 2009; Sioui, Morency, & Trépanier, 2013). Some studies (Becker et al., 2017; Martin & Shaheen, 2016), however, found that the use of these more environmentally friendly modes seems to decline. Knowledge about the net effects on public transport is insufficient to make any conclusions.

When investigated in more detail, there seem to be particular differences between stationary and free-floating CS. Multiple authors agree that stationary CS encourages a shift away from private cars towards more PT and non-motorised travel modes (Becker et al., 2017; Durand et al., 2018; Nehrke & Loose, 2018; S. A. Shaheen et al., 2009; Sioui et al., 2013). The effect for free-floating CS seems to be less clear or sometimes the opposite. Becker et al. (2017) found a net reduction of the aforementioned environmentally friendly modes of transport among free-floating CS members. They also state that a similar number of free-floating CS members have decreased and increased their private car use. Martin and Shaheen (2016) partly confirm these findings. They investigated free-floating CS users in five US-cities and found that members have reduced their use of PT and taxi use but increased their walking. In four out of five cities more users also reported to increase than decrease their driving.

Another theme that emerged is that shifting modes of transport seem to be an important contributor towards the environmental effects of CS. Chen & Kockelman (2016), assessing cradle-to-grave impacts of CS, found that changes in transport modes are among the most important contributors towards reducing carbon emissions and energy use. Becker et al. (2017) agree with that notion and cite changes in modes as one of the most important impacts of CS.

The literature points to a clear effect of CS on transport modes used. Stationary CS seems to encourage users to opt for more sustainable modes of transport, while the effects for free-floating CS are more mixed. Changed transport modes contribute substantially to the positive environmental effects of CS, policy makers need to consider this when deciding whether and how to support stationary and free-floating CS schemes.

Related to mode shifts are changing ownership patterns of private cars.

2.1.3 Ownership Patterns of Private Cars

Ownership patterns refer to changes in private vehicle ownership induced by CS. There are two different effects at work. Either a person engaging in CS delays or foregoes buying a new car (suppression effect) or they sell a car they already own (i.e. vehicle shedding) (Martin & Shaheen, 2016).

Zhou & Kockelman (2011), for instance, have found that 21% of their survey participants would expect to shed at least one privately held car after joining a CS organisation. Cervero et al. (2007) explored net vehicle shedding effects and concluded that about 10 in 100 CS households shed their vehicles compared to non-CS households. Martin & Shaheen (2016) report a lower number and suggest that between 2% and 5% of free-floating CS members have sold a car due to their CS membership. This translates to between one and three personal cars shed for every CS car. This finding is probably more reliable since the latter study calculates actual vehicles shed across the studied population, while the two former studies report stated answers. Other studies also state that CS membership induces members to shed their vehicles (Becker et al., 2017; Martin & Shaheen, 2011a) but do not provide the magnitude of the effect.

Suppressing vehicle ownership seems to be the larger of the two effects. Martin & Shaheen (2016) state that between 7% and 10% of their survey participants did not purchase a vehicle due to their CS membership. This translates to a suppression effect of between 4 and 9 vehicles per CS car. Again, the variation is substantial, but it is significantly larger than their findings for the shedding effect. Le Vine & Polak (2017) also compared the suppression and shedding effect among free-floating CS members. Their results indicate that the shedding effect is much larger, finding it among 30% of London-based CS users, as compared to only 4% for shedding. These disparities between the two studies are hardly surprising since different geographical areas with different regional circumstances were studied. Other reasons for the disparities could include methodology choices and circumstances.

The overall effect of CS use on car ownership seems to be a reduction in private vehicle holdings. Early studies have led the way and highlighted the potential of CS to reduce car ownership by 40% - 44% (Meijkamp, 1998; Whitelegg & Britton, 1999). A more recent study (Martin & Shaheen, 2011b), conducted nationwide in the US, paints a similar picture: After joining CS the number for average cars per household dropped from 0.47 before to 0.24 after joining CS. Even though most of the sample does not own a car, Martin & Shaheen (2011b) demonstrate that car ownership is reduced, mainly from one car to no car households. In Germany Firnkorn & Müller (2011) examined the effect of free-floating CS in the city of Ulm. They find that close to 14% of members of a free-floating CS scheme would reduce their car ownership. This result depends heavily on the context of the study as the participants of the survey were asked if they could imagine foregoing the purchase of a new vehicle if the CS scheme in question were to establish itself. The hypothetical nature of the question sheds some doubt on the findings by Firnkorn & Müller (2011).

Different researchers have also estimated the vehicles replaced through CS. The results are summarised in Table 2. If the value by Lane (2005) is disregarded as an outlier, the number of vehicles replaced by one CS car is around 13. Therefore, CS contributes to a net reduction of private vehicle holdings. Other studies agree with that notion, without, stating the magnitude of the impact (Baptista, Melo, & Rolim, 2014; Chen & Kockelman, 2016; Durand et al., 2018; S. A. Shaheen, Mallery, & Kingsley, 2012).

Table 2 summarises studies mostly conducted in the US. Their findings might not translate to German CS members as investigated in this thesis.

Table 2. Summary of number of vehicles replaced per CS car.

Number of vehicles replaced per CS car	**Source**	**Type of CS scheme**
9 – 13	Martin, Shaheen, & Lidicker (2010)	Stationary
23	Lane (2005)	Stationary
15	Frost & Sullivan Research Service (2010), Millard-Ball et al. (2005), Stasko et al. (2013)	Stationary
7 – 11	Martin & Shaheen (2016)	Free-floating

German data is available via the German federal CS association (Nehrke & Loose, 2018). They conducted a comprehensive study of free-floating, stationary and combined CS offers in multiple German cities. Combined CS refers to providers who offer both stationary and free-floating CS. Among other variables, their focus is on ownership patterns and car-free households. They asked for ownership levels at three different times: One year before signing up for CS, when people signed for CS and car ownership at the time of filling out the questionnaire.

Their findings indicate that stationary and combined CS members have a strong effect on private car holdings. In both groups, ownership falls to about one third of ownership that was reported a year before signing up for CS. At the time of taking the survey stationary and combined CS users held 108 and 104 vehicles per 1 000 persons, respectively. This translates to about 80% car-free households in both combined and stationary CS and is below the goal of the German Environment Agency for climate-just urban transport of 150 vehicles per 1 000 persons (Nehrke & Loose, 2018).

The picture for free-floating CS looks quite different. At the time of the survey free-floating members reduced their ownership by about 5%, holding about 485 private vehicles per 1000 persons. This is the same figure as reported for non-CS users (Nehrke & Loose, 2018). It is therefore not surprising that only about 32% of free-floating CS users lived in car-free households. Figure 4 and Figure 5 summarise the findings by Nehrke & Loose (2018).

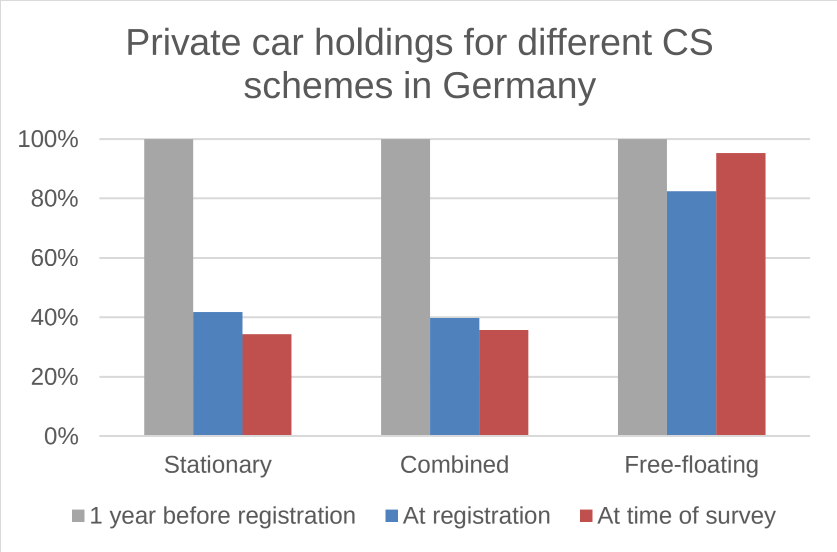

Figure 4. Private car holdings for stationary, combined and free-floating CS users 1 year prior to registration, at registration and at the time of the survey in Germany.
Based on Nehrke & Loose (2018).

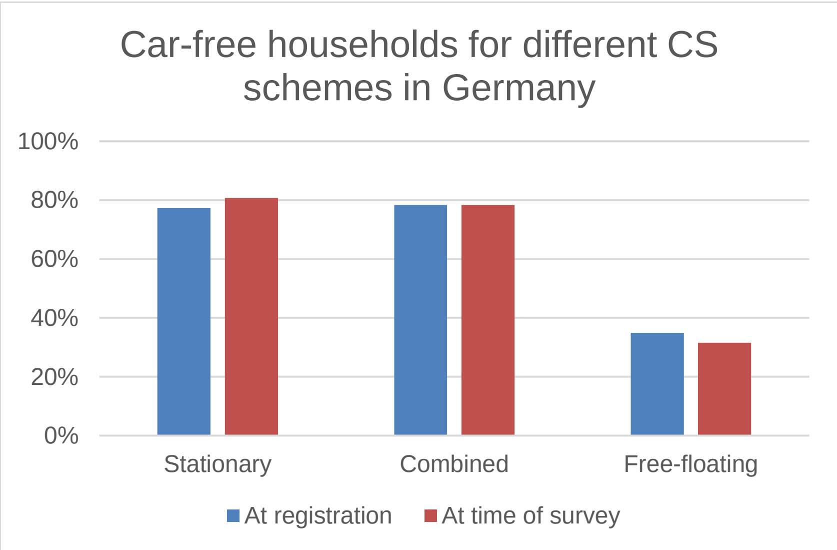

Figure 5. Car-free households among stationary, combined and free-floating CS users at registration and at the time the survey was conducted in Germany.
Based on Nehrke & Loose (2018).

Considering these findings, CS in Germany also seems to replace privately owned vehicles and contributes to a car-free lifestyle. This statement is supported by Nehrke & Loose (2018). When asked if CS was an adequate replacement for a private car, between 63% and 65% among stationary and combined CS users agreed with the statement. Among free-floating users only 33% agreed and 43% disagreed.

The literature strongly suggests that CS reduces vehicle ownership, either via the shedding or the larger suppression effect, as one CS car replaces about 13 privately owned cars. Data from Germany proposes that stationary CS seems to be a better private car replacement than free-floating CS since car holdings have reduced more for combined and stationary CS offers and the share of car-free household is higher. As in the precious section the literature indicates that stationary CS has more sustainability benefits than free-floating CS.

2.1.4 Non-Behaviour Related Findings

The themes presented before relate to the behaviour of CS users. There are, however, other findings that explore issues that are not related to the behaviour of CS users.

Most studies have collected socio-demographic data of CS users and results are quite similar. The average CS user tends to be younger than the average population, more educated and has a higher income. Furthermore, CS seems to be more popular among men and people who live in urban environments (Becker et al., 2017; Chen & Kockelman, 2016; Le Vine & Polak, 2017; Millard-Ball et al., 2005, p.; Nijland et al., 2015).

Other studies looked at attitudes of CS members. Millard-Ball et al. (2005) divided CS users in North America into five subgroups according to their agreement or disagreement to different statements and report that they tend to have strong views about social and environmental issues. Costain et al. (2012) investigated attitudes towards safety and the environment by assessing decisions to buy carbon offsetting and a collision deductible, respectively. They conclude that most CS members are environmentally conscious since their willingness-to-pay for carbon offsetting tends to be relatively high. The goodness-of-fit value for modelling attitudes towards safety is very low and no clear inferences can be made from it. Becker et al. (2017) compared attitudes of free-floating and stationary CS users in Switzerland. They found that no considerable differences in attitudes towards environmental and social concerns. However, 13% of free-floating CS members see the private car still as a status symbol, compared to 6% among stationary and 12% in the control group. Also, compared to the control group (76%), 95% and 85% of free-floating and stationary CS users agreed that "they liked to try new things".

Multiple studies exploring the climate impacts of CS have generally found a reduction of carbon emissions. Firnkorn & Müller (2011) assessed the impact of a free-floating CS in the German city of Ulm and found a carbon reduction between 5 and 11% for the average CS user. They explored three scenarios with different fuel consumption and kilometres driven (best, most likely and worst-case) and found a carbon reduction even for the worst-case scenario (5%). The authors, however, acknowledge several limitations, such as e.g. stated vs. observed responses to a survey, disregarded seasonal variations of modal choices, assessed carbon emissions resulting only from the use phase of the vehicles and disregard of rebound effects. Especially the last two limitations highlight narrow system boundaries indicating that results only display partial effects.

Martin & Shaheen (2016) assess the carbon impact of CS in five North American cities and report a carbon reduction in all of them. For Calgary, San Diego, Seattle, Vancouver and Washington they find household carbon reductions of 4%, 6%, 10%, 15% and 18%, respectively.
The study entails similar limitations as Firnkorn & Müller (2011). They also rely on stated preferences which is in some cases unavoidable, for example when assessing causal relationships between CS and vehicle ownership levels. Life cycle impacts and rebound effects are also not considered. Furthermore, they do not include a control group to represent the general population. The effects are thus partial in nature as well.

In contrast, Chen & Kockelman (2016) conduct one of the most rigorous assessments of carbon impacts of CS. They assess life-cycle implications, considering alternative modes of transport, ownership levels, fuel economy of the fleet, travel distances and parking demand in a US context. Their findings suggest that CS users reduce their transport-related carbon emissions by about 51%, mostly attributable to shifts in transport modes and reduced vkt. They also include the rebound effect in their analysis which reduces the estimated savings considerably. The findings about the

rebound effect will be discussed in chapter 2.3 in more detail.
Chen & Kockelman (2016) rely on data from previous studies. All limitations from these studies are carried forward into their analysis. They also do not distinguish between free-floating and stationary CS, so carbon impacts might be different for the two schemes and macro-economic impacts of CS are not considered. It is not clear if including them would have an impact but it would rather increase savings (Chen & Kockelman, 2016). Other studies have also find carbon reductions but are bound to similar limitations (Baptista et al., 2014; Martin & Shaheen, 2011b; Nijland et al., 2015).

The evidence that CS reduces parking demand is more comprehensive (Baptista et al., 2014; Chen & Kockelman, 2016; Millard-Ball et al., 2005; S. A. Shaheen, Rodier, Murray, Cohen, & Martin, 2010). In most studies this is largely an indirect result of lower private vehicle ownership levels.

A summary of the findings is presented in Table 3.

Table 3. Summary of non-behaviour related findings about CS.

Topic	Findings	Author(s)
Socio-demographic data	Average CS user: Young, urban, well-educated, above average income. More likely male.	Becker et al. (2017), Chen & Kockelman (2016), Le Vine & Polak (2017), Millard-Ball et al. (2005), Nijland et al. (2015)
Attitudes	Environmentally and socially conscious	Millard-Ball et al. (2005), Costain et al. (2012), Becker et al. (2017),
Impact on carbon emissions	Reduction	Firnkorn & Müller (2011), Martin & Shaheen (2016), Chen & Kockelman (2016), Baptista et al. (2014), Martin & Shaheen (2011b), Nijland et al. (2015)
Parking demand	Reduction	Baptista et al. (2014), Chen & Kockelman (2016), Millard-Ball et al. (2005), Shaheen et al. (2010)

A typical CS user is young, urban well-educated, has a high income and is more likely to be male. This is not surprising as CS works best in dense neighbourhoods (Chen & Kockelman, 2016) and challenges familiar patterns which might be more attractive and apparent to younger people. That CS users are more conscious about environmental and social issues points to the fact that they are a special group of people that could differ significantly from the average population. For both parking demand and carbon emissions the literature points to a reduction. It is notable that most studies assessing carbon impacts do not consider indirect effects, like indirect rebound effects or CCE.

2.2 Indirect Rebound Effects and Carbon Emissions

The rebound effect is a complex phenomenon with different actions assessed and sub-effects at work. To use a clear language, some terminology is provided first.

2.2.1 Terminology

For the purpose of this thesis, the terminology that can be found in Chitnis et al. (2013, 2014) will be used. Most of the following effects refer to energy use and carbon emissions. As carbon emissions are the focus of this thesis, only they will be mentioned. The direct, indirect and economy wide rebound effect are defined in the Introduction section. When the term "rebound effect" is used in the following chapter, the direct and indirect rebound effect is referred to, unless stated otherwise.

- **Sufficiency and efficiency measures:** As Chitnis et al. (2014) explain, households can engage in two different types of measures to reduce emissions. Efficiency measures refer to technological changes, like acquiring a new type of energy efficient boiler or car. Sufficiency measures relate to changes in behaviour, like reducing the indoor air temperature or reducing food waste. Typically, efficiency measures have to be acquired, while sufficiency measures require no additional capital costs. Another distinction is that efficiency measures result in direct and indirect rebound effects (e.g. a more efficient car induces people to drive more and spend more money on other goods due to lower operating costs), while sufficiency measures only lead to indirect rebound effects.
- **Energy and carbon rebound effects:** Rebound effects can occur for energy use and carbon emissions. Depending on the carbon intensity of energy systems, energy rebound effects may be larger or smaller than carbon rebound effects (Chitnis et al., 2013). In this thesis, the term rebound effect always refers to *carbon* rebound effects, if not stated otherwise. Carbon intensity in this case refers to the amount of carbon equivalents emitted per unit of energy consumed (U.S. Energy Information Administration, 2017).
- **Direct and embodied emissions:** Direct emissions refer to emission that are directly emitted by households. Examples exclude the electricity used for various uses and heating or transport fuels. Embodied emissions, however, relate to the supply-chain carbon emissions for goods and services. The embodied emissions of a smartphone, for example, include the emissions related to extracting the raw material, producing and transporting the smartphone. Direct rebound effects usually occur from direct emissions, indirect rebound effects relate to both direct and indirect emissions (Chitnis et al., 2014).
- **Engineering effect (EE):** The estimation of the direct reduction in carbon emissions under the assumption that consumption of the energy service assessed remains stable (Chitnis et al., 2014).
- **Embodied effect (EmE):** The embodied effect is related to embodied emissions. Efficiency measures typically have associated emissions related to production, transport and installation of the equipment. Chitnis et al. (2014) therefore define the embodied effect as the difference in embodied emissions of the efficiency measure and the applicable alternative.
- **Income effect (IE):** Efficiency or sufficiency measures not only lead to reduced emissions, they also typically lead to cost savings which can be treated as additional disposable income. This additional income can be either saved or spent. The income effect is an estimation of the impact caused by additional household consumption or savings. For efficiency measures it consists of increased consumption of the same good plus increased consumption of other goods and services. For sufficiency measures only the latter effect is relevant (Chitnis et al., 2013).
- **Substitution effect:** If the unit price of a commodity (heating water) falls, two effects come into force: First, as heating becomes cheaper, the household may consider heating more and consuming less substitute goods and services. Second, the household considers consuming more complementary goods to heating because it has become cheaper. The net result of these two contradictory effects is difficult to assess (Chitnis et al., 2014).

Considering these definitions and explanations Chitnis et al. (2013, 2014) define the total impact of their assessed measures according to Equation 1. The engineering effect tends to be negative, while the embodied effect and the income effect tend to be positive.

Equation 1. Total impact of measures assessed

$$Total\ Impact\ (TI) = EE + EmE + IE$$

Source: Chitnis et al. (2013, 2014).

The rebound effect (RE, in percent) for energy efficiency improvements is defined according to Equation 2. A rebound effect of 50%, for example, means that only half of the predicted (engineering) carbon emission reductions are realised. If the rebound effect is 100% or more, backfire occurs (Chitnis et al., 2014; Druckman et al., 2011; Sorrell, 2007). This means that the predicted reductions are more than offset by the rebound effect.

Equation 2. The rebound effect.

$$RE = 100 * \frac{EE - TI}{EE}$$

Source: Chitnis et al. (2013, 2014).

The indirect rebound effect has been investigated by multiple studies, focussing on different actions such as efficiency improvements in electricity, heating and personal transport (Brännlund et al., 2007; Chitnis et al., 2013, 2014; Druckman et al., 2011; Kratena & Wüger, 2010; Lenzen & Dey, 2002; Mizobuchi, 2008; Murray, 2013; Thomas & Azevedo, 2013). Other actions assessed are sufficiency-related, like reducing car use or food waste (Alfredsson, 2004; Chitnis et al., 2014; Druckman et al., 2011; Lenzen & Dey, 2002; Murray, 2013). Some authors do not make such a clear distinction and examine both, sufficiency and efficiency measures.

2.2.2 The Indirect Rebound Effect

Brännlund et al. (2007) conducted one of the most widely cited studies in the field at the time (Druckman et al., 2011). They assumed an exogenous energy efficiency improvement of 20% for all transport modes, for space heating and then for transport and heating combined for households in Sweden. By combining the estimated demand changes with applicable emission coefficients, the combined direct and indirect rebound effect is estimated. The size of this effect is substantial, ranging between 120 and 175% (Druckman et al., 2011). Therefore, the energy efficiency improvements backfire, leading to higher emissions. The driver behind these increases in emissions are the income and the substitution effect, caused by lower relative prices for transport and space heating.

The study is now criticised by other authors. For one, according to Brännlund et al. (2007) the direct rebound effect contributes more than 100% to the overall rebound effect. This is deemed unrealistic by more recent studies (Chitnis et al., 2014; Druckman et al., 2011). Secondly, other researchers have also estimated the direct rebound effect for space heating and transport and reported a figure of less than 30% (Sorrell, 2007; Sorrell & Dimitropoulos, 2007; Thomas & Azevedo, 2013).

Another Swedish example comes from Alfredsson (2004). She assessed scenarios of “green” food consumption, travel, housing and a combination of the three, for an overall “green” lifestyle for households. The scenarios each consisted of a mixture of sufficiency and efficiency measures, mostly focussing on sufficiency. For the analysis direct and indirect rebound effects were estimated. The terminology of Alfredsson (2004) seems at odds with the terminology introduced before. What she refers to as substitution or second order effect, is classified as income effect in this thesis. This terminology will be used for the following sections.

In the combined scenario Alfredsson (2004) estimates the income effect at 20% for carbon emissions. The income effects for single scenarios vary widely, from 10% for "green travel" to more than 200% for "green food" (Alfredsson, 2004). In this case backfire occurs.

Green food refers to a diet drawn up by the Swedish National Food Administration that is more sustainable than the average diet (Sverige & Naturvårdsverket, 1997). It generally consists of more vegetables and less meat, fish or dairy products. Green housing consists of technological and behavioural improvements, like improved energy efficiency improvements of boilers or a reduction in the use of hot water or electricity (Alfredsson, 2004).

Especially relevant for this thesis is the section about green travel. Among actions like green driving behaviours, changes like improved energy efficiency of cars, joining a CS organisation, reduction in car ownership and reduced vkt are assessed. Similar effects were discussed before in the section about CS use. There are no estimations of income effects for these single measures, but the overall income effect of "green travel" is estimated at 10% (Alfredsson, 2004). Compared to other studies, it is relatively small.

A more recent study, conducted by Druckman et al. (2011), focussed on three sufficiency measures. They explored rebound effects for reducing food purchased, lowering the ambient indoor air temperature by one degree Celsius and walking or biking instead of using the car. To estimate emissions from additional household expenditure (income effect), COICOP household consumption categories and subcategories are used. The carbon intensity of these categories is then estimated by dividing carbon emissions by the corresponding expenditure. Carbon intensity in this case (and throughout this thesis) is defined by units of carbon equivalents emitted per EUR spent on the respective consumption category (European Environment Agency, 2013). Since only sufficiency measures are investigated, only the indirect rebound effect is assessed.

Druckman et al. (2011) estimate the size of the indirect rebound effect for the three sufficiency measures at 34%. This is in line with the findings by Alfredsson (2004). The authors, however, refer to this similarity as "largely accidental" (Druckman et al., 2011, p. 3578) since the former study also includes efficiency measures. Druckman et al. (2011) investigate multiple re-spending scenarios which are summarised in Table 4.

Both the least worst and the worst-case scenario are unrealistic, but it is apparent that the size of the rebound effect is sensitive to re-spending behaviour. The other variable influencing the rebound effect are the carbon intensities of the expenditure categories and investment (Druckman et al., 2011).

For the investment scenarios Druckman et al. (2011) used the average carbon intensity of UK investments. To arrive at these values, they use standard Environmentally Extended Input–Output analysis (Leontief, 1986) by dividing investment related carbon emissions by the monetary value of the investment in the UK.

The levels of investment are taken from existing data and represent extreme cases. The low investment case is based on the lowest observed investment rate in the UK between 1964 and 2009. The negative value implies a withdrawal of savings. The high investment scenario is based on saving rates in China in 2008 (Ma & Yi, 2010). In the last scenario a 100% investment rate is assumed. As investment rates increase, the rebound effect decreases. This highlights that the carbon intensity of investing seems to be lower than the average carbon intensity of consumption. The authors also point to the theoretical possibility of a negative rebound effect. In this case, all of the additional expenditure is spent on green investments (Druckman et al., 2011).

Table 4. Effect of different re-spending scenarios.

Scenario	**Explanation**	**Size**
Least worst	All of the avoided expenditure is spent on the least carbon intensive category – housing.	12%
Worst case	All of the avoided expenditure is spent on the most carbon intensive category – gas.	515%
Low investment	Assumed level of investment: -4%	35%
High investment	Assumed level of investment: 40%	31%
100% investment	Assumed level of investment: 100%	26%

Source: Druckman et al. (2011)

The work by Chitnis et al. (2013) is based on a similar methodology to Druckman et al. (2011). They also estimate the size of the rebound effect for UK households with a combination of income elasticities for different consumption categories and data about the carbon intensity for these categories. The assessed measures are all energy efficiency related, therefore the direct and indirect rebound effect are calculated. For these measures the size of the rebound effect is estimated at 5-15%. The key driver for this process is the income effect towards non-energy services and goods. The reason for the small size of the rebound effect is that the carbon intensity of these services and goods is relatively low. The direct rebound effect is reported to contribute little to the result because energy accounts for a small share of total household spending. Consequently, the indirect rebound effect plays a large part.

Chitnis et al. (2013) also conduct a sensitivity analysis and find that results are *insensitive* to the assumed elasticities. This stands in contrast to what Druckman et al. (2011) report. The reasons for that could be that heating and electricity are carbon intensive, compared to other consumption categories. The size of the rebound effect is not significantly changed since consumption flows from a carbon intensive category (heating, electricity) to one that is relatively less intensive. However, the estimates seem to be sensitive to changed carbon intensities of electricity use. As the carbon intensities decline, the rebound effect increases. This finding is not surprising since the difference in carbon intensities between electricity and non-energy services and goods decreases. Another noteworthy point is that the category “other transport” seems to contribute most, more than 25%, to the income effect (Chitnis et al., 2013). Consequently, in connection to the income effect transport seems especially relevant to study.

Another study by Chitnis et al. (2014) also investigated the rebound effect for UK households, this time for both efficiency and sufficiency measures. These measures can be categorised in three broad categories: domestic energy use, vehicle fuel use and reduction of food waste. The sizes of combined direct and indirect rebound effects for these measures are 0-30%, 25-65% and 66-106%, respectively. They also state that, on average, the direct rebound effect contributes little to the overall effect, making up around 19%. Indirect rebound effects, therefore, make up most of the effect. In addition, the rebound effect is mostly made up of embodied emissions, making up 60% of total emissions. The remaining 40% consist of direct emissions.

Chitnis et al. (2014) add to previous knowledge by studying the rebound effect for different income groups. They find that it is largest for the lowest-income group because they spend a greater share of their cost-savings on carbon intensive categories. In this low-income group direct emissions also make up more than 50% of total emissions. In contrast, in the highest income group this figure is not even at 30%.

The authors also distinguish between the rebound effect for efficiency and sufficiency measures. Efficiency measures have a comparatively small rebound effect, just exceeding 14%. For sufficiency measures this figure is more than twice as high, over 35%. Not surprisingly, for both types of measures the embodied emissions contribute the largest part to the rebound effect. This is more pronounced for sufficiency measures where they contribute more than 97% compared to about 80% or efficiency measures (Chitnis et al., 2014).

Table 5 provides a summary of the main studies discussed in this section.

Table 5. Summary of findings for rebound effects.

Author	**Type of measure**	**Direct/indirect**	**What is assessed?**	**Size**	**Contribution direct**
Brännlund et al., (2007)	Efficiency	Combined	Transport, heating, combined	120-175%	>100%
Alredsson (2004)	Efficiency & Sufficiency	Combined	Food, transport, housing, combined	20%	Not given
Druckman et al., (2011)	Sufficiency	Indirect	Food, heating, transport	34%	Only indirect
Chitnis et al., (2013)	Efficiency	Combined	Energy efficiency for heating and electricity	5-15%	Small part
Chitnis et al. (2014)	Efficiency & Sufficiency	Combined	Energy, vehicle fuel, food	0-106%	19%

Source: Chitnis et al. (2013, 2014).

The diversity of findings from previous studies suggests that there are multiple variables influencing the size of rebound effects. Types of measures assessed (efficiency, sufficiency), specific measures assessed (transport, housing, food), methodologies and underlying assumptions all have an impact on the size of rebound effect. But some inferences are still possible. The specific types of measures assessed heavily influence the size of the rebound effect because of the different carbon intensities of consumption categories. When a highly carbon intensive category, for example Transport, is studied, the income effect is smaller because consumption is shifted towards consumption categories that are relatively less carbon intensive. This implies that in this thesis not just shifts towards other consumption categories have to be studied, but also shifts *within* the transport category to arrive at sound conclusions about consumption induced emissions of CS users. Another takeaway from this section is that transport-related rebound effects are sizeable but rarely exceed 100%. Their size justifies further research to arrive at a more comprehensive picture of sustainability implications of CS.

Indirect rebound effects have also been studied in connection to CS which will be discussed in the next chapter.

2.3 Indirect Rebound Effects and Car Sharing

The two studies discussed in this section (Briceno et al., 2005; Chen & Kockelman, 2016) both use a life cycle assessment (LCA) framework as a method of analysis. Briceno et al. (2005) supplement LCA with an Input-Output analysis (United Nations. Statistical Division, 1999) to estimate consumption impacts across non transport related sectors, simulating different scenarios to arrive at an estimation of the rebound effect. In the scenarios they compare different transport profile consisting of:

- Only car use
- Car and bus use
- Only bus use
- Car sharing and bus
    - Car sharing "light" and bus
    - Car sharing "intensive" and bus

The difference between CS light and CS intensive is the assumption that under CS intensive the travelled distance by CS is nearly three times larger.

Briceno et al. (2005) use three scenarios to test these transport profiles for their transport global warming potential (GWP) and (indirect) rebound GWP. GWP "is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2)" (US Environmental Protection Agency, n.d.).

In the first scenario they assume that the same amount of distance, 27 769 pkm, is travelled with these different transport profiles. Briceno et al. (2005) acknowledge that this scenario is somewhat unrealistic since the distance travelled depends heavily on the mode(s) of transport used. The money saved from the overall household budget, which is the same in all scenarios, is assumed to be spent uniformly across the other non-transport sectors. In this scenario, bus use has the lowest overall GWP, followed by CS light and intensive, bus and car and car only.

The second scenario assumes that different distances are travelled by different modes of transport which seems closer to reality. The allocation of the remaining household budget is the same as in scenario 1. Total GWP results are similar to the first scenario with CS light and bus only changing positions.

The third scenario is the most interesting one. It also uses variable travel distances depending on transport mode but assumes that the remaining household budget is solely spent on air travel. This, admittedly, strong assumption reverses the picture. Affordable modes of transport, namely only bus and CS light and intensive, have the highest environmental impact, followed by the more expensive modes car only and bus and car.

The assumption that the total remaining amount is spent on air travel is a drastic one and may not be realistic for average CS users. The effects of that assumption are also drastic, leading to a scenario where solely using the private car induces a smaller environmental impact than using only the bus. The assumption that the remaining amount is spent uniformly across non-transport sectors is also somewhat unrealistic, since different consumption categories have different income elasticities. It is, for example, more likely that surplus income is spent on transport, a high impact category, than on health, a low impact category (Chai, 2018; European Environment Agency, 2013). Briceno et al. (2005) therefore show that "[d]epending on how the rebound expenditure is spent, it may lead to very different environmental impacts" (Briceno et al., 2005, p. 9).

Chen & Kockelman (2016) discuss cradle-to-grave life-cycle impacts of both stationary and free-floating CS schemes on carbon emissions and energy use in the US. They consider the impact of changes in "ownership levels, travel distances, fleet fuel economy […], parking demand […] and alternative modes" (Chen & Kockelman, 2016, p. 276). They find that CS users cut their energy demand and carbon emissions by about half. They also find that about 10% of the US population can be considered candidates for CS because they fulfil different criteria like dense neighbourhoods, good access to PT and below average mileage with private vehicles. In a scenario where these CS candidates all adopted CS, national transport-related household savings of carbon emissions and energy would amount to 5%. Chen & Kockelman (2016) state that these savings can mostly be attributed to changes in transport modes and avoided travel.

If the authors factor in indirect rebound effects, the total savings of 5% are reduced to 3% in the worst-case scenario. This is a reduction of 40%. The authors acknowledge that indirect rebound effects are difficult to calculate and thus use previous estimations by Thomas & Azevedo (2013), Druckman et al. (2011) and Sorrell (2007). Chen and Kockelman (2016) state that lower estimations range between 5-15% (from Thomas & Azevedo (2013) and Druckman et al. (2011) but use the low-impact estimation by Druckman et al. (2011) of 12% and not the medium-impact result of 34%. Furthermore, both studies explore other fields than CS. Thomas & Azevedo (2013) study investments in residential energy efficiency while Druckman et al. (2011) investigate sufficiency measures by households, of which only one is mobility related.

Both articles discussed in this section (Briceno et al., 2005; Chen & Kockelman, 2016) study indirect rebound effects among CS users. Briceno et al. (2005) use unrealistic assumptions to demonstrate the potential impact of indirect rebound effects. Chen & Kockelman (2016) investigate cradle-to-grave impacts of CS and use previous estimations of indirect rebound effects as basis for their own. These estimations are mostly not related to mobility. It is therefore doubtful if they can be applied to CS.

Both studies highlight that indirect rebound effects can significantly alter the environmental impacts of CS. The fact that only two studies explore indirect rebound effects among CS users, and the limitations within these studies, emphasize the need to further investigate the issue.

2.4 Summary and Conclusions

The first part of this literature review discussed the variable “CS use”. The focus was placed on three overarching behavioural themes; usage patterns, mode shift and ownership patterns. Here CS seems to have multiple positive effects, from reducing vkt, a shift towards more sustainable means of transport to reducing private vehicle ownership levels (Durand et al., 2018; Martin & Shaheen, 2016; Nehrke & Loose, 2018). Other studies (Becker et al., 2017; Chen & Kockelman, 2016) have explored non-behaviour related issues, investigating socio-demographic data, attitudes and parking demand. Perhaps the most interesting finding is that there seems to be general agreement that CS lowers the carbon impact of its users. Most of the aforementioned effects play a role but primary reasons for that seem to be shifts in transport modes and reduced mileage.

Rebound effects have been studied for many actions and measures. There are different effects for different actions at work that sometimes enforce each other. To choose relevant articles for this literature review, multiple aspects were considered. One criterion that all discussed articles fulfil is the relevance for the topic of indirect rebound effects. There are many studies that discuss only direct or economy-wide rebound effects which do not relate to the thesis topic and are therefore not included.

Another criterion is prominence. An example of this is the article by Brännlund et al. (2007). It is one of the most widely cited studies in the field, maybe because the estimated rebound effects are very high and likely represent overestimations. Alfredsson’s (2004) work is interesting because it is an early example for estimating rebound effects in a European context. Especially the section about green travel seems to be relevant for this thesis. In this section changes in mobility behaviour and efficiency of cars are discussed, which correspond with the effects of CS use. The income effect for these measures is reported to be small (10%). Druckman et al. (2011) provide a different view on indirect rebound effects by assessing various re-spending scenarios, including investments. The study also distinguishes itself form previous ones by focussing on sufficiency measures. They find that the size of the rebound effect is sensitive to re-spending behaviour and conclude that putting additional income into savings (investments) is less carbon intensive than spending when the average carbon intensity of UK investments is used. In contrast, Chitnis et al. (2013) offer a more recent study that explore only efficiency measures. Compared to Brännlund et al.'s (2007) estimations for efficiency measures their results are much more moderate, ranging between 5-15%. This suggests that Brännlund et al. (2007) have overestimated the size of the rebound effect, especially because other studies report similar results (Thomas & Azevedo, 2013). Chitnis et al. (2014) provide similar estimations for efficiency measures (around 14%) but further examine the rebound effect for different income groups. The lower the income, the larger the rebound effect.

This summary shows how the field of indirect rebound effects has developed, focussing on more and more aspects and assessing different scenarios. Studies earlier than from 2014 are relatively less sparse. Maybe a point of saturation was reached, and more recent studies explore indirect rebound effects for more specific fields.

It is difficult to draw conclusions from these findings since methodologies, geographical areas, measures investigated, assumptions and assessed households differ significantly. Furthermore, many researchers point to the difficulties of estimating the size of rebound effects (Chen & Kockelman, 2016; Druckman et al., 2011). It is therefore not surprising that estimations differ significantly.

Another conclusion is that backfire seems to be a rarity. Apart from Brännlund et al. (2007) it either occurs under extreme assumptions or only for very specific actions like reducing food waste. It is therefore unlikely that backfire would occur for CS.

The two main variables that influence rebound effects are re-spending patterns and the assumed carbon intensities for the different expenditure categories. Rebound effects tend to be lower, if consumption is shifted from high to low carbon intensive categories. An example would be Chitnis et al. (2013), where energy efficiency improvements for heating and electricity (high carbon intensity) shifted consumption towards categories with lower carbon intensities.

Consequently, rebound effects for CS will only be significant, if CS users shift their consumption to more carbon intensive consumption categories than Transport. Since Transport has a high carbon intensity (European Environment Agency, 2013) it is also interesting how consumption shifts *within* this category. It is therefore important to investigate the transport category in more detail.

The next section presents how the research questions were answered and the hypotheses tested.

3 Methodology

This thesis is conducted from a post-positivist philosophical worldview. This implies that the world is governed by laws and theories that are expressed in cause and effect relationships. To approach these laws and theories, variables are identified and operationalised in measurable and testable data. We cannot be positive about knowledge, especially when studying human behaviour. Our knowledge (or perceived knowledge) is expressed in theories and hypotheses that can be tested and are then either rejected or fail to be rejected. From this process claims about the objective reality can be formulated. If a new claim is developed that is more warranted by the collected data and subsequent analysis than the previous claim, the previous claim will be amended or replaced by the new claim. To ensure a high quality of research, objectivity is key. Therefore, methods and conclusions need to be tested for bias (Creswell, 2014; D. C. Phillips & Burbules, 2000).

In this thesis, therefore, hypotheses are developed and tested. These hypotheses can never be proven, only rejected or not rejected. The goal of this thesis is to make warranted claims and possibly add to claims from others to make their statements more warranted. To make these claims, data was collected, analysed and tested for potential biases to be as objective as possible.

3.1 Guiding Assumptions and Hypotheses

Both articles that investigate indirect rebound effects and CS find that consumption patterns could significantly alter the environmental consequences of CS. However, they use highly aggregated data and either unrealistic assumptions or previous, non-transport related estimations of the rebound effect to arrive at their conclusions. It is not clear whether the average CS user behaves in the same way as the average person.

This thesis contributes to addressing a research gap by using a survey design to arrive at values for CCE among CS users and relevant baselines. Re-spending patterns and carbon intensities of consumption categories are the two key variables that influence the impact of consumption and they are both influenced by user behaviour. Using aggregated data about these two variables might therefore yield an incomplete picture since the group of CS users might behave differently than the average population. This is why in this thesis primary data from CS users about re-spending patterns is gathered. Also, the category Transport is examined closer because it is a carbon intensive consumption category. Assessing shifts *within* the Transport category, towards or away from carbon intensive transport modes, will yield a more complete picture of CCE impacts of CS users.

From the literature review multiple hypotheses are derived that will be tested in the course of this thesis. They are based on the research questions and on their assumed causal relationship, shown in Figure 3.

H1: CS affects the disposable income of 75% of CS users either positively or negatively.

For the causal relationship between CS use and CCE to hold, the disposable income of CS users must be affected significantly. H1 postulates that for the population.

H2: The consumption patterns of CS users differ significantly from the baseline.

The disposable income of CS users might change but this does not mean that their consumption patterns are altered as well. For the purpose of this thesis consumption patterns are defined as the allocation of monetary resources on different household consumption categories. The consumption categories will be discussed further below. H2 postulates that the consumption patterns of the population of CS users differ from the baseline which represents the second element of the causal relationship between CS use and CCE.

H3: The carbon induced carbon emissions of CS users differ significantly from the CCE of the baseline.

H3 discusses carbon impacts of changed consumption patterns and the last element of the causal relationship. As pointed out in the literature (Alfredsson, 2004; Briceno et al., 2005; Chen & Kockelman, 2016; Chitnis et al., 2013; Druckman et al., 2011) changed consumption patterns can have a significant effect on carbon emissions. This hypothesis assumes that CS members have significantly different carbon emissions due to their altered consumption patterns.

A step by step overview of the research design is presented below.

3.2 Research Design

The different parts of the thesis are organised according to the following principles. The structure of the literature review is based on the research questions and their assumed relationship. It was executed by searching Lund University's LUBsearch and Google scholar by using a combination of different key terms related to the relevant subsection. The literature confirmed the need for further research, outlined key variables (re-spending patterns and carbon intensities) and high-lighted the need to further explore the consumption category Transport. It also inspired some guiding assumptions and the hypotheses.

Empirical data was collected using a survey design. The survey was developed by the author, pilot-tested multiple times and distributed with the help of the company and snowballing efforts. The obtained data was used to assess the changes in disposable income, the distribution of the re-expenditure from which CCE were calculated. The collected mobility patterns were helpful in es-timating alternative scenarios to validate results and to evaluate the shift of consumption within the category Transport. In this thesis "mobility patterns" is used as a collective term for the share of different transport modes on overall distance covered. The collected socio-demographic data was helpful in discussing and comparing results.

Reliability of the survey was ensured by using a tried and tested measure for most items, the Likert scale. Reliability is defined by "the extent to which repeated measurement yields constant re-sults…(Sapsford, 2007, p. 16)". Likert scales are a type of standardised test and are one of the most frequently used tests in social science research. Most commonly they are associated with questions about attitudes but they can also be applied to inquiries about perceived likelihoods (Wal-liman, 2006). Another part of reliability is standardisation, that every participant is asked the same question in exactly the same manner. This is achieved by default in a self-administered survey.

The primary data was supplemented with secondary data. The classification of individual consump-tion by purpose (COICOP) categories established by the United Nations were key in designing the questions inquiring about changing consumption patterns. Values for the carbon intensities of these categories (European Environment Agency, 2013) were crucial in arriving at CCE.

Analysis of the data was conducted using statistical tools offered by Microsoft Excel and IBM SPSS Statistics. Descriptive statistics and statistical tests were used to summarise the data and test the hypotheses. The calculation of environmental impacts was conducted step by step from changes in the disposable income, their effects on consumption patterns and effects on CCE.

In the analysis three subsamples, group 1 (G1), group 2 (G2) and group 3 (G3), with differing socio-demographic characteristics and CCE are distinguished. To ensure validity of design, "the extent to which the comparisons being made are appropriate to establish the arguments which rest on them" (Sapsford, 2007, p. 10), the three groups are compared to different baselines, derived from the statistical yearbook of Berlin (Amt für Statistik & BWV Berliner Wissenschafts-Verlag

GmbH, 2018). The baselines correspond to the three groups in terms of average household income because in this thesis the effect of changing consumption patterns is explored.

The next chapter describes the primary data gathering process in more detail.

3.3 Survey

For this thesis a cross-sectional survey design was used. The aim is to study a sample of a population that has the properties (in terms of sample size and composition) so that statements about the sample can be generalised for the whole population (Creswell, 2014).

3.3.1 Survey Design

A survey design was chosen to get data from a large amount of people that represent the population, CS users, as best as possible. Perceived savings and the re-expenditure of these savings are two of the key data points of this thesis. Both of them could be calculated from average data, as previous research has done. But in this thesis CS users are examined, and average data might not be representative. It is likely that the group of CS users differs from the average population. Studies have pointed out that attitudes about environmental and social issues of CS users differ from attitudes of the average population (Costain et al., 2012; Millard-Ball et al., 2005). Thus, consumption patterns of CS users might also be different from those of an average person. A survey design helps to ask CS users about their consumption patterns and perceived savings which makes it easier to draw conclusions about the population of CS users.

The survey (see Appendix) was designed using an online survey tool (*Survey&Report*, 2019) and is divided into five sections. Before section 1 an introductory text explains the purpose and non-commercial nature of the study. The participants then have to consent to the anonymised saving of their data to continue with the survey and section 1. This section contains simple questions to get some basic information from the participants and to introduce them to the survey.

Categorical data like car ownership and the used CS platform(s) is collected. Question 4 then asks one of the key questions in the survey: Whether the disposable income of CS members increases, decreases or remains roughly the same *due to* participation in CS. Depending on the answer to this question, the participants are separated into three different lines of questioning as depicted in Figure 6.

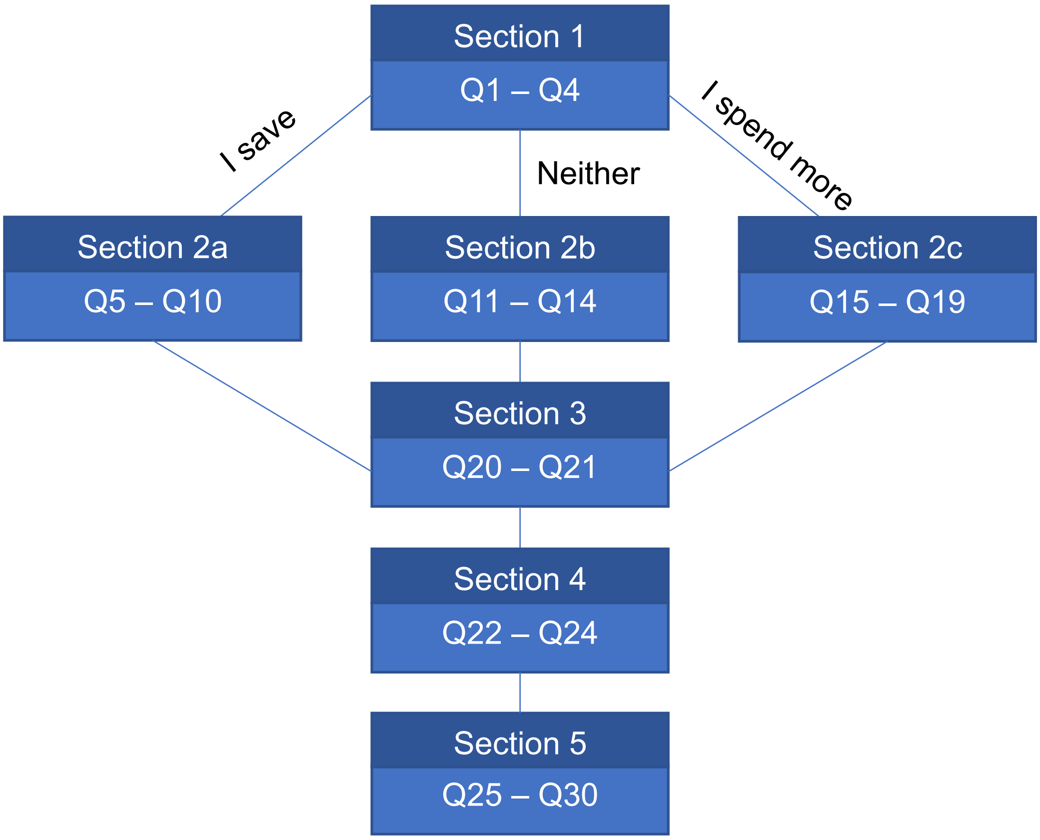

Figure 6. Flow chart of the survey.
Source: Author.

The participants who report that their disposable income had increased, shall be referred to as Group 1 (G1), Group 2 (G2) are the participants who state that they neither save nor spend more due to CS and Group 3 (G3) state that they spend more due to CS. They are mainly asked questions about their costs per booking and consumption patterns in sections 2a, 2b and 2c. G2 were confronted with a hypothetical increase in income. It is important to note that people might treat a hypothetical increase in income differently than an actual increase in income. Asking these hypothetical questions makes is possible to obtain data from participants who would otherwise have been discarded. The data might not be as reliable as the data from G1, but it is better than discarding that data in the first place. It also makes it possible to draw some potentially interesting comparisons between G1 and G2. From section 3 on all participants answer the same questions. Section 3 collects data about mobility patterns, section 4 is included for the company to learn more about their customers and section 5 is concerned with socio-demographic data.

Table 6 summarizes the survey and cross-references variables, RQs and hypotheses and the corresponding items on the survey.

Table 6. Cross-reference of variables, hypotheses, and items on the survey.

Variable name	RQ/Hypothesis	Item on survey
Mediating variable income	RQ/H1: Change in disposable income	Qu 4, 5, 6, 11, 12, 15, 20
Mediating variable consumption patterns	RQ/H2: Consumption patterns	Qu 7, 13, 18
Dependent variable CCE	RQ/H3: CEE	Qu 4, 6, 7, 13, 18

Source: Author.

Apart from categorical questions mostly a 5-point Likert scale is used in the survey. An odd number was used intentionally to provide the participants with a neutral option. Sometimes it is recommended to avoid giving a neutral option, so participants have to decide (as in Question 21). In this case it was provided to ensure that participants who selected the more extreme options, did so out of free will and not because the survey design forced them to.

Five points, as opposed to more, were deemed a good compromise between accuracy and manageability. More points would have made the results more precise, but it might have meant less clarity for participants. Furthermore, some of the questions were quite abstract and hypothetical. Providing too many options would have been more work and might have confused participants. This would likely have resulted in higher non-completion rates.

The Likert scale is ideal for this type of research, since it makes it possible to collect and classify quantitative data about behaviour. One common limitation of the Likert-scale is the so-called social desirability bias (Kelly, Harpel, Fontes, Walters, & Murphy, 2017). It entails that participants select the answers they assume is socially desirable or that the researcher wants to find.

3.3.2 Data Collection

The survey was targeted at German CS users living in Hamburg or Berlin.. Its size is estimated using data from various sources. The federal CS association of Germany reports about 2.46 million CS users in Germany (Bundesverband Carsharing, 2019a). The German population is reported at 82.89 million people (Statistisches Bundesamt, 2018) and the urbanisation rate of Germany, the urban population in per cent of the total population, is 77% (United Nations Population Division, 2018). This leads to a urbanised German population of 63.83 million. The combined population of Hamburg and Berlin is 5.59 million, 1.84 million in Hamburg (Statistisches Amt für Hamburg und Schleswig-Holstein, 2019) and 3.75 million in Berlin (Amt für Statistik Berlin-Brandenburg, 2019). The share of the Hamburg and Berlin population of the urbanised population is about 9%. The population is then estimated according to Equation 3, where share of Hamburg/Berlin refers to the 9% described before. This leads to a population size of about 215 500 users.

Equation 3. Estimation of the population size.

$$Population\ size = CS\ user\ in\ Germany * share\ of\ Hamburg/Berlin$$

Source: Author.

There are certain characteristics that apply to this population. Previous studies (Becker et al., 2017; Le Vine & Polak, 2017) have found that CS users tend to live in dense urban areas, are younger than the average population and have a higher education and income. These characteristics likely apply to the population at hand as well. Using an online survey size calculator ('Sample Size Calculator', n.d.) with the following parameters a recommended sample size has been established.

Parameters:

- Margin of error: 5%
- Confidence level: 90%
- Population size: 215 500

Considering these parameters, the recommended sample size for the survey is 271 respondents. Due to several limitations this was not reached which will be discussed in the Limitations section.

They survey was published with help from the company. They included a link to the survey in their newsletter to customers in Berlin which was sent on 11 July 2019. On the same day, the company also published a tweet with a reference to the survey. In addition, the author made further efforts to increase the number of answers. A snowballing approach was used to reach further CS users as it was sent in mailing lists to people living in Hamburg with the reference that only CS users should reply to the survey. The survey was also published on social media groups related to CS.

It remained active for about a month and was closed on 5 August 2019. The major part of answers was collected during the first few days, but the snowballing approach yielded ten additional answers towards the end of July. About 70% of the answers arose from the cooperation with the CS company and therefore B2C CS customers of the company in Berlin. A small part of answers (less than 5%) was received from CS users all over Germany who were interested in social media pages about CS. They were analysed and found not to distort results, thus they were included.

Apart from the survey, also secondary data was collected. The main data sources are discussed in the next section.

3.4 Other Relevant Data Sources

3.4.1 Consumption Categories

One aspect that is central to this thesis are the consumption categories on which participants redistribute their expenditure. They are based on the COICOP categories established by the United Nations and are defined as "a classification developed by the United Nations Statistics Division to classify and analyze individual consumption expenditures incurred by households […] according to their purpose. It includes categories such as clothing and footwear, housing, water, electricity, and gas and other fuels" (Eurostat, n.d. n.p.).

A selection of eight out of thirteen COICOP consumption categories was used in this thesis. These are:

- Food and Beverages (F&B)
- Clothing and Footwear (C&F)
- Furnishings and Equipment (F&E)
- Restaurants and Hotels (R&H)
- Transport (Tran)
- Communication (Comm)
- Recreation and Culture (R&C)
- Miscellaneous goods and services (Misc)

The abbreviations in brackets are used in various figures and tables throughout the thesis. To reduce the amount of options for participants, to make it comparable with German data and because of the low likelihood that they would be chosen based on income elasticities (Chai, 2018) the following categories were summarised under category Miscellaneous goods and services:

- Alcoholic beverages, tobacco and narcotics
- Housing, water, electricity, gas and other fuels
- Health
- Education services
- Insurance and financial services

A detailed description of what these categories entail can be found at United Nations (2018).

3.4.2 Carbon Intensities

Related to the point before are the carbon intensities of the consumption categories. They are based on EU wide data and consider direct emissions from households as well as emissions embodied in the production of services and goods. The European Environment Agency (2013) provides data from 2000, 2004 and 2007 of which data from 2007 is used in this thesis.

3.5 Statistics to Analyse the Survey Results

The data was analysed using the computer programmes Microsoft Excel and IBM SPSS Statistics. Descriptive statistics were compiled to summarise the data and visual representations yielded an overview of trends and distributions. The data was also divided into subsamples, most notably into G1, G2 and G3.

Survey results are subjected to multiple statistical significance tests. One test that applies is Pearson's chi-squared test, depicted in Equation 4. It is often used to compare different groups and helps determining whether the differences in the sample also exist in the population (Sapsford, 2007). Sapsford (2007) describes the method as model fitting. It determines how different the observed values are from the expected values. If they are different enough, the null hypothesis of "no difference" is rejected and a statistically significant difference is found. It is applicable for the purposes in this thesis because it makes it possible to test hypotheses one and two. Both hypotheses postulate that the differences in terms of disposable income and consumption patterns also apply to the population. The test can be applied to any size of table as long as the expected values are at least five in every cell (Sapsford, 2007), which applies when the test is used in this thesis.

Equation 4. Pearson's chi-squared test

$$\chi^2 = \frac{(O - E)^2}{E}$$

Source: Sapsford (2007).

Where O denotes the observed and E the expected value.

Another test that is used is the One-Group t-test (Equation 5). It is commonly used to compare a sample with a comparison value and assess whether the difference is significant (Quirk, 2016). This applies to hypothesis three of this thesis which postulates that the CCE of CS users differ from the baseline. The One-Group t-test was used to compare these two values.

Equation 5. One-Group t-test

$$t = \frac{\bar{X} - \mu}{S_{\bar{X}}}$$

Source: Quirk (2016).

Where $\bar{X}$ denotes the sample mean, μ the population mean and $S_{\bar{X}}$ the standard error of the mean.

The following assumptions apply to the formula of the One-Group t-test:

- "The data are independent of each other (i.e., each person receives only one score),
- the population of the data is normally distributed, and
- the data have a constant variance…" (Quirk, 2016, p. 71).

Seltman (2018) points out that it is difficult and sometimes impossible to verify the assumption of independence from the data. The independence of the data could be jeopardised by a participant completing the survey multiples times. This seems unlikely as the participants do not have a reason to do so. To prevent a second submission, survey access was locked for 20 minutes per device after completion. The independence of the data is therefore assumed.

The second assumption, normality of the data, is generally assumed for a sample size of 20 or more, due to the central limit theorem (Seltman, 2018). If the sample size is less than 20 a Shapiro-Wilk test can be used to test the normality of the data. It is depicted in Equation 6. The null hypothesis of the Shapiro-Wilk test is that the sample is distributed normally (Shapiro & Wilk, 1965). Low values (significantly below one) in the test statistic indicate significance and a rejection of the null hypothesis (Lohninger, n.d.). The Shapiro-Wilk test is especially powerful for a smaller sample size (Shapiro & Wilk, 1965) and is thus useful for this thesis. It is used to test the normality of distribution of CCE for G2 and G3.

Equation 6. Shapiro-Wilk test statistic

$$W = \frac{\left(\sum_{i=1}^{n} a_i x_{(i)}\right)^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2}$$

Source: Shapiro & Wilk (1965)

In this equation n stands for the number of observations, x_i denotes the values of the sample ordered by increasing order, a_i refers to tabulated constants generated from the means, variances and covariances of the sample from a sample that is normally distributed and $\bar{x}$ denotes the sample mean (Glen, 2014; Lohninger, n.d.).

The third assumption is evaluated by examining boxplots and checking the occurrence of outliers. This is done when testing the hypothesis.

3.6 Calculation of Environmental Impacts

This section describes how the main variables in this thesis, change in disposable income, consumption patterns and carbon emissions, were operationalised and environmental impacts were calculated.

3.6.1 Change in Disposable Income

The operationalisation of the change in disposable income, started by asking participants whether their disposable income had increased, decreased or remained the same *due to* CS. The question inquiring about the income change stresses that CS must be the cause. This is to eliminate other causes for changes of the disposable income. The participants in G1 were asked about their monthly savings which can be difficult to estimate. For reference, the total monthly costs (including depreciation) of a small (Citroen C1) and medium sized car (Skoda Octavia) were provided to help participants answer the question. G2 was asked what amount of monthly savings they would consider significant and the obtained value was used for the further estimations. G3 was asked about their average expenditure per booking because it was deemed an easier question than average expenditure per month. Expenditure was used for G3 because they stated that they spent more due to CS. With a question about the frequency of use for CS, monthly expenditure was calculated.

To arrive at the change in disposable income for G3, data about frequency of use (Question 20) was used. First, answers from participants had to be translated into continuous values according to Table 7. Then frequency of use could be calculated according to Equation 7 below, where "number of answers" stands for the number of respondents who chose a certain option. This was done for G1, G2, G3 and for all participants. Change in disposable income for G3 was then calculated by multiplying the frequency of use per person (G3) by the expenditure per booking (Question 15).

Table 7. Translation of survey answers into continuous values.

Q20: How often on average do you use CS?	Assumed usage per year [times]
Never	0
1-2 per year	1.5
Multiple times per year	6
1-2 times per month	18
1-2 times per week	78
3-4 times per week	156
5-6 times per week	312
daily	360

Source: Author.

Equation 7. Calculation of frequency of use per year for different transport modes.

$$Frequency\ of\ use = \frac{Assuemd\ usage\ (year) * number\ of\ answers}{Number\ of\ particpants}$$

Source: Author.

3.6.2 Consumption Patterns

All three groups were asked about the likelihood of spending the amount on consumption categories. For G1 "amount" was their stated monthly savings, for G2 amount refers to what they stated to be significant savings and for G3 it refers to their expenditure on CS. The likelihood was inquired with a 5-point Likert scale, ranging from 1 (very unlikely) to 5 (very likely). To get an associated Euro amount spent per category, the points from the Likert scale were translated into percentages according to Equation 8. The participant with the ID 31, for example, distributed in total 25 points as depicted in Source: Author.

Table 8.

For the category Food & Beverages this would be 5 divided by 25, i.e. 20%. The stated savings of the participant with ID 31 are EUR 220 and they are distributed according to the calculated per cent values. These Euro amounts were then added to the expenditure of the baseline. The baselines are derived from the statistical yearbook of Berlin (Amt für Statistik & BWV Berliner Wissenschafts-Verlag GmbH, 2018). Different baselines are used for G1, G2 and G3 according to the average net household income of the groups. CS users are compared to Berlin inhabitants with an average net household income between EUR 3 600 and 5 000 for G1, between EUR 2 600 and 3 600 for G2 and EUR 2 000 – 2 600 for G3 (Amt für Statistik & BWV Berliner Wissenschafts-Verlag GmbH, 2018).

The sum of the baseline expenditure and the re-expenditure leads to the overall consumption patterns of CS users as depicted in Equation 9. "Amount" refers to the savings for G1 and G2 and for the expenditure for G3.

For the category Transport an additional step was necessary. Since the EUR 220 savings occurred within Transport, the stated savings were subtracted from the value of the baseline, before the re-spending was added (Equation 10).

The row titled Total shows the total expenditure of ID 31 on all these categories. The highest spending occurs in Miscellaneous because it summarises multiple consumption categories. This process was repeated for every participant to arrive at individual and average expenditures.

Equation 8. Operationalisation of the distribution in per cent for the consumption categories.

$$Distribution\ (\%) = \frac{Points\ per\ category}{\sum Points}$$

Source: Author.

Table 8. Example for the operationalisation of re-expenditure of stated savings for G1.

Categories	F&B[1]	C&F	F&E	R&H	Tran	Comm	R&C	Misc.
Answer	Very likely	Unlikely	Unlikely	Likely	Likely	Very unlikely	Likely	Neither
Points	5	2	2	4	4	1	4	3
Distribution [%]	20	8	8	16	16	4	16	12
Re-expenditure [EUR]	44.00	17.60	17.60	35.20	35.20	8.80	35.20	26.40
Baseline [EUR]	448.00	179.00	148.00	233.00	361.00	93.00	398.00	1 220.00
Total [EUR]	492.00	196.60	165.60	268.20	176.20	101.80	433.20	1 246.40

Source: Author.

Equation 9. Calculation of consumption patterns for all consumption categories except Transport.

$$Consumption\ patterns = Basline + Distribution\ (\%) * Amount$$

[1] The abbreviations can be found in chapter 3.4.1.

Source: Author.

Equation 10. Calculation of consumption patterns for Transport.

$$Consumption\ patterns = (Baseline - Amount) + \ Distribution\ (\%) * Amount$$

Source: Author.

The method of arriving at the re-expenditure distribution in per cent has its flaws, since selecting "very likely" results in a different percentage amount depending on the overall sum of points. But it also reflects the reality of participants since "very likely" might mean different things for different people. The reason for why this method was chosen though is a mixture of convenience for participants and limitations of the survey tool. A seven- or nine-point Likert scale would have resulted in more precise distributions, but it would have been harder to answer for the participants. Ideally, participants would have been able to distribute percentage values themselves, with a total sum of 100. This option was not available in the survey tool and it was deemed unlikely that participants would be willing to distribute the percentages themselves accordingly. Hence the method presented above was chosen.

3.6.3 Carbon Emissions

The step from expenditure to associated carbon emissions is short. Every consumption category has associated carbon emissions, depicted in kg of carbon equivalents per Euro spent (European Environment Agency, 2013). The data is aggregated from the EU. CCE are calculated according to Equation 11 and a value per category (Table 9) is obtained.

Equation 11. Calculation of CCE for the consumption categories.

$$CCE = Expenditure * carbon\ intensity$$

Source: Author.

Table 9. Carbon intensities of consumption categories and total carbon emissions of participant ID 31.

Categories	F&B	C&F	F&E	R&H	Tran	Comm	R&C	Misc.
Total [EUR]	492.00	196.60	165.60	268.20	176.20	101.80	433.20	1 246.40
Carbon intensity	0.8	0.1	1.1	0.4	1.2	0.1	0.3	0.79[2]
Carbon emissions [kg]	393.60	19.66	182.16	107.28	211.44	10.18	129.96	979.24[3]

Sources: European Environment Agency (2013), Author.

3.7 Scrutiny of Results

In this thesis the obtained results are scrutinised to check whether and to what extent they are realistic. For that purpose, secondary data was obtained and manipulated.

[2] The value for Miscellaneous goods and services is a combination of the carbon intensities of the omitted consumption categories. It is weighted by the expenditure on these categories of the baseline. In this case, Berlin residents with a household income between EUR 3 600 and 5 000 which was used as baseline for G1.

[3] Deviations due to rounding errors may occur.

3.7.1 Estimation of Cost Savings

Stated cost savings are one of the key data points in this thesis. Relying on stated answers can be risky, so savings due to CS were estimated by comparing the stated mobility patterns of CS users with mobility patterns of a baseline. The mobility patterns of CS users were stated answers as well, but it might be easier for participants to state what types of transport modes they use than estimating monthly savings *due to* CS. First, the baseline has to be established.

The Kilometres per Year for the Baseline

The baseline was calculated by using secondary data for the total annual travel distance (km/year) of an average person for different modes of transport. Table 10 provides an overview of the values, sources and information about how the values were derived. "Calculated" refers to some manipulation of the data, no comment means that the data was directly taken from the source. Operating with different sources for pkm may cause errors because different studies likely used differing methods, definitions and assumptions. It was not possible to acquire all values from the same source. The section below outlines how the values were derived in detail. If not stated otherwise, values on a yearly basis are used.

Table 10. Overview of the km per year and person for different transport modes for the baseline ,their source(s) and how they were derived.

Transport mode	Km/year/person	Source(s)	Derived
Private car	9 668	Leopold & Friedheim (2018)	
Motorbike	117	Kraftfahrt-Bundesamt (2018)	Calculated
Bicycle	430	Bundesministerium für Verkehr, Bau und Stadtentwicklung & Deutsches Institut für Wirtschaftsforschung (2018), Nobis & Kuhnimhof (2018), Statistisches Bundesamt (2018)	Calculated
Walking	430	Bundesministerium für Verkehr, Bau und Stadtentwicklung & Deutsches Institut für Wirtschaftsforschung (2018), Nobis & Kuhnimhof (2018)	Calculated
Taxis, Uber and similar	34	'Fakten und Zahlen' (2016), Statistisches Bundesamt (2018)	Calculated
Plane	5 430	Statistisches Bundesamt (2019a), Statistisches Bundesamt (2018)	Calculated
PT local	1 350	Bundesministerium für Verkehr, Bau und Stadtentwicklung & Deutsches Institut für Wirtschaftsforschung (2018), Statistisches Bundesamt (2018)	Calculated
PT long distance	600	Statistisches Bundesamt (2019b), Statistisches Bundesamt (2018)	Calculated

Before discussing how the values are derived in detail, some terminology must be examined.

- Total distance: The distance travelled in km with a given mode of transport over a year.
- Pkm: Passenger-kilometre. "A passenger-kilometre is performed when a passenger is carried one kilometre" ('Passenger-kilometres performed', n.d. n.p.).
- German population refers to the population of Germany in the year 2018 based on the 2011 census (Statistisches Bundesamt, 2018). It is 82.89 million.

Motorbike: The km/year/person for motorbikes are calculated according to Equation 12, using total distance travelled with motorbikes in a year (9741 mill km). Pkm would have been a better value to use but it was difficult to obtain. Since a motorbike tends to be used by one person, total distance is an adequate proxy for pkm.

Equation 12. Calculation of km per person and year for motorbikes.

$$km\ per\ person = \frac{Total\ distance}{German\ population}$$

Source: Author.

Bike: The km/year/person for bikes are calculated according to Equation 13. The total pkm for all modes in Germany in 2017 was 1 195 billion (Bundesministerium für Verkehr, Bau und Stadtentwicklung & Deutsches Institut für Wirtschaftsforschung, 2018). The value for walking is derived with the same method, the share of biking and walking of overall pkm is the same, with 3% (Nobis & Kuhnimhof, 2018).

Equation 13. Calculation of km per person and year for bikes.

$$km\ per\ person = \frac{pkm\ (all\ modes) * share\ pkm\ of\ bikes}{German\ Population}$$

Source: Author.

Taxi: The value for taxis was calculated by dividing the pkm for taxis in 2016, 2.8 billion km ('Fakten und Zahlen', 2016), by the German population, as depicted in Equation 14.

Equation 14. Calculation of km per person and year for taxis, planes and local PT.

$$km\ per\ person = \frac{pkm}{German\ population}$$

Source: Author.

The km/year/person for planes and PT local are calculated according to Equation 14, with the relevant values for yearly pkm. They are about 450 billion km for planes and 112 billion km for local PT.

For long distance PT the pkm for long distance rail and coaches (long distance busses) were summed before it was divided by the German population (Equation 15). They were about 43 billion km for long distance trains (Statistisches Bundesamt, 2019b) and about 7 billion km (Statistisches Bundesamt, 2019b) for coaches both in 2018.

Equation 15. Calculation of km per person and year for long distance PT.

$$km\ per\ person = \frac{pkm\ (ld\ rail) + pkm\ (coaches)}{German\ population}$$

Source: Author.

After calculating values for km per person for the baseline, the same value has to be estimated for CS users, using primary and secondary data.

Kilometre per Year for CS Users

To arrive at a value for km travelled for CS users the distance per trip is needed. In the survey, CS users were asked how often they used different transport modes. From these answers use on a yearly basis was estimated using Table 7 and Equation 7 as a basis.

After arriving at values for times used per year, the average distance per trip is needed. Table 11 depicts the values, their sources and how they were derived. “Estimated” refers to a situation where no value could be derived from the literature, “calculated” refers to a manipulation of the source data to arrive at the needed value and no comment means the value was taken directly from the source.

Table 11. Km/trip for different transport modes , their sources and how they were derived.

	Km/trip[4]	Source(s)	Derived
Private Car	15	Steinmeyer & Herrmann-Fiechtner (2017)	
Stationary CS	71	Company representative (personal communication, August 2019)	
Free-floating CS	15	n./a.	Esti-mated
Motorbike	15	n./a.	Esti-mated
Bicycle	7	Steinmeyer & Herrmann-Fiechtner (2017)	
Walking	2	Steinmeyer & Herrmann-Fiechtner (2017)	
Taxis, Uber and similar	15	n./a.	Esti-mated
Plane	3112	Statistisches Bundesamt (2019a)	Calcu-lated
Local PT	19	Steinmeyer & Herrmann-Fiechtner (2017)	
Long-distance PT	273	Statistisches Bundesamt (2019b), “Über uns (About us)“ (n.d.)	Calcu-lated

For the private car, the bicycle, walking and local public transport average annual data from Berlin was used (Steinmeyer & Herrmann-Fiechtner, 2017), the value for stationary CS was provided by the CS company for their German operations (i.e. the data refers to roundtrips). The figure for free-floating CS, motorbikes and taxis were assumed to be equal to the private car.

Plane: The average flight distance (km per trip) was calculated according to Equation 16.

Equation 16. Calculation of km per trip for planes.

$$Km\ per\ trip = \frac{Total\ distance}{Number\ of\ flights}$$

Source: Author.

As a basis German data was used with the number of flights (759 181) and total distance (1 181 mill km) between January and May 2019 from German airports (Statistisches Bundesamt, 2019a). Using

[4] ”Trip” refers to a roundtrip.

these two data points leads to an average flight distance of about 1 550 km or 3 100 km for a round trip.

PT_long distance: For long distance public transport, the distance per sold ticket was used, according to Equation 17.

Equation 17. Estimation of km per trip for long distance PT.

$$km\ per\ trip = \frac{pkm}{tickets\ sold}$$

Source: Author.

The statistical federal office of Germany (Statistisches Bundesamt, 2019b) reports around 40 billion pkm a year travelled with long distance trains. The Deutsche Bahn (German rail) states that they sell 860 000 tickets a day ('Über uns (About us)', n.d.) or about 314 million a year. This leads to a distance of about 129 km per ticket or 258 km for a roundtrip. This value is likely an overestimation since the number of tickets does not correspond to the number of trips because there are weekly, monthly and yearly tickets. However, they are most commonly purchased for short distances which is not part of long-distance public transport and should thus not influence the value too much.

From these values, the average number of kilometres travelled per mode was calculated according to Equation 18. They are depicted in Table 12.

Equation 18. Average number of km travelled per mode.

$$Km\ per\ mode = Average\ distance\ per\ trip * Number\ of\ trips\ per\ person$$

Source: Author.

Table 12. Kilometres per person and year for the different transport modes for CS users.

	PC	CS_St	CS_ff	M	B	W	T	P	PT_loc	PT_ld
Km/p/y	378	771	209	188	1 615	565	92	8 154	3 328	6 871

Source: Author.

Abbreviations: PC stands for private car, CS_St and CS_ff for stationary and free-floating CS, M for motorbike, B for bicycle, W for walking, T for taxis, Uber or similar operators, P for planes and PT_loc and PT_ld for local and long-distance public transport.

Cost per Kilometre

To arrive at a value for savings, the costs per km are needed. Table 13 shows the cost/km for different modes, their sources and how they were derived.

Table 13. Cost/km for different modes , their sources and how they were derived.

	Cost/km	Source(s)	Derived
PC_CS	0.91	"Vergleichen Sie doch mal. Es lohnt sich! (n.d.), 'ADAC Autokosten-Rechner' (n.d.)	Calculated
PC	0.43	'ADAC Autokosten-Rechner' (n.d.)	
CS_St	1.00	'Vergleichen Sie doch mal. Es lohnt sich!' (n.d.)	Calculated
CS_ff	1.00	'Vergleichen Sie doch mal. Es lohnt sich!' (n.d.)	
M	0.27	'ADAC Autokosten-Rechner' (n.d.)'	
B	0.04	Dambeck (2011)	
W	0.02	Dambeck (2011)	
T	2.66	'Taxikosten in Deutschland' (n.d.)	Calculated
P	0.14	'2018 Global Flight Price Ranking' (2018), 'Historic Exchange Rates' (2018)	
PT_loc	0.23	'Umweltkarte in 3 Schritten' (n.d.)	Calculated
PT_ld	0.15		

For the private car for CS users the users were divided into two groups: Car owners and car borrowers. It was assumed that nine people of the sample owned a car because they reported to use it once or twice per week or more. Their km per user values are calculated according to Equation 19, around 2 800 km. This value is then the denominator in Equation 20 which calculates the cost per km for car owners. The numerator is the total costs for the "km per user", calculated by a cost calculator ('Vergleichen Sie doch mal. Es lohnt sich!', n.d.). This cost calculator is based on values from the general German car club – ADAC ('ADAC Autokosten-Rechner', n.d.). It was used to calculate the costs of private vehicle ownership for a Ford Fiesta that is driven 2 800 km a year, factoring in depreciation, operating costs (fuel, oil, maintenance), fixed costs (tax), and repair ('ADAC Autokosten-Rechner', n.d.). This value is about EUR 6 400 for 2 800 km. The cost per km (owner) is then EUR 2.29.

15 people in the sample report to drive a car between once and twice per year and once and twice per month. They are assumed not to own a car but borrow one when they use it and only pay for fuel. The km per user for borrowers are also computed according to Equation 19, about 110 km. Assuming a fuel price of EUR 1.30 per litre and fuel consumption of seven litres per 100 km we arrive at fuel costs for 110 km of EUR 9.10, the nominator in Equation 21. The denominator is the calculated km per user, 110 km. Borrowers pay significantly less per km, only about EUR 0.09. Averaging the two values according to the number of owners and borrowers leads to a value of EUR 0.91 per km. The rest of the sample (n = 47) report to never use a private car.

Equation 19. Calculation of km per user for car owners and borrowers.

$$km\ per\ user = \#Trips\ per\ user * Average\ distance\ per\ trip$$

Source: Author.

Equation 20. Calculation of cost per km for car owners.

$$cost\ per\ km\ (owner) = \frac{Costs\ for\ km\ per\ user\ (owner)}{km\ per\ user}$$

Source: Author.

Equation 21. Calculation of cost per km for car borrowers.

$$cost\ per\ km\ (borrower) = \frac{fuel\ cost\ for\ km\ per\ user\ (borrower)}{km\ per\ user\ (borrwer)}$$

Source: Author.

The baseline value for cost per km for the private car, was taken from the general German car club for a Skoda Octavia ('ADAC Autokosten-Rechner', n.d.) at EUR 0.43 per km.

The cost calculator ('Vergleichen Sie doch mal. Es lohnt sich!', n.d.) was also used to calculate the costs for stationary CS. Participants stated that they used stationary CS about 11 times per year. With an average distance of 71 km this leads to about 800 km per year and about EUR 1 per kilometre ('Vergleichen Sie doch mal. Es lohnt sich!', n.d.). For free-floating CS the same price was assumed. For motorbikes the value of the cheapest car in the ADAC ranking was used (Citreon C1) that is assumed to be driven 15,000 km per year for five years, i.e. around EUR 0.27 per km ('Die 10 günstigsten Kleinstwagen im ADAC Autokosten-Check', 2019).

Bicycles are inexpensive and cost around EUR 0.04 per km (Dambeck, 2011). The time cost given in the article was disregarded. Walking is assumed to cost half of cycling. For taxis, Uber and similar offerings the taxi tariffs of Hamburg were used as baseline ('Taxikosten in Deutschland', n.d.) to calculate the costs for an average one way ride of about 7 km. This makes about EUR 2.66 per km.

Flying has different prices depending on the destination. As a basis data from the company rome2rio was used who compiled economy class fares over a two-month period in 2018 for different airlines. The median value for international flights is US$ 0.17 per km ('2018 Global Flight Price Ranking', 2018) or EUR 0.14 in April 16, 2018 prices ('Historic Exchange Rates', 2018).

For local public transport it was assumed that an annual pass for the public transport network in Berlin was purchased which costs EUR 761('Umweltkarte in 3 Schritten', n.d.). This leads to a price per km of EUR 0.23, according to Equation 22. This value was also used for the baseline, although they use local public transport a lot less and may thus pay more.

Equation 22. Calculation of cost per km for local PT.

$$cost\ per\ km = \frac{Annual\ PT\ pass}{km\ per\ user}$$

Source: Author.

Costs for long distance public transport also differ significantly, depending on how early the booking is made and what kind of discounts apply. A value of EUR 0.15 per km was used in the estimations ('Kilometerkosten beim Bahnfahren', n.d.).

Having the km travelled per mode and the cost per km for the different transport modes makes it possible to arrive at the costs per mode according to Equation 23 and subsequently cost savings.

Equation 23. Calculation of cost per mode.

$$Cost\ per\ mode = km\ travelled * cost\ per\ km$$

Source: Author.

Equation 23 was used to estimate the costs for each transport mode for both groups. Comparing these costs then makes it possible to arrive at a valve for savings or extra expenditure for CS users.

Apart from analysing cost savings in more detail, the category Transport was also explored further.

3.7.2 Shifts Within Category Transport

The Transport category was examined in more detail to investigate how consumption had shifted *within* that category. There are some reasons why this is important. For one, it is the most carbon intensive consumption category of the categories presented to the participants with 1.2 kg of carbon equivalents emitted per Euro spent (European Environment Agency, 2013). Secondly, the Transport category also has a high income elasticity of 1.97 (Chai, 2018). This means that e.g. for a 10% increase in income, nearly 20% more of the good (transport) is demanded. The combination of a high-income elasticity and carbon intensity makes the transport category especially relevant to study in detail.

Another reason to examine the Transport category is that CS users seem to be different from the average population, as expressed in their attitudes (Costain et al., 2012; Millard-Ball et al., 2005). The data basis to calculate carbon intensities is highly aggregated over the EU which only serves as a limited proxy for Germany and especially German CS members. Investigating the Transport category in more detail, helps to understand whether the EU average serves as a good approximation. For example, many survey participants may report an increase in flights as a result of their changed income. This would be an indication that the carbon intensity of the category transport is higher than the average EU carbon intensity. On the other hand, if bicycle and public transport use were to rise, the reported carbon intensity for transport might be too high.

To understand how consumption had shifted within the category Transport, G1 and G2 were asked (Questions 8 and 14) whether they would reduce or increase their use of different transport modes *due to* their stated or hypothetical savings. G3 was asked how their modes of transport would change if they would not use CS (Question 19). This was used to find out what modes of transport CS had replaced.

Respondents could choose on a 5-point Likert scale from 1 = reduce a lot to 5= increase a lot, where 3 means no change. As in the operationalisation of consumption patterns, every answer received a point. Reported reductions ("reduce a lot" and "somewhat reduce") received negative values (-2 and -1), reported increases ("increase a lot" and "somewhat increase") positive values (2 and 1). The neutral option ("neither increase nor reduce") received a 0 to reflect that no changes had taken place. The values are normalised according to Equation 24 below, where "Subsample Size" refers to the sample size of G1, G2 and G3.

The normalised value then indicates whether the respective mode of transport is used more or less du to CS, the size of the value indicates the size of the increase or reduction.

Equation 24. Calculation of the normalised value to show shifts within the Transport category.

$$Normalised\ Value = \frac{\sum Points\ per\ Category}{Subsample\ Size}$$

Source: Author.

The results and findings that were obtained are presented in the following section.

4 Results

From the survey and secondary data sources multiple results were obtained of which the most important ones are presented in this section.

4.1 Sample Results

In this section information about the sample will be presented. Two seemingly similar groups of CS users were approached with the same survey through different channels and a response rate of 79% (71 valid answers) was obtained.

The average participant is about 41 years old, is more likely to be male than female (56% vs. 42%[5]) and has an above average education. The vast majority (90%) have graduated from high school (Abitur) and 75% of participants have a degree in higher education. The average household income is about EUR 3 200, with most respondents (24% each) stating that they earned between EUR 2 600 – 3 599 or EUR 5 000 or more. For comparison, the average household income in Berlin is EUR 2 471 (Amt für Statistik Berlin-Brandenburg, 2015). Most respondents are part of a couple (62%) of which more than 60% have kids. The third biggest household type is single with no kids (20%). The average household size is 2.8 with most people stating that two people lived in their household (28%). Only 3% stated to live in a household with six or more people. Table 14 provides a summary of the data.

These findings correspond well with previous socio-demographic data of CS users. They also find that CS users are younger, more educated, earn more and haver a higher percentage of men than the average population (Becker et al., 2017; Nijland et al., 2015).

About 90% of the sample do not own a car. When asked which CS companies they use regularly, the company was unsurprisingly used most often, followed by the offers from other German car sharing companies, such as DriveNow and car2go (with both 18% of responses). On average, every respondent uses two CS companies regularly – on average about 25 times a year. Only about 7% stated they used CS either on a daily or weekly basis. More than half stated that they used CS “a couple of times a year” (Questions 3 in the survey). This is not uncommon for CS use and similar figures can be found in previous studies (Costain et al., 2012).

[5] One person identified as non-binary.

Table 14. Summary of socio-demographic data of the sample.

Sample summary	
Average age [years]	41
Share female [%]	42
Education high school or higher [%]	90
Average household income [EUR]	3 200
Most common household type	Couple with kids
Average household size [number of people]	2.8
Car ownership rate [%]	11
Average number of CS offers used	2
Average frequency of use [times/year]	25

Source: Author.

About 45% state that their disposable income had increased due to CS, 28% do not see a significant change and 27% assert that they spend more *due to* the use of CS. This is the question that divides participants into the groups G1, G2 and G3 as depicted in Figure 6.

A Pearson's chi-squared test was used to examine the relationship between the indication of change in disposable income and net household income. For that purpose, participants were divided into a high- and low-income group and compared to G1, G2 and G3. The high-income group reports an income between EUR 3 100 and EUR 5 000, the low-income group ranges between EUR 0 and EUR 3 100. The null hypothesis states that there is no relationship between the income level and perceived savings or extra expenditure. The null hypothesis cannot be rejected at the 95% confidence interval, $\chi^2(2, N = 71) = 5.70$, $p = 0.06$, but the size of the association is still noteworthy. Under the assumption that no relationship between income level and perceived savings or extra expenditure exists, we should get a sample with this large an association about six times in a hundred. It is therefore likely that the income affects the perception of savings.

The difference in results between sampled groups appear quite different as depicted in the following chapter.

4.2 Results for Groups 1, 2 and 3

Table 15 provides a summary of descriptive findings for G1, G2 and G3. G1 refers to the people who respond in the survey that they save money due to CS use whereas G3 states that they spend more. The disposable income of G2 is stated to remain stable. G1 is the largest group (n = 32), followed by a similar amount for G2 (n = 20) and G3 (n = 19). The average ages in G1 and G2 are quite similar with 44 and 42 years respectively, whereas respondents of G3 are younger with an average age of 36. In contrast, the per centage of women in G2 and G3 is similar (50% and 47%), in G1 it is only 34%. Members of G1 report the highest monthly household income of nearly EUR 4 000, followed by G2 with about EUR 3 100 per month and G3 with EUR 2 300/month. G1 spends the most per booking, followed by G2 and G3. The greatest number of bookings is reported by G2 with 38 annually, G1 has the lowest amount (18/year) and G3 reports 23 bookings per year. This translates to an annual expenditure on CS of nearly EUR 1 170 for G2, EUR 730 for G1 and EUR 640 for G3. G1 reported to save EUR 2 400 per year due to CS use, the value used to calculate hypothetical CCE reductions for G2 is EUR 1 100[6] and G3 stated to spend about EUR 640 per year *more* due to CS use.

Table 15. Summary of descriptors for the three statistical groups G1, G2 and G3.

	G1	G2	G3	Summary
Number of people	32	20	19	71
Average age	44	42	36	41
Share female [%]	34	50	47	42
Average household income per month [EUR]	4 000	3 100	2 300	3 200
Expenditure per booking [EUR]	40	31	28	34
Bookings per year	18	38	23	25
Expenditure per year on CS [EUR]	730	1 170	640	860
Savings/extra expenditure per year [EUR]	2 400	1 100	640	-

Source: Author.

The relationship between the stated amount of savings and the net household income was examined for G1, using a Pearson's chi-squared test. G1 was divided into a high and low savings group with the low savings group stating to save between EUR 0 and 180 per month and the high savings group more than EUR 180 and 320+ per month (see Question 6 in the survey). The income groups were divided as outlined in the previous chapter. The null hypothesis postulates no relationship between the size of the income and the amount of savings reported exists. If the null hypothesis is true, the chance of this large an association is extremely small, $\chi^2(1, N = 32) = 32.00, p < .001$, less than 0.1 times in 100. The null hypothesis can thus be rejected. This means that there is a very high chance that the income influences whether high or low savings are reported.

The re-expenditure patterns of the three groups across consumption categories will be examined in the following section. In this thesis re-expenditure patterns refer to the re-allocation of expenditure across household consumption categories formerly spent on the consumption category Transport.

4.2.1 Distribution of Re-Expenditure

Figure 7 provides that information for G1, G2 and G3. G1 was asked to distribute their stated savings and G2 their hypothetical savings. G3 was asked how they would spend the money now spent on CS, if they would not engage in CS. This type of question was used to find out what kind of consumption CS had replaced

For both G1 and G2 the most popular category to spend additional income on is Recreation & Culture. For G1 Food & Beverages comes second and Restaurants & Hotels comes third. G2's second choice is Miscellaneous goods and services narrowly followed by Food & Beverages. In both groups Transport is neither very popular nor unpopular and Communications is clearly the least preferred consumption category.

G3 was asked how they would spend the money now spent on CS, if they would not engage in CS. Not surprisingly, the largest share of re-expenditure would be spent on Transport because they have to find other means of transport. Second, third and fourth are Recreation & Culture, Food &

[6] The value is derived by asking G2 what amount of savings they would consider to be significant (Question 12), since they report neither to save nor to spend more due to CS use.

Beverages and Miscellaneous, which closely resembles the spending of G1 and G2. Communication is also least popular.

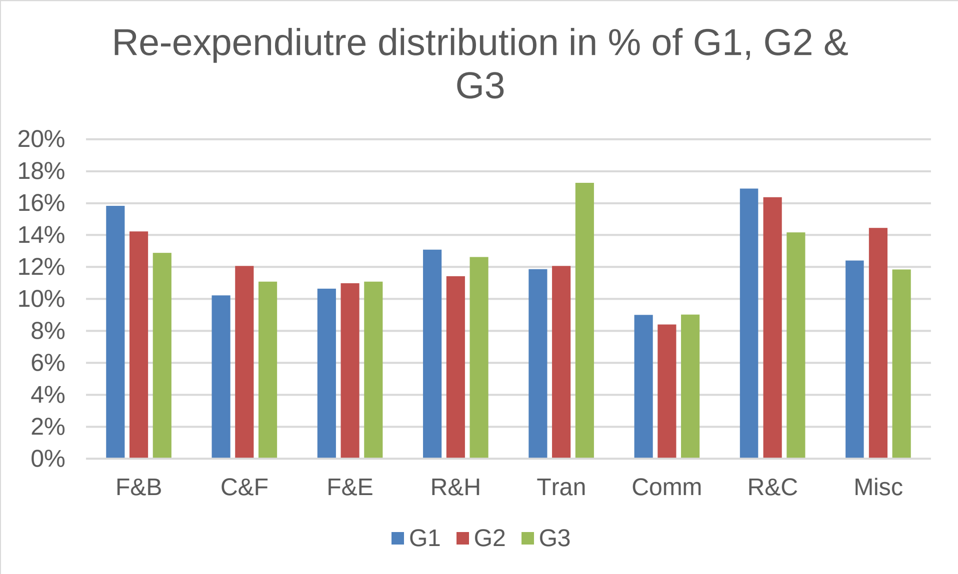

Figure 7. Distribution of re-expenditure across consumption categories for G1, G2 and G3 in per cent. Source: Author.

A Pearson's chi-squared test was used to compare the re-expenditure patterns of G1, G2 and G3. The patterns of G2 and G3 do not differ significantly from G1, $\chi^2(7, N = 94) = 1.04, p = .99$ and $\chi^2(7, N = 88) = 3.15, p = .87$, respectively.

Consumption can also shift *within* consumption categories which could be especially relevant for Transport since it is the most carbon intensive consumption category (European Environment Agency, 2013). This is why it was investigated further.

4.2.2 Re-Expenditure on the Category Transport

For G1 and G2 re-expenditure patterns of savings were examined, for G3 it was investigated which modes of transport CS had replaced. Results are shown in Figure 8. The values on the y-axis refer to the normalised value discussed in the methodology section. Positive values indicate an increase of the use of the transport mode and negative values a decrease. The higher the value the more pronounced that change is.

G1 reports the largest shifts for the private car, followed by local public transport and biking. The private car shift is a negative one, meaning G1 uses the private car less because of CS induced savings, the other two shifts are positive which entails an uptake of these modes of transport. G2 sees the largest shift also for private cars, with taxis and similar operators second and free-floating CS third. They report a reduction in the use of private cars and taxis and an increase in the use of free-floating CS. G3 sees only positive shifts, the largest towards local PT, then bicycles and long-distance PT.

The values for G2 ($M = 0.23$, $SD = 0.18$) and G3 ($M = 0.46$, $SD = 0.33$) are considerably less pronounced than the values for G1 ($M = 0.74$, $SD = 0.36$) when comparing the mean (M) of the absolute values.

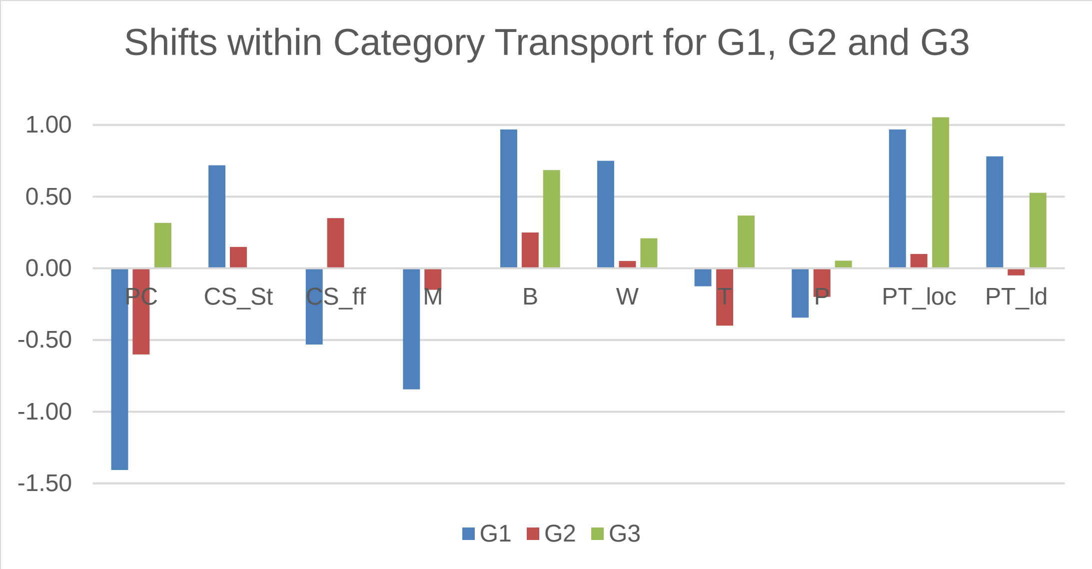

Figure 8. Shifts within the category Transport for G1, G2 and G3.
Source: Author.

Abbreviations: PC stands for private car, CS_St and CS_ff for stationary and free-floating CS, M for motorbike, B for bicycle, W for walking, T for taxis, Uber or similar operators, P for planes and PT_loc and PT_ld for local and long-distance public transport.

The distribution of re-expenditure *across* consumption categories has an influence on CCE, since different consumption categories have different carbon intensities. Results for G1, G2 and G3 differ significantly but show similar patterns.

4.2.3 Consumption Induced Carbon Emissions

From the re-expenditure patterns of G1, G2 and G3 and carbon intensities of consumption categories, CCE were calculated according to Equation 11. Figure 9 displays the savings of CCE in per cent and in kg per year in comparison to the respective baseline for G1, G2 and G3.

It is evident that both G1 and G2 reduced their CCE compared to their corresponding baseline. G1 reduce CCE by 6% or about 1 400 kg annually. G2 also reduces CCE but by only 3% or 650 kg per year. This indicates that when CS users report to save money from CS, their CCE are reduced.

The result of G3 should be interpreted somewhat differently. The group reduces its CCE compared to the baseline, by about 2% or 350 kg annually. However, the group was asked how they would spend the amount that they are spending on CS now, *if* they would not engage in CS. Therefore, the answer collected from G3 on this aspect displays the CCE in case it would not use CS and spend the amount differently. In this scenario the results show that not engaging in CS leads to lower CCE. This is in contrast to the two scenarios presented before and highlights that CCE are not automatically reduced when CS adopted. When CS is seen as more expensive, then CCE increase.

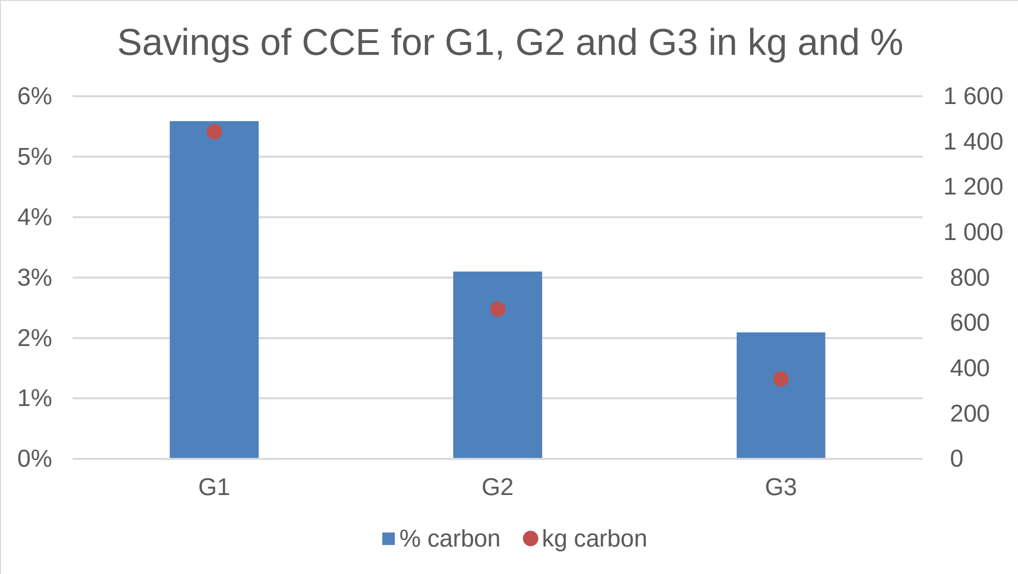

Figure 9. Comparison of savings in CCE for G1, G2 and G3 in kg per year and per cent. Source: Author.

The following sections will present some alternative scenarios.

4.3 Alternative Scenarios

The results presented so far are based on highly aggregated data or stated answers. To test these values and assess results with different, more realistic data, some alternative scenarios are presented.

4.3.1 Carbon Intensity of Transport

The carbon intensities of the consumption categories used in the calculations are based on highly aggregated EU-wide data (European Environment Agency, 2013). Especially for the Transport category, they might not apply to CS users (nor CS users specific to Germany or the analysed cities). Comparing the mobility patterns of CS users and the baseline discussed in the methodology section (see Figure 10) shows that the value used for the calculations presented above (i.e. 1.2 kg carbon equivalent per Euro spent) is likely to be an overestimation.

CS users travel for the most part with sustainable means of transport. For instance, they tend to use PT (short and long distance) and cycling for more than 50% of their overall distance covered. However, they also use the plane for more than one third of their total distance travelled, or 2 000 km/year more than the baseline. For the baseline the private car is the dominant means of transport, followed by flying and local PT. Still, PT and cycling play a limited role, as not even 15% of all kilometres are travelled using these modes. CS was assumed to be zero for the baseline and does not play a major part for CS users. In total, CS users travel about 22 000 km per year (all travel modes) compared to about 18 000 km for the baseline.

When divided into low and high carbon modes of transport, CS users travel around 55% of their total distance covered with low carbon means of transport, compared to 15% for the baseline. Bikes, walking and PT (long and short distance) are classified as low carbon, meanwhile private cars, CS (stationary and free-floating), taxis and planes represent travel modes with higher carbon intensities.

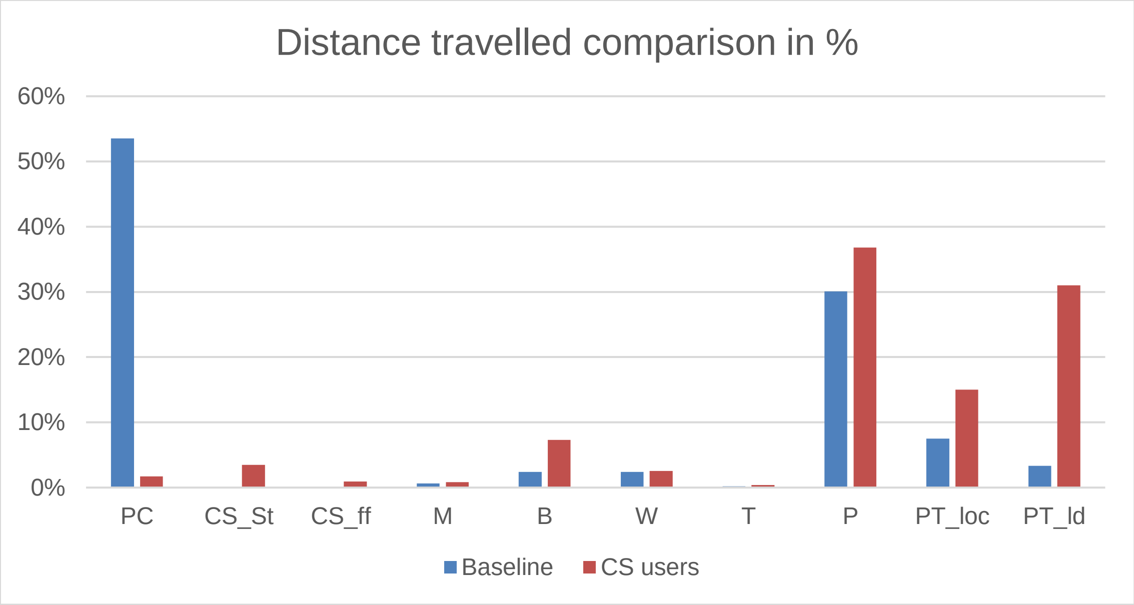

Figure 10. Comparison of distances travelled with different transport modes for the baseline and CS users in %. Source: Author.

It is apparent from these figures that the EU-wide carbon intensity for Transport might be an overestimation for CS users. It is difficult to arrive at a definite value for the carbon intensity, but it is lower than 1.2 carbon equivalents per Euro spent (European Environment Agency, 2013). Considering the distribution of low and high carbon means of transport, half the carbon intensity for Transport is assumed for CS users, which is 0.6 carbon equivalents per Euro spent.

Figure 11 depicts the CCE savings of the Standard and Transport scenario for all three groups. The Standard scenario refers to the scenario presented in chapter 4.2.3, Consumption Induced Carbon Emissions. The Transport scenario is the scenario introduced in this section, with half the carbon intensity for the Transport category for CS users. Under the Transport scenario G1 reduces CCE by about 11% or 2.8 tons of carbon per year, G2 by about 2.2 tons or 10% and G3 by about 1.6 tons or 10%, highlighting that results are more pronounced than under the Standard scenario for all three groups. The largest difference in percentage points is observed for G3, followed by G2 and G1.

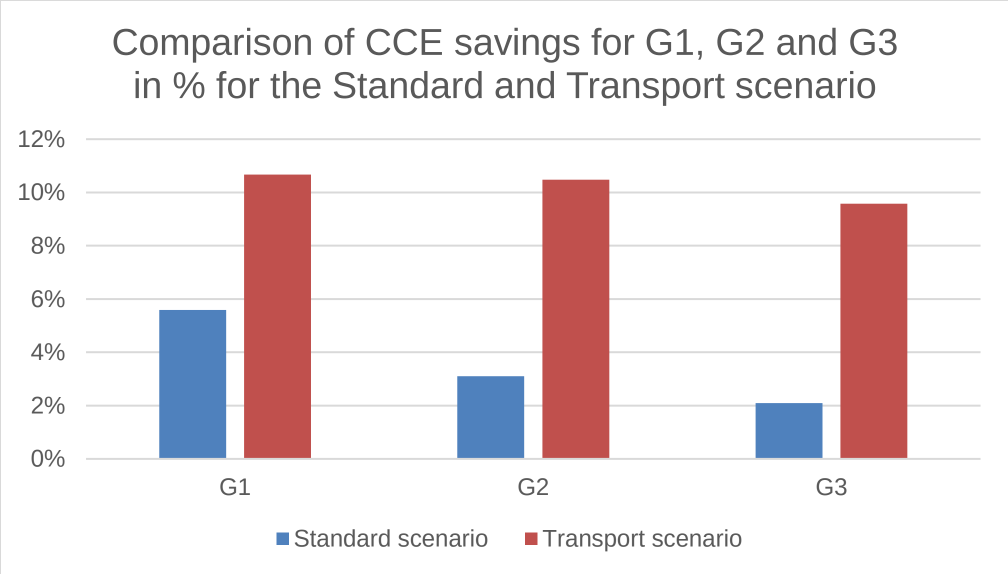

Figure 11. Comparison of CCE savings for G1, G2 and G3 in % for the Standard and Transport scenario. Source: Author.

The next alternative scenario uses a different value for savings.

4.3.2 Stated Savings

The reported savings by CS users is another value that is examined in more detail because it is difficult to estimate monthly savings *due to* CS. An alternative value for savings is therefore calculated comparing mobility patterns of CS users and the baseline.

Table 16 shows the calculation of the annual transport costs for CS users, Table 17 displays the same calculation for the baseline.

Table 16. Breakdown of annual transport costs for CS users[3].

CS users	PC	CS_St	CS_ff	M	B	W	T	P	PT_loc	PT_ld
Trips per year	26	11	14	13	245	314	6	3	179	25
Distance/trip[4] [km]	15	71	15	15	7	2	15	3 112	19	273
Km/year	378	771	209	188	1 615	565	92	8 154	3 328	6 871
Cost/km [EUR]	0.91	1.00	1.00	0.27	0.04	0.02	2.66	0.14	0.23	0.15
Costs/y [EUR]	345	772	209	50	63	11	244	1 120	761	1 030
Total costs/y [EUR]	4 600									

Source: Author.

Table 17. Breakdown of annual transport costs for the baseline[3].

Baseline	PC	M	B	W	T	P	PT_loc	PT_ld
Km/y	9 668	118	433	433	34	5 430	1 351	598
Cost/km [EUR]	0.43	0.27	0.04	0.02	2.66	0.14	0.23	0.13
Costs/y [EUR]	4 200	31	17	9	90	750	310	80
Total costs/y [EUR]	5 500							

Source: Author.

The comparison of the two tables above results in annual Transport savings for CS users of about EUR 900. This translates to EUR 72[3] per month which is significantly less than the EUR 200 per month of stated savings reported by G1. The values used for G2 and G3, EUR 94/month and EUR 53/month, respectively, are more within that range.

Figure 12 displays the CCE savings from the Savings scenario, with a monetary savings value of EUR 72 and the carbon intensity used in the Standard scenario, compared to the CCE savings of the Standard and Transport scenario for reference. In the Savings scenario CCE reductions are lowest for G1 and G2 and slightly higher for G3 compared to the Standard scenario. G3 reduces CCE by about 3%, for both G1 and G2 CCE decrease by roughly 2%. In absolute terms savings are about the same for all three groups, ranging between 480 kg of carbon annually for G3 and 520 kg/year for G1.

It is important to highlight that the situation is different for G3, where participants stated that they spend more of the disposable income on CS. Thus, the results depicted for this group is the effect of their expenditure replacement due to CS on CCE. Especially the Savings scenario is not directly applicable for G3, since they do not save, but spend more. For reference it is still presented.

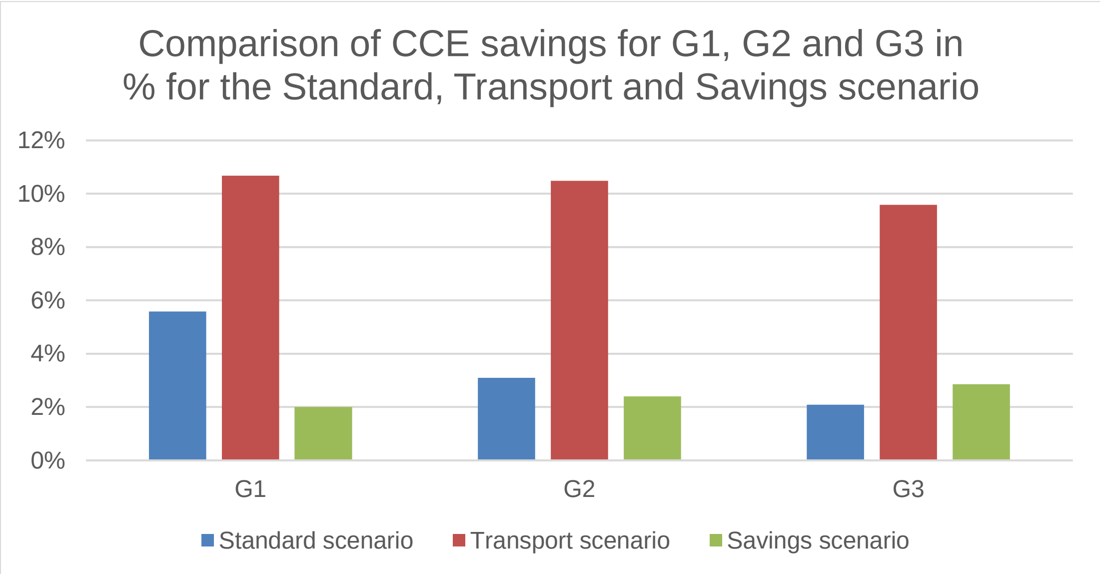

Figure 12. Comparison of CCE savings for G1, G2 and G3 in % for the Standard, Transport and Savings scenario.
Source: Author.

The next chapter explores the effects of combining the Transport and Savings scenario.

4.3.3 Combined Transport and Savings Scenario

Combining the Transport and Savings scenario described before leads to CCE reductions as shown in Figure 13. For all three groups CCE reductions range around 10% with translates to 2.7 tons of carbon annually for G1, 2.2 tons/year for G2 and 1.6 tons/year for G3. The results of the Transport + Savings scenario are most similar to the Transport scenario and differ significantly from the Standard and especially the Savings scenario.

Depending on the scenario, the magnitude of the savings differs rather significantly. The extremes range from 11% savings for G1 under the Transport scenario to 2% for G1 under the Savings and G3 under the Standard scenario. The Savings scenario produces low values for all three groups, results for the Standard scenario are more mixed. The Transport and the combined scenario produce fairly similar, but higher results per group for the Transport scenario.

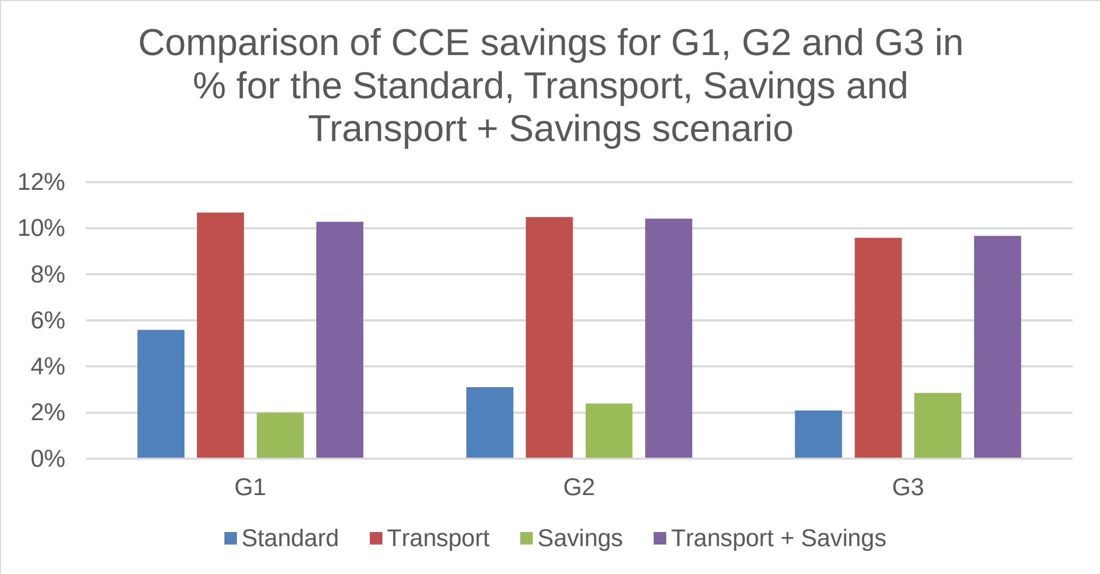

Figure 13. Comparison of CCE savings for G1, G2 and G3 in % for the Standard, Transport, Savings and a Transport + Savings scenario.
Source: Author.

If these results are significant for the population will be discussed in the following chapter, the other hypotheses are tested as well.

4.4 Hypothesis Testing

In this chapter the hypotheses from chapter 3.1 "Guiding Assumptions and Hypotheses" are outlined and tested.

H1: CS affects the disposable income of 75% of CS users either positively or negatively.

This thesis aims to investigate CCE of CS users. A prerequisite for changed consumption patterns is that the disposable income of CS users changes. Therefore, H1 is tested using a Pearson's Chi-squared test with the null hypothesis that the disposable income of more than three quarters (75%) of CS users is affected due to CS, either positively or negatively. The distribution of answers from the sample is depicted in Figure 14.

In the sample about 45% of participants reported that they saved money due to CS and 27% stated that they spent more, therefore the disposable income changed for 72% in the sample. The observed values do not differ from the expected values under the null hypothesis with $\chi^2(1, N = 71) = 0.38$, $p = .54$. Therefore, the null hypothesis that the disposable income of 75% of CS users is affected cannot be rejected. This means that the H1 applies for the studied population.

To test whether more people save money, the Pearson's Chi-squared test is used. The null hypothesis states that the share of people who report to save (G1) is just *less* than the share of people who report to spend more (G3) (35% and 37% respectively). The share of people who state to see no change in their disposable income (G2) remains at 28%. The null hypothesis cannot be rejected with $\chi^2(2, N = 71) = 3.84$, $p = .15$. The difference between the share of people in G1 and G3 is not sufficiently large to be statistically significant at the 95% confidence level. This means that we cannot be 95% confident that more people report to save money than spend more on CS in the population.

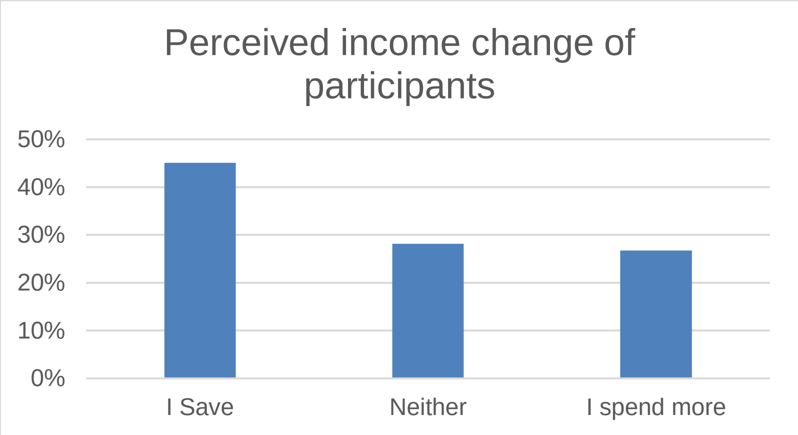

Figure 14. Perceived income change of participants in per cent.
Source: Author.

H2: The consumption patterns of CS users differ significantly from the baseline.

The second step in investigating CCE of CS users is to assess whether their consumption patterns differ significantly from those of the baseline. Figure 15 displays these consumption patterns for G1 under the Standard scenario compared to the applicable baseline. A Pearson's chi-squared test is conducted to assess whether these differences also occur in the population with the H0 that there is no difference. This is done for all three groups and two scenarios. Table 18 displays the results where indicator "Df" refers to the degrees of freedom, "N" to the sample size, "χ^2" to the Pearson's chi-squared value and "p" to the significance value. Degrees of freedom are a statistical term and are defined as "[t]he number of independent values or quantities which can be assigned to a statistical distribution" ('Degree of freedom', n.d. n.p.) The scenarios Transport and Transport + Savings have the same re-expenditure patterns as Standard and Savings, respectively and are thus not included.

The null hypothesis is rejected in all cases with 95% confidence because the p-value is below the critical value of 0.05 except for G1 under the Savings scenario (p = 0.06). The differences in the amount spent per category are significant with 95% confidence for the Standard, Transport, Savings and Transport + Savings scenario (excluding the exception mentioned before). This means that they likely apply to the population, even for the case where the null hypothesis is not rejected because the significance level is close to the critical value.

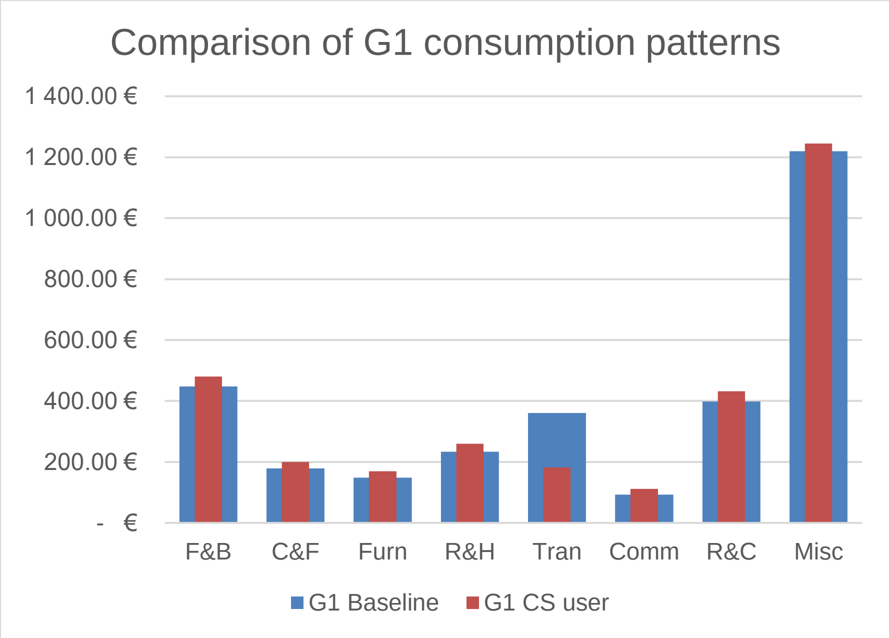

Figure 15. Comparison of monthly G1 consumption patterns for the Baseline and CS users under the Standard scenario.
Source: Author.

Table 18. Summary of the Pearson's chi-squared test statistic for the three groups and the Standard and Savings scenario.

Scenario		Df	N	χ2	p
Standard	G1	7	3 080	106.11	0.00
	G2	7	2 477	27.25	0.00
	G3	7	1 943	29.48	0.00
Savings	G1	7	3 080	13.57	0.06
	G2	7	2 477	16.35	0.02
	G3	7	1 943	19.93	0.01

Source: Author.

H3: The carbon induced carbon emissions of CS users differ significantly from the CCE of the baseline.

H3 postulates that the CCE reductions for the three group are significant and likely apply to the population. A One-Group t-test is conducted to test whether the reductions in CCE for the three groups under the Standard and Transport scenario are significant. The calculated CCE for the three groups (sample mean) are compared to the corresponding baselines (population mean). The first assumption, independence of the data, for the One-Group t-test is assumed to be met since it is very improbable that participants influenced each other's answers due to the nature of the survey.

The second assumption, normal distribution of the data, is met by G1 due to the central limit theorem because the sample size (n =32) is significantly above 20 (Seltman, 2018). For G2 (n = 20) and G3 (n = 19) the Shapiro-Wilk test is used to test for normality of distribution. It tests the range of data that lists the CCE for every individual participant in kg per month for G2 (M = 1 724, SD = 48) and G3 (M = 1 375, SD = 58). Results are presented in Table 19 where "Statistic" refers to the value of the Shapiro-Wilk Test, "Df " stand for degrees of freedom and "Significance" refers to the p-value. Low values (significantly below one) in the test statistic suggest significance and a rejection of the null hypothesis (Lohninger, n.d.).

Results indicate that neither G2 nor G3 are distributed normally with G2, $W(20) = .647, p < .001$ and G3, $W(19) = .621, p < .001$. Since the sample is equal for G2 and very close to the critical value for G3, the condition is seen as partly fulfilled. This implies that the results of the One-Group t-test have to be taken with caution.

The third assumption, constant variance of the data, can be explored using boxplots for CCE of G1, G2 and G3, depicted in Figure 16. The y-axis depicts CCE in thousand kg. The variance for G1 is constant since there are no outliers. For G2 and G3 the picture looks different, G2 has one, and G3 has two outliers. The assumptions are satisfactorily met for G1, the results of the One-Group t-test for G2 and G3 should be treated with more caution.

G1 fulfils the three assumptions satisfactorily indicating that results for G1 are relatively robust. G2 and G3 meet the second and third assumption, normal distribution and constant variance of the data, only partially implying that results may be less robust.

Table 19. Results of the Shapiro-Wilk test for normality for CCE of G2 and G3.

	Statistic	**Df**	**Significance**
CCE_G2	.647	20	.000
CCE_G3	.621	19	.000

Source: Author.

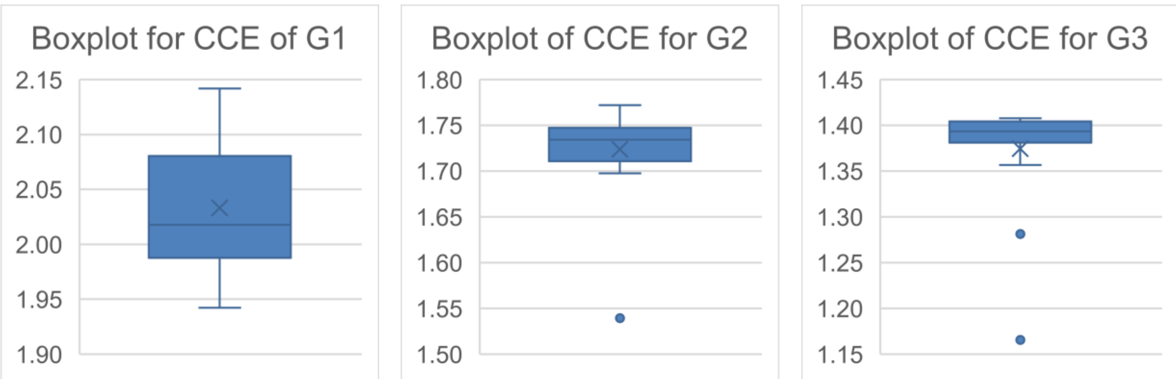

Figure 16. Boxplots of CCE for G1, G2 and G3 in the Standard scenario.
Source: Author

In the Standard scenario the reported reductions are highly significant for all three groups. Results are most pronounced for G1, $t(31) = 11.30$[7], $p < .001$, and G2, $t(19) = 5.01$[7], $p < .001$. The results for G3 are also significant but at a lower level, $t(18) = 2.68$[7], $p < .02$. Keeping the partially met assumptions for G2 and G3 in mind, these results suggest that being a CS user saving money leads to a shift in consumption that results in reduced CCE (G1 and G2). Also, they imply that when CS users shift consumption away from Transport towards other consumption categories, their CCE are reduced (G3). The reductions in CCE are likely to apply to the population.

The same test was conducted for the Transport scenario. The assumption about the independence of the data is met due to the reasons outlined before. The normality assumption is met by G1 due to the sample size ($n = 32$), for G2 and G3 a Shapiro-Wilk test is used to test for the normality of

[7] Absolute values are depicted.

distribution, for G2 (M = 1 592, SD = 6) and G3 (M = 1 275, SD = 6) depicted in Table 20. G2 and G3 are not normally distributed with G2, $W(20) = .795$, $p < .005$ and G3, $W(19) = .678$, $p < .005$. As in the example before, the condition is seen as partially fulfilled due to the reasonable sample size of G2 and G3. This suggests that findings for G2 and G3 may not yield the most reliable results.

The constant variance assumption is investigated using boxplots for the CCE of G1, G2 and G3, as shown in Figure 17, where the y-axis represents CCE in thousand kg. G1 has a relatively small outlier, G2, a more drastic one and G3 has two outliers. The condition of constant variance is therefore partially met for all groups. This implies that the One-Group t-test results should be regarded with some caution for all groups, but especially G2 and G3 since they only meet the first assumption, independence of data, satisfactorily. The other two assumptions are considered to be partially fulfilled.

Table 20. Results of the Shapiro-Wilk test for normality for CCE of G2 and G3 under the Transport scenario.

	Statistic	**Df**	**Significance**
CCE_G2_Transport	.795	20	.001
CCE_G3_Transport	.678	19	.000

Source: Author.

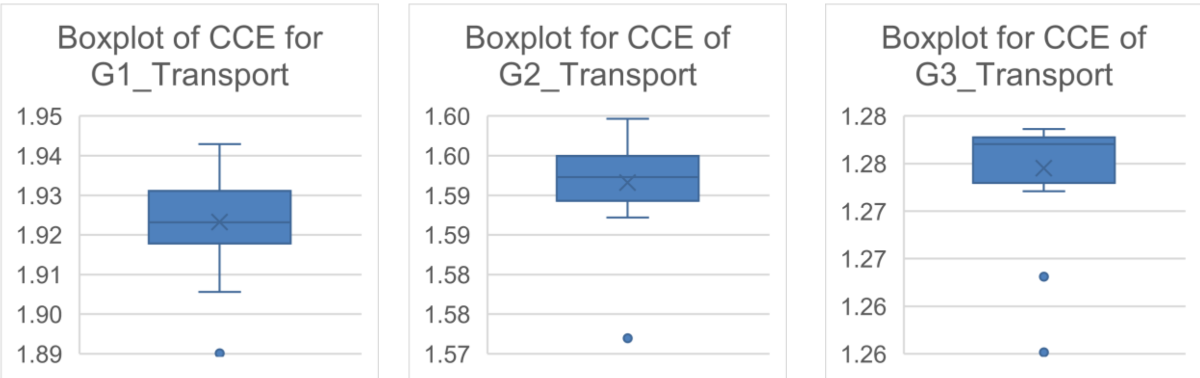

Figure 17. Boxplots of CCE for G1, G2 and G3 in the Transport scenario.
Source: Author

The One-Group t-test in the Transport scenario results in even more pronounced values with G1, $t(31) = 123.11$[7], $p < .001$, G2, $t(19) = 147.33$[7], $p < .001$ and G3 $t(18) = 100.26$[7], $p < .001$. They are highly significant for all three groups. H3 can therefore not be rejected and is likely to apply to the population for the Standard and the Transport scenario with the caveat that the assumptions for the One-Group t-test are not always satisfactorily met. The differences between the three groups and their respective baselines in the Transport scenario thus likely apply to the population.

It is not possible to conduct a One-Group t-test for the Savings and Savings + Transport scenario because no range of data was obtained.

5 Discussion

The results from the survey indicate that CS affects the disposable income of most CS users. It increases for about half and decreases for about a quarter of the CS users. Changes in disposable income induce detectable consumption shifts and in turn change total carbon emission embedded in consumption. The results show that when the expenses on the category Transport decrease and the resulting savings are divided across other consumption categories, the total consumption induced carbon emissions (CCE) are generally reduced. This is especially prominent within the G1 sample group, which reports largest savings in the Transport category. The G3 sample group does not report savings in the Transport category but states that their participation in CS induces them to spend more. They are asked to imagine a scenario where they do not use CS and re-distribute the amount spent on CS now, to investigate what kind of consumption CS had replaced. In this case their expenditure on the Transport category is reduced and thus CCE as well. CCE are automatically reduced when consumption shifts away from Transport towards other consumption categories because Transport is the most carbon intensive consumption category presented to participants of the survey. Consumption does not just shift across but also *within* consumption categories (i.e. away from PT towards flying). To explore these shifts, the Transport category was investigated in more detail.

One reason why these differences between G1 and G3 occur could be due to the personal basis of comparison. In the survey it was assumed that the participants would compare their current transport expenditures to the most likely alternative scenario. But the most likely alternative scenario for G1 might be rather different from that of G3. G1 represents the oldest group (M = 44) with the highest household income (M = EUR 4 000), while G3 has the lowest household income (M = EUR 2 300) and is the youngest group (M = 36). G1 may compare their costs now with owning a car which is typically more expensive than using CS (Loose, 2010) when the annual distance driven is less than 12 000 km. In this case, CS saves money and induces sustainability benefits compared to owning a car. In this scenario, G1 reduces CCE by changing from owning a car to using CS as well as other more sustainable modes of transport. For G3, on the other hand, CS might induce an extra expense and G3 compares CS use to a scenario where it mostly uses PT and cycling, which are more sustainable and less expensive modes of transport than driving a car. As a result, CS is less sustainable for G3 than their likely alternative modes of transport and therefore the CCE increase.

The impacts of CS on CCE thus depend in part on the personal basis of comparison, e.g. compared to car ownership scenarios, CCE reduce. Considering that owning and driving a car is the dominant mode of transport in German cities (Nobis & Kuhnimhof, 2018), the potential of CS to have a reducing effect on CCE is large because owning a car tends to be more expensive than using CS.

However, the effect of lower CCE for CS users is not certain on the long run. If a shift towards a CS lifestyle was adopted by a large part of the German city population, the potential for higher CCE of CS users increases. First, mobility patterns of CS users have been shown to be less carbon intensive than those of the current average person in Berlin. This implies that the relative carbon intensity of other categories increases for CS users. Second, CS is still a marginal phenomenon adopted by a distinct group of people. The population of CS users in Berlin and Hamburg was estimated at around 216 000 users or about 4% the combined population of the two cities and many use CS only sporadically. Besides, the analysed sample likely differs from the German average also in other ways than consumption patterns. CS users have, for example, been shown to be more concerned with environmental and social issues than the average population (Costain et al., 2012; Millard-Ball et al., 2005). This may imply lower carbon intensities of other consumption categories (i.e. Food & Beverages) for CS users. As more people use CS, the group of CS users becomes more diverse and more aligned with the average population, potentially increasing the relative carbon intensities of non-transport consumption categories. A lower carbon intensity of Transport and higher carbon intensities of other consumption categories could then lead to higher CCE of CS users.

Participants were asked in the survey how the reported changes in their disposable income induced through CS use, influenced their use of transport modes. The implications of these findings are discussed below.

5.1 Hotspot Consumption Category Transport

The worst-case scenario in terms of CCE would have been a substantial re-allocation of savings to high carbon intensity transport modes such as air travel. Such a scenario was simulated by e.g. Briceno et al. (2005), who estimated the effects of CS-induced savings being spent on aviation.

The obtained data in this study cannot support this scenario, as both G1 and G2 report a decrease in aviation due to the savings from CS. These findings are somewhat surprising. Standard economic theory suggests that an increase in income leads to an increase in overall consumption, not the opposite. One reason why participants report a decrease in flying could be due to the social desirability bias (Kelly et al., 2017), i.e. when people report what they think is socially more acceptable. They might be aware that sustainability implications of CS are explored and they therefore report a reduction of flights, a very carbon intensive mode of transport.

A similar effect can be observed for other modes of transport that might be perceived as less sustainable, like private cars, motorbikes and taxis and similar services. 22 of 32 participants of the G1 group have reported to use private cars a lot less *due to* savings from CS. The results are similar for other transport modes. This either suggests a very strong social desirability bias or, perhaps more likely, a misunderstanding of the question.

Meanwhile G3 reports increases in all transport modes. The group was asked how they would increase or decrease the use of different transport modes, if they would not use CS (and have the amount available that is now spent on CS). Since they do not have CS as a means of transport anymore, they must find a replacement and they thus increase the use of all other transport modes. It is noteworthy that again three more sustainable means of transport are reported to increase the most (local and long-distance PT and bikes). This strengthens the theory that for G3 CS is seen as an extra expense and owning a car is not considered a viable option. It also aligns well with the argument about social desirability bias. It is doubtful that the reported shifts in Transport reflect the reality of participants in all three groups, thus the results (Figure 8) should be treated with caution.

The two main variables affecting the results regarding CCE are monetary savings and carbon intensities. It is uncertain to what extent they represent an accurate description of the situation of CS users. This is why they were scrutinised further.

5.2 Commentary on CCE under Multiple Scenarios

Four scenarios were simulated in this study – the Standard, Transport and Savings scenario and a combination of the latter two (Transport + Savings).

The Standard scenario included values directly derived from the survey for the amount of re-expenditure (savings for G1 and G2, redistribution of CS expenditure for G3) and aggregated values for the carbon intensities of consumption categories based on EU-wide data (European Environment Agency, 2013). Under the Standard scenario CCE reductions are highest for G1, followed by G2 and G3 (see Figure 9). They are directly proportional to the reported changes in disposable income, as G1 reports to save around EUR 2 400 annually and G2 EUR 1 100/year[6] while G3 reports additional expenditures of EUR 640 annually on CS. The amount of re-expenditure that is shifted away from the consumption category Transport towards other consumption categories thus determines the magnitude of the CCE reductions in the Standard scenario.

The Transport scenario featured a lower Transport carbon intensity of CS users because they choose a more sustainable mobility portfolio. Under this scenario the resulting CCE reductions are considerably higher for all three groups, in some cases more than double compared to the Standard scenario. The Transport scenario indicated that the assumed carbon intensity of the consumption category Transport plays an important role in shaping results. The lower it is for CS users, the higher the CCE reductions relative to the baseline, assuming that the Transport carbon intensity for the baseline is not altered. CCE reductions under the Transport scenario follow the same pattern as in the Standard scenario, with G1 reporting largest and G3 lowest reductions (see Figure 13). But the variations are less pronounced which implies that the magnitude of the monetary re-expenditure impacts results less than the changed carbon intensity of the consumption category Transport.

It is difficult to reliably estimate a new carbon intensity of the Transport consumption category for CS users. But the values of carbon intensity used in the Standard scenario were based on EU-wide estimates which are likely to be an overestimation. The Transport scenario represents a more realistic approach to estimating CCE reductions because it takes into account the differing mobility portfolios of CS users. This issue would benefit from further research based on more precise values of carbon intensities.

The Savings scenario illustrates how difficult it is to estimate monetary savings due to CS. The obtained result for calculated savings (EUR 900 annually) suggests that G1 have overestimated their savings almost two-fold. When the calculated savings are used, CCE reductions are much lower in G1 and G2, and slightly higher in G3 (see Figure 13). The order of the share in CCE reductions is reversed in the Savings scenario with G3 reporting the highest and G1 the lowest share of reductions. This is because the same value of re-expenditure (EUR 900 annually) was used for all three groups. Since the groups are compared to baselines according to their net household income, the baselines for the three groups differ, with G1's baseline reporting the highest and G3's baseline the lowest overall expenditure. Thus, the *share* of the calculated savings compared to the overall expenditure is lowest for G1 and highest for G3, as reflected in the Savings scenario. Due to some challenges (outlined in chapter 5.4 in the Limitations section) in arriving at the Savings scenario, the value for calculated savings should be treated with caution.

The combined scenario of Savings + Transport supports the notion that a lower carbon intensity of Transport influences results more strongly than a change in disposable income. In this scenario reductions are considerably higher than under the Standard scenario and are nearly as pronounced as in the Transport scenario (refer to Figure 13). These findings suggest that as long as the carbon intensity of Transport for CS users is considerably lower than for the baseline, the monetary savings play a minor role in reducing CCE. This also sends a message to policy makers. Consumers are probably more easily attracted to CS through cost savings, while the environmental effect of switching to CS can be improved by reducing the carbon intensity of Transport for CS users.

More conclusions for policymakers and interpretation of the tested hypotheses are discussed now further down.

5.3 Commentary on Hypothesis Testing

H1 postulates that CS affects the income of three quarters of CS users and a Pearson's chi-squared test confirms that this hypothesis cannot be rejected for the population. What H1 actually tests, is whether 75% of CS users *perceive* their income to change. However, if it really changes is not possible to verify from the obtained data. In fact, the results suggest that most participants perceive a change which implies that there is an effect. These findings indicate that the first part of the assumed relationship between CS use and consumption induced carbon emissions (see Figure 3) likely applies to the population.

H2 frames the discussion around the consumption patterns of CS users by comparing the consumption patterns of CS users with the baseline. Testing the hypothesis for the three groups and two scenarios "Standard" and "Savings" (the "Transport" and "Transport + Savings" scenarios have the same re-expenditure patterns), with a Pearson's chi-squared test results in significant results except for G1 in the Savings and Savings + Transport scenario. Here, the test of the significance level turns out to be very close to the critical value of $p = .05$. The results indicate with 95% confidence that the consumption patterns of the population of CS users are altered.

H3 then investigates the last part of the assumed relationship and tests whether CCE of CS users differ from the baseline using a One-Group t-test. Results are highly significant for the Standard and Transport scenario and indicate, with 95% confidence, that the reported differences occur in the population as well.

The obtained data indicate that the assumed relationship proposed at the beginning of this thesis (see Figure 3), likely applies to the studied population in nearly all of the different scenarios introduced. With a minimum of 95% confidence CS use affects the disposable income of most CS users which leads to changes in consumption patterns and altered carbon emissions. For the major part of the baseline, a shift towards CS would save money and reduce CCE. This finding contributes to a more complete picture of the environmental impacts of CS in stating that indirect effects, like increased CCE of CS users, likely do not play a significant role.

These findings align well with the results from Briceno et al. (2005) who discuss rebound effects in connection to different transport profiles, among them CS. In two of their three scenarios CS is the second most sustainable mode of transport (behind bus use) and has a lower environmental effect than a combination of bus and car use and only car use. In the third scenario they assume that the money saved from the household budget is solely spent on air travel and backfire occurs. This scenario was shown to be unrealistic in this thesis since the survey participants distributed their income relatively uniformly among the eight consumption categories explored in this study.

In contrast, the results do not align well with the findings by Chen & Kockelman (2016). They assess cradle-to-grave life cycle impacts of CS and find that CS users reduce their carbon emissions. Chen & Kockelman's (2016) study focusses on largely direct environmental impacts and uses narrow system boundaries that scope out the effects of re-spending of savings. If the re-expenditure of CS induced savings is factored in, the reductions estimated by Chen & Kockelman (2016) decrease, partially offsetting the initial carbon savings. Therefore, the consumption patterns of CS users are more carbon intensive than the baseline consumption patterns, thus causing more carbon emissions. In this thesis, however, the CCE of CS users are lower if they report savings from CS.

One explanation for the disparities could be that Chen & Kockelman (2016) do not calculate the size of the indirect rebound effect for CS themselves but use previously estimated values for investments in residential energy efficiency by Thomas & Azevedo (2013) and estimates of different sufficiency measures by Druckman et al. (2011). The study by Chen & Kockelman (2016) estimates the indirect rebound effect for CS in the range of 0-40%. The results of this thesis suggest that the more likely effect is close to zero per cent, or even negative.

Another reason for the discrepancy may be that the Transport category is the most carbon intensive consumption category presented to participants in this thesis. A reduction in expenditure there and re-expenditure on another consumption category available by default leads to lower CCE. The analysis of whether consumption had shifted within Transport proved not reliable due to the potential social desirability bias and a possible misunderstanding of questions. The methodologies used by Druckman et al. (2011) and Thomas & Azevedo (2013), the references used by Chen & Kockelman (2016), seem to be based on more robust analysis. Using similar methods in this thesis may have resulted in findings closer to those estimated by Chen & Kockelman (2016).

While Chen & Kockelman (2016) might have overestimated the effects of CCE, it is possible that they were underestimated in this thesis. Further research, inspired by approaches in this thesis combined with methods used by Chen & Kockelman (2016), Druckman et al. (2011) and Thomas & Azevedo (2013) would yield further indications.

5.4 Limitations

5.4.1 Methodology

One limitation is that most data originates from stated behavioural answers, which may poorly represent the actual behaviour (Pearce, Atkinson, & Mourato, 2006). Key data points, such as monthly savings due to CS, are based on the perception of survey participants. The question demands factual knowledge of actual current costs and the costs of the most realistic alternative scenario, which may be perceived differently by the participants.

To address this limitation, the survey used cost illustrations of one of the most common alternative scenarios, the total costs of ownership of a representative small and medium sized car (Citroen C1 and Skoda Octavia). Furthermore, a second value for savings was estimated in the Savings scenario by comparing the costs of the mobility portfolio of CS users and a Berlin-based average. The mobility portfolio of CS users was also obtained via the survey, and thus from stated answers, but it is deemed easier to express the frequency of use of different transport modes than monthly savings due to CS.

The nature of a self-administered survey with closed-ended questions is another limitation. The available answer options can influence participants (Reja, Manfreda, Hlebec, & Vehovar, 2003) and restrict them in providing other answers. One related effect is called the central tendency bias (Douven, 2018) where survey participants tend to avoid the extremes of a scale. This limitation is inherent in the survey design, but some measures were implemented to address it.

A considerable amount of thought went into the design of the questions and the multiple-choice answers to ensure that their influence on the survey participants is minimised. Where probable average values were unknown (i.e. savings per month), a wide range of possibilities was presented and answers were pilot-tested with experts before the survey. To limit the possible negative effect of the closed-ended questions, the option for open-ended answers was provided by adding the "other" category to the answer options.

Aggregating the survey results on re-spending across the eight consumption categories presents another limitation. A higher disaggregation level of consumption would lead to more detailed research outcomes, but the practicalities of survey design and limited data availability made it impractical for this study. This limitation was in part addressed by examining the re-expenditure of savings within the Transport category. Also, the author tried to convey the differences between categories to his best ability but due to limited space in the questionnaire, some respondents inevitably may have had to make assumptions regarding what is included in the different consumption categories provided.

In this thesis alternative scenarios were simulated to scrutinise results and assess the influence of different variables. To arrive at these scenarios, estimations were made and different sources were used as reference information. These issues will be discussed in the following section.

5.4.2 Data and Estimations

The two alternative scenarios discussed, Transport and Savings, entail limitations of their own. In the Transport scenario, the carbon intensity of Transport is changed by the author to a value that is deemed more realistic for CS users than the estimation based on EU-wide averages used in the Standard scenario. But the carbon intensities of the other categories remain EU-wide averages. CS users differ from the average population, so carbon intensities for other consumption categories are probably different as well. Due to a lack of data and resources, the other carbon intensities were not estimated, which may lead to a distorted picture.

In the Savings scenario, the validity of design namely making valid comparisons (Sapsford, 2007) (see chapter 3.2 Research Design), is in question. The baseline used to calculate monetary savings due to CS use, consists of the average population of Berlin or Germany. CS users differ significantly from that in terms of average income, education and possibly many more aspects. Comparing these two groups may not yield the most reliable results. This is for example apparent in the overall annual distance covered, which is 4 000 km more for CS users. A better comparison would have been on the basis of some socio-demographic variable, e.g. income or education, but it is difficult to obtain the needed data for these different groups to construct a baseline.

The data and methods used to estimate the Savings scenario are sometimes not the most reliable. For example, the value for km travelled per mode for CS users is mostly based on average German national, and not on Hamburg or Berlin specific data. This point especially applies to the values for distance per trip for long-distance public transport and flights. These are the two main categories for CS users in terms of km travelled and a small alteration in distance per trip could have big implications for the overall distance covered. In other instances, the distance per trip and cost per km are taken from seemingly less reliable sources, and assumptions were used to arrive at values for several transport modes.

There are also some limitations that are connected to the survey. Biases like the coverage, non-response and sampling error are discussed.

5.4.3 Survey

This discussion is based on Couper (2000) who reviewed issues of web-based surveys. He states that the quality of web-based surveys can vary wildly and lists most common biases. To understand his reasoning an introduction to his terminology is in order:

- Target population: "… the set of persons one wishes to study" (Couper, 2000, p. 476).
- Frame population: "… the set of persons for whom some enumeration can be made prior to the selection of the sample" (Groves, 2004, p. 82).

An example of the frame population would be all e-mail addresses of CS users in Berlin and Hamburg. Possible errors are listed and described below.

The coverage error: Couper (2000) describes the coverage error as a mismatch between the target and the frame population. Two aspects are relevant: The frame population might not cover all of the target population *and* the portion not covered might differ from the portion that is covered (Groves, 2004). For this thesis the population is defined as CS users in Berlin and Hamburg. By including the survey in a newsletter of the company, activity on social media and snowballing it is likely that both, some of the CS users in the two cities as well as unrelated users, were reached. Furthermore, the people that were reached might be more interested in CS than the average CS user and thus subscribe to newsletters and follow a CS company on Twitter. They might therefore give different answers. The coverage error is likely relevant for the survey at hand and influences results but no effort was made to estimate its size.

Non-response error: The non-response error refers to the issue that not everyone included in the sample is willing or able to finalise it. It can only be influenced if the frame and the likelihood of selection are known (i.e. in probability-based surveys) (Couper, 2000). This is not possible for this thesis, but the response rate can still be calculated in part. The survey was sent to about 4 500 CS users in Berlin (company representative, personal communication, August 2019), and the company has about 1 500 followers on Twitter. The number of answers from the tweet and the newsletter is 49, which corresponds with a response rate of less than 1%. Although it seems to be a low number, it is not uncommon for typical "click-rates" of newsletters ('Email Marketing Benchmarks', n.d.). Mailchimp, a commonly used email marketing tool, defines the click rate as: "The click rate is a percentage that tells you how many successfully delivered campaigns registered at least one click" ('About Open and Click Rates', n.d. n.p.). The response rate might be higher because it is not clear whether it was all 5 500 people who received the newsletter and/or read the tweet. Any increase in the response rate would be marginal, however. For the remaining answers it is not possible to calculate response rates because it is not known how many people potentially had access to the survey and how many completed it.

Reasons for low response rates usually stem from both technical limitations and confidentiality concerns (Couper, 2000). The current survey relied on a popular and easy-to-use survey tool while the respondents were likely to be people confident with online media. They are not expected to have difficulties to complete an online survey. Confidentiality is also likely not to play a role since participants had to agree to the anonymised saving of their data before they started the survey. The answers collected during the survey were unlikely to allow conclusions about the person giving the answers. The main limitation for the low sample size is the wariness of the company not to disturb customers. Upon signing up for the newsletter, the company ensures the participants that they would only contact them to inform them about new prices or new stations (company representative, personal communication, 11 June 2019). This is why the survey was not distributed more aggressively by sending out direct emails, for example.

The sampling error: The calculated sample size of 271 respondents ('Sample Size Calculator', n.d.) was not reached and thus the sample results are not representative for the population. Even if that number would have been reached, results are likely biased due to the sampling error. Couper (2000) would classify the sampling method as a self-selected web survey where respondents are not chosen randomly but by self-selection. Even a high number of responses cannot overcome this issue (Couper, 2000). This error is inherent in the data and cannot be addressed sufficiently for this thesis. Further research could use a more robust sampling method which would lead to a larger, more representative sample.

The measurement error: The errors discussed before are errors of non-observation. The measurement error, or validity of the measurement (Sapsford, 2007), differs from them because it entails a deviation of the participants' answers from their "true" answers. Couper (2000) lists two main sources for the error, the respondent and the instrument. The respondent might lose motivation to answer truthfully, not comprehend the questions or deliberately distort answers. Respondents may also be affected by the social desirability bias (Kelly et al., 2017). Possible causes for the measurement error resulting from the instrument may be poorly worded questions or technical flaws (Couper, 2000).

A substantial amount of focus was placed on designing the survey to minimise measurement errors. It was pilot-tested multiple times to assure high-quality, easy to comprehend questions and instructions. To keep the motivation of participants high, it was designed to be as concise as possible and only acquire information that is necessary for the research topic. A progress bar was included to show participants how they were advancing. The anonymity of answers was mentioned in the various communication channels (newsletter, tweet) and in the cover letter at the beginning of the survey, which participants had to agree to before starting the survey. A significant amount of thought went into the order of questions so that previous questions might not affect later answers. For more elaborate types of questions, Sapsford (2007) suggests validating answers which in this thesis is done by checking survey results with data provided by the company and estimations of alternative scenarios. Finally, a clear theme and the logo of Lund university as a header ensured a professional appearance of the survey.

Some efforts were made to address the biases in the survey. The company provided some data from their operations. This data was used to compare to collected data like expenditure and the average distance per booking, the average number of bookings per user per year and the average number of km per user and year. Another effort was made to triangulate one of the key variables in this thesis, savings of CS users, by estimating them comparing mobility patterns of CS users and a baseline.

Considering these limitations, results have to be treated with caution. Especially the sampling error is likely to be quite pronounced and generalisations about the population are more suggestive. The measures to address the limitations helped in adjusting estimates and thus improve the quality of the findings. The author acknowledges, however, that ultimately further research with a more robust sampling method is needed to test the results presented in this thesis.

6 Conclusions

In recent years several studies have been exploring the environmental effects of car sharing (CS). Most of them focussed largely on the direct environmental effects from e.g. changes in car ownership, distances driven and substitutions of transport modes. Indirect effects, like the impacts of changed disposable income and re-spending behaviour have been poorly explored. Some studies that estimated consumption-induced carbon emissions (CCE) of CS users suggested sizeable rebound effects. In worst cases, e. g. when CS-induced consumer savings are directed to carbon-intensive activities like air travel, the rebound effects even backfire. Such scenarios set the sustainability effects of CS in question. More knowledge about the significance of such indirect effects as well as the enabling scenarios is important for many actors in the society, especially for local governments seeing the sustainability potential of CS and supporting its development. So far, the evidence of the negative effects of CS is inconclusive because too few studies often simulating worst-case scenarios have been conducted. This warrants more research.

This thesis aimed to explore how CS affects the disposable income of CS users, how it influences their consumption patterns and how consumption induced carbon emissions depend on changes in consumption patterns. The study is based on a survey of CS users and supplemented by secondary data to support the analysis. The collected data was subjected to different statistical tests corroborating the robustness of results. The findings showed changes in the disposable income for most CS users. This induces changes in consumption patterns and has an effect on consumption induced carbon emissions. Among several results and tested hypotheses, the main finding is that when CS is perceived to induce savings, CCE of CS users are lower relative to an applicable baseline. However, when CS is seen as a more expensive option to personal mobility, the CCE increase.

The findings in this research contribute to the CS literature by providing more comprehensive insights into broader environmental impacts of CS. In contrast to previous research, the examined indirect effect of consumption induced carbon emissions among CS users, may contribute to the positive environmental impact of CS, suggesting that rebound effects are negligible and may not partially offset but induce additional carbon savings.

The results also suggest that increasing CS membership and changes in car-bound mileage, would lead to a reduction in CCE among CS users compared to the national average baseline scenario used in this study. For decision makers this means that support for CS schemes helps addressing the issue of increasing carbon emissions from transport. But as uptake of CS increases, the dynamics affecting CCE may change, i.e. through changes in CS users' carbon intensities of consumption categories. Therefore, researchers must continue to investigate the long-term effects of CS so that policy makers will make informed decisions.

This thesis highlights various areas that future work could expand upon. CS users' carbon intensities of consumption categories need to be estimated with higher accuracy, e.g. by calculating them based on observed behaviour instead of perceived behaviour as applied in this study. This would yield more precise results and a more detailed understanding of the differences between CS users and the average population.

Another area for further research are the changed consumption patterns of CS users. They were collected by asking participants about their behaviour but stated and observed actions tend to differ. Also, the operationalisation from likelihoods of expenditure to values of money spent is rather inaccurate. Therefore, future work could observe consumption patterns of CS users and use them as a basis to compare with an applicable baseline.

Long-term implications of a switch away from private cars towards CS also have to be examined, which was beyond the scope of this study. At the moment CS is used by a very distinct group of people who have differing views about social and environmental concerns than the average population and may thus also act differently. As more people become CS users, the relative carbon intensity of the consumption category Transport is likely to be reduced and the potential for increasing CCE and backfire rises. Both the magnitude of this effect and potential countermeasures need to be further investigated.

Finally, a study that assesses full life cycle impacts of CS would be interesting. Combining the approaches described in this study to estimate CCE with life cycle approaches, like e.g. by Chen & Kockelman (2016), would yield a comprehensive picture of the direct and indirect impacts of CS.

The results from this thesis point to the fact that support for CS seems to be one part of a solution towards a decarbonised, sustainable transport sector of the future, especially in cities. Changing consumption patterns do not seem to be an issue, they may even contribute to the positive environmental effects found in other studies. However, this thesis should rather be treated as a point of departure as further research is needed to arrive at more robust conclusions.

7 References

2018 Global Flight Price Ranking. (2018, April 16). Retrieved 14 August 2019, from Rome2rio website: https://www.rome2rio.com/labs/2018-global-flight-price-ranking/

About Open and Click Rates. (n.d.). Retrieved 2 September 2019, from Mailchimp website: https://mailchimp.com/help/about-open-and-click-rates/

ADAC Autokosten-Rechner. (n.d.). Retrieved 14 August 2019, from ADAC website: https://www.adac.de/infotestrat/autodatenbank/autokosten/autokosten-rechner/default.aspx

Alfredsson, E. C. (2004). "Green" consumption—No solution for climate change. *Energy*, *29*(4), 513–524.

Amt für Statistik, B.-B., & BWV Berliner Wissenschafts-Verlag GmbH. (2018). *Statistisches Jahrbuch 2018: Berlin.*

Amt für Statistik Berlin-Brandenburg (Series Ed.). (2015). *Einkommen und Einnahmen sowie Ausgaben privater Haushalte im Land Berlin 2013* (No. O II 3 – 5j / 13). Retrieved from https://www.statistik-berlin-brandenburg.de/publikationen/stat_berichte/2015/SB_O02-03-00_2013j05_BE.pdf

Amt für Statistik Berlin-Brandenburg (Ed.). (2019). *Einwohnerinnen und Einwohner im Land Berlin am 30. Juni 2019* [Data set]. Retrieved from https://www.statistik-berlin-brandenburg.de/publikationen/stat_berichte/2019/SB_A01-05-00_2019h01_BE.pdf

Baptista, P., Melo, S., & Rolim, C. (2014). Energy, environmental and mobility impacts of car-sharing systems. Empirical results from Lisbon, Portugal. *Procedia-Social and Behavioral Sciences*, *111*, 28–37.

Barth, M., & Shaheen, S. A. (2002). Shared-Use Vehicle Systems: Framework for Classifying Carsharing, Station Cars, and Combined Approaches. *Transportation Research Record: Journal of the Transportation Research Board*, *1791*(1), 105–112. https://doi.org/10.3141/1791-16

Becker, H., Ciari, F., & Axhausen, K. W. (2017). Comparing car-sharing schemes in Switzerland: User groups and usage patterns. *Transportation Research Part A: Policy and Practice*, *97*, 17–29. https://doi.org/10.1016/j.tra.2017.01.004

Brännlund, R., Ghalwash, T., & Nordström, J. (2007). Increased energy efficiency and the rebound effect: Effects on consumption and emissions. *Energy Economics*, *29*(1), 1–17. https://doi.org/10.1016/j.eneco.2005.09.003

Briceno, T., Peters, G., Solli, C., & Hertwich, E. (2005). *Using life cycle approaches to evaluate sustainable consumption programs: Car-sharing*. Retrieved from https://brage.bibsys.no/xmlui/bitstream/handle/11250/242569/121813_FULLTEXT01.pdf?sequence=1

Broberg, T., Berg, C., & Samakovlis, E. (2015). The economy-wide rebound effect from improved energy efficiency in Swedish industries–A general equilibrium analysis. *Energy Policy*, *83*, 26–37.

Bundesministerium für Verkehr, Bau und Stadtentwicklung, & Deutsches Institut für Wirtschaftsforschung (Eds.). (2018). *Personenkilometer—In Milliarden Kilometer* [Data set]. Retrieved from https://www.deutschlandinzahlen.de/tab/deutschland/infrastruktur/verkehr-und-transport/personenkilometer

Bundesverband Carsharing. (2007, March 28). Begriffsbestimmung. Retrieved 9 September 2019, from Bcs Bundesverband CarSharing e.V. website: https://www.carsharing.de/alles-ueber-carsharing/ist-carsharing/begriffsbestimmung

Bundesverband Carsharing. (2017, August 1). CarSharing-Städteranking 2017. Retrieved 9 September 2019, from Bcs Bundesverband CarSharing e.V. website: https://www.carsharing.de/alles-ueber-carsharing/carsharing-zahlen/carsharing-staedteranking-2017

Bundesverband Carsharing. (2019a). CarSharing in Deutschland. *bcs Bundesverband CarSharing e.V.* Retrieved from https://carsharing.de/alles-ueber-carsharing/carsharing-zahlen/aktuelle-zahlen-daten-zum-carsharing-deutschland-1

Bundesverband Carsharing. (2019b). Die größten CarSharing Anbieter. *bcs Bundesverband CarSharing e.V.* Retrieved from https://carsharing.de/alles-ueber-carsharing/carsharing-zahlen/aktuelle-zahlen-daten-zum-carsharing-deutschland-1

Bundesverband Carsharing. (2019c). Entwicklung des CarSharing differenziert nach Varianten. *bcs Bundesverband CarSharing e.V.* Retrieved from https://carsharing.de/alles-ueber-carsharing/carsharing-zahlen/aktuelle-zahlen-daten-zum-carsharing-deutschland-1

Bundesverband Carsharing. (2019d). Wachstum des CarSharing im Jahr 2018. *bcs Bundesverband CarSharing e.V.* Retrieved from https://carsharing.de/alles-ueber-carsharing/carsharing-zahlen/aktuelle-zahlen-daten-zum-carsharing-deutschland-1

Bundesverband Carsharing. (n.d.-a). Aktuelle Zahlen und Daten zum CarSharing in Deutschland. Retrieved 5 July 2019, from Bcs Bundesverband CarSharing e.V. website: https://carsharing.de/alles-ueber-carsharing/carsharing-zahlen/aktuelle-zahlen-daten-zum-carsharing-deutschland-1

Bundesverband Carsharing. (n.d.-b). Was ist CarSharing? Retrieved 9 September 2019, from Bcs Bundesverband CarSharing e.V. website: https://www.carsharing.de/alles-ueber-carsharing/ist-carsharing/ist-carsharing

Cervero, R., Golub, A., & Nee, B. (2007). City CarShare: Longer-term travel demand and car ownership impacts. *Transportation Research Record*, *1992*(1), 70–80.

Chai, A. (2018). *Household consumption patterns and the sectoral composition of growing economies: A review of the interlinkages* (No. 03). Retrieved from UNIDO website: https://www.unido.org/api/opentext/documents/download/10166980/unido-file-10166980

Chen, D., & Kockelman, K. (2016). Carsharing's life-cycle impacts on energy use and greenhouse gas emissions. *Transportation Research Part D: Transport and Environment*, *47*, 276–284. http://dx.doi.org/10.1016/j.trd.2016.05.012

Chitnis, M., Sorrell, S., Druckman, A., Firth, S. K., & Jackson, T. (2013). Turning lights into flights: Estimating direct and indirect rebound effects for UK households. *Energy Policy*, *55*, 234–250. https://doi.org/10.1016/j.enpol.2012.12.008

Chitnis, M., Sorrell, S., Druckman, A., Firth, S. K., & Jackson, T. (2014). Who rebounds most? Estimating direct and indirect rebound effects for different UK socioeconomic groups. *Ecological Economics*, *106*, 12–32. https://doi.org/10.1016/j.ecolecon.2014.07.003

Cooper, G., Howe, D. A., & Mye, P. (2000). *The Missing Link: An Evaluation of CarSharing Portland Inc. Portland, Oregon*.

Costain, C., Ardron, C., & Habib, K. N. (2012). Synopsis of users' behaviour of a carsharing program: A case study in Toronto. *Transportation Research Part A: Policy and Practice*, *46*(3), 421–434. https://doi.org/10.1016/j.tra.2011.11.005

Couper, M. P. (2000). Web surveys: A review of issues and approaches. *Public Opinion Quarterly*, *64*(4), 464–494.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed). Thousand Oaks: SAGE Publications.

Dambeck, H. (2011, March 28). Kostenvergleich Rad gegen Auto: Das Velo ist Sieger der Herzen. *Spiegel Online*. Retrieved from https://www.spiegel.de/auto/aktuell/kostenvergleich-rad-gegen-auto-das-velo-ist-sieger-der-herzen-a-753206.html

Degree of freedom. (n.d.). In Lexico (Ed.), *Lexico Dictionaries | English*. Retrieved from https://www.lexico.com/en/definition/degree_of_freedom

Die 10 günstigsten Kleinstwagen im ADAC Autokosten-Check. (2019, March 5). Retrieved 14 August 2019, from ADAC website: https://www.adac.de/rund-ums-fahrzeug/auto-kaufen-verkaufen/kostencheck/guenstigste-kleinstwagen-autokosten/

Douven, I. (2018). A Bayesian perspective on Likert scales and central tendency. *Psychonomic Bulletin & Review*, *25*(3), 1203–1211. https://doi.org/10.3758/s13423-017-1344-2

Druckman, A., Chitnis, M., Sorrell, S., & Jackson, T. (2011). Missing carbon reductions? Exploring rebound and backfire effects in UK households. *Energy Policy*, *39*(6), 3572–3581.

Durand, A., Kennisinstituut voor Mobiliteitsbeleid, & Ministerie van Infrastructuur en Milieu. (2018). *Mobility-as-a-Service and changes in travel preferences and travel behaviour: A literature review*. The Hague: KiM|Netherlands Institute for Transport Policy Analysis.

Email Marketing Benchmarks. (n.d.). Retrieved 2 September 2019, from Mailchimp website: https://mailchimp.com/resources/email-marketing-benchmarks/

European Environment Agency. (2013). Greenhouse gas emissions induced by household consumption, per Euro spent of expenditure in 12 household consumption categories, 2000-2007. *European Environment Agency*. Retrieved from https://www.eea.europa.eu/data-and-maps/figures/direct-and-indirect-green-house-1

Eurostat. (n.d.). Glossary:Classification of individual consumption by purpose (COICOP)—Statistics Explained. Retrieved 9 July 2019, from Eurostat website: https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Classification_of_individual_consumption_by_purpose_(COICOP)

Fakten und Zahlen. (2016). Retrieved 13 August 2019, from TAXIPEDIA - Wissenswertes rund ums Taxi website: http://taxipedia.info/zahlen-und-fakten/

Firnkorn, J., & Müller, M. (2011). What will be the environmental effects of new free-floating car-sharing systems? The case of car2go in Ulm. *Ecological Economics*, *70*(8), 1519–1528. http://dx.doi.org/10.1016/j.ecolecon.2011.03.014

Frost & Sullivan Research Service. (2010). *Analysis of the Market for Carsharing in North America*. Retrieved from Frost & Sullivan website: http://www.frost.com/prod/servlet/report-overview.pag?repid=N748-01-00-00-00

Gao, P., Kaas, H.-W., Mohr, D., & Wee, D. (2016). *Automotive revolution–perspective towards 2030: How the convergence of disruptive technology-driven trends could transform the auto industry*. Retrieved from McKinsey&Company website: https://www.mckinsey.com/~/media/mckinsey/industries/high%20tech/our%20insights/disruptive%20trends%20that%20will%20transform%20the%20auto%20industry/auto%202030%20report%20jan%202016.ashx

German Environment Agency. (2017). Emission of greenhouse gases covered by the UN Framework Convention on Climate. *Umweltbundesamt*. Retrieved from https://www.umweltbundesamt.de/en/indicator-greenhouse-gas-emissions

German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. (2019). *Klimaschutz in Zahlen*. Retrieved from German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety website: https://www.bmu.de/fileadmin/Daten_BMU/Pools/Broschueren/klimaschutz_zahlen_2019_broschuere_bf.pdf

Glen, S. (2014, November 19). Shapiro-Wilk Test: What it is and How to Run it. Retrieved 4 September 2019, from Statistics How To website: https://www.statisticshowto.datasciencecentral.com/shapiro-wilk-test/

Groves, R. M. (2004). *Survey errors and survey costs* (Vol. 536). John Wiley & Sons.

Historic Exchange Rates. (2018, April 16). Retrieved 14 August 2019, from X-rates website: https://www.x-rates.com/historical/?from=USD&amount=1&date=2018-04-16

Kelly, N., Harpel, T., Fontes, A., Walters, C., & Murphy, J. (2017). An examination of social desirability bias in measures of college students' financial behavior. *College Student Journal*, *51*(1), 115–128.

Kenton, W. (n.d.). Disposable Income. In *Investopedia*. Retrieved from https://www.investopedia.com/terms/d/disposableincome.asp

Kilometerkosten beim Bahnfahren. (n.d.). Retrieved 13 August 2019, from DieEinsparInfos.de website: http://www.dieeinsparinfos.de/guenstige-mobilitaet/bahn/kosten/

Kraftfahrt-Bundesamt (Ed.). (2018). *Erneut mehr Gesamtkilometer bei geringerer Jahresfahrleistung je Fahrzeug* [Data set]. Retrieved from https://www.kba.de/DE/Statistik/Kraftverkehr/VerkehrKilometer/2017_vk_kurzbericht_pdf.pdf?__blob=publicationFile&v=14

Kratena, K., & Wüger, M. (2010). *The Full Impact of Energy Efficiency on Households' Energy Demand*. WIFO Working Papers.

Lane, C. (2005). PhillyCarShare: First-year social and mobility impacts of carsharing in Philadelphia, Pennsylvania. *Transportation Research Record*, *1927*(1), 158–166.

Le Vine, S., Adamou, O., & Polak, J. (2014). Predicting new forms of activity/mobility patterns enabled by shared-mobility services through a needs-based stated-response method: Case study of grocery shopping. *Transport Policy*, *32*, 60–68.

Le Vine, S., & Polak, J. (2017). The impact of free-floating carsharing on car ownership: Early-stage findings from London. *Transport Policy*.

Lenzen, M., & Dey, C. J. (2002). Economic, energy and greenhouse emissions impacts of some consumer choice, technology and government outlay options. *Energy Economics*, *24*(4), 377–403. https://doi.org/10.1016/S0140-9883(02)00007-5

Leontief, W. (1986). *Input-output economics*. Oxford University Press.

Leopold, J., & Friedheim, D. (2018). *Durchschnittliche Pkw-Fahrleistung 2017 nach Wohnort, Alter und Geschlecht des Versicherungsnehmers*. Retrieved from Check24 website:

https://www.check24.de/files/p/2018/1/b/e/12499-2018-02-19_check24_studie_durchschnittliche-fahrleistung.pdf

Lohninger, H. (n.d.). Shapiro-Wilk Test. Retrieved 4 September 2019, from Fundamentals of Statistics website: http://www.statistics4u.info/fundstat_eng/ee_shapiro_wilk_test.html

Loose, W. (2010). The state of European car-sharing. *Project Momo Final Report D*, *2*. Retrieved from https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/momo_car-sharing_the_state_of_european_car_sharing_en.pdf

Ma, G., & Yi, W. (2010). China's high saving rate: Myth and reality. *Economie Internationale*, (2), 5–39.

Martin, E., & Shaheen, S. A. (2011a). Greenhouse Gas Emission Impacts of Car Sharing in North America. *IEEE Transactions on Intelligent Transportation Systems*, *12*(4), 1074–1086.

Martin, E., & Shaheen, S. A. (2011b). *The impact of carsharing on household vehicle ownership*.

Martin, E., & Shaheen, S. A. (2016). Impacts of Car2Go on vehicle ownership, modal shift, vehicle miles traveled, and greenhouse gas emissions: An analysis of five North American Cities. *Transportation Sustainability Research Center, UC Berkeley*, *3*. Retrieved from http://innovative-mobility.org/wp-content/uploads/2016/07/Impactsofcar2go_FiveCities_2016.pdf

Martin, E., Shaheen, S. A., & Lidicker, J. (2010). Impact of Carsharing on Household Vehicle Holdings: Results from North American Shared-Use Vehicle Survey. *Transportation Research Record: Journal of the Transportation Research Board*, *2143*(1), 150–158. https://doi.org/10.3141/2143-19

Meijkamp, R. (1998). Changing consumer behaviour through eco-efficient services: An empirical study of car sharing in the Netherlands. *Business Strategy and the Environment*, *7*(4), 234–244.

Millard-Ball, A., Murray, G., Ter Schure, J., Fox, C., & Burkhardt, J. (2005). Carsharing: Where and how it succeeds (Transit Cooperative Research Report 108). *Washington, DC: Transportation Research Board of the National Academies*.

Miller, G. T., & Spoolman, S. (2012). *Living in the environment: Principles, connections, and solutions* (17th ed). Belmont, CA: Brooks/Cole.

Mizobuchi, K. (2008). An empirical study on the rebound effect considering capital costs. *Energy Economics*, *30*(5), 2486–2516. https://doi.org/10.1016/j.eneco.2008.01.001

Mooney, H. (2019, March 1). Car2Go cars to go away, fleet to rebrand after BMW merger. *Vancouver Sun*. Retrieved from https://vancouversun.com/news/local-news/share-now-car2go-cars-to-go-away-fleet-to-rebrand-after-bmw-merger

Morency, C., Habib, K. M. N., Grasset, V., & Islam, M. T. (2012). Understanding members' carsharing (activity) persistency by using econometric model. *Journal of Advanced Transportation*, *46*(1), 26–38. https://doi.org/10.1002/atr.142

Morency, C., Trépanier, M., & Martin, B. (2008). Object-oriented analysis of carsharing system. *Transportation Research Record*, *2063*(1), 105–112.

Muheim, Peter. (1998). *Mobility at your convenience: CarSharing—The key to combined mobility*. Zurich; Berne: Energie 2000, Transport Section c/o Ecoprocess ; Orders : Eidg. Drucksachen- und Materialzentrale EDMZ. /z-wcorg/.

Murray, C. K. (2013). What if consumers decided to all 'go green'? Environmental rebound effects from consumption decisions. *Energy Policy*, *54*, 240–256. https://doi.org/10.1016/j.enpol.2012.11.025

Nehrke, G., & Loose, W. (2018). *Nutzer- und Mobilitätsverhalten in verschiedenen Carsharing Varianten*. Retrieved from Bundesverband Carsharing e.V. website: https://carsharing.de/sites/default/files/uploads/stars_wp4_t41_projektbericht_bcs_deutsch_final_1.pdf

Nijland, H., van Meerkerk, J., & Hoen, A. (2015). *Impact of car sharing on mobility and CO2 emissions* (No. 1842). Retrieved from PBL Netherlands Environmental Assessment Agency website: https://www.pbl.nl/sites/default/files/cms/publicaties/PBL_2015_Note%20Impact%20of%20car%20sharing_1842.pdf

Nobis, C. (2006). Carsharing as key contribution to multimodal and sustainable mobility behavior: Carsharing in Germany. *Transportation Research Record*, *1986*(1), 89–97.

Nobis, C., & Kuhnimhof, T. (2018). *Mobilität in Deutschland – MiD Ergebnisbericht* (No. FE-Nr. 70.904/15). Retrieved from Bundesministerium für Verkehr und digitale Infrastruktur website: http://www.mobilitaet-in-deutschland.de/pdf/MiD2017_Ergebnisbericht.pdf

Passenger-kilometres performed. (n.d.). In Eurocontrol ATM Lexicon (Ed.), *Eurocontrol ATM Lexicon*. Retrieved from https://ext.eurocontrol.int/lexicon/index.php/Passenger-kilometres_performed

Pearce, D. W., Atkinson, G., & Mourato, S. (2006). *Cost-benefit analysis and the environment: Recent developments*. Paris: Organisation for Economic Co-operation and Development.

Phillips, D. C., & Burbules, N. C. (2000). *Postpositivism and educational research*. Rowman & Littlefield.

Phillips, S. (2018, May 17). Carsharing Market Analysis: Growth and Industry Analysis. Retrieved 5 March 2019, from Movmi.net website: http://movmi.net/carsharing-market-growth/

Plepys, A., & Singh, J. (2019). Challenges and research needs in evaluating sustainability impacts of sharing economy using input- output analysis. In O. Mont (Ed.), *A Research Agenda for Sustainable Consumption Governance*. Retrieved from https://www.e-elgar.com/shop/a-research-agenda-for-sustainable-consumption-governance

Quirk, T. J. (2016). *Excel 2016 for Social Science Statistics*. https://doi.org/10.1007/978-3-319-39711-5

Reja, U., Manfreda, K. L., Hlebec, V., & Vehovar, V. (2003). Open-ended vs. Close-ended questions in web questionnaires. *Developments in Applied Statistics*, *19*(1), 159–177.

Rudman, L. M. (1979). Vehicle kilometers traveled: Evaluation of existing data sources. *Transportation Research Record*, *726*, 19–28.

Rydén, C., & Morin, E. (2005). *Environmental assessment* (No. Report WP 6). Retrieved from MOSES-Mobility Services for Urban Sustainability website: http://www.communauto.com/images/Moses_environnement.pdf

Sample Size Calculator. (n.d.). Retrieved 2 September 2019, from Raosoft website: http://www.raosoft.com/samplesize.html

Sapsford, R. (2007). *Survey research*. Retrieved from http://site.ebrary.com/id/10504430

Seltman, H. J. (2018). *Experimental design and analysis*. Retrieved from http://www.stat.cmu.edu/~hseltman/309/Book/Book.pdf

Shaheen, S. A. (2018). Innovative Mobility: Carsharing Outlook (Spring 2018). *University of California, Institute of Transportation Studies*. https://doi.org/10.7922/g2cc0xvw

Shaheen, S. A., Cohen, A. P., & Chung, M. S. (2009). North American Carsharing: 10-Year Retrospective. *Transportation Research Record: Journal of the Transportation Research Board*, *2110*(1), 35–44. https://doi.org/10.3141/2110-05

Shaheen, S. A., Mallery, M. A., & Kingsley, K. J. (2012). Personal vehicle sharing services in North America. *Research in Transportation Business & Management*, *3*, 71–81.

Shaheen, S. A., Rodier, C., Murray, G., Cohen, A., & Martin, E. (2010). *Carsharing and public parking policies: Assessing benefits, costs, and best practices in North America*.

Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, *52*(3–4), 591–611. https://doi.org/10.1093/biomet/52.3-4.591

Sioui, L., Morency, C., & Trépanier, M. (2013). How Carsharing Affects the Travel Behavior of Households: A Case Study of Montréal, Canada. *International Journal of Sustainable Transportation*, *7*(1), 52–69. https://doi.org/10.1080/15568318.2012.660109

Sorrell, S. (2007). *The Rebound Effect: An assessment of the evidence for economy-wide energy savings from improved energy efficiency*.

Sorrell, S., & Dimitropoulos, J. (2007). *UKERC Review of evidence for the rebound effect: Technical Report 2: Econometric studies* (No. UKERC/WP/TPA/2007/010). UK Energy Research Centre.

Sorrell, S., Dimitropoulos, J., & Sommerville, M. (2009). Empirical estimates of the direct rebound effect: A review. *Energy Policy*, *37*(4), 1356–1371. https://doi.org/10.1016/j.enpol.2008.11.026

Sperling, D., & Shaheen, S. (2000). Carsharing, niche market or new pathway? *KFB RAPPORT*, (2000: 15).

Stasko, T. H., Buck, A. B., & Oliver Gao, H. (2013). Carsharing in a university setting: Impacts on vehicle ownership, parking demand, and mobility in Ithaca, NY. *Transport Policy*, *30*, 262–268. https://doi.org/10.1016/j.tranpol.2013.09.018

Statistisches Amt für Hamburg und Schleswig-Holstein (Ed.). (2019). *Die Bevölkerung in Hamburg nach Alter und Geschlecht 2018*. Retrieved from https://www.statistik-nord.de/fileadmin/Dokumente/Statistische_Berichte/bevoelkerung/A_I_3_j_H/A_I_3_j18_HH.pdf

Statistisches Bundesamt. (2018). Population based on the 2011 Census. *Federal Statistical Office*. Retrieved from https://www.destatis.de/EN/Themes/Society-Environment/Population/Current-Population/Tables/census-sex-and-citizenship-2018.html

Statistisches Bundesamt (Series Ed.). (2019a). *Verkehr Luftverkehr* (No. 2080600191054). Retrieved from https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Transport-Verkehr/Personenverkehr/Publikationen/Downloads-Luftverkehr/luftverkehr-2080600191054.pdf?__blob=publicationFile

Statistisches Bundesamt (Series Ed.). (2019b). *Verkehr Personenverkehr mit Bussen und Bahnen* (No. 2080310193214). Retrieved from https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Transport-Verkehr/Personenverkehr/Publikationen/Downloads-Personenverkehr/personenverkehr-busse-bahnen-vierteljahr-2080310193214.pdf?__blob=publicationFile

Steinmeyer, I., & Herrmann-Fiechtner, M. (2017). *Mobilität der Stadt Berliner Verkehr in Zahlen 2017*. Retrieved from Senatsverwaltung für Umwelt, Verkehr und Klimaschutz website: https://www.berlin.de/senuvk/verkehr/politik_planung/zahlen_fakten/download/Mobilitaet_dt_komplett.pdf

Stewart, N. (2019, February 28). Car2Go merges with BMW's car-sharing service. *Global News*. Retrieved from https://globalnews.ca/news/5011141/car2go-merges-with-bmws-car-share-service/

Survey&Report (Version 4.3.9.5). (2019). Retrieved from www.sunet.se

Sverige, & Naturvårdsverket. (1997). *Att äta för et bättre miljö: Slutrapport från systemstudie Livsmedel*. Stockholm: Naturvårdsverket förlag.

Taxikosten in Deutschland. (n.d.). Retrieved 12 August 2019, from HRS Holidays website: https://holidays.hrs.de/journal/heimatinsider/taxikosten-in-deutschland-was-kostet-das-verkehrsmittel/

The Joint Venture—Our Story. (n.d.). Retrieved 10 July 2019, from Your-now.com website: https://www.your-now.com/our-story

Thomas, B. A., & Azevedo, I. L. (2013). Estimating direct and indirect rebound effects for U.S. households with input–output analysis. Part 2: Simulation. *Ecological Economics*, *86*, 188–198. https://doi.org/10.1016/j.ecolecon.2012.12.002

Über cambio. (n.d.). Retrieved 10 July 2019, from Cambio carsharing website: https://www.cambio-carsharing.de/cms/carsharing/de/1/cms_f2_256/cms?cms_knuuid=c2aee204-5821-445a-afc4-1cab62479fcd

Über stadtmobil. (n.d.). Retrieved 10 July 2019, from https://www.stadtmobil.de/stadtmobil/ueber-stadtmobil/

Über uns (About us). (n.d.). Retrieved 14 August 2019, from DB Vertrieb website: https://www.db-vertrieb.com/db_vertrieb/view/wir/firmenprofil.shtml

Umweltkarte in 3 Schritten. (n.d.). Retrieved 15 August 2019, from BVG website: https://www.bvg.de/de/abo-online/vbb-umweltkarte

United Nations. (2018). *Classification of Individual ConsumptionAccording to Purpose (COICOP) 2018* (No. 99). Retrieved from United Nations website: https://unstats.un.org/unsd/classifications/business-trade/desc/COICOP_english/COICOP_2018_-_pre-edited_white_cover_version_-_2018-12-26.pdf

United Nations Population Division. (2018). *Urban population (% of total population)*. Retrieved from https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=DE

United Nations. Statistical Division. (1999). *Handbook of input-output table compilation and analysis* (Vol. 74). UN.

U.S. Energy Information Administration. (2017, May 1). Carbon intensity of energy use is lowest in U.S. industrial and electric power sectors. Retrieved 16 September 2019, from U.S. Energy Information Administration website: https://www.eia.gov/todayinenergy/detail.php?id=31012

US Environmental Protection Agency. (n.d.). Understanding Global Warming Potentials. Retrieved 16 September 2019, from US EPA website: https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

Verboven, H., & Vanherck, L. (2016). The sustainability paradox of the sharing economy. *Uwf UmweltWirtschaftsForum*, *24*(4), 303–314.

Vergleichen Sie doch mal. Es lohnt sich! (n.d.). Retrieved 12 August 2019, from Stadtmobil.de website: https://www.stadtmobil.de/

Walliman, N. (2006). *Social research methods*. London ; Thousand Oaks, Calif: SAGE.

What is Business-to-Consumer (B2C)? (n.d.). Retrieved 19 September 2019, from Shopify website: https://www.shopify.com/encyclopedia/business-to-consumer-b2c

Whitelegg, J., & Britton, E. (1999). Carsharing 2000-A hammer for sustainable development. *World Transport Policy and Practice (Special Issue)*, *5*(3).

Zhou, B. (Brenda), & Kockelman, K. M. (2011). Opportunities for and Impacts of Carsharing: A Survey of the Austin, Texas Market. *International Journal of Sustainable Transportation*, *5*(3), 135–152. https://doi.org/10.1080/15568311003717181

Appendix

The Survey

The survey was distributed in German. It was translated to increase transparency.

Introductory text:

Dear car sharing user,

Thank you for opening the link and participating in the questionnaire! My name is Samuel, I am from Austria and I am a Master student in the programme "Environmental Management and Policy" at Lund University in Sweden. Currently I am writing my Master thesis and for that I need data from car sharing users like you. I am especially interested in the indirect effect of car sharing.

The following questionnaire will take around five minutes to complete and your complete answers will help me a lot! Please be aware that sometimes it may seem as if you were skipping some questions. This is the way it is supposed to be, please continue to complete the questionnaire. There are no right or wrong answers, please fill in what is most applicable to you.

Of course, your answers will remain anonymous. Thank you again for your help!

☐ I agree to the anonymized saving of my answers.

Section 1:

Q1: Do you own a car?

- Yes
- No

Q2: Which CS companies do you use on a regular basis? Multiple answers are possible. Please note that car rental companies or services like Uber do not belong to CS.

- DriveNow
- Car2go
- Stadtmobil
- Cambio
- Greenwheels
- Miles
- Ubeeqo
- Flinkster
- Drivy
- Other

Comment field: Other – Please enter

Q3: How often do you use CS?

- Nearly daily
- A couple of times a week
- A couple of times a month
- A couple of times a year

Q4: Because I use CS, I… (please complete)

- rather save money.
- do not save but also do not spend more money.
- rather spend more money.

Section 2 – Questions for G1

Q5: How much do you spend on average for one CS booking? Please consider all costs of CS like costs per ride and the monthly fee (if applicable).

- EUR 0 – 20
- EUR 21- 40
- EUR 41 – 60
- EUR 61 – 80
- EUR 81 – 100
- EUR 101 – 120
- EUR 121 – 140
- More

Comment field: More – please enter:

Q6: How much money do you save per *month* because you use CS.
For comparison: According to ADAC (2018) owning a car classified as very small (i.e. Citroen C1) costs more than 300 Euros per month, a car classified as medium sized (i.e. Skoda Octavia) nearly 500 Euros per month.

- EUR 0 – 40
- EUR 41 – 80
- EUR 81 – 120
- EUR 121 – 160
- EUR 161 – 200
- EUR 201 – 240
- EUR 241 – 280
- EUR 281 – 320
- More

Comment field: More – please enter:

Q7: What is the likelihood that you spend the saved amount on the following categories?

	Very un-likely	Rather un-likely	Neither likely nor un-likely	Rather likely	Very likely
Food and Beverages					
Clothing and Footwear					
Furnishings and Equipment					
Restaurants and Hotels					
Transport					
Communication					
Recreation and Culture					
Miscellaneous goods and services					

Q8: Because I save money from CS, I use the following modes of transport… (please indicate)

	A lot less	Rather less	Same amount / No difference	Rather more	A lot more
Private car					
Stationary CS (cambio, Flinkster)					
Free-floating CS (Sharenow, Miles…)					
Motorbike					
Bicycle					
Walking					
Taxis, Berlkönig[8], Uber and other providers					
Plane					
Local public transport (Metro, tram, S-Bahn, busses)					
Long distance public transport (rail, coach)					

Q9: Do you consider your *monthly* savings due to CS significant?

- Yes
- No

Q10: Which minimum *monthly* amount would you consider significant?

- EUR 0 – 20
- EUR 21 – 40
- EUR 41 – 60
- EUR 61 – 80
- EUR 81 – 100

[8] Ridesharing operator in Berlin

- EUR 101 – 120
- EUR 121 – 140
- EUR 141 – 160
- More

Comment field: More – please enter:

Section 3 – Questions for G2

Q11: How much do you spend on average for one CS booking? Please consider all costs of CS like costs per ride and the monthly fee (if applicable).

- EUR 0 – 20
- EUR 21- 40
- EUR 41 – 60
- EUR 61 – 80
- EUR 81 – 100
- EUR 101 – 120
- EUR 121 – 140
- More

Comment field: More – please enter:

Q12: Imagine you would save money due to CS. Which minimum *monthly* saving would you consider a significant amount?

- EUR 0 – 20
- EUR 21 – 40
- EUR 41 – 60
- EUR 61 – 80
- EUR 81 – 100
- EUR 101 – 120
- EUR 121 – 140
- EUR 141 – 160
- More

Comment field: More – please enter:

Q13: What is the likelihood that you would spend the indicated amount on the following categories?

	Very unlikely	Rather unlikely	Neither likely nor unlikely	Rather likely	Very likely
Food and Beverages					
Clothing and Footwear					
Furnishings and Equipment					
Restaurants and Hotels					
Transport					

Communication					
Recreation and Culture					
Miscellaneous goods and services					

Q14: Please still assume that you are saving the previously indicated amount due to CS. In this case would you increase or reduce the use of the following modes of transport?

	Reduce a lot	Rather reduce	No difference	Rather increase	Increase a lot
Private car					
Stationary CS (cambio, Flinkster)					
Free-floating CS (Sharenow, Miles…)					
Motorbike					
Bicycle					
Walking					
Taxis, Berlkönig[8], Uber and other providers					
Plane					
Local public transport (Metro, tram, S-Bahn, busses)					
Long distance public transport (rail, coach)					

Section 4 – Questions for G3

Q15: How much do you spend on average for one CS booking? Please consider all costs of CS like costs per ride and the monthly fee (if applicable).

- EUR 0 – 20
- EUR 21- 40
- EUR 41 – 60
- EUR 61 – 80
- EUR 81 – 100
- EUR 101 – 120
- EUR 121 – 140
- More

Comment field: More – please enter:

Q16: Do you consider your expenditure on CS to be significant?

- Yes
- No

Q17: Which minimum amount of costs per *month* would you consider significant?

- EUR 0 – 20
- EUR 21 – 40
- EUR 41 – 60
- EUR 61 – 80
- EUR 81 – 100
- EUR 101 – 120
- EUR 121 – 140
- EUR 141 – 160
- More

Comment field: More – please enter:

Q18: Please imagine that you do not use CS. What is the likelihood that you would spend the amount you are spending on CS now, on the following categories?

	Very unlikely	Rather unlikely	Neither likely nor unlikely	Rather likely	Very likely
Food and Beverages					
Clothing and Footwear					
Furnishings and Equipment					
Restaurants and Hotels					
Transport					
Communication					
Recreation and Culture					
Miscellaneous goods and services					

Q19: Pleases still imagine that you do not use CS. In this case would you increase or reduce the use of the following modes of transport?

	Reduce a lot	Rather reduce	No difference	Rather increase	Increase a lot
Private car					
Stationary CS (cambio, Flinkster)					
Free-floating CS (Sharenow, Miles…)					
Motorbike					
Bicycle					
Walking					
Taxis, Berlkönig[8], Uber and other providers					
Plane					
Local public transport (Metro, tram, S-Bahn, busses)					
Long distance public transport (rail, coach)					

Section 5

Q20: How often do you use the following modes of transport on average. A roundtrip counts as one trip, the distance is not relevant.

	Not at all	1-2 times a year	Multiple times a year	1-2 times a month	1-2 times a week	3-4 times a week	5-6 times a week	Daily
Private car								
Stationary CS (cambio, Flinkster…)								
Free-floating CS (Sharenow, Miles…)								
Motorbike								
Bicycle								
Walking								
Taxis, Berlkönig[8], Uber and similar providers								
Plane								
Local public transport (Metro, tram, S-Bahn, busses)								
Long distance public transport (rail, coach)								

Q21: Please imagine that you do not use CS. What is the likelihood that you would use the following modes of transport as an alternative to CS?

	Very unlikely	Rather unlikely	Rather likely	Very likely
Private car				
Motorbike				
Bicycle				
Walking				
Taxis, Berlkönig[8], Uber and similar providers				
Plane				
Local public transport (Metro, tram, S-Bahn, busses)				
Long distance public transport (rail, coach)				

Section 6: Questions for the company:

Q22: Why do you use the company? Multiple answers are possible.

- Price
- Nice service
- I like the company
- The company acts sustainably and is certified with the blue angel
- Habit
- Position of the stations
- Maintenance and care of the cars
- Choice of different cars
- Other reasons

Comment field: Other reasons – please enter:

Q23: Why did you start to use CS? Multiple answers are possible.

- Higher wages
- Birth of a child
- Move to another district/city
- End of my education
- New job
- Start of a relationship
- End of a relationship
- Other reasons

Comment field: Other reasons – please enter:

Q24: Why do you use CS? Multiple answers are possible.

- For ecological reasons
- To save money
- It is comfortable
- CS is new and modern
- I want to use car without owning one
- People in my surroundings also use CS
- It is difficult to get a parking spot with my own car
- Other reasons

Comment field: Other reasons – please enter:

Section 7

Q25: How old are you?

- 18 – 27
- 28 – 40
- 41 – 65
- 66 and older

Q26: Gender?

- Female
- Male
- Non-binary

Q27: Highest completed education?

- No degree
- Basic school qualification
- Intermediate secondary school
- Vocational school
- Higher education entrance qualification (Abitur)
- Higher education degree (University, Bachelor, Master, PhD)

Q28: What is your net *monthly* household income? Household income refers to the total net income of all household members.

- EUR 0 – 1,299,-
- EUR 1,300 – 2,599,-
- EUR 2,600 – 3,599,-
- EUR 3,600 – 4,999,-
- EUR 5,000 and more

Q29: Which option best describes your household?

- Single adult without children
- Single adult with children
- Couple with children
- Couple without children
- Other type of household with children
- Other type of household without children

Q30: How many people live in your household, including yourself?

- 1
- 2
- 3
- 4
- 5
- More

Comment field: More – please enter

Thank-you message: Thank you for answering my questions. Have a nice day!