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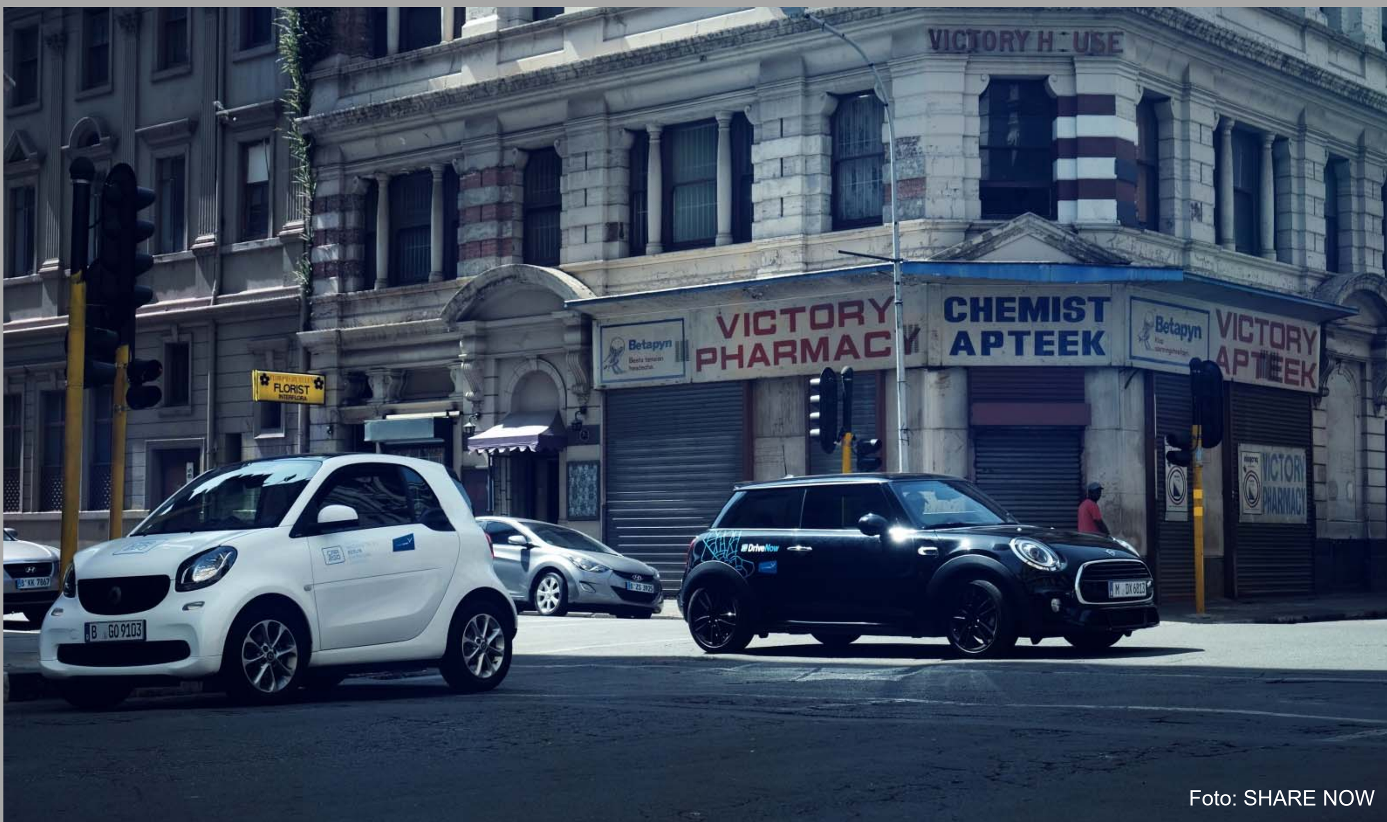

Foto: SHARE NOW

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This study has been funded by car2go Group GmbH and DriveNow GmbH & Co. KG and has been accomplished by the authors. For further information you may conatact Prof. Dr. Hansjörg Fromm (hansjoerg.fromm@kit.edu) or PD Dr. Patrick Jochem (jochem@kit.edu).

1. Summary

Free-floating carsharing, i.e., carsharing that allows pick-up and return of a car anywhere within a specified area in a city, has now been available in European cities for more than 10 years. As an important example of the sharing economy, carsharing strives for a more efficient use of resources with positive economic, social, and environmental impacts. After a decade of operation and user experience, an evaluation seems appropriate.

car2go and DriveNow, who merged into SHARE NOW in 2019, are the largest carsharing operators in the world. They commissioned this study to identify the impact of carsharing on vehicle holdings, modal shift, vehicle kilometers traveled (VKT), and greenhouse gas emissions. The study was conducted in 2018 and 2019. It is based on a survey among car2go and DriveNow customers in 11 European cities. A previous study was performed by the University of California, Berkeley, for 5 North American cities in 2016 [7].

Over 10,000 carsharing users regularly using the service ("regular users") participated in the European online survey. We consider the survey participants as a representative sample[1] of all regular car2go and DriveNow users. This allows to extrapolate the answers of the survey participants to the overall population of regular car2go and DriveNow users in 2017 and 2018, respectively. In the survey, participants were asked detailed questions on how the availability of car2go or DriveNow changed their travel behavior and vehicle ownership. One group of questions centered around their change in travel behavior (e.g. trips overall, carpooling) and mode choice (e.g. use of taxis and public transportation). Another group of questions concerned the change in vehicle holdings.

Carsharing has a considerable impact on the participants' choice of other transportation modes. Participants were asked to what extent they had changed their use of urban rail, bus, taxi, intercity rail, bicycles, and motorcycles, and whether they had changed their walking habits. There is a general trend that carsharing users reduce the use of taxis and – to a lower extent – use of urban rail and busses. Only a few participants report that they have increased the use of public transportation. The figures, however, show noticeable differences from city to city. Not surprisingly, participants who have sold a car show a slightly different behavior: a higher percentage of them increases the use of public transportation and a lower percentage reduces the use of public transportation. Additionally, a higher percentage of these participants increases the use of bicycles and the quantity of walking.

To study the impact on private vehicle holdings, participants were asked to specify how many and which cars they had owned before and after subscribing to the carsharing services and if they had sold or acquired cars within this time period. They were asked if they had attributed the sale or acquisition entirely or partially to the services provided by car2go or DriveNow. These answers allow us to determine the absolute number of sold vehicles and the percentage of participants who sold a vehicle.

There is a significant other effect of the availability of carsharing: people forego or postpone the acquisition of a car which they otherwise would have purchased. The number of these suppressed vehicle purchases is not easy to capture. However, in order to estimate the number of suppressed vehicle purchases, we asked the hypothetical question "Would you acquire a car if car2go or DriveNow disappeared from your region?". If the answer is "yes" and the participant would not simply replace a previously sold car, then we count this as a suppressed vehicle purchase.

Other than the response concerning a vehicle sale, which could principally be verified by checking a participant's vehicle ownership documents, the response concerning vehicle purchase suppressions is not verifiable at all. Even though we know that the survey participants are aware of this, we consider the respondents' statements on suppressed vehicle purchases with the same appreciation as we consider the statements on

[1] In this report, we use the terms *sample* and *population* as defined in statistics. A sample is a subset of a population. If the sample is representative of the population, results obtained from the sample can be extrapolated to the population.

sold vehicles even though the latter is more reliable. Based on the participants' answers concerning sold, acquired, and suppressed vehicle purchases we report the percentage of participants in a city who sold a vehicle and the percentage who suppressed a vehicle purchase. Assuming sample representativeness, these percentages can be applied to the overall population of regular car2go and DriveNow users. This gives us an estimate of the total numbers of sold and suppressed vehicle purchases in each city. We report sold and suppressed vehicles in absolute numbers and on a per-carsharing-vehicle basis.

According to our study, between 3.6% and 16.1% of the regular carsharing users in the individual cities have claimed to have sold a vehicle due to the carsharing service. Between 14.3% and 40.7% claimed to have suppressed the purchase of a vehicle. This would amount to 18,948 vehicles sold and 62,900 vehicles suppressed across all cities. Berlin and Hamburg (both car2go) stand out with 4,616 resp. 3,100 vehicles sold and 11,834 resp. 11,020 vehicles suppressed. Per carsharing vehicle, between 2.1 and 5.3 vehicles have been sold in the individual cities and between 7.8 and 18.6 vehicles have been suppressed.

The numbers of vehicles sold and suppressed allow us to estimate the impact of carsharing on VKT. From the responses of the participants, neither the VKT of a sold vehicle nor the VKT of a not purchased vehicle can be directly determined. Therefore, we make assumptions for both cases. If participants sold a vehicle, we assume that they sold the vehicle with the lowest VKT in their ownership and count this VKT as a reduction. For a suppressed vehicle purchase, we base our VKT estimate on the average VKT of all participant-owned vehicles in the corresponding city. Our conservative scenario (lower estimate) assumes that the suppressed vehicle would have been used with 20% of this average VKT, and our optimistic scenario (upper estimate) assumes that the suppressed vehicle would have been used with 80% of this average VKT. As a replacement of their private cars, customers will now use (fewer) carsharing vehicles and other modes. Therefore, the VKT reduced by sold and suppressed vehicles must be netted with the VKT that customers drive with carsharing vehicles. These net VKT reductions are reported on a per-customer and on a per-carsharing vehicle basis.

The impact on CO_2 emissions is a direct consequence of the VKT reductions. VKT reductions are transformed into CO_2 emission reductions by multiplying them with the official emission factors (g CO_2 per km) for the individual countries obtained from the Eurostat database. Since sold vehicles are reported to be approximately 10 years old, we took the average emission factors for newly registered vehicles in 2008/2009. For suppressed vehicles, we used the 2016/2017 factors. According to the International Council on Clean Transportation (ICCT), real use phase emissions are on average 40% higher than the officially reported testing cycle emissions (NEDC). Therefore, we added 40% to the Eurostat emissions in our calculations. To obtain the net reduction of CO_2 emissions induced by the carsharing service, we had to balance the emission reductions caused by reduced and suppressed private vehicles with the emission increase caused by the carsharing fleet. For fleet vehicle emissions, we used model-specific factors of the fleet operating, again with the 40% adjustment as described above. Net CO_2 emission reductions are reported in absolute numbers, and on a per-customer and a per-carsharing-vehicle basis for each individual city.

Finally, it can be said that the availability of car2go and DriveNow has a diverse impact on the travel behavior of carsharing users in the 11 cities that have been studied. The differences could be attributed to the individual characteristics of the public transportation networks in the metropolitan areas of the cities. Accordingly, the shift towards other transportation modes varies between cities. Although only the minority of car2go and DriveNow users report having sold a vehicle or suppressed the purchase of a vehicle, the reductions in private vehicle holdings sum up to a considerable number. Consequently, each fleet vehicle of the carsharing services turns out to remove a multiple of private vehicles. This frees up space in the streets (roadside parking) and parking lots of the cities. We have estimated the VKT reduction based on the information given by the respondents who participated in our survey. Our estimations are based on cautious assumptions. Even under the conservative assumptions, the resulting amount of VKT reductions and corresponding CO_2 emission reductions are remarkable.

2. Introduction

Carsharing is an important segment of the sharing economy. The sharing economy strives for more efficient use of resources with positive economic, social, and environmental impacts. In a new culture of non-ownership, people increasingly prefer temporary access to resources over permanent ownership of resources.

There are different types of carsharing: one type is peer-to-peer carsharing where private owners of cars offer temporary use of their cars to others, typically facilitated by an Internet platform. This report is concerned with the other type of carsharing where a fleet of cars is made available to customers by a service provider. In more detail, our report is on free-floating carsharing, i.e. whenever a customer gets hold of a free car, he or she can pick it up, use it, return it, and pay for it on an hourly or distance basis. Rental and payment are facilitated by a smartphone app.

The main difference to station-based carsharing is that the rental (pick-up) and return are bound to a specific predefined location within the city while free-floating carsharing allows pick-up and return anywhere within a predefined service area (typically the city limits with some extensions). Station-based carsharing is often combined with the requirement for a round-trip (pick-up and return at the same station). Free-floating carsharing allows the one-way use of a car as long as the return point is within the predefined area. It is evident that station-based (round-trip) carsharing is more similar to the use of rental cars, and free-floating (one-way) carsharing more to the use of taxis.

Station-based carsharing has a history of more than 20 years and is often operated locally [1]. Free-floating carsharing has been on the market for almost 10 years and is mainly provided by automotive companies and rental car companies. Carsharing has seen a double-digit growth over the last few years [1]. In Europe, the number of carsharing users has grown from 200,000 in 2006 to 4.4 million in 2016 [2] and is expected to increase to 15.6 million through to 2020 [1].

car2go launched its first free-floating carsharing service in Ulm, Germany, at the end of 2008 [3]. Since then, car2go has been growing rapidly and the number of customers has been increasing substantially. At the beginning of 2018, car2go offered its services in 26 cities worldwide. In January 2018, more than three million customers were registered. From the 26 locations, 14 are in Europe (7 in Germany), 11 in North America, and one in Asia (China). The majority of customers of car2go are in Europe (1.7 million), closely followed by North America (one million). In China, 237,000 customers are currently registered in Chongqing, thus making it the city with the most car2go customers worldwide, followed by Berlin (223,000 customers), and Madrid (196,000). Also among the top ten locations are Hamburg (184,000), Milan (170,000), Rome (166,000), Vancouver (155,000), Vienna (142,000), Calgary (120,000), and the Rhineland (117,000). The number of operating vehicles totals around 14,000. Purely electrical fleets with a total of 1,400 vehicles are available in three locations (Stuttgart, Amsterdam, and Madrid) [4].

In June 2010, DriveNow launched its first free-floating carsharing service in Munich, Germany. [5]. DriveNow has grown rapidly, and the number of customers has increased substantially. At the beginning of 2018, DriveNow offered its services in 13 cities worldwide, and more than one million customers were registered in January 2018. The cities where DriveNow has been operating are all located in Europe. The number of fleet vehicles totals around 6,400. Electric vehicles are available in all cities with a total amount of 970 vehicles. There are more than 750,000 trips per month with DriveNow vehicles [6].

car2go and DriveNow, who merged into SHARE NOW in 2019, commissioned this study to identify the impact of their carsharing services on vehicle holdings, modal shift, vehicle kilometers traveled (VKT), and greenhouse gas emissions. The study design was aligned with a previous North-American study [7] to ensure comparability.

Our study was conducted from March to May 2018 in the six European cities of Berlin, Hamburg, Vienna, Madrid, Rome, and Amsterdam and in June and July 2019 in the five European cities of Brussels, Copenhagen, Helsinki, Lisbon, and London.

The first impact we looked at was the modal shift. As customers get more and more used to the convenience of a carsharing service, they might reduce their previous usage of one mode or they might combine carsharing with public transportation and thus increase their use of intermodal transportation to cover their mobility needs. The North American car2go study [7] shows that car2go not only substitutes but also complements public transportation and other transportation modes like walking or bicycling. However, in most cities, the majority of car2go users did not report a change in public transportation use due to car2go. Considerable differences between the cities indicate that the impact on modal shift is highly dependent on urban city structures as well as availability and coverage of public transportation systems.

The second impact studied concerns vehicle holdings. It is possible that users of car2go – due to the new mobility that carsharing provides – (a) sell their only car or reduce the number of cars they own, (b) avoid or postpone the purchase of a new car, or (c) even buy a new car. The latter case (c) might occur if a person who has not owned a car before became convinced of the convenience of owning a car after using the carsharing service. Candidates for the first two cases (a) and (b) are e.g. persons who might have little desire for car ownership and want to turn the fixed costs associated with the ownership of a car (cost of purchase, maintenance, insurance, tax) into variable costs merely depending on use. Previous studies show that especially young people with a relatively high educational background and people living in small households belong to this customer segment [8].

The North American car2go study [7] revealed that 2% to 5% of the car2go users sold their cars due to the availability of the carsharing service. 7% to 10% of the respondents did not acquire a new car because of car2go. Even if these percentages seem to be small, the impact becomes noticeable if we relate the overall number of private vehicles reduced with the number of car2go vehicles operating in the cities under consideration: 1 to 3 vehicles were sold for each car2go vehicle operating, and 4 to 9 vehicle purchases were avoided for each vehicle operating. This accumulates to an overall number of 28,000 vehicles in the five cities.

The situation appears to be even more pronounced in Europe. This was demonstrated by a study investigating a free-floating carsharing service in London [9] three months after the service had been launched. 6% of the users indicated that they sold or plan to sell their private car in response to the carsharing service. But a notable 30% share of the users indicated that during the three months prior to the survey, they had not purchased a car which they otherwise would have purchased.

The third impact that we investigated addresses the VKT by customers before and after subscription to the carsharing service. Reductions of VKT are calculated based on the numbers of sold vehicles and suppressed vehicle purchases. Since mileages of suppressed vehicles are by definition not assessable, the North American car2go study used a lower and an upper estimate for this unknown number. The lower and upper estimates correspond to 20% and 80% of the average VKT by carsharing users with their private vehicles in the city [7]. With these assumptions, the study estimated a range of 20 million to 37.5 million miles (32 million to 60 million kilometers) saved due to the mobility alternative provided by car2go (upper estimate).

The fourth impact studied is the impact on CO_2 emissions. We calculate emission reductions as a direct consequence of the VKT reductions induced by sold and suppressed vehicles. A carsharing study in the Netherlands identified 30% less car ownership among carsharing users and 15% to 20% fewer kilometers traveled than before and showed a reduction of 240 to 390 kilograms of CO_2 emissions per user per year [10]. This corresponds to a 13% to 18% reduction of CO_2 emissions due to the change in car ownership and car use. The North American car2go study [7] indicated a reduction of GHG emissions in the range of 5,300 to 10,000 tons per year across the five cities or 10 to 14 tons per car2go vehicle. This is based on the optimistic (80%)

mileage[2] assumption for avoided car purchases. For the conservative (20%) mileage assumption, a reduction of 2,200 to 4,200 tons per year across the five cities or 4 to 7 tons per car2go vehicle was reported.

Overall, the results of the previous studies show that considerable positive impacts result from successfully introducing carsharing services. The objective of this study is to examine if these hypotheses are also valid for the car2go and DriveNow services in 11 European cities and to identify differences between the cities considered. car2go provided us the questionnaire used in the North American study. We adjusted the questionnaire to the European situation and applied a similar methodology to obtain comparable results. In European cities, we expect that users will discard even more vehicles than in the United States due to the well-developed public transportation systems. Moreover, at the time when the study was carried out, car2go had been in operation for a longer period of time in European cities than in American cities. DriveNow-specific services have been introduced in the cities considered somewhat later.

3. Survey Design

The survey among car2go customers that were registered in the cities of Berlin, Hamburg, Vienna, Madrid, Rome, and Amsterdam was conducted from March to April 2018. In all cities, car2go has been available for several years. In Hamburg, Amsterdam, and Vienna car2go's service was launched in 2011, in Berlin in 2012, in Rome in 2014, and in Madrid in 2015. In Madrid and Amsterdam, car2go uses solely electric vehicles (Smart Fortwo electric drive). In the other cities, car2go provides only combustion engine vehicles. Apart from their most frequently used carsharing vehicle, the Smart Fortwo, car2go uses other Mercedes-Benz cars (A-Class, CLA, GLA, Smart Forfour). In Berlin, Hamburg, Vienna, and Madrid, the survey was sent to customers that had used car2go at least three times in the previous 91 days. In order to reach a sufficient number of participants, more customers were contacted in Rome and Amsterdam. In Rome, customers with at least one rental in the previous 91 days and in Amsterdam customers with at least one rental in the previous 182 days were contacted. In all cities, we contacted only customers who indicated their willingness to participate in surveys and to receive newsletters from car2go. As an incentive, participants who completed the survey in Madrid, Berlin, Hamburg, Amsterdam, and Vienna were entered into a drawing for Amazon vouchers with a value of 30 Euro. In Rome, participants had a chance to win a voucher for a free 30-minutes use of car2go.

In the case of DriveNow, customers registered in the cities of Brussels, Helsinki, Copenhagen, Lisbon, and London were invited to participate in the survey conducted in June and July 2019. DriveNow has been available for several years in these cities. In London, DriveNow started its service at the end of 2014, in Copenhagen in 2015, in Brussels in 2016, and in Helsinki and Lisbon in 2017. In all cities studied, electric vehicles (BMW i3) are part of the vehicle fleet. In Copenhagen, the BMW i3 represents the major share of vehicles. Besides the BMW i3, other models are used (BMW 1 Series, Mini 5-Doors, Mini 3-Doors, Mini Clubman, Mini Cabrio, BMW 2 Series Active Tourer, BMW X1, and BMW 2 Series Cabrio). In all the DriveNow cities selected, the survey was sent out to customers who had used DriveNow at least once during the past 91 days. The link to the survey was distributed to customers who agreed to receive Newsletters from DriveNow. As an incentive, the customers participating in the survey had the possibility to win one out of 20 driving credit prizes per market area which were selected during random drawings.

The questionnaire was developed in German and was translated into the corresponding national languages. We asked questions about changes in vehicle holdings, changes in travel behavior for different modes of transport, and basic demographics.

[2] We use the word mileage for a driven distance, even if we measure it in kilometers.

Table 1: Numbers of survey participants

	City	Questionnaires completed	Reduced sample (plausibility check)	Final sample (residential check) (n)	Number of regular users (N)
car2go	**Amsterdam**	341	311	258	16,486
	Berlin	1,339	1,280	1,127	53,714
	Hamburg	1,193	1,151	1,001	42,995
	Madrid	2,065	1,985	1,691	31,550
	Rome	1,505	1,444	1,224	35,912
	Vienna	867	800	699	26,286
	Total	**7,310**	**6,971**	**6,000**	**209,943**
DriveNow	**Brussels**	1,345	1,090	922	10,665
	Copenhagen	1,172	1,025	893	30,136
	Helsinki	1,008	912	738	5,696
	Lisbon	2,103	1,680	1,369	9,557
	London	995	773	674	12,622
	Total	**6,623**	**5,480**	**4,596**	**68,676**

Table 1 shows the numbers of survey participants in the different cities where car2go and DriveNow are operating. The numbers vary considerably. Only 341 carsharing users participated in Amsterdam, while 2,065 users participated in Madrid. These differences cannot only be explained by differences in the size of the customer base but also by other circumstances. In Amsterdam, for example, a high percentage of customers had not agreed to receive newsletters, which explains the comparably low number of completed questionnaires.

For the purpose of *data quality*, we applied different plausibility checks to the respondents' answers in order to derive a *reduced sample*. Records of answers were sorted out if survey participants completed the questionnaire in less than five minutes. At this time, it is hardly possible having read through and answered every survey question carefully. The average time that car2go users needed to complete the questionnaires was about 11 minutes. For some questions, we defined minimum response times. If the actual response time of participants was shorter than this minimum time, response records were also excluded from the sample. We also excluded response records with incorrect answers to control questions and records with implausible responses. For example, response records were excluded if participants indicated that they use car2go and DriveNow on average more than four times per week but stated that they would drive only very few kilometers each month with car2go / DriveNow. Overall, we excluded between two and nine percent of the completed questionnaires to obtain the reduced samples for the individual cities.

The study focuses on carsharing users who live in metropolitan areas. If survey participants stated not to live in the metropolitan areas of the cities considered, their response records were excluded from the sample. Also excluded were response records of participants who relocated (home or workplace) recently and who stated that the relocation had a bigger impact on their change in mobility behavior than the existence of car2go or DriveNow. This additional filtering leads to our *final samples*, which we henceforth use in our study. All evaluations are made city by city so that we can refer to samples of between 258 and 1,691 participants in the car2go case and samples between 674 and 1,369 participants in the DriveNow case.

The survey contained questions on the personal background of the participants, e.g. gender, age, income, level of education, and individual travel behavior. The responses allow us to statistically characterize our samples which are supposed to represent the communities of regular car2go / DriveNow users in each individual city. The majority of the participants is male (car2go: between 61% in Madrid and 76% in Vienna; DriveNow:

between 78% in Copenhagen and London and 85% in Lisbon), young, and has a high level of education. Regarding these sociodemographic characteristics, the samples of all cities are very similar. However, for behavioral characteristics, considerable differences are observed. For example in Hamburg, 46% of the survey participants are also customers of bikesharing systems, in Helsinki 52%. In Amsterdam, only 9% indicate to use a bikesharing service, in Copenhagen only about 11%. Percentages for the other cities vary in between. Many of the survey participants not only use car2go or DriveNow, but also other carsharing services. In Madrid, we observe the highest rate of 83%, in Helsinki the lowest rate of 24%. Differences can also be observed in the current average vehicle holdings per household. In the Southern European cities (Rome, Madrid, Lisbon), survey participants indicate a higher motorization rate. In all cities, the average vehicle availability of the households increased by becoming a member of car2go or DriveNow.

We assume that the samples are representative of the populations of regular car2go and DriveNow users in the individual cities. In order to check whether this assumption is valid, we compare the samples with the customer populations concerning age, gender, carsharing service use frequencies as well as average kilometers traveled with car2go and DriveNow vehicles per month. car2go and DriveNow provided us with the corresponding data for the customer populations of each city in April 2018 and in August 2019. The distribution of gender is very similar between our samples and the customer populations. To analyze age distributions, we categorized the different populations into age groups[3]. Small deviations between our samples and the customer populations can be observed. The age group of 30-39 is slightly underrepresented in all of car2go's city-specific samples. The other age groups are slightly overrepresented. In the DriveNow samples, respondents aged 40 years and older are overrepresented. In Copenhagen in particular, respondents under the age of 30 are underrepresented with 27.5% in the sample compared to 44.9% in the population. Regarding use frequencies and monthly kilometers traveled, the samples used do not differ substantially from those of the populations represented in Amsterdam, Berlin, Hamburg, and Vienna. In Rome and Madrid, users extensively using car2go are slightly overrepresented in our samples. Distributions of monthly kilometers traveled in the DriveNow-specific samples show that persons traveling more than 25 kilometers are underrepresented.

Despite some minor exceptions as indicated, we assume that the final samples are representative of the populations of regular car2go and DriveNow users in the individual cities. Inferential statistics permit to extrapolate the results obtained from the survey participants to the corresponding overall populations.

4. Methods of Data Collection and Analysis

In this section, we briefly describe how we derived the results on the impacts of car2go and DriveNow on modal shift, vehicle ownership, VKT, and CO_2 emissions from the answers collected from car2go and DriveNow customers in the questionnaires.

To study the *impact of car2go and DriveNow on modal shift*, we asked questions concerning the use of other transportation modes like bus, rail, taxi, etc. Being asked how car2go / DriveNow affected the use of other transportation modes, participants could respond on a five-point ordinal scale with response options "much more than before", "more than before", "about the same as before (car2go / DriveNow have no influence)", "less than before", and "much less than before". They could also state that their use had changed, but not due to car2go / DriveNow, or that they had not used a particular transportation mode at all, neither before nor after becoming a customer of car2go / DriveNow. Survey participants who answered the latter two questions positively were excluded from further analyses on modal shift.

[3] <20 years, 20-29 years, 30-39 years, 40-49 years, 50-59 years, 60-69 years, >69 years

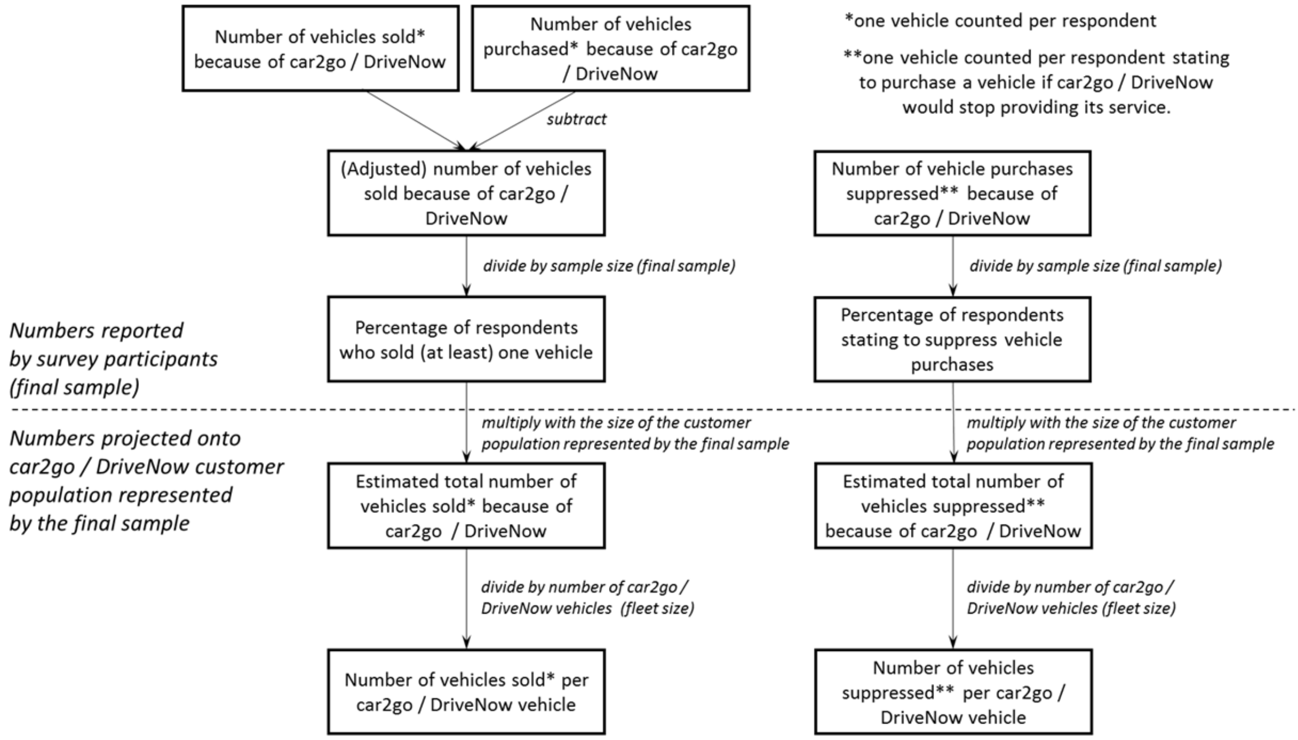

Figure 1: Calculation of the impact on vehicle holdings by car2go / DriveNow

To study the *impact on vehicle holdings*, users of car2go / DriveNow were asked to provide a list of their currently owned vehicles indicating the brand, model, year of manufacture, drivetrain, and annual kilometers traveled for each individual vehicle. The same information was requested for vehicles they had possessed before joining car2go / DriveNow. If there had been a change (a sale[4] or a purchase), participants were asked to indicate if car2go / DriveNow had been the reason for this change. Only in this case, we considered this change in our calculation. If the participants reported more than one vehicle sale or purchase, we conservatively attributed only one to car2go / DriveNow. Since the number of vehicle purchases due to car2go / DriveNow is low, we do not report this number furthermore. Instead, we simply adjust the number of sold vehicles by subtracting the number of purchased vehicles (cf. Figure 1).

The second kind of reduction in cars is induced by suppressed vehicle purchases. Suppressed purchases reduce the hypothetical number of vehicles that would be in the city if car2go / DriveNow were not available. The question if participants suppressed vehicle sales was not asked directly. Instead, participants were asked whether they would acquire a vehicle if car2go / DriveNow disappeared. If the survey participants stated to definitely or probably buy a car and did not indicate having sold a car due to car2go / DriveNow, we counted one suppressed vehicle purchase (cf. Figure 1).

From these basic numbers, we calculate the percentage of participants who sold or suppressed the acquisition of a vehicle and apply this percentage to the car2go / DriveNow populations represented by the final samples in the cities analyzed. This allows us to get an estimate of the total number of sold and suppressed vehicles due to the availability of car2go / DriveNow. Dividing these total numbers by the number of car2go / DriveNow vehicles (sizes of the fleets operating) provides us with an estimate of the numbers of sold and suppressed vehicles per car2go / DriveNow vehicle (cf. Figure 1).

[4] For reasons of simplicity, we call all reductions sales, even if a vehicle could have been scrapped or donated.

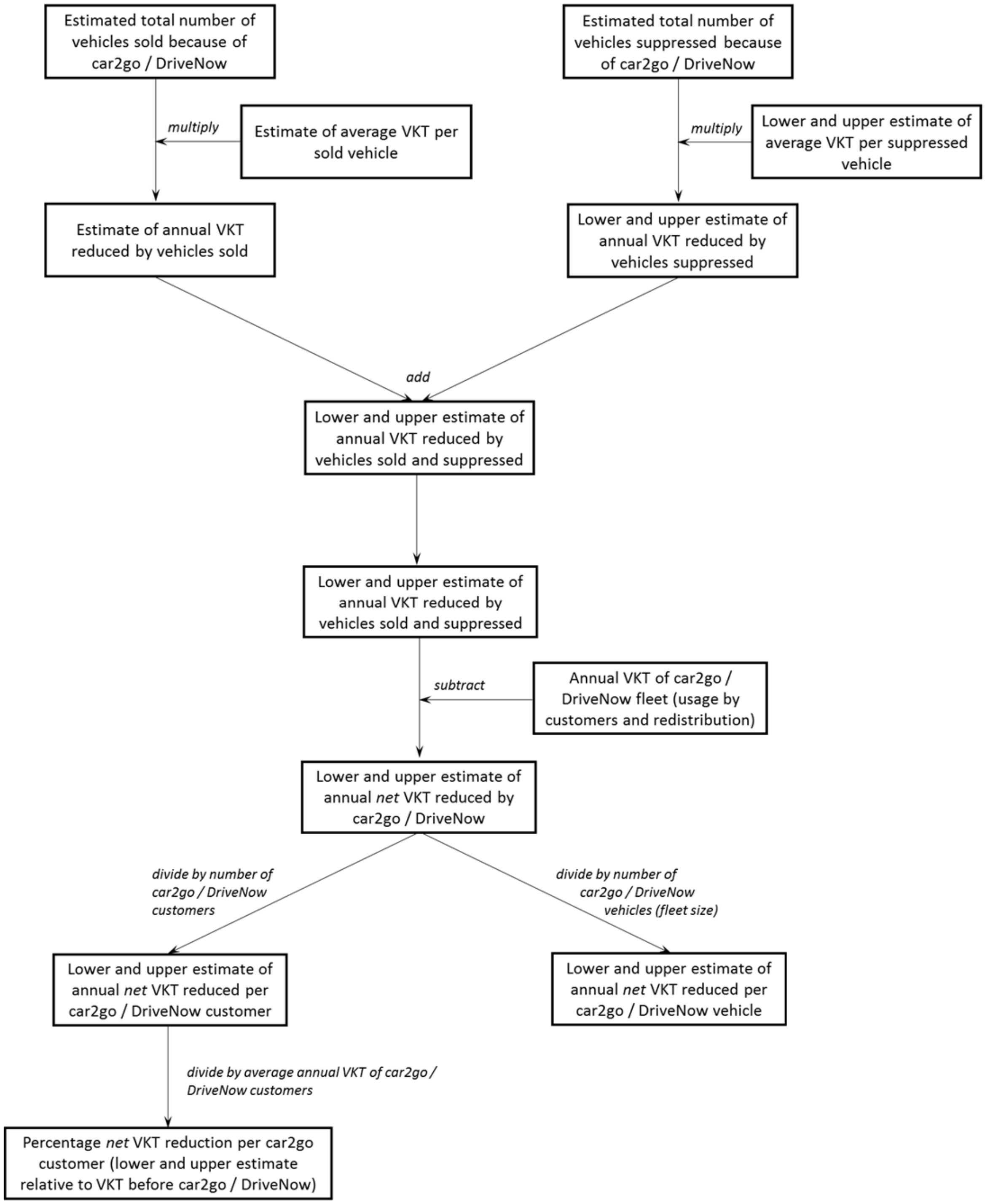

Figure 2: Calculation of the resulting change in VKT

With the determined impact on vehicle holdings, we further analyze the *impact of car2go / DriveNow on VKT*. Participants provided an estimate of the annual VKT of each vehicle they possess.

To determine the impact of a vehicle sale on VKT reduction, we record either (a) the reported mileage of the single-vehicle that the participant owned and sold or (b) the lowest mileage of all listed vehicles if the participant sold one of several previously owned vehicles. The latter is a conservative assumption since we do not know what the exact use of the sold car was before.

The VKT reduction due to suppressed vehicles is speculative and can only be estimated, as we do not know how the participants would have used the newly acquired vehicles if carsharing had not been available (counterfactual question). Like in [7], we make a lower and an upper estimate of this unknown VKT. As the lower estimate, we take 20% of the average VKT of the vehicles owned by respondents' households in each individual city today (conservative scenario). The upper estimate is set to 80% of the average VKT of the vehicles available in the respondents' households of each city (optimistic scenario).

From the annual VKT reduced by vehicles sold and vehicles suppressed, we subtracted the annual VKT of the car2go / DriveNow fleet – including kilometers traveled by customers as well as kilometers driven by service personnel for vehicle redistribution. This difference gives us the annual *net* VKT reduced by car2go (lower and upper estimates), which is additionally reported per car2go / DriveNow customer and per car2go / DriveNow vehicle (cf. Figure 2). Our basis for calculating the car2go / DriveNow fleet VKT is the year 2017 in the case of car2go and the year 2018 in the case of DriveNow.

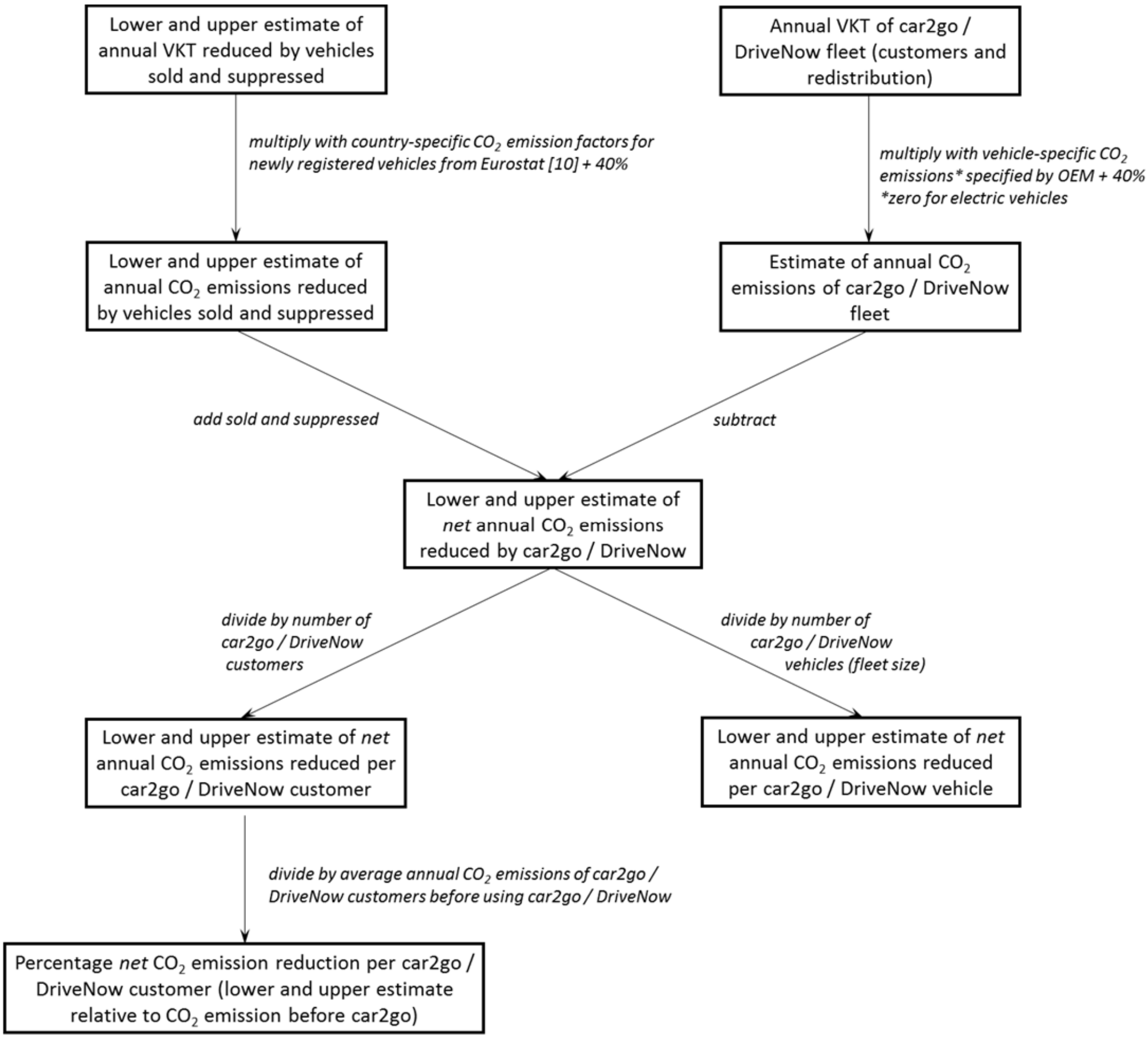

Figure 3: Calculation of the resulting change in CO_2 emissions

Since the participants have reported their individual VKT before using car2go in the survey, we calculate the average VKT of all participants and express the annual net VKT reduced per car2go / DriveNow customer as a percentage relative to the VKT before car2go / DriveNow (lower and upper estimates).

Based on the annual VKT reductions of sold and suppressed vehicles and considering the annual VKT of the car2go / DriveNow fleet, we estimate the *impact of car2go / DriveNow on CO_2 emissions* (cf. Figure 3). This is done by multiplying the annual VKT with an emission factor (in g CO_2 per km) that we obtained from official sources, i.e. the Eurostat database [11]. According to the answers provided by the survey participants, their vehicles are on average around ten years old. Therefore, for vehicles sold, we use country-specific CO_2 emissions of vehicles newly registered in 2008 in the car2go case and 2009 in the DriveNow case. For vehicles suppressed, we use the 2016 country-specific emissions from Eurostat in the case of car2go, and the 2017 country-specific emissions from Eurostat in the case of DriveNow. The reported values are emissions in grams per vehicle and kilometer traveled. According to the International Council on Clean Transportation (ICCT), real use phase emissions are on average 40% higher than those stated in official testing cycles [12]. Therefore, we add 40% to the reported CO_2 emissions in our calculations.

With these calculations, we obtain a lower and an upper estimate of the annual CO_2 emission reductions by sold and suppressed vehicles. In order to obtain the *net* impact of car2go / DriveNow on CO_2 emissions, we subtract the emissions caused by the car2go / DriveNow fleet. For fleet emissions, we use model- and VKT-specific CO_2 emissions provided by car2go and DriveNow and add them up considering the mix of vehicles in the fleet. As before, we added 40% to the CO_2 emissions reported. For electric vehicles in the fleet, we assume zero CO_2 emissions according to the New European Driving Cycle (NEDC) and the recently established Worldwide Harmonized Light Vehicles Test Procedure (WLTP).

We report the *net* reduction of CO_2 emissions first absolutely and then per car2go / DriveNow customer and per car2go / DriveNow vehicle. Since we know the average VKT of all participants before using car2go / DriveNow (see above), we determine their average CO_2 emissions before car2go / DriveNow based on the country-specific CO_2 emission factors of the year 2008 in the car2go case and 2009 in the DriveNow case [11]. This allows us to express the annual net CO_2 emissions reduced per car2go / DriveNow customer as a percentage of the CO_2 emissions before car2go / DriveNow for a lower and upper estimate (cf. VKT calculations).

5. Impacts on Modal Shift

In this section, we discuss the impacts of carsharing on modal shift. Table 2 shows how the availability of car2go / DriveNow impacted the participants' use of urban rail, intercity rail, bus, and taxi. There is no uniform trend: we find participants who increase the use of other traveling modes, participants who decrease the use of other traveling modes, and still others who report no change.

Concerning the use of *urban rail*, few participants state that they increased use due to car2go / DriveNow. Many use car2go / DriveNow as a substitute for urban rail and decreased urban-rail use. In all cities, a similar trend is observable. However, the magnitude is different. In Madrid, one out of two participants stated having reduced urban rail use, while in Helsinki, this is only the case for one out of eight participants. In Brussels, the share of respondents indicating an increase in the use of urban rail is about the same as the share of respondents indicating a decrease.

Similar effects can be observed concerning the use of *buses*. While some users indicate having increased traveling by bus, more of the users state that their bus use has decreased. In Vienna, Brussels, and Helsinki, reductions in bus use are comparably low. On the other hand, reductions in bus use due to car2go in Amsterdam, Madrid, and Rome, and reductions due to DriveNow in Copenhagen are comparably high. Especially in the two cities of Amsterdam and Madrid where car2go causes a stronger decline in the use of public transport, car2go operates with an electric car fleet in a rather small operating area [3]. This relation can also be observed in Copenhagen where the share of electric vehicles as part of DriveNow's fleet operating is comparably large.

Table 2: Modal shift due to car2go / DriveNow: public transport and taxis

		Urban rail				Bus			
		n_U	Increased use	No change	Decreased use	n_B	Increased use	No change	Decreased use
car2go	**Amsterdam**	233	4.3%	49.8%	45.9%	199	4.5%	46.2%	49.2%
	Berlin	991	9.7%	54.2%	36.1%	920	7.1%	58.6%	34.3%
	Hamburg	897	9.8%	58.4%	31.8%	851	7.2%	55.8%	37.0%
	Madrid	1,321	5.8%	44.9%	49.4%	1,459	5.2%	41.5%	53.3%
	Rome	977	11.4%	52.2%	36.4%	968	9.5%	42.1%	48.3%
	Vienna	611	11.5%	62.8%	25.7%	534	8.1%	70.6%	21.3%
DriveNow	**Brussels**	763	18.0%	62.8%	19.3%	750	12.9%	62.9%	24.1%
	Copenhagen	822	6.3%	51.6%	42.1%	769	6.0%	46.0%	48.0%
	Helsinki	652	6.1%	81.0%	12.9%	619	4.0%	77.2%	18.7%
	Lisbon	1,083	7.8%	53.5%	38.7%	869	5.1%	53.2%	41.8%
	London	625	7.0%	68.2%	24.8%	616	4.4%	64.1%	31.5%
		Intercity rail				**Taxi**			
		n_I	**Increased use**	**No change**	**Decreased use**	n_T	**Increased use**	**No change**	**Decreased use**
car2go	**Amsterdam**	199	7.1%	86.9%	6.0%	179	7.3%	27.4%	65.3%
	Berlin	805	9.9%	85.5%	4.6%	840	3.8%	24.8%	71.4%
	Hamburg	743	10.4%	86.4%	3.2%	761	3.2%	27.0%	69.8%
	Madrid	1,217	4.4%	91.9%	3.7%	1,501	2.5%	12.0%	85.5%
	Rome	1,032	8.9%	84.5%	6.6%	948	2.8%	19.4 &	77.8%
	Vienna	506	8.3%	84.6%	7.1%	569	3.0%	18.5%	78.5%
DriveNow	**Brussels**	663	10.0%	78.7%	11.3%	669	6.0%	26.2%	67.9%
	Copenhagen	725	3.4%	76.6%	20.0%	734	2.6%	24.5%	72.9%
	Helsinki	586	2.6%	92.2%	5.3%	663	1.4%	31.4%	67.3%
	Lisbon	810	6.8%	67.5%	25.7%	957	2.1%	23.9%	74.0%
	London	581	5.9%	80.2%	13.9%	567	2.8%	34.0%	63.1%

The changes observed in urban rail and bus use might be linked to some of the car2go and DriveNow customers' decisions to sell vehicles. A comparably high share of customers who sold a car due to car2go or DriveNow uses public transport more often than before using car2go / DriveNow. However, for many customers, it seems that car2go and DriveNow are comfortable alternatives to public transport.

In the case of *intercity rail use*, major shares of respondents state not having changed their behavior. However, across the car2go samples, more of the participants reporting a change rather indicated an increase in intercity rail use than a decrease. A reason for this could be that car2go offers a better connection to the station. For all cities where car2go is operating, more than 7% of participants indicated to have increased use of intercity rail whereas in Madrid, this is only true for 4% of the participants. On the other hand, more of the respondents of the DriveNow population indicating a change show a decrease rather than an increase in intercity rail use.

car2go / DriveNow strongly substitutes the use of *taxis*. A consistent result can be observed in all cities. Especially in Madrid, many people have reportedly replaced their use of taxis by car2go.

Table 3 provides results for the change in the use of carpooling, bicycle use, walking, and overall trips. Concerning *carpooling*, car2go's / DriveNow's impacts on use patterns vary notably between the cities analyzed. For Berlin, Hamburg, Madrid, Vienna, Brussels, and Copenhagen, we can support the statements found in the literature that carsharing encourages carpooling and that it increases the average occupation in vehicles [13]. In Amsterdam, Rome, Helsinki, Lisbon, and London, about the same number of survey participants reported an increased and decreased use of carpooling activities due to the services provided by car2go and DriveNow. However, most of the survey participants indicated that they neither carpool today, nor did before they started using car2go / DriveNow. Therefore, corresponding behavioral changes are only true for parts of the customer population.

Concerning *bicycle* use, we explicitly included electric bicycle in the survey question. The majority of users has not changed behavior concerning bicycle use. Parts of the populations indicate behavioral change in both directions. Throughout all cities where car2go is operating, a slight decline in bicycle use can be observed. In Berlin and Vienna, the difference between increased use and decreased use is comparably small. However, in Amsterdam and Madrid, it is clearly larger. On the other hand, the changes observed for the DriveNow populations are rather balanced. In Brussels and London, slightly more of the respondents indicate an increase in bicycle use. In Copenhagen, Helsinki, and Lisbon, the share of respondents indicating an increase is about as high as the share of respondents indicating a decrease in bicycle use.

Most users do not report a change in *walking* habits. Three groups of cities can be distinguished. In Amsterdam and Madrid, more of the survey participants report that they walk less (in Madrid almost one of four survey participants). In Berlin, Hamburg, Rome, Vienna, Copenhagen, Lisbon, and London, about the same share of survey participants report having increased and decreased their walking frequency. In Brussels and Helsinki, more of the respondents indicate having increased their walking activities.

Overall trips are diversely impacted by car2go / DriveNow in the different cities. Survey participants of all cities stated that they make more trips in total. With about one fourth, the share of respondents indicating a decrease in trips is particularly high in Brussels. In Amsterdam, Berlin, Hamburg, Vienna, Copenhagen, and Helsinki, only a little more than 10% of the survey participants state that their number of trips decreased after becoming customers of car2go / DriveNow. In Madrid, Rome, Lisbon, and London, only a few of the survey participants reported making fewer trips. The number of respondents indicating an increase in trips is comparably low in Rome. Here, many survey participants have not changed their behavior. The share of respondents indicating an increase in trips is particularly high in Amsterdam, Berlin, Hamburg, and Vienna. Here, around 40% report to have made more trips overall.

The results of the modal shift study indicate that some participants complement the use of carsharing with other transportation modes, while other participants substitute other transportation modes by carsharing. This behavioral change is certainly influenced by several factors, such as the individual mobility demand of the participant within the geography, the structure of the public transportation network, and the question if the participant has reduced private vehicles.

While the first two factors are difficult to grasp, the latter is known from the participant's survey response. To assess the impact of private vehicle reduction on modal shift, we repeated our evaluation for the subgroup of users who have sold a car. The results are remarkable.

For example in Berlin, the share of participants who increased the use of urban rail grows from 9.7% to 31.8%, if we consider the subgroup of users who have sold a car. For intercity rail, the percentage increases from 9.9% to 32%, for bus from 7.1% to 21.3%, for bicycle from 13.5% to 39.8%, for walking from 16.1% to 28.8%.

Even if the percentage of participants who sold a car is still moderate (3.6% to 16.1% for the different cities, cf. Table 4), the removal leads to considerable reductions of private VKT. The relatively high modal shift percentages of participants who sold a car indicate where these saved kilometers might have gone: to public transportation in combination with walking and biking.

Please consider that the questions asked concerning impacts on modal shift are questions with the possibility to answer on ordinal scales. car2go and DriveNow users that drove somewhat more are equally weighted as car2go / DriveNow users that decreased overall driving significantly. We will see in the section on impacts on VKT that the mileage driven with car2go and DriveNow vehicles is relatively small, while the mileage saved due to vehicle selling and not purchasing cars is significantly larger.

Table 3: Modal shift due to car2go and DriveNow: carpooling, bicycle use, walking, and overall trips

		Use of carpooling				Bicycle use			
		n_C	Increased use	No change	Decreased use	n_B	Increased use	No change	Decreased use
car2go	Amsterdam	43	16.3%	69.7%	14.0%	215	8.4%	68.8%	22.8%
	Berlin	299	23.7%	65.6%	10.7%	807	13.5%	70.4%	16.1%
	Hamburg	254	19.7%	72.4%	7.9%	761	9.9%	73.7%	16.4%
	Madrid	320	23.8%	65.0%	11.2%	523	8.2%	72.1%	19.7%
	Rome	207	16.4%	64.3%	19.3%	505	10.9%	74.1%	15.0%
	Vienna	174	24.7%	67.8%	7.5%	407	10.6%	76.4%	13.0%
DriveNow	Brussels	356	18.8%	76.1%	5.1%	570	21.2%	71.6%	7.2%
	Copenhagen	727	15.5%	78.5%	5.9%	767	12.0%	75.9%	12.1%
	Helsinki	238	9.7%	81.9%	8.4%	549	8.4%	83.6%	8.0%
	Lisbon	333	15.6%	66.4%	18.0%	799	10.6%	78.0%	11.4%
	London	214	21.5%	59.3%	19.2%	413	13.6%	76.0%	10.4%
		Walking				**Trips overall**			
		n_W	Increased	No change	Decreased	n_T	Increased	No change	Decreased
car2go	Amsterdam	243	8.2%	74.9%	16.9%	237	43.5%	46.4%	10.1%
	Berlin	1,069	16.1%	67.8%	16.1%	1,071	44.1%	44.6%	11.3%
	Hamburg	954	15.6%	68.4%	16.0%	955	40.5%	48.3%	11.2%
	Madrid	1,649	9.6%	66.7%	23.7%	1,647	33.5%	65.1%	1.4%
	Rome	1,195	19.8%	61.5%	18.7%	1,185	14.7%	81.7%	3.6%
	Vienna	664	14.6%	68.5%	16.9%	662	39.3%	47.1%	13.6%
DriveNow	Brussels	894	25.8%	66.1%	8.1%	872	24.1%	51.5%	24.4%
	Copenhagen	853	11.6%	80.3%	8.1%	862	21.8%	65.0%	13.2%
	Helsinki	694	12.1%	83.1%	4.8%	689	32.9%	55.0%	12.0%
	Lisbon	1,311	17.5%	67.0%	15.6%	1,336	26.6%	69.7%	3.7%
	London	653	16.1%	71.5%	12.4%	662	32.9%	61.6%	5.4%

6. Impacts on Vehicle Holdings

The survey responses for vehicle holdings indicate that regular users of car2go / DriveNow have sold private vehicles or suppressed the acquisition of private vehicles throughout all cities (Table 4). The percentage of participants who acquired a new car and attributed this to the carsharing service is negligible. Instead of reporting these small numbers, we subtract them from the sales and adjust the percentage of participants who sold a vehicle accordingly. In seven out of the eleven cities, this percentage lies between 7% and 10%. Exceptions are Madrid, Copenhagen, and Lisbon, where only 3.6%, 4.9%, and 5.3% of the participants indicate that they have sold a vehicle. In Brussels, the percentage is highest (16.1%).

Table 4: Summary of car2go's and DriveNow's impacts on vehicle holdings

	City	Percentage of participants who sold a vehicle	Vehicles sold per car2go / DriveNow vehicle[1]	Percentage of participants who suppressed a vehicle	Vehicles suppressed per car2go / DriveNow vehicle[2]
car2go	**Amsterdam** (n = 258, N = 16,486)	8.1%	3.4	24.8%	10.3
	Berlin (n = 1,127, N = 53,714)	10.0%	4.6	24.8%	11.3
	Hamburg (n = 1,001, N = 42,995)	8.7%	4.0	29.4%	13.4
	Madrid (n = 1,691, N = 31,550)	3.6%	2.1	14.3%	8.4
	Rome (n = 1,224, N = 35,912)	7.8%	3.8	29.4%	14.4
	Vienna (n = 699, N = 26,286)	10.0%	3.3	23.2%	7.7
DriveNow	**Brussels** (n = 922, N = 10,665)	16.1%	5.3	26.1%	8.6
	Copenhagen (n = 893, N = 30,136)	4.9%	3.2	28.6%	18.6
	Helsinki (n = 738, N = 5,696)	8.7%	2.9	27.2%	9.0
	Lisbon (n = 1,369, N = 9,557)	5.3%	2.1	26.1%	10.4
	London (n = 674, N = 12,622)	7.4%	2.4	40.7%	13.3

[1] indicated car selling [2] indicated hypothetical car purchase

In the cities studied, the customers sold on average between 2.1 and 4.6 vehicles per car2go vehicle and between 2.1 and 5.3 vehicles per DriveNow vehicle. Madrid and Lisbon have the lowest rate, Berlin and Brussels the highest. For the vehicles sold per car2go / DriveNow vehicle, we do not observe the same order in size as for the share of survey participants having sold vehicles. In Madrid, Copenhagen, and Lisbon, the rate is clearly lower than in the other cities. The estimated number of sold vehicles per car2go / DriveNow vehicle is impacted by the size of the customer population and the size of the vehicle fleet. A high share of sold vehicles (i.e., the share of respondents who sold at least one vehicle) does not automatically result in a high selling rate (i.e., the number of vehicles sold per car2go / DriveNow vehicle). This can be illustrated by the example of

Vienna. Although Vienna is the city with a comparably high percentage of customers having sold a vehicle (10.0%), the rate of 3.3 sold vehicles per car2go / DriveNow vehicle is comparably low. Vienna has a comparably large fleet size for its customer population. This means that one carsharing vehicle is driven on average by fewer users than in most other cities. This results in a comparably small number of sold vehicles per car2go vehicle despite a high percentage of customers having sold a vehicle.

The number of suppressed vehicles per car2go / DriveNow vehicle is much higher than the number of sold vehicles per car2go / DriveNow vehicle throughout all cities. Rome, Hamburg, and Copenhagen have the highest rates with 14.4, 13.4, and 18.6 vehicles suppressed per car2go / DriveNow vehicle. In Vienna, Madrid, and Brussels, this rate is on a comparably low level with 7.7, 8.4, and 8.6 suppressed vehicles per car2go / DriveNow vehicle.

In the survey, we asked the participants for the reason why they sold a car. They had multiple-choice options. The reason for most participants was to save costs by getting rid of a car. In Berlin, Vienna, Hamburg, and Helsinki, many participants stated that good public transportation infrastructure was important for their decision. In these cities, a comparably high share of sold vehicles can be observed. Other reasons provided by car2go / DriveNow users show that carsharing sufficiently fulfills the users' needs, addresses the scarcity of parking space within these cities, and contributes to environmental protection.

Table 5: Estimated total vehicles sold and suppressed due to car2go / DriveNow

		Estimation of total vehicles sold	Estimation of total vehicles suppressed	Estimation of total vehicles sold and suppressed due to car2go / DriveNow
car2go	**Amsterdam**	1,113	3,393	4,506
	Berlin	4,742	11,750	16,492
	Hamburg	3,250	10,982	14,232
	Madrid	954	3,846	4,800
	Rome	2,388	8,953	11,341
	Vienna	2,300	5,323	7,623
DriveNow	**Brussels**	1,512	2,462	3,974
	Copenhagen	1,367	7,922	9,289
	Helsinki	424	1,331	1,755
	Lisbon	425	2,079	2,504
	London	868	4,757	5,625

In Table 5, we give estimates for the total numbers of vehicles sold and suppressed. The numbers are the result of applying the percentages of participants having sold and suppressed a vehicle to the overall populations of regular carsharing users. The total estimated numbers of sold vehicles differ considerably between the cities. Most vehicles were sold in Berlin, least in Helsinki and Lisbon. Berlin not only has the highest percentage of customers having sold a vehicle, but also the biggest customer base. It is followed by Hamburg, Rome, and Vienna. Amsterdam and Madrid show the lowest numbers of vehicles sold and vehicles suppressed among the cities where car2go is operating. These are the cities with the smallest car2go fleets and comparably small operating areas. They are the only cities in our study where car2go deployed only electric vehicles. Among the cities where DriveNow is operating, Brussels shows the highest estimated number of total vehicles sold. However, the estimated number of vehicles suppressed is comparably small in Brussels. The number of suppressed vehicles due to DriveNow is comparably high in Copenhagen. Helsinki shows the smallest estimated numbers of vehicles sold and suppressed amongst all cities considered.

7. Impacts on VKT

Estimating car2go's and DriveNow's impacts on VKT suggests that the presence of the carsharing services results in less VKT. Table 6 shows the average mileage of vehicles that are used for further estimations. In the first line, the average mileage per sold vehicle is shown. Because of the uncertainty concerning suppressed-vehicle VKT, we use two different estimates as explained in the methodological overview.

Table 6: Mileages resulting from VKT analysis [in km/yr]

	car2go						DriveNow				
	Amsterdam	Berlin	Hamburg	Madrid	Rome	Vienna	Brussels	Copenhagen	Helsinki	Lisbon	London
Average mileage of sold vehicles	14,762	14,036	12,320	15,083	11,203	11,826	12,812	11,143	13,660	12,618	12,660
Average mileage of suppressed vehicles (conservative scenario)	3,528	2,693	2,724	2,736	2,563	2,783	2,885	2,946	2,906	2,825	2,253
Average mileage of suppressed vehicles (optimistic scenario)	14,110	10,770	10,896	10,945	10,250	11,130	11,539	11,785	11,624	11,301	9,012
VKT on car2go / DriveNow vehicles per customer of population per year	243	365	334	211	194	376	176	132	181	89	134

The average mileage of sold vehicles ranges from 11,143 kilometers per year in Copenhagen to 15,083 kilometers per year in Madrid and 14,036 kilometers for Berlin (Table 6). Recall, we assumed that the sold vehicle is the one with the lowest VKT in the household. Often, this was a second or third vehicle that was used for comparably short and few trips. In Berlin, 75% of the customers who sold a vehicle sold their only vehicle. Therefore, the average mileage reduced is relatively high compared to other cities. In London, the mileages of sold and suppressed vehicles are on a similar level. As in Berlin, a high share of the DriveNow users in London sold their only vehicle.

Average mileages on car2go fleet vehicles range from 194 kilometers per customer per year to 376 kilometers per customer per year. Average mileages in Rome and Amsterdam are lower than in Berlin, Hamburg, and Vienna. This could be explained by different conditions when sending the survey to the customers. In addition to frequent car2go users, less frequent users were also asked to answer the survey questionnaires in Rome and Amsterdam. It can be assumed that these less frequent users also have lower mileages on car2go vehicles. However, in Madrid, the number is also low. This might again be explained by the comparably short operating time of car2go in Madrid. Average mileages on DriveNow vehicles range between 89 and 181 kilometers per customer per year. Differences in car2go might be partly explained by the fact that as in Rome and Amsterdam, less frequent users are considered in the sample.

Table 7 shows the estimates (rounded to the thousand, where appropriate) for the VKT that we derived for vehicles sold and vehicles suppressed – the latter in two scenarios that correspond to the conservative and optimistic estimate as described in Section 4. This allows us to calculate the total VKT reduction that is attributable to car2go / DriveNow in the cities considered by netting the VKT reduced by sold and suppressed vehicles with the VKT driven with car2go / DriveNow fleet vehicles. Across the six car2go (five DriveNow) cities, VKT reductions range from 24 (10) million kilometers per year to 98 (39) million kilometers per year in the conservative scenario, and from 56 (21) million kilometers per year to 193 (109) million kilometers per year in the optimistic scenario. Key factors for the difference between the cities are the impact car2go / DriveNow had on personal vehicle holdings, the average mileage saved due to vehicles sold, the average mileage in the specific cities, the amount of driving on car2go / DriveNow vehicles, and the customer population. The results show that car2go and DriveNow reduced VKT per customer by more than a thousand for the two scenarios in most of the cities. Only in Madrid, the reduced VKT per customer is lower than 1,000 km in the conservative scenario. The change in VKT per customer varies slightly between the other cities. For Amsterdam, Berlin, Hamburg, and Rome, the reduction in the optimistic scenario is between around 3,500 and 3,900 kilometers per customer and year. With around 3,000 km per customer and year in Vienna, this number is somewhat lower. In Madrid, reduced VKT is clearly lower (around 1,400 km per customer and year). The key factor in Madrid is the low number of sold vehicles. In Amsterdam, the number of sold vehicles is also at a low level. VKT reductions per customer in the cities where DriveNow is operating also vary considerably. In the conservative scenario, the range of VKT reduction in the case of car2go is between 500 and 1,800 kilometers per customer per year, in the case of DriveNow between 1,100 and 2,600 kilometers per customer per year. In the optimistic scenario, VKT reductions per customer ranging between 3,000 (Lisbon) and 6,700 (London) kilometers per year can be observed. On a per-vehicle basis, the average estimated VKT reduction range from 55,000 to 95,000 kilometers in the conservative scenario and from 124,000 to 195,000 kilometers per car2go vehicle in the optimistic scenario. For the DriveNow vehicles, these numbers range between 56,000 and 93,000 kilometers in the conservative scenario and between 144,000 kilometers (Lisbon) and 254,000 kilometers per DriveNow vehicle (Copenhagen) in the optimistic scenario.

We calculated the average percentage reduction in VKT (from before using car2go / DriveNow until today) per customer for both scenarios. In the conservative scenario, the reduction ranges from 3% in Madrid to 36% in London. In the optimistic scenario, the reduction ranges from 10% in Madrid to 92% in London. Individual customers might deviate from these values considerably. Some participants stated that they even make more trips due to car2go / DriveNow overall. Our average absolute and city dependent estimations of VKT reductions per customer range at a high level between 1,400 km and 6,700 km in the optimistic scenario. This shows that the reduction of VKT – mainly due to the customers with sold and suppressed vehicles – more than compensates the additional distance driven with car2go / DriveNow vehicles.

Table 7: Estimates of VKT reduction per city

	car2go						DriveNow				
	Amster-dam	Berlin	Hamburg	Madrid	Rome	Vienna	Brussels	Copen-hagen	Helsinki	Lisbon	London
Number of vehicles sold	1,113	4,742	3,250	954	2,388	2,300	1,512	1,367	424	425	868
Number of vehicles suppressed	3,393	11,750	10,982	3,846	8,953	5,323	2,462	7,922	1,331	2,079	4,757
Annually reduced VKT due to sold vehicles	13,330,000	66,559,000	40,040,000	14,389,000	26.753,000	27,200,000	19,370,000	15,232,000	5,790,000	5,364,000	10,990,000
Annually reduced VKT due to suppressed vehicles (conservative scenario)	11,313,000	31,638,000	29,915,000	10,523,000	22,943,000	14,812,000	7,102,000	23,341,000	3,869,000	5,874,000	10,718,000
Annually reduced VKT due to suppressed vehicles (optimistic scenario)	45,252,000	126,552,000	119,660,000	42,094,000	91,772,000	59,247,000	28,408,000	93,365,000	15,474,000	23,496,000	42,873,000
Total estimated VKT reduced by car2go / DriveNow (conservative scenario)	24,643,000	98,197,000	69,955,000	24,913,000	49,696,000	42,012,000	26,472,000	38,573,000	9,659,000	11,238,000	21,708,000
Total estimated VKT reduced by car2go / DriveNow (optimistic scenario)	58,582,000	193,111,000	159,700,000	56,483,000	118,525,000	86,447,000	47,778,000	108,597,000	21,265,000	28,860,000	53,863,000
Number of customers (2017 / 2018)	16,000	46,000	40,000	35,000	30,000	26,000	10,000	24,000	5,000	9,000	8,000
car2go / DriveNow VKT	3,790,000	16,620,000	13,257,000	7,490,000	5,776,000	9,759,000	1,975,000	3,478,000	1,024,000	1,012,000	1,172,000
Reduction in VKT per customer (conservative scenario)	1,338	1,791	1,428	491	1,475	1,244	2,379	1,440	1,693	1,119	2,612
Reduction in VKT per customer (optimistic scenario)	3,515	3,874	3,687	1,380	3,788	2,957	4,449	4,312	3,968	3,047	6,701
Reduction in VKT per car2go / DriveNow vehicle (conservative scenario)	75,000	95,000	85,000	55,000	80,000	61,000	93,000	90,000	66,000	56,000	61,000
Reduction in VKT per car2go / DriveNow vehicle (optimistic scenario)	179,000	186,000	195,000	124,000	191,000	125,000	167,000	254,000	144,000	144,000	150,000
Reduction per customer (conservative scenario)	10%	18%	12%	3%	7%	10%	17%	17%	18%	5%	36%
Reduction per customer (optimistic scenario)	27%	38%	32%	10%	19%	24%	31%	52%	42%	13%	92%

8. Impacts on CO_2 Emissions

Our analysis of the impacts of car2go and DriveNow on CO_2 emissions suggests that the presence of these carsharing service reduces CO_2 emissions in the cities considered (cf. Table 8). As explained in the methodological overview (Section 4), we used country-specific emission factors of the Eurostat database [11] and added 40% to reflect real emissions [12]. According to Eurostat, the average CO_2 emission factors for newly registered vehicles are highest in Germany. Comparably low averages are reported for Southern Europe, applicable to the cities of Madrid, Rome, and Lisbon. The most significant change of fuel efficiency over time is observable in the Netherlands: while in 2008, average CO_2 emissions were third highest, the Netherlands reached the lowest specific emission values in 2016. This might be an effect of the policies strongly supporting the market penetration of electric vehicles – plug-in hybrid electric vehicles, in particular. The resulting high share of electric vehicles explains the main part of the comparably high decrease in specific emissions per newly registered vehicle in the Netherlands.

The emissions caused by the car2go and DriveNow fleets vary considerably between the cities considered. Apart from the cities with an electrical-vehicle fleet (Madrid, Amsterdam), the car2go fleet causes the lowest emissions in Rome. Two main factors can be identified to explain the differences in CO_2 emissions between the cities studied. In Rome, the average mileage per customer using car2go vehicles is the lowest, and the vehicle fleet only consists of rather small vehicles that cause comparably low CO_2 emissions (Smart Fortwo, Smart Forfour). A less important factor is that the vehicle fleet in Rome is slightly smaller than in the other cities. However, only a small part of the CO_2 emission reductions can be explained by the smaller fleet. Amongst the cities where DriveNow is operating, Lisbon shows the lowest DriveNow fleet-specific CO_2 emissions. CO_2 emissions of the DriveNow fleets in Helsinki, Copenhagen, and London are on a similar level. CO_2 emissions in Brussels are comparably high. Despite comparably high overall VKT with DriveNow vehicles in Copenhagen, corresponding CO_2 emissions are comparable to those in Helsinki and London. This can be explained by the high share of electric vehicle use in Copenhagen.

Overall annual CO_2 emission reductions that are attributable to car2go range between 4,602 t CO_2 and 18,590 t CO_2 in the conservative scenario and between 9,633 t CO_2 and 35,452 t CO_2 in the optimistic scenario. Overall CO_2 emission reductions due to DriveNow range between 1,760 t CO_2 and 6,337 t CO_2 in the conservative scenario and between 3,721 t CO_2 and 16,836 t CO_2 in the optimistic scenario. We observe similar levels of CO_2 emission reductions per car2go vehicle for Amsterdam, Berlin, Hamburg, and Rome. In the conservative scenario, annual CO_2 emission reductions range from around 9 t CO_2 to 17 t CO_2 per car2go vehicle. In the optimistic scenario, the reduction of CO_2 emissions in Amsterdam, Berlin, Hamburg, and Rome ranges between around 29 t CO_2 and 35 t CO_2 per vehicle. For Madrid and Vienna, the reduction is lower with around 21 t CO_2 per car2go vehicle. In the cities where DriveNow is operating, the bandwidth of results is similar. CO_2 emission reductions range between 9 t CO_2 and 17 t CO_2 in the conservative scenario and between 22 t CO_2 and 39 t CO_2 per DriveNow vehicle in the optimistic scenario.

Not surprisingly, the order of cities with respect to relative CO_2 emission and VKT reductions per customer is the same. Regarding the cities where car2go is operating, the reduction of CO_2 emissions per customer is highest in Berlin, followed by Hamburg, Amsterdam, Vienna, and Rome. In Madrid, the reduction of emissions per customer is lowest. Ranges of relative CO_2 emission reductions are similar to relative changes in VKT. In the conservative scenario, the reductions of CO_2 emissions per customer range from 4% to 18% (reductions of VKT: 3% to 18%). In the optimistic scenario, the range is from 9% to 33% (reductions of VKT: 10% to 38%). In the cities where DriveNow is operating, the reduction of CO_2 emissions per customer is highest in London and lowest in Lisbon. For the DriveNow cities, corresponding ranges of relative CO_2 emission reductions are also similar to relative changes in VKT. In the conservative scenario, reductions of CO_2 emissions per customer range from 4% to 33% (reductions of VKT: 5% to 36%). Corresponding reductions in the optimistic scenario range from 11% to 79% per customer (reductions of VKT: 13% to 92%).

Table 8: Estimates of CO_2 emission reductions per city

	car2go						DriveNow				
	Amsterdam	Berlin	Hamburg	Madrid	Rome	Vienna	Brussels	Copenhagen	Helsinki	Lisbon	London
Emissions of newly registered vehicles 2008 / 2009 [g/CO_2 per km][1]	219	231	231	207	203	221	199	195	220	187	210
Annual CO_2 emissions prevented by sold vehicles [t/yr]	2,924	15,356	9,238	2,986	5,420	6,020	3,854	2,966	1,273	1,005	2,303
Emissions of newly registered vehicles 2016 / 2017 [g/CO_2 per km][1]	148	178	178	160	159	169	162	150	165	147	170
Annual CO_2 emissions prevented by suppressed vehicles (conservative scenario) [t/yr]	1,677	5,621	5,315	1,685	3,639	2,497	1,152	3,500	640	861	1,817
Annual CO_2 emissions prevented by suppressed vehicles (optimistic scenario) [t/yr]	6,709	22,483	21,259	6,742	14,557	9,987	4,609	13,999	2,561	3,444	7,269
car2go / DriveNow CO_2 emissions [t/yr]	0	2,387	1,933	0	762	1,456	220	129	112	105	118
CO_2 emission reduction due to car2go / DriveNow (conservative scenario) [t/yr]	4,602	18,590	12,620	4,671	8,296	7,061	4,786	6,337	1,801	1,760	4,002
CO_2 emission reduction due to car2go /DriveNow (optimistic scenario) [t/yr]	9,633	35,452	22,564	9,727	19,214	14,551	8,243	16,836	3,721	4,343	9,454
CO_2 emissions reduced per car2go / DriveNow vehicle (conservative scenario) [t/yr]	14.0	17.9	15.4	10.2	13.3	10.2	16.8	14.8	12.2	8.8	11.2
CO_2 emissions reduced per car2go / DriveNow vehicle (optimistic scenario) [t/yr]	29.4	34.1	34.8	21.3	30.9	21.1	28.9	39.4	25.2	21.7	26.4
Reduction of CO_2 emissions per customer (conservative scenario)	10%	18%	12%	4%	7%	10%	16%	16%	17%	4%	33%
Reduction of CO_2 emissions per customer (optimistic scenario)	22%	33%	27%	9%	16%	20%	28%	43%	35%	11%	79%

1 Eurostat values [11] plus a 40% surplus for considering real emissions [12]

9. Comparison with the North American Study

In the introduction, we referred to a previous study carried out for car2go in five North American cities in 2016 [7]. We aligned our study as much as possible with this previous study to make results comparable. Not surprisingly, the results show notable differences. Percentages of participants who sold a vehicle were reported to be between 2% and 5% in the five North American cities, and between 3.6% and 16.1% in the 11 European cities. Corresponding percentages of suppressed vehicles were between 7% and 10% in North American cities and between 14.3% and 40.7% in European cities. Private vehicles sold per vehicle of the carsharing fleets ranged from 1 to 3 in North American cities and from 2.1 to 5.3 in European cities. Private vehicles suppressed per carsharing vehicle ranged from 4 to 9 in North American cities and from 7.7 to 18.6 in European cities. In general, private vehicle reductions tend to be higher in European cities compared to North American cities. As a direct consequence, the reductions of VKT and CO_2 emissions are higher in European cities than in North American cities. The reason might be on one hand the better expansion of public transportation systems in Europe, which provide more convenient traveling alternatives, and on the other hand the longer periods of time, for which the carsharing services had been available in the European cities at the time when the studies were conducted. The latter effect can even be observed when comparing results between the 11 European cities. For example in Madrid, where car2go has been available for the shortest period of time, the number of sold vehicles is significantly lower.

Regarding the modal shift, the results are similarly diverse in North American and in European cities. For the shift to urban rail and intercity rail, the percentage of no-changers is much higher in North American cities than in European cities, which again might be attributed to the good public transportation networks in Europe.

10. Limitations

Our survey is based on a questionnaire that was originally developed in German. The questions were carefully translated into the different languages used in the 11 cities. Since terminology for transportation systems varies from country to country and even from city to city survey participants might have had a diverse understanding of what is meant by “urban rail” or “intercity rail”. This might limit the comparability, especially of the modal shift results.

For economic reasons, the survey was conducted as an online survey. Face-to-face interviews, which offer an opportunity to explain questions and terminology in more detail, might have improved the quality of the study. Online surveys often bear the problem that specific groups in the population are underrepresented because they are less experienced with or have less access to online tools. This problem is not existing in our case since all carsharing customers need online apps to sign up for and use the carsharing service. A second problem is the so-called self-selection bias. Carsharing customers who positively responded to the survey might form a subgroup of interested people or people who have more time to complete a survey and might thus be not representative of the overall population. We examined the representativeness by comparing the socio-demographic and behavioral characteristics of the samples with those of the overall population. Despite the generally high accordance, a few exceptions are explicitly documented indicating that self-selection biases exist.

Our survey is focused on the community of carsharing users who regularly use the services provided by car2go and DriveNow. All participants can authentically report how carsharing impacted their vehicle holdings and travel behavior. There is no reason to believe that respondents may give dishonest answers. Some groups of questions are designed in a way so that answers can be cross-checked for validity and plausibility. There is only one question in the survey which is hypothetical by nature: “Would you acquire a car if car2go or DriveNow disappeared from your region?” The answer to this question cannot be verified and has to be treated with care.

In our calculations of per-person and per-carsharing-vehicle numbers of sold and suppressed vehicles, VKT, and CO_2 emission reductions, we used fixed numbers for the average fleet sizes of car2go (DriveNow) during the year 2017 (2018) and the car2go (DriveNow) customer population at the end of 2017 (2018). These two numbers change over time and thus influence the relative numbers of sold and suppressed vehicles.

Based on the answers provided by the survey participants, we calculated estimates for the kilometers saved by avoiding private vehicles. Additionally, information on kilometers traveled with carsharing vehicles were supplied by car2go and DriveNow. However, based on the answers provided on the carsharing providers' impacts on the modal shift, only qualitative estimates are possible. Participants indicated if they used certain transportation modes much more, more, unchanged, less, or much less. Requesting quantitative information on the use of different transportation modes might have overstrained the survey participants. This means, however, that detailed information on the transfer of kilometers between the different modes, e.g. from private vehicles to public transportation is missing. Such an evaluation could be the subject of future research.

11. Conclusion

Our study, which was conducted from March 2018 to July 2019 in 11 European cities, is based on a survey of 10.596 regular users of the carsharing services of car2go and DriveNow. The study reveals considerable impacts of free-floating carsharing on modal shift, vehicle ownership, VKT, and CO_2 emissions.

Most notable are the impacts on vehicle holdings. 3.6% to 16.1% of the survey participants in the different cities reported that they have sold a car due to the carsharing services provided by car2go and DriveNow. Besides vehicle reduction through actually realized sales, there is a second effect with an even higher impact on the number of vehicles in the cities: carsharing users postpone or forego the acquisition of a car which they otherwise would have purchased. 14.3% to 40.7% of the survey respondents in the individual cities reported such a purchase suppression. Suppressed vehicles represent a hypothetical inventory of vehicles that would come into the cities as soon as the carsharing service disappeared. We have explicitly asked survey participants if they suppressed vehicle purchases. However, due to the hypothetical nature of this question, the reported numbers cannot be treated with the same confidence as the number of vehicle sales.

If we relate the number of sold or suppressed vehicles to the number of carsharing fleet vehicles in the individual cities, we get the following results: 2.1 to 5.3 private vehicles have been sold by participants per car2go or DriveNow vehicle, 7.7 to 18.6 private vehicles have been suppressed per carsharing vehicle. The significance of these numbers is obvious: a single carsharing vehicle replaces a multiple of private vehicles. This frees up space in the streets (roadside parking) and parking lots of the cities.

Private vehicle reductions evidently lead to a reduction in private VKT. We used a conservative estimate for the VKT of sold vehicles and two estimates, a conservative and an optimistic one, for the VKT of suppressed vehicles. The estimates are based on information provided by the survey participants. The VKT estimates for sold vehicles are roughly around 13,000 kilometers, the VKT estimates for suppressed vehicles roughly between 3,000 (conservative) and 11,000 (optimistic) kilometers. This leads to VKT reductions measured in tens or hundreds of millions of kilometers across the cities.

VKT reductions can be converted into CO_2 emission reductions. For the conversion, we apply emission factors obtained from official sources. The CO_2 emission reductions induced by sold and suppressed private vehicles must be netted with the CO_2 emissions of the carsharing fleet. After netting, they range between 1,766 and 18,590 tons/year for each individual city in the conservative scenario and between 3,721 and 35,452 tons/year in the optimistic scenario. Netted CO_2 emission reductions per car2go / DriveNow vehicle are between 8.8 and 17.9 tons/year in the conservative scenario and between 21.1 and 39.4 tons/year in the optimistic scenario.

The introduction of carsharing in a city is supposed to lead to shifts in the customers' choice of transportation modes. The results of our survey are different from city to city. However, some general trends can be observed: the share of respondents indicating a decrease of urban rail and bus use is higher than the share of respondents indicating an increased use. However, the majority of participants (with a few exceptions in individual cities) reports no change. The use of taxis has been decreased by the majority of participants (63.1% to 85.5%), only between 1.4% to 7.3% of the respondents report an increase. This means that the use of taxis, urban rail, and busses has been substituted by the carsharing services provided. However, the small percentage of participants who report increased use of urban rail and busses (and to a lesser extent taxis) indicates that these transportation modes are also used to complement carsharing. The use of intercity rail is hardly impacted by carsharing. 67.5% to 92.2% of the participants report no change. Roughly around 70% of the participants (with a few local exceptions) report no change in walking and cycling, the remaining 30% split into increasers and decreasers, which again indicates that walking and cycling are both substituted by carsharing and complementing carsharing.

The situation changes significantly if we focus our evaluation on the subgroup of participants who have sold a car. The percentages of participants who increased the use of public transportation often grow by a factor of three. In Berlin, for example, these percentages jump from 9.7% to 31.8% for urban rail, from 9.9% to 32% for intercity rail, and from 7.1% to 21.3% for the bus. The percentages of participants with increased bicycle use grow from 13.5% to 39.8%, and with increased walking from 16.1% to 28.8%. These numbers indicate where the kilometers formerly traveled with private vehicles might have gone: to public transportation in combination with walking and cycling.

After free-floating carsharing offerings have been available in major European cities for more than 10 years, positive impacts on vehicle holdings, modal shift, and CO_2 emission reductions can be observed. A respectable percentage of regular car2go and DriveNow users have sold private cars. Private vehicle reduction frees up traffic space in the cities, fosters public transportation as a complement to carsharing, and has environmental advantages. The willingness of carsharing users to sell a car certainly depends on many factors. However, it might increase with the time that the carsharing system has been in operation. Therefore, it can be expected that in the coming years the trend to reduce private vehicles with its positive effects will continue.

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