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Free-floating electric carsharing-fleets in smart cities: The dawning of a post-private car era in urban environments?

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ABSTRACT

Free-floating carsharing-systems allowing users to start and end vehicle-rentals at any point in cities (e.g. using smartphones to locate available cars) are expanding internationally. This article reports on the private car reduction potential of *car2go*, the first free-floating carsharing-system, which was launched in Germany in 2009. A randomised controlled trial of different electrification-scenarios was incorporated into an online survey of *car2go*-users. The results indicated that the shown electrification-scenario (e.g. regional vs. green electricity) influenced the respondents' car reduction willingness. An additional split-sample comparison of users having previously driven electric vs. gasoline *car2go*-cars showed that having driven an electric-*car2go* increased the willingness to forgo a private car purchase. Policymakers and carsharing-providers could use the findings to increase the environmental gains achieved by carsharing-systems.

1. Introduction

The automobile has changed the earth's natural and built environment more than any other invention. This was not obvious in its first days, given that the scientific community initially contrasted automobiles with horses regarding hygienic aspects (The Lancet, 1896a), safety (The Lancet, 1896b), and maintenance (Automobilist, 1899). Some early proponents speculated that "[p]robably the horse will never be banished, but (...) [s]ome day, perhaps, motor-cars will have tracks of their own" (The Lancet, 1901, p. 1429). However, neither scientists nor policymakers anticipated the automobile's unparalleled environmental impacts which have unfolded over the last century.

As of 2014, there are 1 billion passenger cars worldwide, with projections of up to 2.8 billion by 2050 (Meyer et al., 2012). For the *natural environment*, this global diffusion of cars means climate change, waste, and pollution (Aamaas et al., 2013; Chae, 2010; Tolón-Becerra et al., 2012), and these problems get worse: "Amongst the industries, transport is the sector with the fastest growth of greenhouse gases emissions, both in developed and in developing countries" (Berrittella et al., 2008, p. 307). For the *built environment*, cars brought a redefinition of urban life from the way people commute to work (García-Palomares, 2010) to where they go shopping (Reimers, 2013) – and ultimately cars are the decisive technology causing urban sprawl. The resulting problems in car-centric cities worldwide are well known, including congestion, noise, energy use, and parking shortage

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(Loukopoulos et al., 2005). However, policymakers struggle to find solutions as even experts disagree on complex transportation policies (Berrittella et al., 2008), and as policies assumed to reduce car use often turn out (empirically) to be ineffective (Graham-Rowe et al., 2011).

Free-floating electric carsharing-fleets could simultaneously solve several problems resulting from the traditional use of private automobiles. ''Shared'' cars driven alternately by different users save resources compared to private cars – which are normally driven less than 1 hour per day (Firnkorn and Müller, 2012). ''Electric'' vehicles can reduce carbon dioxide (CO_2) emissions relative to cars powered by gasoline, depending on the mode of electricity generation (Oxley et al., 2012; Mao et al., 2012). ''Free-floating'' fleets enable location-independent car usage based on the global positioning system (GPS)-localisation of the cars (e.g. by smartphone apps), which offers a degree of flexibility similar to private cars: ''[A] free-floating set-up allows users to start and end a vehicle hire at any point within a specified area, which therefore enables discretionary one-way usage'' (Firnkorn and Müller, 2011, p. 1519). In summary, free-floating electric carsharing-fleets could combine all the above-indicated advantages regarding ownership (shared), power-train (electric), and system functionality (free-floating).

But the effects of free-floating electric carsharing-fleets are still unknown. Will such systems reduce private car ownership in cities? Should policymakers support such systems? As of March 2014, few studies on free-floating carsharing-systems exist – which is likely to be a temporary state given that the technology is new but spreading rapidly. The first free-floating carsharing-system was ''*car2go*'', launched by the automaker *Daimler* in 2009 in the city of Ulm, Germany. At present, *car2go*-fleets of 250–1200 vehicles are offered in 26 European and North American cities (www.car2go.com). Although other companies have started to offer similar free-floating systems (e.g. *BMW* in 2011, *CITROËN* in 2012), this article focuses on *car2go* in Ulm for two methodological reasons. First, Ulm has globally the longest operating free-floating carsharing-system. Second, *car2go* in Ulm offers a mixed fleet of electric and gasoline vehicles – an experimental advantage allowing a split-sample comparison of the associated user-behaviour (all other parameters being equal).

This article reports on *car2go*'s potential to reduce private car ownership in urban environments given the ongoing electrification of the system. The methodology consisted of a randomised controlled trial testing the *car2go*-users' willingness to reduce private car ownership depending on different electrification-scenarios. In addition, the answer patterns of the respondents who had already driven electric-*car2go* or only gasoline-*car2go* were compared. The results could support policymakers developing transportation policies for new free-floating electric carsharing-systems for which (as of March 2014) few empirical analyses exist and for which the science-policy discourse (Wesselink et al., 2013) has just begun. Schwedes et al. indicated that ''[i]t is still far from clear whether e-cars could be part of a sustainable transport strategy'' (Schwedes et al., 2013, p. 79). The present article contributes to a better understanding of electric cars in the context of free-floating carsharing-systems combining electric mobility with further technologies (e.g. real-time connectivity, instant and shared access, GPS-localisation) associated with future smart cities. While a standard definition of ''smart city'' does not exist (Hollands, 2008; Neirotti et al., 2014), ''a common recognition [is] that electric vehicles (EVs) form one of the most important elements of the FSC [future smart city]'' (Yamagata and Seya, 2013, p. 1467).

2. Method

The methodological core of this article is a randomised controlled trial of four *different* scenarios (stimuli) given to carsharing-user as the basis for consecutive *identical* questions about their mobility behaviour. This study was implemented in an online survey answered by *car2go*-users registered with *car2go* in the city of Ulm, Germany. The survey participants saw only one of the four scenarios displayed in Fig. 1.

As shown in Fig. 1, the survey participants were randomly asked to imagine one of the future scenarios ''Base'' (no electric cars mentioned), ''E-*car2go*'' (fully electric fleet), ''E-*car2go* & green'', or ''E-*car2go* & regional'' (the latter two scenarios differed by additional stimuli regarding the electricity generation). The scenario-randomisation (Fig. 1) was applied to avoid a selection bias (Caplow et al., 2011) and served to understand the impacts resulting from different electrification-variants.

The specific point in time of the measurement of the survey was chosen with the aim of approximately 50% of the *car2go*-users having driven either an electric-*car2go* or only a gasoline-*car2go* (an electric/gasoline mixed fleet is offered in Ulm). In the cleaned dataset used in this article ($N = 743$), 49.3% of the respondents had driven an electric-*car2go* at the time of the survey (Section 3.2.2), which allowed an additional split-sample comparison of the results via the dichotomous variable ''electric-*car2go* driving experience''.

3. Results

3.1. *Generated sample of carsharing-users*

The dataset of the present article was generated using an online survey of *car2go*-users. The authors programmed and pretested the survey, and *car2go* sent out the survey invitations via a group-mail software on 9 February 2013. Of the 17,000 *car2go*-members in Ulm in possession of a second-generation *car2go*-RFID-chip (required to access *car2go*-vehicles since March 2011), the survey was sent to all 4,577 *car2go*-newsletter subscribers (due to data protection laws). The invitation links were unique through URL-variables to exclude biases from multiple participations, yet no individual user-data was matched via the links (due to data protection laws). The survey worked independently of JavaScript (to ensure its functionality independent of browser settings and on mobile devices), the emails were sent non-HTML formatted (to avoid biases from filters), and the group-mailing was sent in batches (to avoid biases from firewalls). Of all completed cases, 93.4% were collected within the first week after the invitation emails were sent.

The raw dataset was verified regarding technical aspects and content. The *technical data verification* included checks for

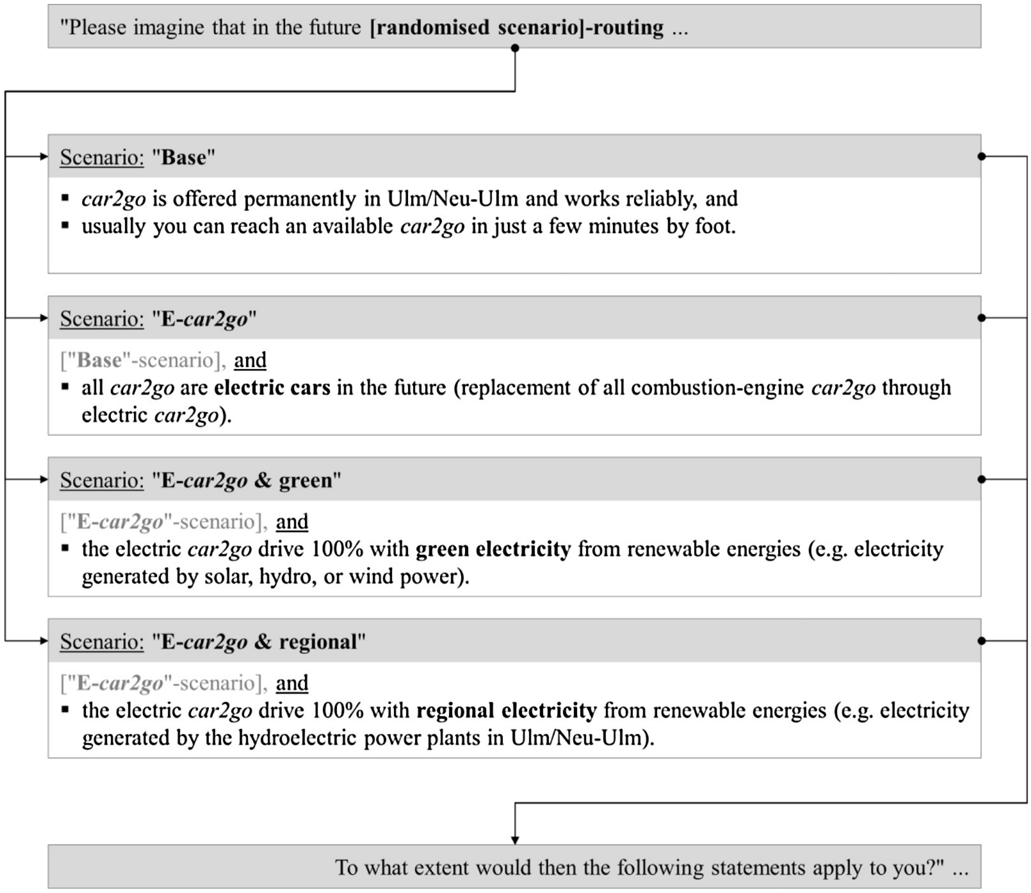

Fig. 1 – Randomised controlled trial of four scenarios as the basis for consecutive adaptation questions. Note: Neu-Ulm is Ulm's neighbouring city in another German state. Although all local *car2go*-customers are registered in Ulm, the local operating area of the free-floating *car2go*-fleet includes parts of the city of Neu-Ulm, and therefore, all scenarios and questions refer to "Ulm/Neu-Ulm".

mutually exclusive data entries (e.g. caused by browser-back button usage over routing-points). Such technical issues were corrected using timestamps and logic-rules programmed into the survey. Incomplete cases (i.e. final survey page not submitted) were excluded from the analysis, although respondents could complete the survey without answering every question. The *content verification* included logic-checks regarding the plausibility of the combination of different answers by the same respondent. For example, if three questions generated the answers (a) "I never drove a gasoline-*car2go*", (b) "I drove an electric-*car2go* *x* times" (with $x > 0$), and (c) "My first *car2go*-rental was in [month/year]" with a date stated in (c) earlier than the date when the first electric *car2go*-vehicles were added to the local fleet, then respondents were removed as this combination is impossible. A variety of similar logic-checks were carried out. The last applied quality filter (as the filter order affected the result) removed respondents who completed the survey in an implausibly short time relative to other participants. In total, 1207 *car2go*-members started and 905 completed the survey, passing all data quality filters.

From the "cleaned total sample" ($N = 905$) further cases were removed by an activity filter because "the less active car-sharing members are, the less likely is the causality of their membership being the reason for their reduced car ownership" (Firnkorn and Müller, 2012, p. 268). The applied activity filter removed respondents with a lower average usage-frequency than one *car2go*-rental per half-year, a cut-off criterion consistent with previous empirical studies on *car2go* (Firnkorn, 2012; Firnkorn and Müller, 2012). This final activity filter reduced the "cleaned total sample" ($N = 905$) by 162 cases, resulting in the "cleaned active sample" ($N = 743$). The central figures of the data generation and processing are summarised in Table 1.

The demographics of the "cleaned active sample" ($N = 743$) are presented in Table 2.

Table 2 presents from left to right the demographics for the entire "cleaned active sample" ($N = 743$) (Table 1) and for the four sub-groups of the [randomised scenario]-split (Fig. 1). The sub-sample sizes vary from $N = 178$ to $N = 190$ due to technical reasons (e.g. different impacts of the data processing steps and because of non-response cases). Table 2 shows that the demographics for all four random sub-samples are similar, which confirms the independence of the randomisation-mechanism from the respondents.

Table 1 – Cleaned total and cleaned active sample size.

Group	Size
Population of *car2go*-members in Ulm/Neu-Ulm (with a second-generation *car2go*-RFID-chip)	>17,000
Newsletter-subscribers having received the survey-invitation	4,577
Cleaned total sample	905
Cleaned active sample	743

3.2. *Private car reduction willingness dependent on the randomised scenario*

3.2.1. *Baseline of household vehicle availability and usage*

The analysis of the car reduction potential of any shared-mobility system should be understood within the local context of the existing household vehicle stock. For example, if the vehicle reduction by a carsharing-system is measured in densely populated cities with few average household vehicles (e.g. downtown New York), lower car reduction impacts can be

Table 2 – Demographics.

	Cleaned active sample	[Randomised scenario]-split			
		Base	E-*car2go*	E-*car2go* & green	E-*car2go* & regional
Sex	N = 739	N = 190	N = 178	N = 189	N = 182
Male	68.3%	70.0	66.3%	69.3%	67.6%
Female	31.7%	30.0%	33.7%	30.7%	32.4%
Age category	N = 736	N = 187	N = 178	N = 189	N = 182
17–19	3.1%	2.7%	5.1%	2.6%	2.2%
20–24	12.5%	10.2%	15.2%	13.8%	11.0%
25–29	13.5%	13.4%	10.1%	14.3%	15.9%
30–34	16.6%	20.3%	15.2%	19.0%	11.5%
35–39	10.7%	9.6%	13.5%	13.2%	6.6%
40–44	12.1%	13.9%	10.1%	7.9%	16.5%
45–49	11.0%	9.6%	9.0%	11.1%	14.3%
50–54	9.2%	10.2%	11.2%	7.9%	7.7%
55–59	5.6%	4.3%	4.5%	6.3%	7.1%
60–64	3.1%	4.3%	2.8%	2.1%	3.3%
65–69	1.2%	0.0%	1.7%	0.5%	2.7%
70+	1.4%	1.6%	1.7%	1.1%	1.1%
Education	N = 735	N = 188	N = 177	N = 189	N = 181
No school graduation certificate	0.0%	0.0%	0.0%	0.0%	0.0%
Basic secondary school (9 total years in school)	5.0%	3.2%	3.4%	7.9%	5.5%
Middle secondary school (10 total years in school)	16.3%	17.6%	15.3%	13.8%	18.8%
Higher secondary school (13 total years in school)	27.5%	22.9%	34.5%	30.2%	22.7%
University or technical college	51.2%	56.4%	46.9%	48.1%	53.0%
Occupation	N = 728	N = 188	N = 174	N = 186	N = 180
In school/student/apprentice	18.4%	16.0%	20.7%	20.4%	16.7%
Voluntary service (e.g. social/environmental, army)	1.2%	1.6%	1.1%	1.1%	1.1%
Housewife/househusband	3.3%	2.1%	4.0%	1.6%	5.6%
Seeking work	1.4%	2.1%	1.1%	1.1%	1.1%
Part-time employed	9.5%	10.6%	6.9%	11.3%	8.9%
Full-time employed	66.2%	67.6%	66.1%	64.5%	66.7%
Net household income per month	N = 729	N = 186	N = 176	N = 187	N = 180
Less than 500 EUR	1.0%	1.6%	0.6%	1.1%	0.6%
500–999 EUR	2.6%	2.7%	0.6%	2.7%	4.4%
1000–1499 EUR	4.1%	3.8%	2.8%	5.3%	4.4%
1500–1999 EUR	5.3%	7.0%	6.3%	5.9%	2.2%
2000–2499 EUR	7.8%	9.7%	10.2%	4.8%	6.7%
2500–2999 EUR	10.2%	10.8%	8.5%	10.2%	11.1%
3000–3499 EUR	10.6%	8.1%	13.6%	9.6%	11.1%
3500–3999 EUR	9.1%	12.4%	5.7%	7.5%	10.6%
4000–4499 EUR	8.2%	5.4%	7.4%	8.0%	12.2%
4500 EUR or more	20.7%	18.8%	19.9%	23.0%	21.1%
"I prefer not to give this information despite anonymity"	20.4%	19.9%	24.4%	21.9%	15.6%

Note: The sample sizes within each column may deviate from each other as the demographic questions were not compulsory. The percentage-sum per category and sample may deviate from 100% due to rounding.

expected compared to cities with a higher initial number of average household vehicles: "[C]arsharing impacts are potentially greater in low-density urban environments where car ownership is more widespread" (Martin and Shaheen, 2010, p. 55).

The *car2go*-users in the "cleaned active sample" ($N = 743$) (Table 1) stated the following household vehicle availabilities: "0 cars" 17.2%, "1 car" 46.4%, "2 cars" 28.7%, "3 cars" 5.1%, "4 cars" 2.0%, and "5 (or more) cars" 0.5%. In addition to the *number* of available vehicles, the vehicle *usage* should also be considered as part of the baseline analysis – in particular given the beginning electrification of cars and frequently expressed concerns regarding the (perceived) too limited range of electric vehicles. Therefore, the average daily usage of the participants' household cars is displayed in Fig. 2.

Fig. 2 shows that 81.5% of the cars in the participants' households are driven less than 61 min per day – a usage intensity that could be maintained by most currently available electric cars even if conservative parameters are assumed (e.g. regarding the electric cars' range, speed and distance driven, and outside temperatures possibly requiring in-car heating or air-conditioning).

3.2.2. *Vehicle reduction potential as a function of car2go's electrification-scenario*

How will the respondents' car reduction willingness depend on *car2go*'s future electrification-scenario? This was analysed by comparing the answer patterns to the statements displayed in Table 3.

Table 3 shows that the willingness to forgo an own car purchase (Statement A) and the likelihood of a currently co-used car being abolished (Statement B) are both reduced by the stimulus "electric". The scores in the category "completely applies/rather applies" are the highest for the "Base"-scenario, which is the only scenario without any reference to "electric cars" (Fig. 1). However, the E-*car2go*-scenario with the additional stimulus "regional" generated answer patterns similar to the "Base"-scenario. These results could support policymakers and carsharing-operators to maximise the car reduction potential of electric carsharing-systems (e.g. by cooperating with utility providers (regional electricity) and targeted branding campaigns; see Section 4.1).

But how do the results in Table 3 depend on previous driving experience with electric-*car2go*? Given that *car2go* offers a mixed fleet of electric- and gasoline-*car2go* in Ulm, some of the respondents in the aggregated analysis (Table 3) had driven an electric-*car2go* (49.3% of $N = 743$) while others had only driven gasoline-*car2go*. This allowed the additional split-sample comparison via the dichotomous variable "E-*car2go* driven?", as displayed in Table 4.

Table 4 shows that the willingness to forgo an own car purchase is greater for respondents who had driven an electric-*car2go* compared to those who had not – in every scenario. For example, the "Base"-scenario was seen by 191 respondents of whom 88 had never driven an electric-*car2go*, and this sub-group had a score of 34.1% in the category "completely applies/rather applies". In contrast, the 103 respondents who had seen the same stimulus ("Base"-scenario) and had already driven an electric-*car2go* had a score of 46.6% in the same category.

Further research is necessary to distinguish clearly correlation from causation in the results (Section 4.1). However, these first empirical insights on the electrification-dependent car reduction potential of a free-floating carsharing-system could support policymakers and carsharing-operators to increase the private car reduction effect of

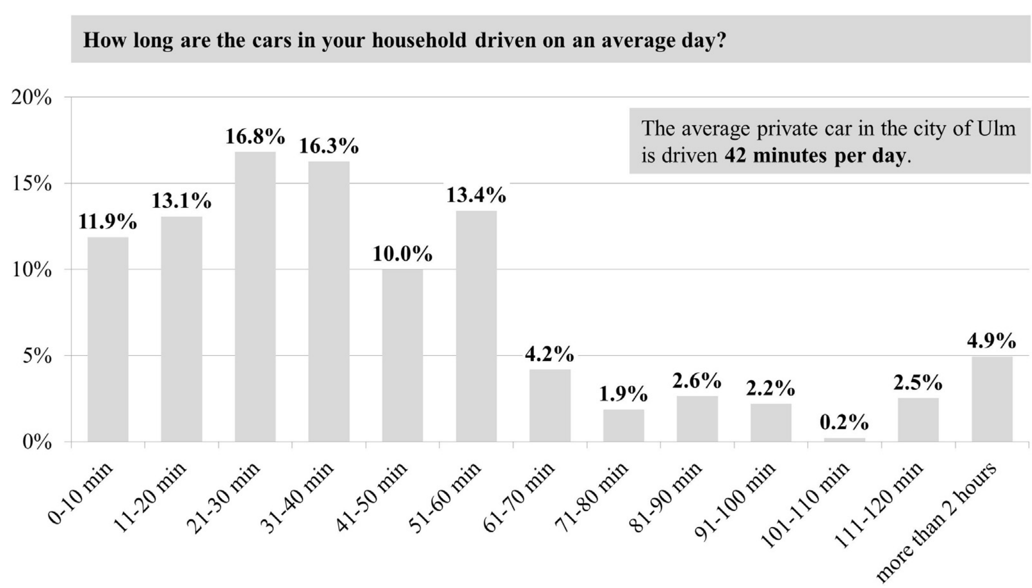

Fig. 2 – Average daily usage of private household cars ($N = 910$). Note: The respondent-households in the "cleaned active sample" ($N = 743$) (Table 2) had a total of 965 cars available, of which 910 are included in the data shown in Fig. 2; excluded in Fig. 2 are 25 cars for which the respondents selected the answer "I cannot estimate the driven time" and a further 30 cars for which the respondents did not provide any answer (non-compulsory question). The 42 minutes per day are the sum-product of the class-percentages and the exact class-medium values. For the open class "more than 2 hours" the calculation-value "120 minutes" was used.

Table 3 – Car reduction potential as a function of the randomised scenario (*N* = 743).

	Completely applies/rather applies	Undecided	Rather does not apply/does not apply at all
	Statement A: "If *car2go* is offered permanently in Ulm/Neu-Ulm, I could imagine forgoing the purchase or replacement purchase of an own car in the future."		
Base (*N* = 191)	40.8%	10.5%	48.7%
E-*car2go* (*N* = 179)	34.6%	15.1%	50.3%
E-*car2go* & green (*N* = 190)	34.2%	12.1%	53.7%
E-*car2go* & regional (*N* = 183)	38.3%	13.7%	48.1%
	Statement B: "If *car2go* is offered permanently in Ulm/Neu-Ulm, a car which I currently co-use (e.g. from a friend or family member) is likely to be abolished."		
Base (*N* = 191)	23.6%	16.8%	59.7%
E-*car2go* (*N* = 179)	19.0%	16.8%	64.2%
E-*car2go* & green (*N* = 190)	20.5%	13.7%	65.8%
E-*car2go* & regional (*N* = 183)	22.4%	16.9%	60.7%

electric carsharing-systems (e.g. by offering incentives to users to drive the electric vehicles of mixed gasoline/electric carsharing-fleets; see Section 4.1).

4. Discussion

4.1. *Policy support for carsharing-systems*

Free-floating carsharing-systems are expanding internationally. Following the start in Ulm in 2009, *car2go*-fleets have (as of March 2014) been launched in 26 cities. While *car2go* aims to offer free-floating carsharing-fleets in up to 50 European and 30 North American cities by 2016, rival *BMW* announced the goal of 1 million carsharing-customers by 2020 (Firnkorn, 2012). Further car manufacturers started to offer carsharing-fleets during the last 2 years, and this market entry of automakers helps the carsharing-industry to reach customers beyond traditionally restricted user-milieus (Wilke and Bongardt, 2005). For example, *car2go* declared in September 2013 that "[w]orldwide a *car2go* rental agreement begins every 3 seconds" (Daimler, 2013a, p. 2). Together with the carsharing-sector's transformation into a mainstream transportation mode, the importance of policy decisions increases as "[n]o variant of any car-sharing system can be implemented on a large scale by simply giving a company a licence without public policy support" (Firnkorn and Müller, 2012, p. 276).

However, as free-floating carsharing-systems have just begun to proliferate, few empirical studies on their impacts exist on which policies can be based. This situation has two implications. First, it requires "reflexivity on the part of scientists working at the science-policy interface" (Wesselink et al., 2013, p. 1) – because early empirical studies on free-floating carsharing-systems will receive a strong resonance in the political sphere. Second, policymakers should strive to filter empirical analyses from the broad and partly emotional public debate about the possible effects of new carsharing-variants. For example, two frequent public speculations (in many countries) about free-floating carsharing-systems are: "They are the breakthrough technology convincing people to abolish private cars!" and "They cannibalise public transport!" – both antipoles usually being equally deduced from "the high user flexibility through the GPS-based system-functionality" (people could theoretically substitute most

Table 4 – Influence of having driven an E-*car2go* (*N* = 743).

	Statement A: "If *car2go* is offered permanently in Ulm/Neu-Ulm, I could imagine forgoing the purchase or replacement purchase of an own car in the future."			
	E-*car2go* driven?	Completely applies/rather applies	Undecided	Rather does not apply/does not apply at all
Base (*N* = 191)	No (*N* = 88)	34.1%	15.9%	50.0%
	Yes (*N* = 103)	46.6%	5.8%	47.6%
E-*car2go* (*N* = 179)	No (*N* = 95)	27.4%	9.5%	63.2%
	Yes (*N* = 84)	42.9%	21.4%	35.7%
E-*car2go* & green (*N* = 190)	No (*N* = 90)	33.3%	11.1%	55.6%
	Yes (*N* = 100)	35.0%	13.0%	52.0%
E-*car2go* & regional (*N* = 183)	No (*N* = 104)	32.7%	13.5%	53.8%
	Yes (*N* = 79)	45.6%	13.9%	40.5%

Note: The identical split-sample comparison for Statement B (Table 3) based on prior E-*car2go* driving experience shows a similar result, yet the table is excluded because the decision of others to abolish a private car (which is co-used) is only indirectly related to the respondents' individual E-*car2go* experience.

public transport trips by free-floating carsharing-systems, taxis, private limousine services, etc., but doing so is too costly, and therefore such services are used sporadically).

One empirical insight from the analysis of *car2go* in Ulm was that the stimulus "electric car" generated the greatest car reduction willingness in combination with the stimulus "regional electricity" (Fig. 1; Table 3). For policymakers and carsharing-providers, this information could help to maximise the private car reduction potential of carsharing-fleets – for example by cooperating with local public utility providers (regional electricity). In addition, should further studies confirm the greater car reduction willingness for "regional electricity" vs. "green electricity" (Fig. 1), this would constitute an easy environmental gain to realise if only the wording in branding campaigns needed an adaptation (in cities were "regional electricity" is available).

A second empirical insight from the analysis of *car2go* was that having driven an electric-*car2go* (within the mixed gasoline/electric-fleet in Ulm) increased the willingness to consider forgoing a private vehicle purchase (Table 4). More empirical research is necessary to clearly distinguish correlation from causation in these answer patterns and to determine the "intention-behaviour gap" (Firnkorn and Müller, 2011, p. 1525). However, these first insights on the electrification-dependent car reduction potential of a free-floating carsharing-system could help policymakers and carsharing-providers to increase the environmental gains achieved by carsharing-systems – for example by offering incentives to users to try electric vehicles within mixed electric/gasoline carsharing-fleets. In addition, the results could provide a basis for future research designs. For example, the *car2go*-users' preference of *regional* over *green* electricity should be verified with further randomised controlled trials analysing the electrification-preferences in greater detail. This would be a valuable next research step because every provider of electric carsharing-fleets needs to choose an electrification-strategy (and a communication-strategy thereof) – understanding user-preferences is essential for this choice. However, implementing *any* free-floating system-variant is likely to generate benefits for cities with details of the electrification-variant being a secondary level of optimisation.

The local analysis of attitudes of *car2go*-users in Ulm is an early empirical glance on an internationally emerging phenomenon which requires a policy response. Just like Ulm, cities worldwide share similar car-related problems (e.g. pollution, congestion), and even though the transportation infrastructure and mobility culture is different in every city, there are generic problems in most urban areas which could be improved by free-floating electric carsharing-fleets. For example, the widespread possession of *private* cars often creates parking space shortages and studies analysing the cause of city traffic found "[b]etween 8 and 74 percent of the traffic was cruising for parking" (Shoup, 2006, p. 479) – this cruising for parking in *private* cars can be reduced through *shared* cars: First, parking privileges for shared cars eliminate the incentive to search for free parking (e.g. *car2go*-vehicles park free on public parking grounds). Second, shared cars free up parking space in cities when a larger number of private cars than the carsharing-fleet size is abolished. However, cities will achieve the largest net gain of space through large carsharing-fleets parked in integrated vertical parking and charging facilities (e.g. http://en.kandivehicle.com/NewsDetail.aspx?newsid=57).

Parking policies for carsharing-vehicles should be developed integrated with other regulations regarding the use of public space. For example, the taxi-industry, bikesharing companies, and food stalls all have the same interest as carsharing-providers in using public space in cities – but based on which general legal framework can public space be allocated to a particular interest group or legal entity? By taking a holistic top-down policy perspective, policymakers can avoid fragmented, non-integrated, and conflicting policies. For example, given that *car*-sharing (e.g. https://us.drive-now.com), *scooter*-sharing (e.g. www.scootnetworks.com), and *bike*-sharing systems (e.g. http://en.velib.paris.fr) all depend on legislative support (e.g. regarding the allocation of public space, permits, insurance requirements, and fees), policymakers may consider developing regulations jointly for all variants of shared-mobility systems, even if they are not yet offered in their city.

Policy decisions on transportation systems often involve subjective value judgements. For example, given that "transportation is a common good, people definitely have individual opinions" (Niemeier, 2010, p. 563), and therefore some people consider it a right to own a private car whereas others consider it a right to live in car-free settlements. While such extreme positions mainly polarise, policymakers on a city level usually face more tangible decisions regarding policies on new shared-mobility systems. For example, a city council discussing whether to allow *car2go* to operate expressed concerns about the expected decrease in new private car sales, and thereby a loss of sales tax for the city (Torrance City Council, 2013). This is a valid concern – but would not less private cars also save money for cities (e.g. by reducing maintenance costs for traffic infrastructure and, in the long-term, by reducing climate change adaptation costs)?

Whether a new mobility-system is "beneficial" for a city will always remain a question of definition (e.g. Wilson, 2014). However, policymakers should use the emergence of new free-floating carsharing-systems as an opportunity to reflect on their path-dependent value judgements. The past century was an automobile age in which city structures (e.g. road and parking capacities) were developed to foster private car usage – the current international expansion of free-floating electric carsharing-systems, which could herald a post-private car era in urban environments, may require that the technological breakthrough is matched by an equally radical adaptation of historically car-centric value systems.

4.2. *Free-floating electric carsharing-fleets in smart cities*

4.2.1. *Smart cities require technological teamwork*

Overcoming car-related problems in cities will require the long-term integration of several complex systems far beyond free-floating carsharing-fleets. For example, with more than half of the human population living in urban areas, "[c]ities consume as much as 80 percent of energy production worldwide and account for a roughly equal share of global greenhouse gas emissions" (World Bank, 2010, p. 15). These aggregated figures depend on the calculation method and are subject of an ongoing debate (Dodman, 2009; Satterthwaite, 2008). However, energy production and electric transportation systems should generally be optimised jointly as otherwise electric vehicles may backfire: For example in China, where most electricity is coal-generated, ''replacing gasoline cars with e-cars will result in increased CO_2 from combustion emissions'' (Ji et al., 2012, p. 2023).

Because cities differ regarding topography, climatic conditions, and population density, they face different local problems which require customised solutions. For example, the average private car of the surveyed *car2go*-users in Ulm was driven 42 minutes per day (Fig. 2) – a usage intensity which could be maintained by most available electric cars. However, in other cities, a higher average private car usage combined with a less developed charging infrastructure may not lead to a similar substitution potential of electric vehicles. Therefore, smart cities should be developed based on local conditions to solve local problems. For example, the integrated optimisation of local electric transportation systems and energy production is a goal for many cities and it has been indicated that ''[d]esigning a future smart city (FSC) that copes with the reduction of CO_2 has become one of the urgent tasks of the next 20 years'' (Yamagata and Seya, 2013, p. 1466).

However, policymakers should consider further connections between electric carsharing-fleets and emissions. First, the production, usage, and scrapping/recycling of carsharing-vehicles (and the private cars they reduce) should be evaluated based on holistic well-to-wheel and lifecycle-analyses (Katrašnik, 2013; Shen et al., 2012) – not based on local CO_2-emissions. Second, electric cars could help to balance the fluctuation of renewable energy sources (Richardson, 2013), for example when electric vehicles are charged overnight using the electricity surplus of wind farms (Borba et al., 2012). Third, electric carsharing-vehicles can influence people's willingness to even buy a private car (Table 4). However, policymakers planning smart cities should continuously reflect on generic alternatives: For example, hydrogen carsharing-vehicles have advantages compared to plug-in battery-electric cars, including refuelling in minutes vs. recharging in hours and a greater range (Kriston et al., 2010).

In addition to integration with energy production systems, free-floating electric carsharing-fleets should be integrated with other transportation systems to maximise the benefits for cities. In particular, policymakers should focus on the first/last-mile problem as ''[c]onvincing car owners to give up a private car will be easier for *car2go* or any other carsharing provider when carsharing users have easy access to transportation modes beyond carsharing'' (Firnkorn, 2012, p. 1670). A full integration with public transport should include pricing, payment systems, and infrastructure (Firnkorn and Müller, 2012).

Regarding the integration with city infrastructure, electric carsharing-systems have several generic integration interfaces. First, parking (Correia and Antunes, 2012). Second, charging – at charging stations, battery exchange stations (Dijk et al., 2013), or via (future) dynamic charging lanes (Ahn et al., 2013). Third, the long-term city development: City councils can incentivise or even require that carsharing-parking spaces are built in new development projects (e.g. City of San Francisco, 2014). However, policymakers and researchers should ultimately develop cities which are not just ''smart'' through *applied technologies* and *system-integration* – but rather through an *urban structure* reducing the need for any motorised travel by designing mixed zones where citizens can live, work, shop, and go out within walking/cycling distance (Banister, 2008; Camagni et al., 2002).

When policymakers planning smart cities consider the integrated optimisation of transportation systems (including carsharing), energy production, and city infrastructure – how can they handle the complexity? There are two generic approaches. First, ''top-down'' by striving for a unified city theory (e.g. Batty, 2013; Bettencourt, 2013; Bettencourt and West, 2010; Pincetl, 2012). Second, ''bottom-up'' by successively integrating single technological elements, such as free-floating electric carsharing-fleets with energy production. The second approach achieves progress through trial-and-error – as in the randomised controlled trial (Fig. 1) and split-sample comparison (Table 4) in the present article. However, trial-and-error is the only possible approach in the absence of a unified city theory and, as Pahl-Wostl et al. indicated: ''Viable methodologies that generate interdisciplinary knowledge are not developed on paper, but in practice'' (Pahl-Wostl et al., 2013, p. 42).

4.2.2. *Autonomous free-floating carsharing-fleets*

Autonomous cars will transform urban mobility. Companies and research institutions have been working for years on driverless cars (e.g. Google, 2013) – but August/September 2013 changed the debate through the first announcements regarding their commercial availability by 2020 (e.g. Daimler, 2013b; Nissan, 2013). To put this development into perspective: By 2020 consumers may buy ''autonomous cars'' with advanced assistance technologies (e.g. cars able to temporarily take over full driving control), but not yet cars driving without any human (backup) driver behind the steering wheel. However, once the regulatory framework is in place and fully autonomous cars are technologically mature, their early deployment in carsharing-fleets is likely, because fully autonomous cars will facilitate the operation of free-floating carsharing-systems and expand their scope.

Autonomous free-floating shared vehicles will be more than the sum of their technological parts. The combined impact of the technologies ''free-floating, electric, shared'' (already offered today) with ''autonomous'' will help to reduce environmental problems resulting from traditional private car usage – which has not changed over the last century (Firnkorn and Müller, 2012). Burns indicated that to overcome car-related problems, ''[i]t is not enough to focus on better batteries or fuel economy or the automobile industry alone. The solution must meet the needs of all users, including business. Fortunately, the technology now exists to build an integrated network of driverless, electrical vehicles that are connected, coordinated and shared'' (Burns, 2013, p. 181).

Policymakers have already issued the first legislation allowing tests of autonomous vehicles on public roads (e.g. State of California, 2014; State of Michigan, 2014; State of Nevada, 2014; years indicating internet-source access, not legislation-enactment). Although there are many open questions regarding technical details, including self-driving algorithms (e.g. Kala and Warwick, 2013; Levinson et al., 2011), fully autonomous cars deployed in public carsharing-fleets within 1–2 decades appear a real possibility.

In the specific use-case of autonomous carsharing-vehicles, driverless technology would solve relocation-problems (e.g. Jorge et al., 2012) and reduce maintenance costs (e.g. by cars heading autonomously for maintenance stations to be charged and cleaned). In addition, the driverless technology would allow carsharing-vehicles to be parked without gaps and to move jointly to improve their efficiency. Will citizens in future smart cities request autonomous carsharing-vehicles by smartphone, allowing them to be picked up by and exit vehicles anywhere? Free-floating electric carsharing-fleets already operate today and they could herald the dawning of a post-private car era in urban environments.

4.3. *Methodological deficits of this study and possible improvements for future research*

This study has limitations. First, a potential selection bias from inviting newsletter-subscribers (Section 3.1). Second, the respondents' knowledge about the ''regional electricity'' in Ulm was not captured (Fig. 1), but the existence of hydroelectric power plants does not mean that people know of them, and this could have affected the results (Table 3). Third, the results of the split-sample comparison (Table 4) do not distinguish between correlation and causation (there could be a disproportionately high self-selection of people wanting to live car-free actively choosing electric-*car2go* over gasoline-*car2go*) – this will require longitudinal measurements.

Future research should attempt to overcome the indicated limitations under consideration of data protection laws, standard business conditions (regarding research), and the trade-off between survey length/complexity vs. response rate. For example, although urban density influences carsharing-impacts (Martin and Shaheen, 2010, p. 57), the authors excluded density-questions (e.g. on the respondents' home and workplace location) in the online survey because pre-tests indicated a risk of a fall in the response rate (in addition, the locally crude postcode-system in Ulm would have limited a density-analysis).

Follow-up studies should compare the stated willingness to reduce private cars with the realised car reduction, ideally using a statistical control group of non-carsharing-users who may also reduce their private vehicle stock over time. This information could help policymakers to understand how electric free-floating carsharing-fleets change the users' mobility behaviour relative to trends in society as a whole.

5. Conclusions

Free-floating electric carsharing-fleets could become an integral part of future smart cities. The analysis of *car2go* in Ulm (Section 3) is an early empirical glance at a globally emerging phenomenon for which policymakers currently have few empirical studies on which to base policies (Section 4). This article's contributions, a randomised controlled trial of electrification-scenarios and a split-sample comparison of users having driven electric vs. gasoline *car2go*-vehicles (Section 2), could support the development of policies increasing the environmental gains achieved through new carsharing-systems.

The introduction reflected on the birth of the automobile around 1900, a time when scientists believed that ''[f]or a man who only needs one horse a motor-car would be of no advantage'' (Charpentier, 1899, p. 1332). Are the long-term impacts of free-floating carsharing-systems equally underestimated in the year 2014? The authors hope that this article's prediction of a post-private car era based on free-floating carsharing-fleets will stand the test of time better than the historic believe that the automobile would not replace the horse. It has been indicated that a ''new thinking is mandatory as we move into the urban era of the 21st century'' (Valentine and Heiken, 2000, p. 231). This *new thinking* should be developed based on further empirical analysis.

Conflicts of interest

The authors are free of conflicts of interest regarding this article.

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