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Capturing the usage of the German car fleet for a one year period to evaluate the suitability of battery electric vehicles – a model based approach

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Abstract

The low driving range of battery electric vehicles (BEV) is often considered as relevant reason for the low BEV sales. In order to verify this assumption, the usage of conventional cars in Germany needs to be analyzed. These analyses may help to make more reliable and realistic statements to what extent German cars could be replaced by BEVs without restrictions for their users. Most travel surveys do only consider a single day or a short period of time in the analysis. Longer time periods should be taken into consideration when analyzing the travel data since the daily car usage is not identical every day. Since there are no representative and detailed car usage surveys over longer periods available a hybrid car usage model was developed to close that gap. This model is mainly based on three mobility surveys: the German Mobility Panel (MOP), the car mileage and fuel consumption survey, and the long distance travel survey INVERMO. We show that 13% of the modeled German private car fleet never exceeds 100 km per day during a full year and could be replaced by BEVs without any usage restrictions for their car owners. Another 16% of the modeled private car fleet is driven more than 100 km on 1-4 days during a full year and can be substituted with slight adjustments. These cars are often second cars of a household and used less intensively (6,600 km/year resp. 7600 km/year) than cars not suited for BEV substitution (14,800 km/year). Households that could replace their cars tend to have a lower disposable income. The crux of the matter, however, is that substitution of conventional cars is often not feasible since the mobility budget of BEV suited households tends to be too low or does not make economic sense due to the low annual mileage.

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Keywords: Car usage; daily car mileage; electric mobility; long distance travel; battery electric cars

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1. Introduction

The German Government targets to increase the electric vehicles' share in Germany to 1 million cars in 2020 (BMVBS, 2011). However, the penetration of electric cars is very low at present: in 2012 there were only 4,500 battery electric vehicles (BEV) and 47,600 hybrid vehicles registered in Germany (KBA, 2012). The low driving range, about 100 km under real life usage conditions, and the long recharging processes, which is six to eight hours with normal charging, of BEVs (ADAC, 2013) are considered as mayor reason for the low BEV sales. In order to verify this assumption, the usage of conventional cars in Germany needs to be analyzed. These analyses may help to make more reliable and realistic statements to what extent German cars could be replaced by BEVs without any restrictions for their users. Most travel surveys do only consider a single day or a short period of time, e.g. one week, in the analysis. However, the daily car usage is not identical over a certain period because the car owners use their car for daily routines, e.g. commuting to work as well as for rather seldom events such as holiday trips. Consequently, longer time periods, e.g. for a full year, should be taken into consideration when analyzing the car travel behavior.

2. Research question and literature analysis

In the first place, it is important to analyze how many cars of the German car fleet could be replaced by BEVs according to the cars' daily mileage observed over one year. However, we should also consider which types of cars could be replaced, how they are used over a year and what the owners' socio-demographic background is in order to evaluate the bare number of replaceable cars. Can households owning a replaceable car even afford to buy a BEV? Is it worth to replace a car by a BEV regarding its annual mileage or the owners financial situation? Considering these questions would probably lower the number of replaceable cars.

In order to answer these questions, a high quantity and quality of data is necessary. Several studies in the US (Gonder, et al., 2007; Bernard, 1996) try to estimate the potential of EV's with either National Household Travel Survey (NHTS) data or GPS survey data of one day. Bernard (1996) shows that 91 % of the vehicles that were used in the survey day travelled less than 161 km. These results may suggest the deduction that those cars could be replaced by BEVs. However, Aultman-Hall et al. (2012) notice that the lack of longitudinal data leads to an overestimation of EV's potential.

To our knowledge, only one longitudinal car travel survey is available. These data were conducted by GPS in the Atlanta, Georgia metropolitan area with a sample size of 470 cars that were observed 50 days to 3 years (Pearre, et al., 2011). They found that the share of cars that is not used for LD-travel is rather low: only 9 % of the cars in the sample never exceed 100 miles within a day during one year. This finding is in contrast to the results based on survey data covering only one day. Lin and Greene (2011) show that their results only based on uniform daily vehicle miles travelled differ significant from their results based on varying daily vehicle miles travelled considering the total energy use of PHEV's. Thus, the analyzed surveys must consequently be longitudinally oriented (periods instead of single days). This requirement explicitly excludes data of the usually cross-sectional oriented national travel surveys.

The idea and approach in this paper is to analyze, compile and collate the car uses for a longer period based on existing data of different granularity. We refined and developed the analysis approach of Chlond et al. (2011) further. The methodology allows identifying vehicles with different probabilities and frequencies of car uses for a period of one year. Therefore, we develop a "hybrid" approach which provides detailed estimations on the driving mileage for each day during the period of one year. These model data are used for a disjoint cluster analysis in order to identify cars that could be replaced by BEVs.

3. Data used

We use two mayor surveys which describe the everyday and the long distance mobility for our model: the German Mobility Panel (MOP) and the long distance survey INVERMO.

3.1. The German Mobility Panel

The MOP is one of the two national travel surveys for monitoring everyday mobility in Germany, which is regularly conducted by the German Ministry of Transport, Building Environment and Urban Development (Zumkeller, 2009; Zumkeller, et al., 1999). The survey collects data about all trips of the household members including start and end times, trip purposes, distances and means of transport used. Moreover, socio-demographic data of households (e.g. number of cars per household, net household income) and household members (e.g. sex, age) are gathered. The same households are surveyed repeatedly during three consecutive years, which offers the opportunity to observe changes in their mobility patterns.

In addition, the car-owning households within this sample are asked to participate in a fuel consumption and odometer reading survey (TANKBUCH) during eight weeks in spring. Consequently, the information of the MOP and fuel consumption and odometer reading survey can be combined on an intra-household base. The survey participants report all dates and mileages between any refuelling stops as well as the total car mileage and fuel consumption. Car related information such as fuel type, car segment and car engine power are additionally collected.

Our analysis is based on the data collected from 2005/06 to 2011/12. We will only take households into account, if they own at least one car, if all car users have reported and if they participated with all cars of the household at the TANKBUCH survey. The net sample amounts 2,438 households, 3,950 car users and 3,141 cars.

3.2. The LD-travel survey INVERMO

The LD-travel survey INVERMO was used in order to gain comprehensive information on the characteristics of long distance car trips (Zumkeller, et al., 2006). LD-trips are defined as trips with a minimum distance of 100 km between a journey's origin and destination. Data were conducted from October 2000 until May 2002.

17,000 persons are interviewed regarding their socio-demographic situation (e.g. number of cars per household, net household income, sex) and mobility behavior (e.g. commuting distance, number of LD-journeys within the last three months). In our analysis, 10,818 long distance car journeys are included.

4. The hybrid approach

We have created the model CUMILE (car usage model integrating long distance events) in order to compute a car's mileage per day during a full year. Even though the data of the German Mobility Panel give a great amount of relevant information for the survey period of one week, further assumptions and other mobility data are needed to investigate the car mileage per day on a longitudinal perspective. As travel survey data over one year are not available, we have combined data on different levels of information and granularities.

The model consists of three parts (see Fig.1). First, the individual mobility data of survey participants during the MOP week are analyzed in order to derive car mileage per day during the survey week and car mileage during a normal week. In the second part, car mileage per day during the period of the fuel consumption and odometer reading survey is calculated. Third, car mileage per day for the remaining days of the year is modeled.

4.1. Summing up the car usage of one week

An explicit identification of a specific car for a trip of an individual is not possible in the MOP (i.e. people report that they have used a car as driver but they do not report which car of the household they have used). We have developed an assignment procedure of cars to individuals in order to close this gap. We use the data of the MOP and of the refuelling survey in order to approximate the daily mileage of a specific car during the MOP week.

The assignment of cars to individuals allows us to calculate the daily mileage of all cars in the sample during the MOP-week. Due to the scope of our research we need to know the car mileages on typical weekdays and on days of the weekends. The survey participants report their trips for every day within the survey period and whether this day was more or less *normal* or rather particular, i.e. that a car is under repair or the car user is ill or on holidays. This information allows us to anticipate the daily mileage of the cars in the sample on *normal* days. A heuristic is developed in order to reconstruct the typical car mileage of days with certain events.

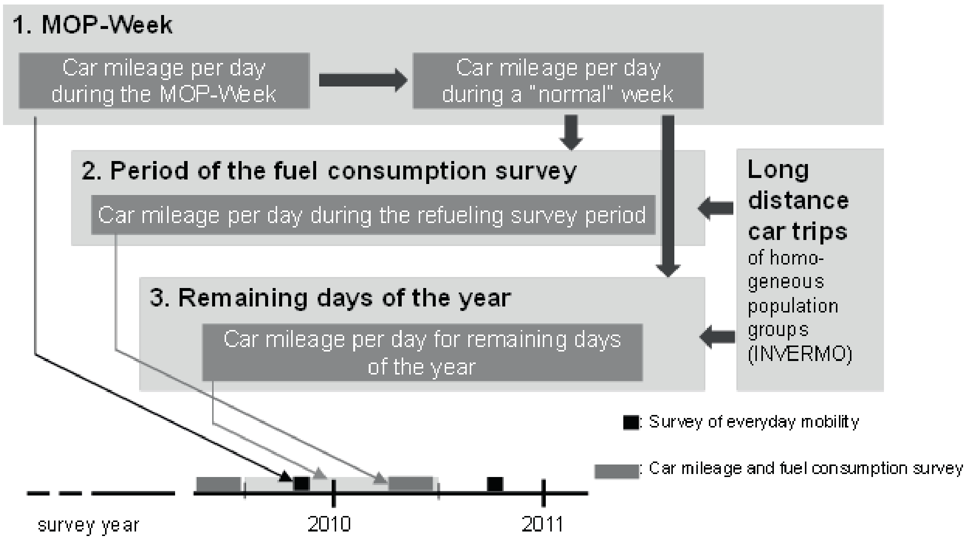

Figure 1. Structure of the car mileage model.

4.2. Assigning and determining the car mileages for a period of 8 weeks

Beyond the detailed car usage data of the MOP survey period car usage data for a period of 8 weeks are provided by the odometer reading and fuel consumption survey in the identical households.

The calendar dates and the distances covered between two refuelling processes are input data for this model step. The daily car mileage during a normal week is furthermore known. In addition, data of more than 10,000 long distance car journeys are provided by the INVERMO survey. Tests were carried out in order to find a link between socio-demographic characteristics of households and their long distance car travel behavior (Manz, 2005). We conclude that households within the same level of household income, who belong to the same household types, and who are situated in the same spatial type, show similar long distance car travel behaviors. This assumption leads to 84 different socio-economic groups with similar long distance car travel behavior. We suppose furthermore that the car mileages of *normal* days within the MOP-week are more or less identical in the course of one year. This assumption is reasonable as most of the trips made during one year are frequently repeated, such as e.g. commuting or daily shopping trips (Verreault & Morency, 2011).

For the period between two refuelling procedures, the car mileage on the days between refuelling procedures is first assumed to be equal to the car mileage on a *normal* survey day. If the car mileage between two refuelling procedures is less than the sum of car mileage of typical days, daily car mileage is set to zero on randomly selected days. Our analysis of car days with particular events shows, that on these days cars are frequently not used at all. If the car mileage between two refuelling procedures is higher than the sum of car mileage of typical days, the model will test whether a LD-trip within this refuelling period is feasible. In this case, a suitable long distance car trip with certain trip characteristics (distance to journey destination, weekday of journey start, duration of the journey, average daily car mileage at travel destination) for the special socio-demographic group is randomly selected. During the LD-journey period, the *normal* car mileage of the affected days is replaced by mileage of the distance of the journey on this day. The case of LD-journeys affecting more than one refuelling period is also included in the model. If a LD-journey within this period is not (any more) feasible, the unexplained mileage will be added on all *normal* days within the refuelling period using a constant summand. This procedure is repeated until the daily car mileage of all days within the refuelling period is calculated, given that the car mileage between two refuelling procedures is represented correctly in the model.

4.3. Assigning and determining the car mileages for the remaining days of one year

All the remaining days of one year which are neither in the MOP survey period nor in the fuel consumption and odometer reading survey have to be considered in an appropriate and adequate level of detailing using a similar approach than in model step 2.

Again, we assume that the car mileage on those days, which are not yet considered, equal the car mileage on a typical day of the *normal* MOP-week. If the total of all daily mileages during the refuelling survey period, MOP week and typical daily mileage on the remaining days, is smaller than 95 % (respectively 85 % if a cars annual mileage does not exceed 5,000 km) of the annual mileage, it is assumed that the car was used for LD-trips. This procedure is repeated until the total of modelled daily car mileages matches the 95 % criteria of the car's annual mileage. If the reported annual car mileage exceeds by up to 5 percentage points the modelled car mileage, unexplained km will be added on typical days of remaining days of the year using a constant summand. If the annual mileage is lower than the intermediate model results, daily car mileage is set to zero on randomly selected days. This procedure is repeated until the model results are in accordance with a car's annual mileage as reported in the survey.

Altogether, this model step 3 provides the car mileages per day for the all days of a year which have not been covered yet. Thus, the coincidence and accordance with the empirical data is ensured.

5. BEV capability to replace the conventional car fleet in Germany

CUMILE gives detailed information of the daily mileages distributions of the German car fleet for the period of one year. Such information is essential for the analysis of the substitution potentials of conventional cars by BEVs in Germany. Therefore, we cluster the private car fleet in Germany by the cars' daily mileage observed over one year. Furthermore, we analyze the characteristics of the cars and car owners as well as the car usage in the different clusters.

5.1. Clusters of car usage

In order to analyze what share of the German car fleet could be substituted by BEVs according to their usage during one year we have created disjoint car usage clusters. The clusters are based on a cars mileage per day. As BEVs have a theoretical driving range of about 130 km (ADAC, 2013) and an estimated driving range of 100 km considering factors as heating and air-conditioning. We also assume that the BEVs are only recharged overnight. Cars in the sample are ranged in the following clusters:

- BEV suited cars without adjustment: cars that are never used more than 100 km/day during a full year. Car owners would not have to adjust their mobility behavior if they own a BEV instead of a conventional car.
- BEV suited cars with slight adjustments: cars that are used more than 100 km/day on one to four days per year. Cars in this cluster could be substituted by a BEV if car owners adjust their mobility behavior (e.g. use the train instead of the car, rent a conventional car) on about one day every three months.
- Not BEV suited: cars with a daily mileage of more than 100 km/day on at least 5 days per year. These cars could only be substituted by BEVs if car users would accept substantial changes in their usage behavior. We assume that car owners are not willing to do so, as their budget will be burdened due to the high purchase price of BEVs anyway.

Table 1. Clusters of the German car fleet according to their BEV substitution potential.

	German car fleet [%]
BEV suited without adjustments	13.1
BEV suited, slight adjustments	15.5
Not BEV suited	71.4

The share of the different usage clusters is shown in Table 1. This analysis indicates that the majority of the German car fleet – 71.4% – is not suited for BEV substitution to our criteria. The car owners of about half of the cars suited for BEV usage do not need do adapt their mobility behavior.

5.2. Characteristics of the car fleet

Not only the questions on how many cars but also what kind of cars could be substituted is essential for e.g. car manufacturers in order to adjust their BEV supply to the needs of potential car buyers.

Figure 2 indicates that the share of small and middle class cars (45 % each) in the BEV suited cluster without adjustments is higher than in the other clusters. 45 % of the cars that can be replaced by BEVs are small cars. On the other hand, 81 % of the upper class cars cannot be substituted by BEVs. This analysis points out that car manufacturers should rather offer BEVs in the small and middle class segment. Second (39 %) and third cars (43 %) of a household are rather suitable for BEV substitution than first cars (25 %) of a household.

Figure 2. Car segment distribution in different usage clusters.

Figure 3 reveals that cars in the clusters suited for BEV substitution are rather older than the not BEV suited cars. Only 14-16 % of the cars in the BEV suited clusters are aged between 0 and 3 years old. Furthermore, 80 % of the new (0-3 years old) private car fleet is not suited to be replaced by BEVs.

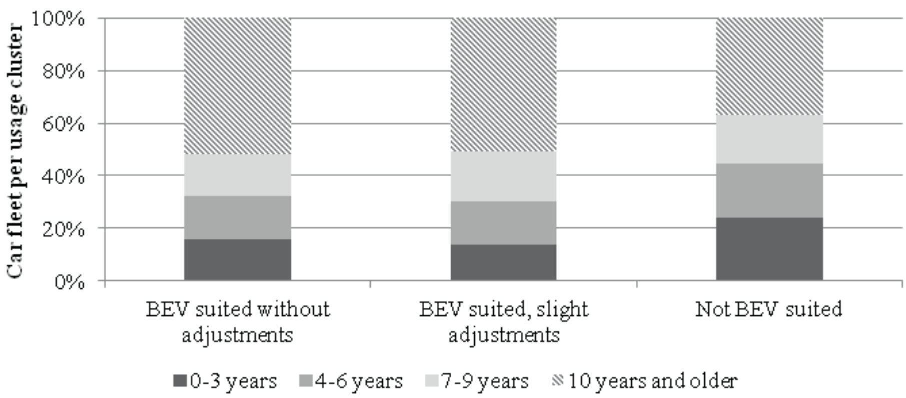

Figure 3. Car age distributions in different usage clusters.

Our analysis indicates that cars suited for BEV replacement are rather old small and medium sized second cars. This could imply that a household's mobility budget for such a car tends to be smaller than for a car in the not BEV suited cluster.

5.3. Characteristics of car usage

Next, the car usage characteristics of the different car clusters in analyzed. Figure 4 shows that cars that are not suited for BEV substitution are used more intensively: their medium annual mileage is twice as high as the medium annual mileage of the two other clusters. Only 25 % of the cars in the BEV suited clusters have an annual mileage of more than 9,000 km (substitution without adjustments) respectively 10,000 km (substitution with slight adjustments). Due to the high purchase prices but low usage costs, Michaelis et al. (2013) suggest that the purchase of a BEV will be only economically feasible, if a car's annual mileage is high. This means that BEV substitution is only economically feasible for a small share of cars in the BEV suited clusters.

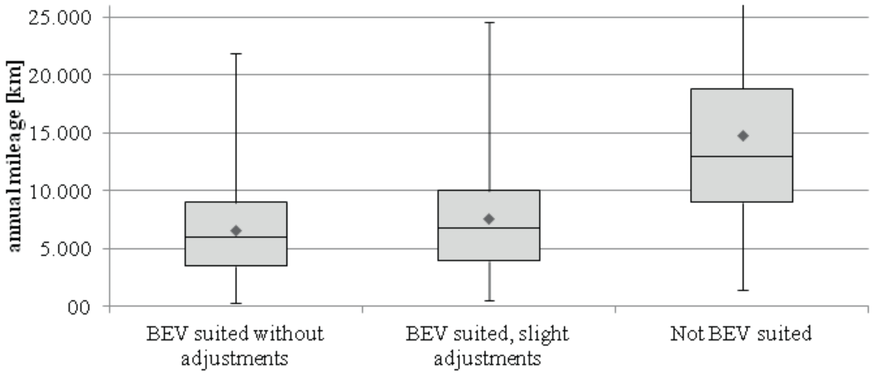

Figure 4. Distributional properties (mean, median, lower and upper quartile) of the annual mileage for different usage clusters.

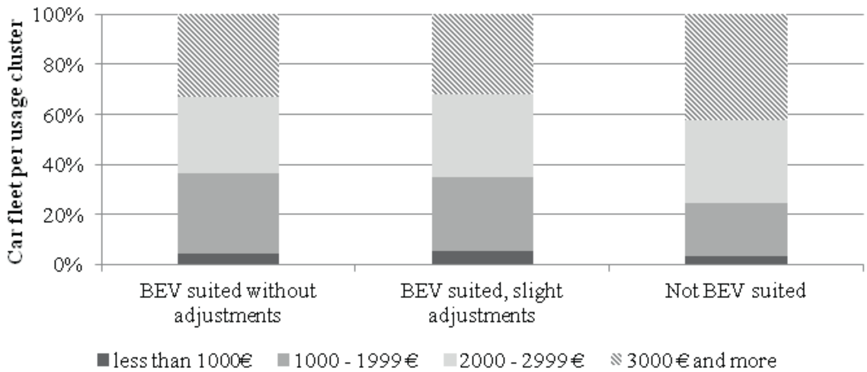

Figure 5. Distribution of disposable household income per month in different car usage clusters.

One reason for the significant differences in the annual mileage distribution between the clusters is the maximum daily mileage, of course, and the long distance car travel intensity. We point additionally out that the number of days in which a car remains unused is highest within the BEV substitution cluster without adjustments (154 days per year on average) and lowest within the cluster of cars that are not suited for BEV substitution (119 days per year on average).

5.4. Characteristics of car owners

This section examines important socio-economic characteristics of car owning households that are suited to replace their car according to their current car mobility behavior.

The group of households that have less than 2,000 € per month disposable is bigger (35-36 %) than in the group of households that will not replace their cars (24 %). 77 % of the cars that are owned by households with a disposable income of 3,000 € per month and more are not suited to be replaced by a BEV.

The regional distribution of the household place of living is in all the clusters similar. 44-46 % of the cars in each cluster are owned by household living in rural areas. Another 27-28 % of the cars belong to car owners who live in suburban respectively urban regions. Most of the car owners (82-86 % in each cluster) do park their car in their own garage or parking space. This is crucial when substituting a car by a BEV (Biere, et al., 2009) as most BEV users recharge their BEV at home. However, we do not have any information if it is technically feasible to install a private recharging infrastructure in their garage or next to their private parking place.

6. Conclusion

We presented a methodology in order to analyze the car mileage of the private car fleet in Germany per day during the period of one year. Due to the lack of appropriate empirical car usage data we evolved the hybrid modem CUMILE which uses empirical input data with different granularities. The disjoint cluster analysis which is based on the model data enables an identification of cars that could be replaced by BEVs according to their current usage characteristics.

Our analysis shows that the car 13 % of the vehicles of the German car fleet could be replaced by a BEV without restrictions in their mobility behavior for the car owners though. Cars suited for BEV replacement are rather old small and medium sized cars. These vehicles are often second cars or cars that are owned by households with a lower income. This could imply that a household's mobility budget for such a car tends to be smaller than for a car in the not BEV suited cluster. Cars suited for BEV replacement also tend to have a low annual mileage. This result conflicts with the fact that only BEVs with a high annual mileage are economically feasible.

Our analysis gives a broad overview of the characteristics of cars that could be substituted by BEVs according to their usage characteristics over one full year. This analysis is a valuable basis for BEV market forecasts. Furthermore, the approach can be refined to the mileages of single trips instead of days, in order to identify places and times of electric vehicle charging. This would give additional scope e.g. for energy providers as the model could support calculating the electric vehicles demand for energy.

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