*EVS26*
*Los Angeles, California, May 6 - 9, 2012*

# Vehicle charging infrastructure demand for the introduction of plug-in electric vehicles in Germany and the US

Till Gnann*, Patrick Plötz, Fabian Kley
**till.gnann@isi.fraunhofer.de*
Fraunhofer Institute for Systems and Innovation Research ISI,
Breslauer Strasse 48, 76139 Karlsruhe, Germany

**Abstract**

Charging infrastructure for plug-in electric vehicles (PEVs) is a widespread topic of discussion. Several experts suggest investments are necessary to develop charging infrastructure outside the home, e. g. at public or semipublic locations, while others advise against this. In this paper we analyze the impact of upgrading charging infrastructure on potential PEV-usage. We use two large data sets of driving behavior from the United States and Germany to study the technical possibility of replacing a conventional car with a battery electric vehicle (BEV) and the share of distance driven in electric mode for plug-in hybrid electric vehicles (PHEVs) in different charging infrastructure scenarios.
Our results show that high shares of vehicles ($>$ 65 % in a weekly analysis and $>$ 90% in a daily analysis) could be operated as BEVs with a 20 kWh net capacity assuming only home charging in the US as well as in Germany. The vast majority of drivers ($>$ 90 %) could cope more than 80 % of their daily driving distance in electric mode in both countries in plug-in hybrid electric vehicles with a 10 kWh net capacity. These shares could be increased if additional charging infrastructure was installed at non-private locations, while increasing the available domestic power rate does not have a significant impact.

*Keywords: infrastructure, BEV (battery electric vehicles), PHEV (plug-in hybrid electric vehicles), electric drive, battery charge*

## 1 Introduction

Electric mobility has been a topic for many years, and enjoyed real hypes around 1900, in the 1990s and once again in the last years, replacing the hydrogen hype of 2000 [1, 2]. Not only the independence from the limited supply of fossil fuels, the reduction of noise pollution at low speed or high energy efficiency are common attributes pro PEV, but electric vehicles also have the ability to significantly reduce GHG-emissions if they are powered with electricity produced from renewable or other low-carbon energies [1, 3].

Despite all the potential advantages of electric vehicles, their limited electric driving range is a real disadvantage. This seems to imply the need for public, semipublic or (if not available) additional home-based charging infrastructure for battery electric vehicles (BEV) to recharge while parked during the day. While plug-in hybrid electric vehicles (PHEV) solve the ”limited range problem” (having an internal combustion engine for range extension on board), they need to drive a significant share of kilometers in electric mode to benefit from lower operating cost and to reduce their total cost of ownership (TCO) [4].

From a technical point of view, users of plug-in electric vehicles (PEVs) should not drive too far per day since they have a limited electric driving range. From an economic angle, driving long distances in electric mode is necessary to amortize the higher investment costs of electric vehicles with lower variable cost for electricity compared to fossil fuels in order for PEVs to be attractive alternatives to conventional vehicles. In this paper we will focus on the technical components of this optimization problem when analyzing the driving behavior and existing current infrastructure options in the United States and Germany in order to answer the following main question: What is the impact of upgrading charging infrastructure on potential PEV-usage? To be more precise, we study the effect of charging infrastructure on the possibility of replacing a conventional vehicle by a BEV as well as the impact on the electric driving share of PHEVs. We choose the US and Germany because they are both industrial nations making high investments in the research and development of electric mobility, but differ in terms of driving behavior and current infrastructure. By considering these differences we assume to obtain a better understanding of the influence of charging infrastructure and driving behavior on PEV adoption and for this reason the probable adoption of PEVs in the US and Germany.

In the following section we will introduce the data sources for driving behavior as well as the current infrastructure options for the US and Germany. Section 3 explains the methods and parameters used for the analysis, while the results are shown and explained in section 4. A discussion and conclusions are presented in section 5.

# 2 Driving Profiles and Charging Infrastructure

Comparing the driving behavior of German and US citizens in light-duty vehicles, we quickly observe the higher number of vehicle kilometers traveled (VKT) per year in the US with approximately 18,000 km per year, while Germans drive around 14,300 km [5, 6]. Calculating the arithmetic average results in around 49 km/day for American car users and circa 39 km/day for German drivers (knowing that most drivers drive less on week-ends). For a PEV with an average energy consumption of 20 kWh/100 km, the (net) capacity of a battery for an average driver would be around 10 kWh for American drivers and circa 8 kWh for German drivers.[1] In this simple calculation based on averages we clearly miss two important points: Firstly, not all drivers drive in the same way and they do not all drive cars of the same size. Secondly, cars could be charged during the day if charging infrastructure were available, which could lead to a reduction of the necessary battery capacity.

## 2.1 Driving behavior

To get an idea of the actual capacity needed for plug-in electric vehicles, we use driving profiles of cars and simulate the capacity of a battery. For German driving behavior, we use the Mobility Panel (MOP), which is a data collection of 12,812 households, who reported their outdoor movements for one week [7]. The survey is performed annually, the data shown below uses all data from 1994–2008. Since the records contained all the movements of persons in a household (and not only the journeys made by car) and because these are person-specific, we allocated movement profiles to cars if possible unambiguously (for further details see [8]). This reduced the movement profiles to 6,629 car-specific driving profiles in total. As the sample does not contain car size information, we assumed all vehicles to be medium-sized, as this is the largest car size segment in Germany with almost 55 % [9].

The U.S. Department of Transportation collected data from around 250,000 people in the 2009 National Household Travel Survey (NHTS) with a total of 1,500,000 single trips collected in 2008 and 2009 [10]. We used only those trips made by cars of medium and large size to obtain a comparable data set.[2] This led to a data set of nearly 720,000 single trips driven by some 180,000 cars. A significant difference between the American and German driving profiles is the time horizon over which car-specific driving profiles were collected. In MOP we have car-specific driving profiles for one week, while the NHTS data is just available for one day. We will discuss the implications of this difference in the following sections.

In Figure 1 we display the cumulative distribution function over the vehicle kilometers traveled (VKT) per day, showing the percentage (abscissa) of the sample which drives less or equal to the daily driving distance in the ordinate.[3] We

[1] The net capacity is usually around 75 % of the gross capacity, because only a specific share of the capacity is used in order to not fully load or unload the battery due to lifetime reasons. In this paper we will only regard net capacities.

[2] We included cars as medium-sized vehicles and vans, SUVs and pickup trucks as large vehicles. All other modes of transportation (ranging from motorcycles over shuttle buses to commuter trains) were excluded.

[3] The cumulative distribution function is given by the frequency $P(i)$ of value $i$ cumulated over the full sample: CDF($k$)= $\sum_{i\leq k} P(i)/\sum_j P(j)$.

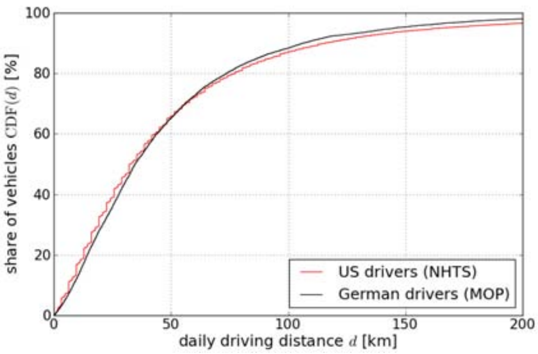


Figure 1: Cumulative distribution function of daily driving distances of American and German drivers. The selected subsample is taken from MOP and NHTS as described in section 2 and analyzed by summing up trips for every day. US sample in red, German data set in black, distance in km, CDF($d$) in %.

observe that the distributions of daily driving distance of German (black) and US drivers (red) are almost the same, which means that driving patterns in the two countries do not differ as much as expected.[4] For both countries, around 65 % of the sample drive less than 50 km (≈31 miles) per day, while only 5 % of the German sample and 7 % of the US sample drive more than 150 km per day.

## 2.2 Charging Infrastructure

As mentioned before, cars could also be charged during the daytime, thus reducing the necessary battery capacity. Therefore it is relevant to the battery capacity simulation if and which type and power of charging infrastructure is available at the different stopping locations. Earlier studies show that Germany's existing infrastructure has usually a higher power at lower electricity levels [8, 11].[5]
Level 1 infrastructure, which is common in households, amounts to 1.44 kW or 1.92 kW in the US if not upgraded. In Germany, the lowest current level is 3.7 kW. At level 2 in the US, 9.6 kW is common which can be raised to 150 kW at level 3 for DC fast charging. The German level 2 is at 11.1 kW, while level 3 amounts to 22.2 kW. In Germany, a 4th current level with 43.6 kW is being discussed, which can be increased up to 100 kW for DC fast charging. Not all of these current levels will be available at every location where vehicles stop, which means that, for drivers of PEVs, it is important where they park their car. It is common to distinguish between three different types of charging locations: private, semipublic and public [12, 13]. Private sites are only accessible to the car owner, while public facilities like charging stations at public car parks are open to everyone. Semipublic locations are accessible to a specific group, e. g. the members of a sports club, or employees of a company. Table 1 shows the power levels available in principle at charging infrastructure locations with the corresponding power rates.[6]

Table 1: Locations and power levels for charging infrastructure in the US and Germany [kW]

| US | private | semipublic | public |
|---|---|---|---|
| level 1 | 1.44–1.92 | 1.92 | 1.92 |
| level 2 | 9.6 | 9.6 | 9.6 |
| level 3 | - | 60–150 | 60–150 |
| GER | private | semipublic | public |
| level 1 | 3.7 | 3.7 | 3.7 |
| level 2 | 11.1 | 11.1 | 11.1 |
| level 3 | 22.2 | 22.2 | 22.2 |
| level 4 | - | 43.6–100 | 43.6–100 |

As US drivers drive longer distances on average and the German infrastructure has higher power (especially at the lower power levels), we are led to expect that the US charging infrastructure at home might be insufficient for plug-in electric vehicles. Therefore we will analyze the impact of charging infrastructure in a battery profile simulation explained in the next sections.

# 3 Methods and scenarios

With the driving profiles described above we calculate the state of charge (SOC) of a battery for a specific point in time $t$ as follows:

$$\mathrm{SOC}(t+1) = \begin{cases} \mathrm{SOC}(t) - d_{\Delta t} \cdot c_{size} & \text{for } d_{\Delta t} > 0 \\ \min\{\mathrm{SOC}(t) + \Delta t \cdot P_{loc_t}, C\} & \text{for } d_{\Delta t} = 0 \end{cases}$$

where the initial value is given by $\mathrm{SOC}(0) = C$. Here $\mathrm{SOC}(t)$ denotes the state of charge at the point of time $t$. The distance driven between the two points of time $t$ and $t + \Delta t$ is given in km

[4] This could derive from the exclusion of commercially used vehicles in both data sets.

[5] These power levels are taken from the vehicle charging infrastructure standards being discussed for both countries and depend on existing charging infrastructure options as well as considered standards [8].

[6] These infrastructure options will be used to define charging infrastructure scenarios in table 2.

in $d_{\Delta t}$, while $\Delta t$ in hours is the time difference. The consumption of electric power in kWh/km is (depending on the car size) denoted as $c_{size}$. Furthermore, $P_{loc_t}$ in kW describes the power for charging at the location where the car was parked at $t$. If no charging infrastructure is available, we have $P_{loc_t} = 0$. $C$ in kWh describes the capacity of the battery analyzed. Therefore, the equation says that if the car is driven (case 1), the battery will be discharged by the energy needed for driving distance $d_{\Delta t}$. Otherwise (case 2), it will be charged with the power $P_{loc_t}$ for the time $\Delta t$ if necessary and charging infrastructure is available ($P_{loc_t} > 0$).

Now we assign values to all variables for the following analysis. We use time sections ($\Delta t$) of 0.25 hours (15 minutes) for the profile generation and record the starting and stopping time, the stopping location, the distance traveled in this time period and – if available – the car size from the two data sets. As consumption parameters we use $c_{medium}$ = 0.194 kWh/km for medium-sized cars and $c_{large}$ 0.239 kWh/km for large cars as in [14].

The power to charge depends on the infrastructure options in Table 1. Since it is not useful to look at all possible infrastructure options, we created three scenarios with comparable infrastructure options in Germany and the US according to the infrastructure standards being discussed for PEV [8]. Scenario 1 is called "home-only" scenario and includes only private charging locations with a power rate of 3.7 kW in Germany and 1.44 kW in the US.[7] Scenario 2 named "home-and-semipublic" assumes the same charging options as scenario 1 plus a 9.6 kW charging option for the US and 11.1 kW for Germany at semipublic locations. The third scenario allows an additional 9.6 kW charging option for the US and a 11.1 kW charging possibility for German drivers at public facilities and is therefore called "everywhere" scenario. These three charging scenarios are listed in Table 2.[8]

Now we generate driving profiles depending on the capacity $C$. For BEV, we set $C = 0$ to find the maximum capacity needed (as a negative value); for PHEV, we look at the net capacities 5 kWh, 10 kWh and 15 kWh and calculate the electric driving shares as all non-negative consumption during the whole observation period in comparison to the total consumption.[9] The results of these simulations are explained in the following section.

[7] Here we added scenario 1b with a power rate of 9.6 kW for the US to have a closer look at the effect of increasing the power rate at home.

[8] We exclude fast charging in this analysis due to its high installation cost and the long stopping times during the day where fast charging options are not necessary. See [8].

Table 2: Charging infrastructure scenarios with power rates [kW]

| US | private | semipublic | public |
|---|---|---|---|
| home-only | 1.44 | - | - |
| home-only b) | 9.6 | - | - |
| home-and-semip. | 1.44 | 9.6 | - |
| everywhere | 1.44 | 9.6 | 9.6 |
| GER | private | semipublic | public |
| home-only | 3.7 | - | - |
| home-and-semip. | 3.7 | 11.1 | - |
| everywhere | 3.7 | 11.1 | 11.1 |

# 4 Results

## 4.1 Battery Electric Vehicles

For battery electric vehicles we calculate the minimal battery capacity needed with the simulation mentioned above to receive the share of drivers that could drive with the same capacities. We show these results in Figure 2 as a cumulative distribution function[10] over the battery capacity $C$, which can be interpreted as the share of drivers in the data set who could replace their car with a BEV based on their driving behavior. In the left panel of the figure we see the results of infrastructure scenario 1 where cars can only charge at home. The blue curve shows the results for Germany with the whole week as the observation period. The black one shows the daily analysis, while the two red curves show the US results varying by power to charge.

Firstly, we can observe the influence of the observation period if we compare the two curves for Germany (driving on a single day and driving a whole week). For a net battery capacity of 10 kWh, around 45 % of weekly driving profiles would be feasible with a BEV, compared to almost 75 % of all daily German profiles. Thus the difference between weekly and daily driving profiles demonstrates the occurrence of a few longer trips that are not covered by analyzing daily driving profiles, but have a significant effect on the substitutability of conventional vehicles. This

[9] All negative values for the SOC would in reality be driven with the internal combustion engine.

[10] The cumulative distribution function is given by the frequency $P(i)$ of value $i$ cumulated over the full sample: CDF($k$)= $\sum_{i \leq k} P(i) / \sum_j P(j)$

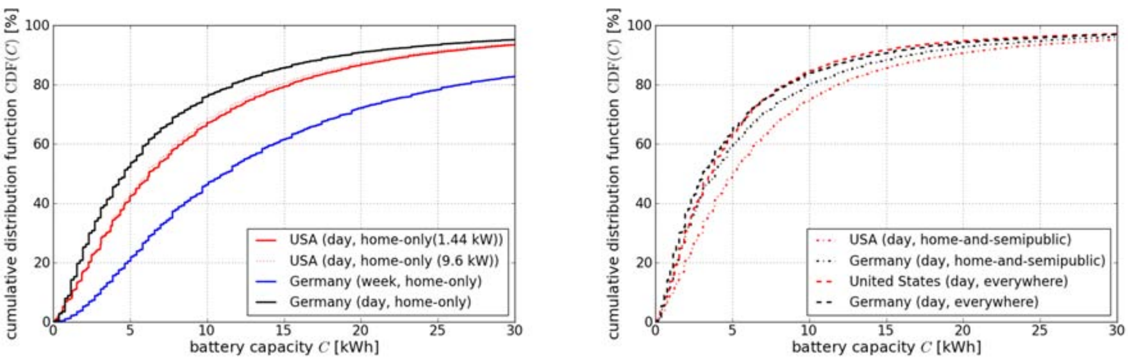


Figure 2: Cumulative distribution function as share of cars that could be replaced by a BEV with the given net battery capacity. *Left panel*: Results for the home-only charging infrastructure scenario with solid lines and an augmentation of power in the US with dotted lines for the country-specific driving data sets (Germany week: blue, Germany day: black, USA day: red). *Right panel*: Results for home-and-semipublic charging infrastructure (dotted) and everywhere infrastructure (dashed and dotted) for the country-specific driving data sets (Germany day: black, USA day: red), battery capacities $C$ in kWh, CDF($C$) in %.

underlines the necessity to compare only the German daily analysis with the US.

Secondly, the difference between the two red curves, the dotted line showing the results with increased power in comparison to the continuous line, is nearly indiscernible. Therefore increasing the domestic power level would not considerably increase the share of cars that could technically be replaced by a BEV.[11]

Thirdly, comparing the red continuous curve with the black curve, i. e. the American and German daily driving profiles, we observe higher shares of BEVs in the German sample with the same battery sizes. Since the charging power does not seem to be very relevant to the results in the US sample, the longer distances and shorter times at a private location must be decisive for these results.

The right panel of Figure 2 displays the effect of additional charging infrastructure. We see the US (red) and the German daily results (black) for the other two infrastructure scenarios: home-and-semipublic (dotted) and everywhere (dotted and continuous). Comparing the two home-and-semipublic curves for the German and US data set, we can still see a difference and higher shares of BEVs in Germany for the same battery capacities, although the gap between the two curves is smaller than in the home-only scenario. On the other hand, there is no significant difference between the two countries in the everywhere-scenario.

Assuming a battery with 10 kWh net capacity for all three infrastructure scenarios in the US sample, we find 67 % in the home-only scenario, 75 % in the home-and-semipublic and 85 % in the everywhere-scenario. With the same battery for the German sample, the home-only scenario yields 76 %, home-and-semipublic 80 % and the everywhere-scenario 84 %. These results indicate that developing charging infrastructure for BEV in more public and semipublic locations could lead to an additional 18 % of drivers who would be able to drive a BEV due to their driving profiles in the US and a 10 % increase in the German sample. This is in agreement with earlier studies for Germany [15].

To sum up the BEV analysis, we observed five main findings:

- The observation period of one week shows significantly lower shares of replaceable BEVs in the German sample and is therefore a relevant impact factor for the analysis.
- An increase in the domestic power rate in the US does not result in a significant increase in the shares of vehicles replaceable by BEVs with the same battery capacities.
- Drivers in the US sample need higher net battery capacities to replace a vehicle by a BEV than German drivers in their data set if charging infrastructure is only available at home or additionally at semipublic locations.
- With widespread charging infrastructure where BEVs can charge nearly everywhere,

[11] A higher power rate might still be necessary though, since short overnight stops in combination with low power rates might be insufficient to fully recharge. This is not covered by this analysis as we only analyze driving profiles for one day.

German and US sample drivers show similar minimum battery capacities.

- A development from a limited (home-only) to a widespread (everywhere) charging infrastructure would result in an increase of 10 % for German and 18 % for American drivers in the sample who could make all their daily trips with a net battery capacity of 10 kWh.

## 4.2 Plug-In Hybrid Electric Vehicles

As plug-in hybrid electric vehicles have an additional internal combustion engine, their technical replaceability is to a certain extent no longer relevant, as the range extender allows longer distances to be driven. However, as described in section 1, it is necessary for a PHEV to drive a significant share of all trips in electric mode in order to be competitive to a conventional vehicle. Hence we analyze the daily distance driven in electric mode as a proportion of the total daily distance. We specify this as electric driving share $s_E$.
The electric driving share is calculated for every driving profile by analyzing the state of charge (SOC), as mentioned above, and is dependent on the battery capacity. Thus we analyze battery capacities of 5, 10 and 15 kWh and show the results for 10 kWh in Figure 3 in a histogram[12] of the electric driving share in the left panel and several cumulative distribution functions[13] of electric driving shares in the right panel. Looking at the last bin in the left panel, we can clearly see that a high share of vehicles is able to drive completely in electric mode. We can observe this result more easily in the cumulative distribution function in the right panel of the figure for the same data. As the abscissa in this graph is reversed, the first value of each curve at 100 % corresponds to the last bin in the histogram, while the subsequent values show driving shares smaller than 100 %. The top blue curve, which is the weekly German driving profiles in the home-only infrastructure scenario, belongs to the histogram in the left panel and can be read from top to bottom. Almost 50 % of drivers would drive in completely electric mode.[14] Upgrading infrastructure to the everywhere scenario (blue dotted curve) would add 18 % to the drivers able to drive completely in electric mode. More interesting are the red (US) and black (German) curves for home-only infrastructure (continuous) and infrastructure everywhere (dotted) scenarios. With a net battery capacity of 10 kWh, already 80 % in the US sample and 85 % in the German one could drive a PHEV fully electrically with home-only infrastructure. An infrastructure upgrade would result in an additional 10 % for the US and 5 % for the German data set. We can also see that, for an electric driving share of less than 60 %, the infrastructure is almost irrelevant, and around 90 % would already reach a higher share.
A further analysis of the electric driving share shows that the influence of charging infrastructure also depends on the battery size.[15] In the simulation of the electric driving share with a net battery capacity of 5 kWh, we perceive 42 % of US sample drivers who could drive fully electrically in the home-only scenario. If we change to the everywhere infrastructure scenario, we find an additional 20 % which sums up to 62 % of drivers able to drive fully electrically. For the German sample with the same battery capacity we observe an increase of 10 % from 53 % to 63 %. By changing the battery size to 15 kWh, we find 92 % as fully electric drivers for the US and 93 % for the German sample in home-only infrastructure and 97 % for both country samples in the everywhere infrastructure scenario. This means increasing battery size from 5 to 10 kWh (by 5 kWh) returns an additional 38 % (80–42 %) while augmenting of infrastructure options from home-only to everywhere infrastructure returns just an additional 20 % (62–42 %). We clearly have to consider who is carrying the cost of these influencing factors, but from a simple technical point of view, it is more effective to increase battery size.
Summing up, we can identify four main findings for PHEVs:

- There is a significant influence of the observation horizon on the electric share of plug-in hybrid electric vehicles shown by comparing the results for Germany in the daily and weekly analysis.

- With a small net battery capacity (5 kWh) in a limited charging infrastructure (home-only), we still have a high share of fully

[12] A histogram shows the frequency $F(i)$ for value $i$, normalized to unity: $\sum_i i \cdot F(i) = 1$ with a variable number of bins.

[13] The cumulative distribution function is given by the frequency $P(i)$ of value $i$ cumulated over the full sample: CDF($k$)= $\sum_{i \leq k} P(i) / \sum_j P(j)$. We reversed the abscissa since we want to look at all vehicles that cannot drive fully electrically.

[14] This also corresponds to the blue curve in the left panel of Figure 2.

[15] These results are not shown in figures.

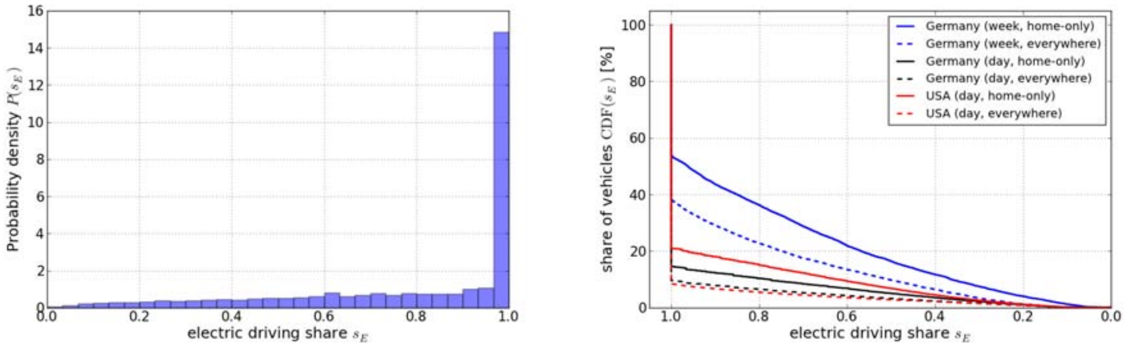


Figure 3: Analysis of electric driving shares for plug-in hybrid electric vehicles with a battery capacity of 10 kWh. *Left panel*: Histogram for home-only infrastructure in German weekly data set. Note that the probability density is normalized to unity, i. e. $\sum_i i \cdot P(i) = 1$, despite the large bar $(P(0.967 < s_E \leq 1.0) \approx 14.8)$ at $s_E \approx 0.98$. *Right panel*: Cumulative distribution function over electric driving shares using the underlying infrastructure scenarios (home-only: solid line, everywhere: dashed line) and driving data sets (Germany week: blue, Germany day: black, USA day: red) with reversed abscissa to observe especially partly electric drivers. Cumulative distribution function in %, other without unit.

electric drivers in the US (42 %) and the German daily sample (53 %).

- An average-sized battery ($C$=10kWh) allows more than 85 % of daily drivers in the US (85 %) and Germany (90 %) to have an electric driving share of more than 80 % with a PHEV, even in a limited infrastructure (home-only). The number of drivers can be raised to 95 % by developing charging infrastructure (everywhere scenario).

- Increasing net battery capacity from 5 kWh to 10 kWh returns a higher additional electric driving share than expanding charging infrastructure from home-only to everywhere.

# 5 Conclusions and Discussion

As the last section showed, there is a high share of driving profiles (> 65 %) that could technically be covered by battery electric vehicles with small batteries (net capacity $C$ < 10 kWh) if there is charging infrastructure available at home. By replacing cars with plug-in hybrid electric vehicles with an average-sized battery (net capacity of $C$ = 10 kWh), the majority (> 60 %) of all driving profiles for the US and Germany could be driven with high electric driving shares (> 80 %) and low infrastructure development. Thus we conclude: For the introduction of plug-in electric vehicles into the US or German market, high shares of vehicles can be operated as PEVs using home-charging only. It is possible to increase the market shares of BEVs or the electric driving shares of PHEVs by installing additional infrastructure in semipublic or public locations. A higher power rate at private locations does not have a significant impact (see also [8]).
However, the analysis presented here is from a technical point of view as mentioned in section 1. An economic analysis that also addresses the payments for charging infrastructure as well as the total costs of ownership should also be taken into account (see e.g. [15] for Germany). This might indicate that smaller batteries are also feasible. It would also be of interest for further research to look at driving profiles with a longer observation horizon, which could also include holiday trips, or at the actual availability of home-charging infrastructure. Considering other countries might also be instructive.

# Acknowledgment

The authors would like to thank Martin Wietschel and David Dallinger for their comments.

# References

[1] Chan, C.C.: The state of the art of electric, hybrid, and fuel cell vehicles. In: Proceedings of the IEEE, 95, 704, 2007.

[2] Kloess, M.: Potentials of hybrid and electric cars to reduce energy consumption and greenhouse gas emissions in passenger car transport. Dissertation, TU Vienna, Austria, 2010.

[3] Wietschel, M., Dallinger, D., Doll, C., Gnann, T., Held, M., Kley, F., Lerch, C., Marscheider-Weidemann, F., Mattes, K., Peters, A., Plötz, P., Schröter, M.: Gesellschaftspolitische Fragestellungen der Elektromobilität, Fraunhofer ISI, Karlsruhe,

[4] Kley, F., Dallinger, D. and Wietschel, M.: What is a right-sized PHEV? Considering users' driving profiles. In: Proceedings of 2nd European Conference Smart Grids and E-Mobility, Brussels, Belgium, October 2010. Germany, 2011.

[5] BMVBS, Bundesministerium für Verkehr, Bau und Stadtentwicklung: Verkehr in Zahlen 2010/2011 (Deutscher Verkehrs-Verlag, 2011), p. 153, 2011.

[6] U.S. Department of Transportation, Federal Highway Administration: Highway Statistics 2009, Annual Vehicle Distance Traveled in Miles and Related Data - 2009 1/ By Highway Category and Vehicle Type, Table VM-1, April 2011. `http://www.fhwa.dot.gov/policyinformation/statistics/2009/vm1.cfm`

[7] Mobilitätspanel Deutschland. Project management by the Institute for transport studies of Karlsruhe University, Karlsruhe, Germany. Data available at `http://mobilitaetspanel.ifv.uni-karlsruhe.de/de/index.html`, 1994–2008

[8] Kley, F.: Ladeinfrastrukturen für Elektrofahrzeuge. Dissertation, Fraunhofer ISI and Karlsruhe Institute of Technology, Karlsruhe, Germany, 2011.

[9] Kraftfahrt-Bundesamt: Fahrzeugzulassungen (FZ) - Bestand an Kraftfahrzeugen und Kraftfahrzeuganhängern nach Haltern, Wirtschaftszweigen (FZ 23), Flensburg, Germany, 2010.

[10] U.S. Department of Transportation, Federal Highway Administration (2009): 2009 National Household Travel Survey, 2009. `http://nhts.ornl.gov`.

[11] Morrow, K., Karner, D., Francfort, J.: Plug-in Hybrid Electric Vehicle Charging Infrastructure Review, U.S. Department of Energy Vehicle Technologies Program Advanced Vehicle Testing Activity, Final Report, Battelle Energy Alliance, Contract No. 58517, November 2008.

[12] Becker, T. A., Sidhu, I., Tenderich, B.: Electric Vehicles in the United States - A New Model with Forecasts to 2030, Center for Entrepreneurship and Technology (CET), University of California, Berkeley, USA, 2009.

[13] Wietschel, M., Kley, F., und Dallinger, D.: Eine Bewertung der Ladeinfrastruktur, Zeitschrift für die Wertschöpfungskette Automobilwirtschaft (ZfAW), Bd. 3, S. 33-41, Bamberg, Germany, 2009.

[14] Helms, H. und Hanusch, J.: Energieverbrauch von Elektrofahrzeugen, ifeu - Institut für Energie- und Umweltforschung Heidelberg GmbH, Heidelberg, Germany, 2010.

[15] Kley, F., Dallinger, D., Wietschel, M. (2010): Assessment of future charging infrastructure International Advanced Mobility Forum, pp. 1-7, 9-10 March 2010.

# Authors

Till Gnann studied Industrial Engineering at the Karlsruhe Institute of Technology (KIT). He works as a scientist in the Competence Center Energy Technology and Energy Systems at the Fraunhofer Institute for Systems and Innovation Research ISI. His current research focuses on electric vehicles and their charging infrastructure.

Patrick Plötz received a PhD in Theoretical Physics from the University of Heidelberg. He is a senior scientist in the Competence Center Energy Technology and Energy Systems at the Fraunhofer Institute for Systems and Innovation Research ISI. His current research focuses on energy efficiency and electric vehicles.

Fabian Kley studied Industrial Engineering (equiv. to MSc) at the University of Karlsruhe, holds an MBA from the University of North Carolina and recently received his PhD from the Karlsruhe Institute of Technology for his work on the charging infrastructure for electric vehicles.